

AIR AND ATMOSPHERIC METHODS

Field Monitoring and Laboratory Analysis for Air Quality

Environmental Analysis Program
Teaching and Research Laboratories, Seeley G Mudd
Pomona College

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STANDARD OPERATING PROCEDURE (SOP)

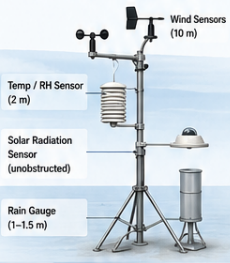
Field and Laboratory Work for Atmospheric Monitoring and Measurement



1. EQUIPMENT OVERVIEW

METEOROLOGICAL INSTRUMENTS	GAS MONITORING INSTRUMENTS	AEROSOL / PARTICULATE EQUIPMENT	SAMPLING EQUIPMENT	FIELD SUPPORT ITEMS
 • Temperature / Humidity Sensor • Barometer • Anemometer / Wind Vane • Pyranometer • Rain Gauge	 • CO₂ Analyzer • CH₄ Analyzer • O₃ / NO_x / SO₂ Analyzer • Multi-gas Monitor • Calibration Gas Cylinders	 • PM_{2.5} / PM₁₀ Monitor • Optical Particle Counter • Aerosol Spectrometer • Air Sampling Pump • Filter Holders and Filters	 • Tedlar® Gas Sampling Bags • Sorbent Tubes • Sampling Manifold • Flow Controller • Vacuum Pump	 • GPS Receiver • Field Tablet / Notebook • Portable Power Supply • Batteries • Tool Kit and Accessories

2. FIELD PROCEDURES

2.1 SITE SELECTION ✓ Choose representative location ✓ Unobstructed airflow ✓ Away from local pollution sources ✓ Secure and accessible ✓ Record GPS, land use and nearby sources 	2.2 INSTRUMENT SETUP (WEATHER STATION EXAMPLE) 	2.3 GAS MONITORING (EXAMPLE: CO₂ ANALYZER) - Place inlet above ground disturbances - Attach inlet filter - Connect sample line - Power on and warm up - Verify stable readings 	2.4 PARTICULATE SAMPLING (PM_{2.5} SAMPLER EXAMPLE) - Install inlet and filter - Set and verify flow rate - Start sample collection - Check periodically - Record final flow rate - Remove and label filter 
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2.5 AIR SAMPLE COLLECTION (GAS BAG) - Flush line - Fill bag slowly - Avoid over-pressure - Seal and label  Record: Sample ID, Date, Time, Location, Weather Conditions, Flow Rate				2.6 FIELD DATA RECORDING <table> <tr> <td>Site Information</td><td>Site code, GPS, Elevation, Land use, Nearby sources</td></tr> <tr> <td>Instrument Information</td><td>Model, Serial No., Calibration date, Operator</td></tr> <tr> <td>Measurement Information</td><td>Start time, End time, Duration, Flow rate</td></tr> <tr> <td>Observations</td><td>Weather, Notes, Issues</td></tr> </table> 				Site Information	Site code, GPS, Elevation, Land use, Nearby sources	Instrument Information	Model, Serial No., Calibration date, Operator	Measurement Information	Start time, End time, Duration, Flow rate	Observations	Weather, Notes, Issues
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Measurement Information	Start time, End time, Duration, Flow rate														
Observations	Weather, Notes, Issues														

3. SAMPLE TRANSPORT

			
	2. Protect from sunlight and extreme temperature		4. Complete chain-of-custody documentation

4. LABORATORY PROCEDURES

4.1 SAMPLE RECEPTION	4.2 SAMPLE PROCESSING	4.3 INSTRUMENT CALIBRATION	4.4 SAMPLE ANALYSIS	4.5 DATA MANAGEMENT	4.6 REPORTING
1 Verify labels 2 Check chain-of-custody 3 Inspect sample condition 4 Assign lab ID 5 Log info system 	A. Filter Samples 1 Condition filters (20–25 °C, 30–40% RH) 2 Weigh (pre-weigh) 3 Analyze or store 4 Re-weigh (post) B. Gas Samples 1 Check pressure 2 Analyze within holding time 3 Use appropriate method 	A. Gas Analyzers 1 Zero calibration (zero air) 2 Span calibration (certified gas) 3 Verify response 4 Log results B. Particle Instruments 1 Zero check 2 Flow rate verification 3 Performance check (manufacturer protocol) 	• Follow standard methods and SOPs • Run blanks, standards, and duplicates • Record all raw data • Check QC criteria 	• Validate data • Apply corrections (calibration, blanks) • Calculate results • Backup data • Maintain metadata 	• Summarize results • Include QA/QC • Interpret data • Archive records 

KEY BEST PRACTICES	ATMOSPHERIC PARAMETERS TYPICALLY MEASURED	DOCUMENTATION
✓ Calibrate instruments regularly ✓ Keep detailed records ✓ Maintain equipment ✓ Follow standard methods ✓ Ensure data quality		• Field logs • Calibration records • Sample logs • Chain-of-custody • Data files and metadata

Pomona College
Claremont, California

AIR AND ATMOSPHERIC METHODS

Air and Atmospheric Methods

Field monitoring and laboratory analysis for air quality and atmospheric measurements

EA Program – Biogeochemistry Lab, Pomona College

Compiled: June 26, 2026

SOP Num- ber	Title
SOP-F501	Air Temperature Monitoring with Portable Sensors
SOP-F502	Air Quality Monitoring with Portable PM Sensors
SOP-F503	Particulate Matter Sampling – Gravimetric Filter Method
SOP-F504	Greenhouse Gas Measurements – Picarro G2508 with Eosense Soil Flux Chambers
SOP-F505	Passive Air Samplers – Diffusion Tubes
SOP-F506	Noise Level Monitoring
SOP-F510	Weather Monitoring and Field Meteorology



Environmental Analysis Program

Pomona College
Biogeochemistry Laboratory

SOP-F501

Air Temperature Monitoring with Portable Sensors

Standard Operating Procedure

SOP Number	SOP-F501
Revision	0.2
Author(s)	Marc Los Huertos
Date	2026-06-26
Organization	EA Program, Pomona College

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1. Purpose

This SOP describes the deployment, calibration, data retrieval, and post-processing of low-cost portable sensor networks for ambient air temperature and relative humidity monitoring. Three sensor platforms are covered: Maxim/Analog Devices Thermochron iButton loggers, Onset HOBO data loggers, and Raspberry Pi single-board computers with BME280 environmental sensor modules.

Dense networks of inexpensive air temperature sensors enable studies of urban heat island (UHI) effects, microclimatic gradients beneath photovoltaic arrays, canopy-vs.-open temperature contrasts, and diurnal and seasonal temperature variability at spatial resolutions not achievable with conventional weather stations (Chapman et al., 2015; Muller et al., 2013). The UHI is one of the most thoroughly documented examples of inadvertent human modification of local climate, driven by impervious surfaces, waste heat, reduced vegetation, and altered radiative and convective energy exchange (Oke et al., 2017; Voogt & Oke, 2003).

When designing a sensor network, characterizing the land cover at each site using the Local Climate Zone (LCZ) framework provides a standardized basis for comparing UHI intensities across cities and studies (Stewart & Oke, 2012).

2. Scope

- **Applies to:** Outdoor ambient air temperature and relative humidity monitoring at 1.5–2.0 m above ground level using portable sensor networks.
- **Does not apply to:** Soil temperature profiles (see [SOP-F404](#)), indoor temperature monitoring, or air quality (PM, gases; see [SOP-F502](#)).
- **Location:** EA Program field sites including the Pomona College campus, Bernard Field Station, photovoltaic study sites, and surrounding Inland Empire communities.

3. Responsibilities

Role	Responsibility
Lab PI	Approve monitoring plan, oversee data quality
Field Lead	Coordinate site access and logistics
Trained Personnel	Calibrate, deploy, retrieve data, process results

Role	Responsibility
New Students	Complete training before independent deployment

4. Safety and Hazards

Hazards

- **Working at height:** Mounting sensors at 1.5–2.0 m on poles or structures may require a stepladder. Follow ladder safety protocols.
- **Traffic:** Some monitoring locations are near roadways. Wear high-visibility vests.
- **Heat exposure:** Deployment and retrieval in summer in the Inland Empire involves significant heat risk. Carry water, work in pairs, and schedule field work for early morning when possible.
- **Electrical:** Raspberry Pi units use low-voltage USB power. Do not expose connections to rain or standing water without weatherproof enclosures.

4.1. Required PPE

- ☐ Closed-toe shoes
- ☐ High-visibility vest (if near roadways)
- ☐ Sun protection (hat, sunscreen)
- ☐ Safety glasses (during mounting/drilling)

5. Definitions

- **Urban Heat Island (UHI):** The phenomenon whereby urban areas experience higher air temperatures than surrounding rural areas due to impervious surfaces, waste heat, reduced vegetation, and altered energy balance. UHI intensity (ΔT_{UHI}) is quantified as the difference between an urban and a rural reference site at a given time (Oke et al., 2017).
- **Local Climate Zone (LCZ):** A classification system that describes the physical properties of the local environment (building density, height, surface cover, land use) at scales relevant to urban temperature variation. LCZ types range from compact high-rise (LCZ 1) to scattered trees (LCZ B), and provide a standardized framework for describing monitoring sites in UHI studies (Stewart & Oke, 2012).
- **Radiation shield:** A louvered or ventilated housing that protects a temperature sensor from direct and reflected solar radiation while allowing ambient air to flow past the sensor. Without shielding, sensors can read 5–15 °C above true air temperature in direct sun (Hubbart et al., 2005; Terando et al., 2017).
- **BME280:** A Bosch environmental sensor measuring temperature, relative humidity, and barometric pressure. Used with Raspberry Pi platforms in the EA Program sensor network.
- **iButton:** A coin-sized temperature (and optionally RH) data logger manufactured by Maxim/Analog Devices (Thermochron series).
- **HOBO:** A family of portable data loggers manufactured by Onset Computer Corporation.

- **Collocation:** The practice of placing multiple sensors at the same location for a period to assess inter-sensor agreement and identify systematic offsets. Collocation is the primary calibration strategy for dense low-cost sensor networks (Meier et al., 2017).
- **Calibration offset:** A systematic difference between a sensor’s reading and a known reference, determined during collocation and applied as a correction to field data.
- **Data completeness:** The percentage of expected readings actually recorded during a deployment period. A minimum of 75% completeness (18 of 24 hours per day) is required for daily summaries.

6. Prerequisites

- [SOP-F001 Field Safety](#)
- For Raspberry Pi deployments: basic familiarity with Raspberry Pi OS, SSH, and file transfer (see also [SOP-F502](#))

7. Sensor Platforms

7.1. Comparison

Feature	iButton DS1921/DS1923	HOBO U23 Pro v2	Raspberry Pi + BME280
Approximate cost	\$20–60	\$130–200	\$40–80
Temperature accuracy	$\pm \$0.5$ –1.0 C	$\pm \$0.21$ C	$\pm \$0.5$ C (BME280)
RH measurement	DS1923 only	Yes	Yes
Logging interval	1 min – 255 min	1 s – 18 h	User-defined (script)
Memory	2048–8192 readings	~42,000 readings	SD card (unlimited)
Communication	1-Wire (download)	USB (download)	Wi-Fi / SD card
Battery life	~1 year	~1 year	Requires continuous power
Size	17 mm coin	6 x 5 x 2 cm	Variable (enclosure)

7.2. Choosing a Platform

- **iButton:** Best for dense spatial networks where low cost and small size are priorities. Limited memory requires periodic retrieval. Ideal for short-term (weeks to months) UHI transects.
- **HOBO:** Best general-purpose option with highest accuracy, long battery life, and large memory. Good for season-long deployments.
- **Raspberry Pi + BME280:** Best for real-time or near-real-time monitoring with Wi-Fi. Requires continuous power. Already available in the EA Program inventory (16 Pi Zero+ units).

8. Radiation Shielding

! Radiation Shields Are Mandatory

Unshielded sensors exposed to direct or reflected solar radiation can read 5–15 C higher than true air temperature. Every deployed sensor **must** be housed in a radiation shield (Hubbart et al., 2005; Terando et al., 2017).

8.1. Shield Options

Shield Type	Cost	Notes
6-plate gill shield (e.g., Davis 7714)	\$20–30	Standard; good ventilation
10-plate aspirated shield	\$30–50	Better in low-wind conditions
DIY stacked-plate shield (white plastic plates)	\$5–10	Acceptable for student projects; see Appendix B for construction
Naturally aspirated PVC tube (white, louvered)	\$10–15	Compact; fits iButtons

All shields must be white (high albedo) and mounted with the sensor opening facing downward to prevent rain intrusion.

9. Calibration

9.1. Ice-Bath Calibration (Single-Point Check)

1. Prepare an ice-water bath: fill an insulated container with crushed ice and deionized water, stir for 2 minutes
2. Submerge the sensor (in a waterproof sleeve for iButtons, or using a sealed bag for non-waterproof units)
3. Wait 5 minutes for equilibration
4. The sensor should read 0.0 ± 0.5 C. Record the reading.
5. If outside tolerance, note the offset; sensors with offsets greater than 1.0 C should be replaced.

9.2. Room-Temperature Inter-Comparison (Collocation)

1. Place all sensors to be deployed together in a shaded, well-mixed indoor environment for at least 24 hours
2. Calculate the mean temperature across all sensors for each timestep. Each sensor's offset is its deviation from the group mean.
3. Record offsets in a calibration log file: `data/calibration/offsets_YYYYMMDD.csv`
4. Apply these offsets as corrections during data processing (Section 11). Collocation under controlled conditions is the most practical calibration approach for networks of 10 or more sensors (Meier et al., 2017).

10. Deployment

10.1. Site Selection and Documentation

Select monitoring sites to represent the range of land cover types and microclimates relevant to the research question. For UHI studies, sample across multiple LCZ types (e.g., compact low-rise, open low-rise, large low-rise, scattered trees, dense trees) (Stewart & Oke, 2012).

At each site, record:

- GPS coordinates per [SOP-F006](#)
- Mounting height (standard: 1.5–2.0 m above ground level)
- Shield type and orientation
- Land cover within 50 m radius (impervious %, tree canopy %, grass %)
- LCZ type (see Stewart & Oke (2012) for classification guide)
- Nearest road (distance and type)
- Sky view factor (estimated or photographed)
- Sensor serial number and platform type

10.2. Mounting

1. Mount the radiation shield on a pole, post, fence, or structure at 1.5–2.0 m height. Ensure the shield is not directly above a paved surface, air conditioning exhaust, or heat-radiating wall.
2. Place the sensor inside the shield, ensuring the sensing element is centered within the shield stack.
3. For Raspberry Pi units, route the power cable through the base of the enclosure. Secure with cable ties.
4. Photograph the installation and record all metadata.
5. Record metadata as above.

11. Data Retrieval

Platform	Retrieval Method	Frequency
iButton	Remove, connect to 1-Wire reader, download in OneWireViewer	Every 2–4 weeks
HOBO U23	Connect USB shuttle or cable, download in HOBOWare	Every 1–3 months
Raspberry Pi	SSH + <code>scp</code> , or remove SD card	Weekly or as needed

After retrieval, archive the raw file immediately. Never modify the original.

12. Data Processing

12.1. Import and Standardize

```
library(tidyverse)
library(lubridate)

# Example: import iButton CSV
raw <- read_csv("data/raw/site01_ibutton_ABC123.csv",
               skip = 14) %>%
  rename(timestamp = 1, temp_c = 2) %>%
  mutate(
    timestamp = mdy_hms(timestamp, tz = "America/Los_Angeles"),
    sensor_id = "ABC123",
    site_id   = "site01",
    platform  = "iButton"
  )

# Apply calibration offset (from Section 9)
offsets <- read_csv("data/calibration/offsets_YYYYMMDD.csv")

raw <- raw %>%
  left_join(offsets %>% select(sensor_id, offset), by = "sensor_id") %>%
  mutate(temp_corrected = temp_c - offset)
```

12.2. Quality Control

```
raw <- raw %>%
  mutate(
    qc_flag = case_when(
      temp_corrected < -10 | temp_corrected > 55 ~ "out_of_range",
      temp_corrected == lag(temp_corrected) &
        temp_corrected == lag(temp_corrected, 2) &
        temp_corrected == lag(temp_corrected, 3) ~ "stuck_sensor",
      abs(temp_corrected - lag(temp_corrected)) > 10 ~ "spike",
      TRUE ~ "valid"
    )
  )

count(raw, qc_flag)
clean <- raw %>% filter(qc_flag == "valid")
```

12.3. Hourly and Daily Summaries

```
hourly <- clean %>%
  mutate(hour = floor_date(timestamp, "hour")) %>%
  group_by(site_id, sensor_id, hour) %>%
  summarize(
    temp_mean = mean(temp_corrected, na.rm = TRUE),
    temp_min  = min(temp_corrected, na.rm = TRUE),
    temp_max  = max(temp_corrected, na.rm = TRUE),
    n_obs     = n(),
    .groups   = "drop"
  ) %>%
  filter(n_obs >= 3)

daily <- hourly %>%
  mutate(date = as_date(hour)) %>%
  group_by(site_id, sensor_id, date) %>%
  summarize(
    t_mean = mean(temp_mean, na.rm = TRUE),
    t_min  = min(temp_min, na.rm = TRUE),
    t_max  = max(temp_max, na.rm = TRUE),
    n_hours = n(),
    .groups = "drop"
  ) %>%
  filter(n_hours >= 18)
```

12.4. Urban Heat Island Intensity

UHI intensity is typically calculated as the difference between an urban site and a rural (or least-developed) reference site (Oke et al., 2017):

$$\Delta T_{\text{UHI}} = T_{\text{urban}} - T_{\text{rural}}$$

```
ref_site <- "site_rural01"

uhi <- hourly %>%
  select(site_id, hour, temp_mean) %>%
  pivot_wider(names_from = site_id, values_from = temp_mean) %>%
  mutate(across(-c(hour, all_of(ref_site)),
    ~ . - .data[[ref_site]],
    .names = "uhi_{.col}"))
```

13. Quality Control Summary

Check	Criterion
Ice-bath calibration	Reading within ± 0.5 C of 0.0 C
Inter-sensor agreement (collocation)	Within ± 0.5 C at night
Hourly data completeness	$\geq 75\%$ of expected readings
Daily data completeness	≥ 18 of 24 hours
Stuck-sensor detection	≥ 4 identical consecutive readings flagged
Spike detection	≥ 10 C change between consecutive readings flagged

14. Data Management

- Raw files archived unmodified: `data/raw/siteID_platform_sensorID.csv`
- Calibration records: `data/calibration/`
- Processed files: `data/processed/`
- Site metadata (coordinates, height, shield type, land cover, LCZ type, sensor serial numbers, deployment/retrieval dates): `data/metadata/site_metadata.csv`
- All scripts version-controlled in the project Git repository

15. References

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16. Related SOPs

SOP	Title	Relationship
F001	Field Safety	Required prerequisite
F101	Electrical Power in the Field	Power for Pi deployments
F404	Soil Temperature Profiles	Companion: soil vs. air temp
F502	Air Quality Monitoring	Companion: PM sensors on same Pi units
F510	Weather Monitoring	Companion: full meteorological context

17. Training Record

Before deploying air temperature sensors independently, personnel must:

1. Read this SOP and [SOP-F001 Field Safety](#) in full
2. Perform a calibration (ice-water bath and room-temperature inter-comparison) under supervision
3. Assemble and mount a radiation shield
4. Deploy and retrieve a sensor at a test site
5. Import, clean, and summarize data using the R workflow
6. Be signed off by the PI or field lead



Environmental Analysis Program

Pomona College
Biogeochemistry Laboratory

SOP-F502

Air Quality Monitoring with Portable PM Sensors

Standard Operating Procedure

SOP Number	SOP-F502
Revision	0.2
Author(s)	Marc Los Huertos
Date	2026-06-26
Organization	EA Program, Pomona College

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1. Purpose

This SOP describes the assembly, deployment, data retrieval, and post-processing of low-cost particulate matter (PM) sensor networks built around Raspberry Pi single-board computers and Plantower PMS5003/PMS5004 laser-scattering sensors. These sensors estimate PM_1 , $PM_{2.5}$, and PM_{10} mass concentrations and report particle counts in six size bins (>0.3 , >0.5 , >1.0 , >2.5 , >5.0 , >10.0 μm).

Low-cost PM sensors (LCS) provide spatial and temporal resolution that is not achievable with Federal Reference Method (FRM) or Federal Equivalent Method (FEM) monitors alone (Snyder et al., 2013). However, LCS data require quality screening, relative humidity correction, and calibration against reference instruments to produce scientifically defensible results (Ardon-Dryer et al., 2023; Barkjohn et al., 2021). When properly corrected and quality-controlled, LCS networks can complement regulatory monitoring by filling spatial gaps, supporting community exposure studies, and providing near-real-time information during wildfire smoke events (Morawska et al., 2018).

2. Scope

- **Applies to:** Outdoor ambient air quality monitoring using EA Program Raspberry Pi + PMS5003/PMS5004 sensor units for PM_1 , $PM_{2.5}$, and PM_{10} .
- **Does not apply to:** Indoor air quality monitoring (different correction factors apply), gas-phase pollutant monitoring (O_3 , NO_2 , CO), or regulatory compliance monitoring.
- **Location:** Field deployment sites in the Pomona College area and surrounding Inland Empire communities.

3. Responsibilities

Role	Responsibility
Lab PI	Approve deployment plan, oversee data quality
Field Lead	Coordinate site access, logistics, and safety
Trained Personnel	Assemble, deploy, retrieve, and process data
New Students	Complete training before independent deployment

4. Definitions

- **PM_{2.5}**: Particulate matter with aerodynamic diameter less than 2.5 μm . PM_{2.5} is a criteria pollutant regulated by the US EPA because of its association with cardiovascular and respiratory health effects.
- **PM₁₀**: Particulate matter with aerodynamic diameter less than 10 μm . Includes both fine (PM_{2.5}) and coarse (2.5–10 μm) fractions.
- **Low-cost sensor (LCS)**: A PM sensor costing less than approximately \$250 per unit, as distinct from regulatory-grade FRM or FEM instruments costing \$10,000–\$50,000 (Snyder et al., 2013).
- **Federal Reference Method (FRM)**: The EPA-designated reference method for measuring criteria pollutants. For PM_{2.5}, the FRM is a gravimetric filter-based method (see [SOP-F503](#)).
- **Federal Equivalent Method (FEM)**: An air quality measurement method approved by the US EPA as equivalent to the FRM (e.g., beta attenuation monitors).
- **CF=1**: “Standard particles” output from the Plantower sensor, factory-calibrated against Chinese ambient aerosol. This is the starting value for the EPA US-wide correction (Barkjohn et al., 2021).
- **AQI**: Air Quality Index. A standardized index for reporting daily air quality developed by the US EPA, with breakpoints tied to health-based PM_{2.5} standards.
- **Collocation**: Placing LCS units alongside a reference instrument (or alongside each other) to assess accuracy, precision, and drift. Pre-deployment collocation is a minimum QC requirement.
- **Sensor drift**: Gradual degradation of sensor accuracy over months to years of continuous operation, caused by fan wear, laser aging, and contamination of the optical chamber (Malings et al., 2020).
- **Hygroscopic growth**: The increase in particle size (and thus light scattering) that occurs when ambient RH exceeds approximately 70%, causing LCS to overestimate PM mass concentration. The EPA correction includes an RH term to account for this (Barkjohn et al., 2021; Jayaratne et al., 2018).
- **PMS-O / PMS-U**: Original (pre-mid-2021) and updated (post-mid-2021) versions of the Plantower PMS5003, which differ in internal calibration. PMS-U sensors read lower at concentrations below approximately 16 $\mu\text{g}/\text{m}^3$ (Ardon-Dryer et al., 2023).

5. Safety and Hazards

Hazards

- **Electrical:** Raspberry Pi units and USB power supplies. Do not expose connections to rain or standing water. Use weatherproof enclosures for outdoor deployment.
- **Heat:** Enclosures can reach high temperatures in direct sunlight, especially in summer in the Inland Empire. Use ventilated or shaded enclosures.
- **Traffic and site access:** Many monitoring locations are near roadways. Follow all traffic safety procedures in [SOP-F001](#).
- **Working at height:** If mounting sensors on poles or structures, follow ladder safety protocols.

5.1. Required PPE

- ☐ Safety glasses (during assembly)
- ☐ Closed-toe shoes
- ☐ High-visibility vest (if near roadways)
- ☐ Sun protection (hat, sunscreen)

6. Prerequisites

- [SOP-F001 Field Safety](#)
- Basic familiarity with Raspberry Pi OS (command line, SSH, file transfer)
- Basic familiarity with R for data processing

7. Background

7.1. How the Sensors Work

The Plantower PMS5003 and PMS5004 are optical particle counters that use a laser (680 ± 10 nm) and a photodiode to detect light scattered by individual particles drawn through the sensing chamber by a small fan. The sensor reports particle counts in six size bins and uses a proprietary algorithm to estimate PM_1 , $PM_{2.5}$, and PM_{10} mass concentrations in $\mu g/m^3$ (Barkjohn et al., 2021).

The sensor outputs data in two formats: CF=1 (“standard particles,” factory-calibrated against Chinese urban aerosol) and CF_atm (“atmospheric environment,” with an additional adjustment at higher concentrations). For ambient monitoring in the US, the CF=1 output is used as the starting point for correction (Barkjohn et al., 2021).

7.2. Known Limitations

- **Relative humidity sensitivity:** At RH >70%, hygroscopic particle growth inflates readings. An RH correction term is essential (Barkjohn et al., 2021; Jayaratne et al., 2018).

- **Particle size dependence:** The sensors underestimate $PM_{2.5}$ when coarse particles (dust) dominate the size distribution. They perform best for fine-mode aerosol (PM_1) (Jaffe et al., 2023; Ouimette et al., 2026).
- **Batch variability:** Plantower changed the PMS5003 calibration in mid-2021, producing sensors that read lower at low concentrations. These can be identified by their particle count ratios and corrected (Ardon-Dryer et al., 2023).
- **Sensor aging:** Fan and laser degradation over months to years of continuous operation can reduce sensitivity. Long-term field evaluations show measurable drift after 6–12 months of continuous outdoor deployment (Malings et al., 2020). Periodic collocation with a reference instrument is needed.

8. Equipment and Materials

8.1. Sensor Unit Components

Item	Qty per Unit	Notes
Raspberry Pi Zero+ (or 3+/4+)	1	With microSD card (32 GB min)
Plantower PMS5004 (or PMS5003)	1	With ribbon cable
BME280 sensor module	1	Temperature, RH, pressure
USB power supply (5V, 2.5A)	1	Or solar panel + battery
Weatherproof enclosure	1	Ventilated; inlet tube for PM
microSD card (32 GB)	1	Pre-loaded with sensor software
Ethernet or Wi-Fi dongle	1	If Pi Zero (built-in on Pi 3+/4+)

8.2. Field Deployment Supplies

Item	Notes
Zip ties, mounting brackets	For securing enclosures
Extension cord or solar panel	Power supply for remote sites
GPS unit or smartphone	For recording coordinates
Field notebook	Site metadata
Laptop with SSH client	For on-site diagnostics

9. Procedure

9.1. Sensor Assembly and Software Setup

1. Flash the microSD card with Raspberry Pi OS Lite.
2. Install the sensor-reading Python script (maintained in the project repository). The script reads the PMS5003/5004 via serial (UART) and the BME280 via I2C, logging timestamped readings to a CSV file on the SD card.

3. Configure the Pi for headless operation (enable SSH, set Wi-Fi credentials if applicable, set timezone to America/Los_Angeles).
4. Connect the PMS sensor ribbon cable and the BME280 module.
5. Power on the unit and verify that the sensor LED illuminates and the fan spins. Check the log file for valid readings.
6. Allow at least 30 seconds of warm-up before trusting data (Plantower Technology, 2016).

9.2. Collocation (Pre-Deployment Calibration)

Before field deployment, collocate all sensor units at a single location for a minimum of 48 hours:

1. Place all units within 1 m of each other, at the same height, with inlets facing the same direction.
2. Compare readings across units to identify outliers or malfunctioning sensors.
3. If a reference instrument (FRM, FEM, or BAM) is available, collocate sensors with it to develop a site-specific correction factor (Barkjohn et al., 2021).
4. Calculate inter-sensor coefficients of variation (CV). Units with CV >15% relative to the group median should be inspected and recalibrated or replaced.

9.3. Site Selection

- Mount sensors 2–4 m above ground level, away from direct emission sources (exhaust vents, barbecues, construction).
- Orient the inlet away from prevailing wind to reduce rain intrusion.
- Ensure access to power (AC outlet, solar panel, or battery).
- Record GPS coordinates, mounting height, distance to nearest road, and land use context.

9.4. Deployment

1. Secure the enclosure at the selected location using zip ties, brackets, or straps.
2. Connect power.
3. Verify operation by SSH into the Pi and checking the live log.
4. Record the deployment date/time, site ID, sensor serial number, and any notes in the field notebook and project metadata file.

9.5. Data Retrieval

Retrieve data at regular intervals (weekly to monthly):

1. SSH into the Pi and copy the CSV log file to your laptop using `scp` or `rsync`.
2. Alternatively, remove the microSD card and copy files directly.
3. Archive the raw file immediately; never edit the original.
4. Check the log for gaps (power outages, sensor freezes).

9.6. Sensor Maintenance

- Inspect the inlet for debris, spider webs, or insect nests at each data retrieval visit.
- Replace sensors after approximately 2 years of continuous outdoor operation, or sooner if collocation checks show degraded performance (Malings et al., 2020).
- Clean the exterior of the enclosure. Do not open the PMS sensor housing.

9.7. Decommissioning

1. Power off the unit.
2. Retrieve the final data file.
3. Remove the enclosure and all mounting hardware.
4. Leave no trace at the site.

10. Data Processing and Correction

10.1. Overview

Raw PM_{2.5} readings from PMS5003/5004 sensors overestimate FRM/FEM concentrations by approximately 40% under typical US ambient conditions (Barkjohn et al., 2021). The EPA US-wide correction reduces root mean square error from approximately 8 $\mu\text{g}/\text{m}^3$ to 3 $\mu\text{g}/\text{m}^3$ (Barkjohn et al., 2021).

10.2. Data Cleaning

```
library(tidyverse)

raw <- read_csv("data/raw/site01_20260101_20260201.csv")

raw <- raw %>%
  filter(
    pm25_cf1 >= 0,
    pm25_cf1 < 1000,
    rh_pct >= 0,
    rh_pct <= 100,
    temp_c > -40,
    temp_c < 60
  )

# Flag and remove sensor freeze periods
raw <- raw %>%
  mutate(frozen = pm25_cf1 == lag(pm25_cf1) &
    pm25_cf1 == lag(pm25_cf1, 2) &
    pm25_cf1 == lag(pm25_cf1, 3)) %>%
```

```
filter(!frozen | is.na(frozen)) %>%
select(-frozen)
```

10.3. EPA US-Wide Correction (Barkjohn et al., 2021)

$$\text{PM}_{2.5,\text{corrected}} = 0.524 \times \text{PM}_{2.5,\text{cf1}} - 0.0862 \times \text{RH} + 5.75$$

where $\text{PM}_{2.5,\text{cf1}}$ is the CF=1 output ($\mu\text{g}/\text{m}^3$) and RH is relative humidity (%) (Barkjohn et al., 2021).

```
raw <- raw %>%
  mutate(
    pm25_corrected = 0.524 * pm25_cf1 - 0.0862 * rh_pct + 5.75,
    pm25_corrected = pmax(pm25_corrected, 0)
  )
```

! Important

This correction was developed for typical ambient and smoke-impacted conditions. It underestimates $\text{PM}_{2.5}$ during dust-dominated events. For dust correction, see Jaffe et al. (2023) and Ouimette et al. (2026).

10.4. Identifying Updated (Post-2021) PMS5003 Sensors

If your sensors are PMS-U (post-mid-2021), apply the additional linear correction from Ardon-Dryer et al. (2023) before the EPA correction. PMS-U sensors can be identified by a $\text{count}_{0.3}/\text{count}_{0.5}$ ratio approximately 3 times lower than PMS-O sensors.

10.5. Hourly and Daily Averaging

```
hourly <- raw %>%
  mutate(hour = floor_date(timestamp, "hour")) %>%
  group_by(hour) %>%
  summarize(
    pm25_mean = mean(pm25_corrected, na.rm = TRUE),
    pm25_sd   = sd(pm25_corrected, na.rm = TRUE),
    rh_mean   = mean(rh_pct, na.rm = TRUE),
    temp_mean = mean(temp_c, na.rm = TRUE),
    n_obs     = n(),
    .groups   = "drop"
  ) %>%
  filter(n_obs >= 45)

daily <- hourly %>%
```

```
mutate(date = as_date(hour)) %>%
group_by(date) %>%
summarize(
  pm25_daily = mean(pm25_mean, na.rm = TRUE),
  n_hours    = n(),
  .groups    = "drop"
) %>%
filter(n_hours >= 18)
```

10.6. AQI Calculation

```
calc_aqi <- function(pm25) {
  breakpoints <- tibble(
    lo_pm  = c(0.0, 9.1, 35.5, 55.5, 125.5, 225.5),
    hi_pm  = c(9.0, 35.4, 55.4, 125.4, 225.4, 325.4),
    lo_aqi = c(0, 51, 101, 151, 201, 301),
    hi_aqi = c(50, 100, 150, 200, 300, 500)
  )
  bp <- breakpoints %>% filter(pm25 >= lo_pm, pm25 <= hi_pm)
  if (nrow(bp) == 0) return(NA_real_)
  with(bp, lo_aqi + (hi_aqi - lo_aqi) / (hi_pm - lo_pm) * (pm25 - lo_pm))
}

daily <- daily %>%
  mutate(aqi = map_dbl(pm25_daily, calc_aqi))
```

11. Quality Control

11.1. Pre-Deployment

- All sensors pass collocation check (inter-sensor CV <15%).
- Software logging verified (valid timestamps, all columns populated).

11.2. During Deployment

- Weekly data check (via SSH or at retrieval) for gaps and anomalies.
- Inspect enclosure and inlet monthly.

11.3. Post-Processing QC Flags

Flag	Condition	Action
F1	RH >95% for >4 consecutive hours	Flag; consider excluding
F2	PM _{2.5} >500 $\mu\text{g}/\text{m}^3$ for >1 hour	Verify against regional monitors
F3	Sensor freeze (identical readings >10 min)	Exclude
F4	Hourly data completeness <75%	Exclude hour
F5	Daily data completeness <75% of hours	Exclude day

11.4. Periodic Collocation

Re-collocate sensors with a reference instrument (or with each other) at least once per year and after any sensor replacement. Document drift and update correction factors if needed (Malings et al., 2020).

12. Data Management

- Archive raw CSV files unmodified in `data/raw/` with the naming convention: `siteID_YYYYMMDD_YYYYMMDD_ra`
- Processed/corrected files in `data/processed/`
- Metadata in `data/metadata/`
- All processing scripts version-controlled per [SOP-L801](#)

13. Reporting

When reporting LCS data in publications or reports, include (Morawska et al., 2018):

- Sensor make and model (Plantower PMS5003 or PMS5004)
- Platform (Raspberry Pi model)
- Correction equation used (cite the reference)
- Whether sensors were collocated with a reference instrument
- Data completeness and QC criteria applied
- Known limitations (RH sensitivity, dust underestimation, sensor age)

14. References

- Ardon-Dryer, K., Kelp, M. M., Stamber, B., & Kohl, S. (2023). Technical note: Identifying a performance change in the Plantower PMS 5003 particulate matter sensor. *Journal of Aerosol Science*, 173, 106215. <https://doi.org/10.1016/j.jaerosci.2023.106215>
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15. Related SOPs

SOP	Title	Relationship
F001	Field Safety	Required prerequisite
F101	Electrical Power in the Field	Power supply guidance
F501	Air Temperature Monitoring	Companion: temp sensors on same Pi
F503	PM Filter Sampling	Reference-quality gravimetric companion
F504	Picarro GHG Analyzer	Companion field instrument SOP

16. Training Record

Before deploying air quality sensors independently, personnel must:

1. Read this SOP and [SOP-F001 Field Safety](#) in full
2. Demonstrate Raspberry Pi setup (OS flash, SSH, sensor script configuration) under supervision
3. Participate in a supervised collocation and deployment

4. Perform a data retrieval and run the correction/QC pipeline
5. Be signed off by the PI or field lead



Environmental Analysis Program

Pomona College
Biogeochemistry Laboratory

SOP-F503

Particulate Matter Sampling – Gravimetric Filter Method

Standard Operating Procedure

SOP Number	SOP-F503
Revision	0.2
Author(s)	Marc Los Huertos
Date	2026-06-26
Organization	EA Program, Pomona College

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1. Purpose

This procedure describes the collection of ambient particulate matter (PM) on pre-weighed filters using active (pump-based) samplers for subsequent gravimetric and/or chemical analysis. Gravimetric filter sampling provides a reference-quality mass concentration that can be used to validate or

calibrate low-cost PM sensors (see [SOP-F502](#)) and to collect PM for compositional analysis (metals, ions, elemental/organic carbon) (Chow, 1995; US Environmental Protection Agency, 2017).

Ambient PM is a complex mixture of solid and liquid particles suspended in air, originating from both primary sources (combustion, dust, sea spray) and secondary formation (gas-to-particle conversion of sulfate, nitrate, and organic compounds) (Seinfeld & Pandis, 2016; [poschl2005?](#)). Gravimetric filter sampling remains the reference standard for PM mass measurement because it directly weighs the collected material, avoiding the indirect assumptions inherent in optical or beta-attenuation methods (US Environmental Protection Agency, 2017).

This SOP covers medium- and low-volume filter-based samplers operated by EA Program personnel. It does not cover Federal Reference Method (FRM) high-volume samplers operated by regulatory agencies.

2. Scope

- **Applies to:** Collection of PM_{2.5} and PM₁₀ on filters using portable or semi-permanent medium-volume or personal air samplers (e.g., MiniVol, BGI PQ200, SKC personal samplers) at EA Program field sites
- **Does not apply to:** Low-cost optical sensors without filters (see [SOP-F502](#)); FRM/FEM high-volume samplers operated by AQMD or EPA; indoor air quality sampling; gas-phase pollutant sampling
- **Location:** EA Program field deployment sites in the Pomona College area and surrounding Inland Empire communities

3. Responsibilities

Role	Responsibility
PI / Field Lead	Approve sampling plan, coordinate site access
Trained Personnel	Condition filters, deploy sampler, retrieve and weigh filters
Lab Manager	Maintain balance, desiccator, and sampler calibration
New Students	Complete training before independent deployment

4. Definitions

- **Particulate matter (PM):** A mixture of solid particles and liquid droplets suspended in air, ranging in size from a few nanometers to tens of micrometers (Seinfeld & Pandis, 2016).
- **PM_{2.5}:** Particulate matter with aerodynamic diameter less than 2.5 μm (“fine particles”). Fine particles penetrate deep into the lungs and are associated with cardiovascular and respiratory health effects ([solomon2001?](#)).
- **PM₁₀:** Particulate matter with aerodynamic diameter less than 10 μm . Includes both fine (PM_{2.5}) and coarse (2.5–10 μm) fractions.

- **Gravimetric analysis:** Determination of PM mass by weighing a filter before and after exposure, under controlled temperature and humidity conditions (US Environmental Protection Agency, 2017).
- **Size-selective inlet:** An impactor or cyclone that removes particles above a defined aerodynamic diameter cutpoint (e.g., 2.5 or 10 μm) before they reach the filter.
- **PTFE filter:** Polytetrafluoroethylene (Teflon) membrane filter. Chemically inert, hydrophobic, and low in artifact mass; the standard substrate for gravimetric PM analysis.
- **Quartz fiber filter:** A filter made of quartz (SiO_2) fibers, used when thermal-optical analysis for elemental and organic carbon is planned. Must be pre-fired at 500 C for 4 hours to remove organic artifacts.
- **Filter conditioning:** Equilibrating filters at controlled temperature (20–25 C) and humidity (30–40% RH) in a desiccator for at least 24 hours before weighing. Conditioning removes adsorbed water that would bias the mass measurement.
- **Field blank:** A conditioned filter transported to the field site, briefly exposed to ambient conditions without running the pump, then resealed and returned for weighing. Field blank mass quantifies contamination introduced during handling and transport.
- **Flow rate:** The volumetric rate at which air is drawn through the sampler, typically expressed in L/min. The flow rate must match the design specification of the size-selective inlet (e.g., 5 L/min for a MiniVol $\text{PM}_{2.5}$ impactor).
- **Chemical speciation:** Analysis of the chemical composition of collected PM (e.g., metals by XRF or ICP-MS, ions by IC, carbon fractions by thermal-optical analysis) (**chow2015?**).

5. Safety and Hazards

Hazards

- **Electrical:** Sampling pumps require AC or battery power. Protect connections from rain and moisture.
- **Traffic:** Many monitoring locations are near roadways. Wear a high-visibility vest and follow [SOP-F001](#) traffic safety procedures.
- **Lifting:** Medium-volume samplers (e.g., MiniVol TAS) and batteries can be heavy (10–15 kg). Use proper lifting technique.
- **Heat:** Enclosures and pumps can overheat in direct sunlight during Inland Empire summers.

5.1. Required PPE

- ☐ Nitrile gloves (when handling filters)
- ☐ Closed-toed shoes
- ☐ High-visibility vest (if near roadways)
- ☐ Sun protection

6. Equipment and Materials

6.1. Sampling Equipment

Item	Notes
Medium-volume sampler (e.g., MiniVol TAS, BGI PQ200) or personal sampler (SKC, Leland Legacy)	With size-selective inlet (PM _{2.5} or PM ₁₀ impactor)
Calibrated flow meter (rotameter or primary standard, e.g., Bios DryCal)	For verifying and adjusting flow rate
Timer or elapsed-time indicator	Built into most samplers
Tripod or mounting pole	For positioning inlet at 1.5–2 m
Battery or AC power source	Sufficient for the planned sampling duration

6.2. Filter Supplies

Item	Notes
Pre-weighed PTFE filters, 47 mm	For gravimetric analysis
Pre-weighed quartz fiber filters, 47 mm	If EC/OC analysis is planned; pre-fire at 500 C for 4 h
Filter cassettes or holders	Matched to the sampler
Petri dishes or filter transport cases	For transporting conditioned filters
Forceps (flat-tipped, non-serrated)	For handling filters
Desiccator with active desiccant	For filter conditioning
Analytical balance (0.01 mg or better)	Per SOP-L200

7. Procedure

7.1. Filter Conditioning and Pre-Weighing

1. Place unused filters in a desiccator at controlled temperature (20–25 C) and humidity (30–40% RH) for at least 24 hours (US Environmental Protection Agency, 2017)
2. Weigh each filter on the microbalance to the nearest 0.01 mg. Record the filter ID and tare weight.
3. Weigh each filter a second time (at least 1 hour later) to confirm stability. The two weights should agree within 0.015 mg.
4. Place the conditioned filter in a labeled Petri dish or cassette. Seal and transport in a cooler if traveling to a remote site.

7.2. Sampler Setup and Flow Calibration

1. Install the appropriate size-selective inlet (PM_{2.5} or PM₁₀ impactor head) on the sampler

2. Load a blank filter cassette and connect the calibrated flow meter downstream of the filter holder
3. Start the pump and adjust the flow rate to the nominal design flow for the inlet (e.g., 5 L/min for a MiniVol PM_{2.5} impactor)
4. Record the calibrated flow rate, temperature, and barometric pressure. If the site is at a different elevation than the calibration location, apply a volumetric correction.
5. Remove the blank cassette and load the pre-weighed sample filter using forceps. Handle the filter only by its edges.

7.3. Deployment

1. Position the sampler with the inlet at 1.5–2 m above ground level, unobstructed by walls or overhangs (at least 2 m from any vertical surface)
2. Record the start date, start time, site ID, filter ID, GPS coordinates, and weather conditions
3. Start the sampler and verify that the pump is running
4. For 24-hour integrated samples, allow the sampler to run for 23–25 hours

7.4. Retrieval

1. Record the stop time and elapsed run time
2. Verify the flow rate with the calibrated flow meter before stopping the pump (post-sampling flow check). Record the value.
3. Stop the pump
4. Remove the filter cassette using gloves. Transfer the exposed filter to its labeled Petri dish using forceps. Do not touch the deposit surface.
5. Seal the Petri dish and place in a cooler for transport
6. Calculate the average flow rate: $Q_{\text{avg}} = (Q_{\text{pre}} + Q_{\text{post}})/2$. If pre- and post-flow rates differ by more than 10%, flag the sample.

7.5. Post-Sampling Conditioning and Weighing

1. Condition the exposed filter in the same desiccator and at the same temperature/humidity as the pre-weighing step for at least 24 hours
2. Weigh the filter to the nearest 0.01 mg. Record the gross weight.
3. Repeat the weighing at least 1 hour later to confirm stability.
4. Calculate the net PM mass:

$$m_{\text{PM}} = W_{\text{post}} - W_{\text{pre}}$$

5. Calculate the PM concentration:

$$C_{\text{PM}}(\mu\text{g}/\text{m}^3) = \frac{m_{\text{PM}}(\mu\text{g})}{Q_{\text{avg}}(\text{L}/\text{min}) \times t(\text{min})} \times 10^3$$

7.6. Filter Archiving and Downstream Analysis

1. After gravimetric analysis, archive filters in sealed Petri dishes at room temperature (or at -20 C if chemical analysis is planned)
2. For elemental/organic carbon analysis, submit quartz filters to the analytical laboratory per their instructions
3. For metals analysis by XRF or ICP-MS, submit PTFE filters per [SOP-L205](#) or [SOP-L410](#)
4. Chemical speciation of collected PM provides source apportionment data that complements the mass concentration measurement (**chow2015?**)

8. Quality Control

- Collect at least one field blank per sampling event: load a conditioned filter into a cassette, transport it to the site, open the cassette briefly (without running the pump), seal, and return to the lab for conditioning and weighing
- Collect duplicate samples (co-located samplers) for at least 10% of sampling events. Duplicate PM concentrations should agree within 15%.
- Verify the balance with NIST-traceable check weights at the start of each weighing session
- Document pre- and post-sampling flow rates; flag samples where the difference exceeds 10%
- Re-condition and re-weigh at least 10% of filters as laboratory duplicates; agreement should be within 0.015 mg
- Negative net masses (post-weight less than pre-weight) can occur due to filter handling artifacts or volatile loss; flag and investigate these, but do not discard without documentation

9. Waste Disposal

Waste Type	Disposal Method
Exposed PTFE or quartz filters (after analysis)	Standard trash (non-hazardous)
Impactor grease and oiled impaction substrates	Chemical waste; EH&S pickup
Used desiccant	Standard trash or regenerate per manufacturer

10. References

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- US Environmental Protection Agency. (2017). *Ambient air monitoring reference and equivalent methods* (40 CFR Part 50, Appendix L). US EPA.

11. Related SOPs

SOP	Title	Relationship
F001	Field Safety	Required prerequisite
F502	Portable PM Sensors	Low-cost sensor companion
F504	Picarro GHG Analyzer	Companion field instrument
F505	Passive Air Samplers	Companion gas-phase sampling
L200	Analytical Balance	Filter weighing
L205	XRF Analysis	Filter metals analysis

12. Training Record

Before deploying PM samplers independently, personnel must:

1. Read this SOP and [SOP-F001](#) in full
2. Demonstrate proper filter handling (forceps, desiccator, conditioning, weighing) under supervision
3. Perform a flow calibration and sampler setup under supervision
4. Deploy and retrieve a sampler for one complete sampling period with acceptable QC results (field blank mass within 0.015 mg of pre-weight; pre/post flow agreement within 10%)
5. Be signed off by the PI or field lead



Environmental Analysis Program

Pomona College
Biogeochemistry Laboratory

SOP-F504

Greenhouse Gas Measurements – Picarro G2508 with Eosense Soil Flux Chambers

Standard Operating Procedure

SOP Number	SOP-F504
Revision	1.01
Author(s)	Marc Los Huertos
Date	2026-06-26
Organization	EA Program, Pomona College

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1. Purpose

This procedure describes how to install Eosense eosAC soil gas flux chambers, connect them to the eosMX-P multiplexer, and operate the Picarro G2508 cavity ring-down spectroscopy (CRDS) analyzer for measuring greenhouse gas fluxes (N₂O, CH₄, CO₂, NH₃, and H₂O) from soil. The SOP also covers data acquisition using the eosAnalyze-AC software and data export for analysis (Eosense Inc., 2019; Picarro, Inc., 2021).

This SOP was originally developed for greenhouse gas emission measurements from strawberry fields in Northern California and has been modified as new projects have come on line.

2. Scope

- **Applies to:** Field deployment of the Picarro G2508 CRDS analyzer coupled with Eosense eosAC dynamic soil flux chambers and the eosMX-P multiplexer for automated soil greenhouse gas flux measurements
- **Does not apply to:** Laboratory (bench-top) Picarro configuration (see [SOP-L504](#)), atmospheric concentration monitoring without flux chambers, or eddy covariance measurements
- **Location:** All EA Program field sites within 30 m cable reach of a power source

3. Responsibilities

Role	Responsibility
Lab PI	Approve deployment plan, review data
Trained Personnel	Set up instruments, run cycles, retrieve data
New Students	Complete training before independent use

3.1. Acknowledgements

We thank Isaac Medina, Neha Vaingankar, and Bailey Lai, who worked with the instrument early on and developed early versions of this SOP. Improvements were made by Allison Joseph and Virginia Paschal.

4. Definitions

- **Cavity ring-down spectroscopy (CRDS):** The laser-based optical detection technique used by the Picarro G2508; a laser pulse is injected into a high-finesse optical cavity and the rate of light decay is measured; the decay rate is proportional to the concentration of absorbing gas molecules, enabling parts-per-billion sensitivity.
- **Chamber closure period:** The time interval during which the eosAC chamber lid is sealed over the soil surface; CO₂, N₂O, CH₄, and NH₃ accumulate in the chamber headspace during this period; flux is calculated from the rate of concentration change.
- **Dead volume:** The total volume of gas in the measurement system (chamber headspace, tubing, and instrument internal volume) that dilutes gas emitted from the soil; must be accurately characterized to calculate flux.
- **Drierite:** Anhydrous calcium sulfate desiccant used to remove water vapor from the gas stream before it enters the Picarro analyzer; must be regenerated or replaced when exhausted (color change from blue to pink for indicating Drierite).
- **eosMX-P multiplexer:** The Eosense controller that cycles sequentially through up to 16 chamber ports, directing flow from each chamber to the Picarro analyzer in turn; automates multi-chamber deployments without manual valve switching.
- **eosAC chamber:** An automated, transparent polycarbonate flux chamber manufactured by Eosense; opens and closes on a programmable schedule; connected to the eosMX-P multiplexer and Picarro analyzer via Teflon tubing.
- **Flux calculation:** Derivation of the gas flux ($\mu\text{mol m}^{-2} \text{ s}^{-1}$ or $\text{nmol m}^{-2} \text{ s}^{-1}$) from the linear or non-linear rate of concentration increase in the chamber headspace, chamber volume, soil surface area enclosed, and air temperature and pressure.
- **N₂O (nitrous oxide):** A potent greenhouse gas (298x CO₂ warming potential over 100 years) produced in soil by nitrification and denitrification; the primary target of many EA Program field campaigns; measured simultaneously with CH₄, CO₂, NH₃, and H₂O by the Picarro G2508.

5. Safety and Hazards

Hazards

- **Physical:** Compressed gas cylinders (calibration standards) pose crush and high-pressure hazards. The generator (if used) presents fuel spill, carbon monoxide, and noise hazards.
- **Chemical:** Drierite desiccant is a mild irritant. Calibration gas cylinders may contain pressurized gases.
- **Electrical:** Power strip, generator, and instrument connections in outdoor conditions; keep connections dry and off the ground.
- **Environmental:** High ambient temperatures (above 35 C) can cause instrument over-heating.

5.1. Required PPE

- ☐ Closed-toed shoes or field boots
- ☐ Safety glasses (when handling gas cylinders)
- ☐ Work gloves (when handling cylinders and generator)
- ☐ Sun protection (hat, sunscreen)
- ☐ Hearing protection (if generator is running nearby)

5.2. Required Training

- [SOP-F001 Field Safety](#)
- [SOP-F101 Electrical Power in the Field](#)

5.3. Emergency Procedures

In case of gas leak from calibration cylinders, move upwind and ventilate the area. For generator fuel spills, contain with absorbent materials. Refer to [SOP-F001 Field Safety](#) for general field emergency response.

6. Equipment and Materials

6.1. Instruments

Item	Serial / Model	Notes
Picarro G2508 CRDS Analyzer	S/N 2143-JFAADS2048	Measures N ₂ O, CH ₄ , CO ₂ , NH ₃ , H ₂ O
Eosense eosMX-P Multiplexer	S/N listed inside device	Connects up to 12 eosAC chambers

Item	Serial / Model	Notes
Recirculation Pump (PN: A0702)	–	Provides vacuum for gas sequencing
Monitor, mouse, and keyboard	–	Connected to Picarro via USB

6.2. Chambers

Chamber S/N (old)	Firmware	Software ID	Field ID	Notes
AC20150501 (1001501)	2.2.4	50501	#1	Unable to identify
NA (1001502)	2.2.4	NA	#2	
AC20150503 (1001503)	2.2.4	50503	#3	
AC20150504 (1001504)	2.2.4	50504	#4	Repaired
AC20150505 (1001505)	2.2.4	50505	#5	
AC20190333 (1001506)	2.2.4	31333	#6	
AC20150507 (1001507)	2.2.4	50507	#7	Unable to identify
AC20150508 (1001508)	2.2.4	50508	#8	
AC20150509 (1001509)	2.2.4	NA	#9	
AC20150510 (1001510)	2.2.4	50510	#10	Fails to close properly / not fully open
AC20150511 (1001511)	2.2.4	50511	#11	
AC20150512 (1001512)	2.2.4	50512	#12	Unsure of status
AC20XX33714 (44714)	??	??	#14	
AC20190315	2.1.1	31315	#15	
AC20190316	2.2.4	31316	#16	
AC20190317	2.2.4	31317	#17	

6.3. Additional Supplies

Item	Notes
Teflon tubing and cables (30 m each)	Lettered; check for damage before use
Corrugated metal hose	Connects pump to analyzer VACUUM port
Swagelok washers	Use new washers each connection
Drierite desiccant	For moisture management
Generator (if no grid power)	Place 100+ feet downwind
Zip ties / Velcro straps	For cable management

6.4. Customer Support Contacts

Organization	Contact
Picarro	Melissa, 408-962-3978; Scott, 408-962-3987; Karrin Alstad (applications/calibration), 408-962-3991

Organization	Contact
Eosense	888-352-8313 (toll-free); support@eosense.com (Eastern Time Zone)

7. Procedure

7.1. Sampling Design

1. Locate the Picarro analyzer, multiplexer, and pump at the base station. Choose a level, shaded location if possible.
2. Use a random number generator to determine the chamber placement locations within the study area
3. All chambers must be within 30 m of the multiplexer (the length of the cables and tubing)
4. If a generator is used, place it at least 100 feet downwind of the chambers to avoid contaminating flux measurements with exhaust

7.2. Hardware Setup

1. Connect the recirculation pump to the analyzer VACUUM port using the corrugated metal hose. Use new Swagelok washers each time. Hand-tighten, then seal with a wrench.
2. Connect the multiplexer to the Picarro through USB ports on the Picarro (any port)
3. Connect the monitor, mouse, and keyboard to the Picarro via the remaining USB ports (two additional ports are available on the front of the Picarro)
4. Connect the blue monitor cable to the Picarro and the monitor power cable to the outlet
5. Ensure all machines are in the off position (circle symbol = off) before connecting power
6. Connect power cables for the CRDS analyzer, multiplexer, and pump
7. Connect the pump to the multiplexer:
 - a. Connect the control and data ports on the back of the pump to the Picarro, ensuring the white triangles face upward
 - b. Insert the other ends into any USB port on the Picarro
8. Connect clear tubing from the pump inlet (left side, clear tube) to the multiplexer inlet (right side, labeled)
9. Connect the outlet tubing: multiplexer outlet to the Picarro inlet (clear tube); pump outlet (right side, silver tube) to the Picarro outlet
10. Attach one end of the power/data cable to the COMM port on the pump and the other end to the matching COMM port on the multiplexer

! Important

Never turn off the pump while the Picarro is running. Never disconnect the vacuum while the analyzer is operating. Doing so can damage the instrument.

7.3. Installing Chamber Rings

Chamber ring installation varies based on experimental design. Install rings in advance of the measurement day to minimize soil disturbance during data collection. *TBD – add project-specific ring installation protocols as needed.*

7.4. Picarro Startup

1. Ensure all instruments are off and turn on the power strip
2. Turn on the recirculation pump first (no wait time required)
3. Switch on the Picarro. The boot-up sequence initializes the CRDS software and analyzer.
4. Switch on the multiplexer. The system requires approximately 30 minutes to warm up; warning alarms are normal until the cavity and other components reach operating temperature.
5. Keep ambient temperature below 35 C. If the DAS temperature approaches 45 C, shut down or use a fan to cool the air around the Picarro.

7.5. Placing Chambers

1. While the Picarro is warming up, connect all tubing and cables. Route tubing along the bed surface; do not let tubes fall into furrows.
2. Place chambers onto the ring bases, pressing down to achieve a good seal. Try to avoid disturbing the chamber after installation.
3. After all chambers have opened, perform a second check for foliage or debris that might obstruct the chamber seal.

7.6. Data Collection

Once the Picarro alarm indicator is green, the system is ready.

1. Verify typical atmospheric concentrations on the Picarro display:

Gas	Expected Ambient Concentration
N ₂ O	Approximately 0.3 ppm
CH ₄	Approximately 2.4 ppm
CO ₂	300–600 ppm
NH ₃	Variable
H ₂ O	1–5%

2. Open the FP-Monitor multiplexer software
3. Uncheck “Default Cycle”
4. Load the appropriate cycle from the user folder. Available cycles include:

- TBD – list current cycle names (e.g., “Straw 5 Chamber,” “Full 12,” “Full 12 minus #4”)
5. When the Picarro G2508 is warm, press “Start Cycle”
 6. Check all chambers to ensure good seals
 7. If a generator is in use, check fuel every two hours and top off. Release pressure before inserting the nozzle into the filler throat. Open the valve and press the green button for 3–5 second intervals, checking between fills to see if fuel is at or near the red line.
 8. Aim for at least 3 complete measurement cycles. For irrigation studies, target 2 cycles before irrigation, 2 during, and 2 after.

7.7. Shutdown

1. After at least two post-irrigation cycles (or at the end of the measurement period), begin retrieving chambers after each one completes its measurement, starting with chamber #1
2. Cap all tube ends with a glove secured by tape
3. Carefully coil each set of tubes and cables to limit twisting and scratching of the Teflon. Zip-tie or Velcro together and stack in order on the ground.
4. Remove chambers from the sampling locations. Separate bases from chambers and repackage into boxes.
5. When the final chamber measurement is complete, end the sampling cycle in the software
6. Connect a spare chamber to a channel and select the “Desiccate” method. Run dry air through the Picarro for 10 minutes to prevent condensation damage (Picarro, Inc., 2021).
7. Initiate the Picarro shutdown sequence; select the option for moving the instrument
8. After the Picarro has fully shut down, manually switch off in this order:
 - a. Multiplexer
 - b. Picarro
 - c. Vacuum pump
 - d. Power strip

8. Calibration

The Picarro G2508 analyzer calibration is intended to be performed infrequently (Picarro, Inc., 2021). The procedure requires three calibration standards per gas species (two points define the calibration line and a third intermediate point is used for verification).

8.1. Calibration Procedure

1. Select calibration standards that span the representative range of concentrations the analyzer will typically measure. A concentration of zero is acceptable for the low-end standard.
2. Introduce the first calibration standard into the analyzer for long enough to yield a stable reading
3. Record the stated concentration of the standard and the analyzer’s displayed value

4. Repeat for the remaining two standards
5. Plot the data with the analyzer's reported concentration on the horizontal axis and the standards' stated concentrations on the vertical axis
6. Calculate a linear best-fit equation. The slope and intercept are used to apply a correction to the analyzer's factory calibration.

i Note

TBD – develop a dedicated calibration SOP including parts to order (permeation tubes, calibration gas cylinders) and a step-by-step calibration workflow. Contact Karrin Alstad at Picarro (408-962-3991) for calibration supplies.

9. Data Export and Analysis

9.1. Using eosAnalyze-AC

1. On the Picarro desktop, open the “eosAnalyze-AC” program. If it is not on the desktop, navigate to Start Menu and search “eosAnalyze-AC.” Open the “eosAnalyze-AC-v3.4.2” folder and run the .exe application.
2. You do not need to wait for the Picarro system to warm up if you are only downloading data.
3. Click “Collect Data.” Enter the start and end times for the period you want to download. Repeat for each cycle separately; combining multiple non-contiguous periods into one export will produce a single table with large time gaps.
4. Ensure the time zone is set correctly. Pacific Time Zone is UTC-8:00.
5. Verify the data under “Measurements.” Check that the correct dates, times, and data graphs look reasonable.
6. Click “Export Data Table” and save the CSV to the desktop or an accessible location.
7. To export additional data tables, close and reopen the program before creating each new export.
8. Transfer the .csv files to a USB drive or external hard drive for analysis on another computer. The files are compatible with Excel or R (R Core Team, 2024).

9.2. Troubleshooting Data Export

If data does not load or you see a “No measurements detected” message:

1. Go to **Data > Analyzer Data Path** in eosAnalyze-AC. The data path should be \UserData\DataLog_Forerunner\. You should see subfolders organized by year.
2. Click OK, then retry collecting data.
3. If the problem persists, use Windows Explorer to search for .DAT files in \UserData\DataLog_Forerunner\YE. The file naming convention is: JFAADS2048-YYYYMMDD-HHMMSS-DataLog_Forerunner.dat where JFAADS2048 is the instrument serial number, followed by the date and time the file was created in 24-hour format.

9.3. Flux Calculation

Soil gas fluxes are calculated from the rate of change of gas concentration within the chamber headspace over the closure period. The eosAnalyze-AC software fits both linear and exponential models to the concentration time series for each closure event (Hutchinson & Mosier, 1981; Livingston & Hutchinson, 1995).

$$F = \frac{V}{A} \cdot \frac{dC}{dt} \cdot \frac{P}{RT}$$

where:

- F = flux (mass per area per time)
- V = chamber headspace volume (L)
- A = chamber area (m²)
- dC/dt = rate of concentration change (ppm/s)
- P = atmospheric pressure (atm)
- R = ideal gas constant
- T = temperature (K)

TBD – clarify in eosAnalyze-AC output what (L) and (E) designations mean for flux values (likely Linear and Exponential fits). Confirm whether “dead band range” and “chamber offset” in the data processor options need to be set for each deployment.

10. Quality Control

- Verify atmospheric background concentrations before starting each measurement cycle (see table in Section 6.6)
- Inspect all tubing connections for leaks before each deployment
- Check chamber seals visually and by monitoring initial concentration traces
- Log any chambers that fail to open or close properly and remove them from the dataset
- Do not disconnect chambers from the multiplexer during an active measurement cycle, as this can cause the data processor to miss measurements
- Ensure the FRMonitor software recognizes all connected chambers at startup; use the “System Info” button to verify. Chambers not recognized will not record data even if they open and close.
- Use FRMonitor software version 1.6.2 or later to schedule measurements

10.1. Biases and Interferences

- Ambient temperature extremes can prevent the analyzer from stabilizing properly
- High-moisture gas samples can cause condensation damage. Always run dry air through the instrument for several minutes before shutdown (Picarro, Inc., 2021).
- *TBD – develop QC criteria for acceptable flux curve fits (r^2 thresholds, maximum allowable dead band)*

11. Waste Disposal

Waste Type	Disposal Method
Spent Drierite desiccant	Regenerate by heating at 210 C or dispose as non-hazardous solid waste
Generator fuel spills	Absorb with spill kit materials; dispose per EH&S
Damaged Teflon tubing	Standard trash (non-hazardous)

12. References

- Eosense Inc. (2019). *eosAC automated soil CO₂ flux chamber and eosMX-P multiplexer: User manual*. <https://eosense.com/products/eosac/>
- Hutchinson, G. L., & Mosier, A. R. (1981). Improved soil cover method for field measurement of nitrous oxide fluxes. *Soil Science Society of America Journal*, 45(2), 311–316. <https://doi.org/10.2136/sssaj1981.03615995004500020017x>
- Livingston, G. P., & Hutchinson, G. L. (1995). Enclosure-based measurement of trace gas exchange: Applications and sources of error. *Biogenic Trace Gases: Measuring Emissions from Soil and Water*, 14–51.
- Picarro, Inc. (2021). *G2508 gas concentration analyzer for N₂O, CH₄, CO₂, NH₃, and H₂O: User's guide*. https://www.picarro.com/environmental/products/g2508_gas_concentration_analyzer
- R Core Team. (2024). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. <https://www.R-project.org/>

13. Training Record

Before deploying this instrument independently, personnel must:

1. Read this SOP, [SOP-F001 Field Safety](#), and [SOP-F101 Electrical Power in the Field](#)
2. Observe a trained operator perform a full deployment (setup through shutdown)
3. Demonstrate competence with hardware connections (pump, multiplexer, tubing, chambers)
4. Perform a supervised deployment including startup, data collection, and shutdown
5. Demonstrate ability to export data using eosAnalyze-AC
6. Be signed off by the PI or field lead

14. Appendix A: Troubleshooting

14.1. Days with Unexpected Data

If data appears on unexpected Julian days, check whether the system clock or local time on the analyzer has been changed. Compare the processed measurements against field notes to identify obvious gaps that may correspond to mislabeled days.

14.2. Days That Should Have More Data

Errors in FRMonitor log files can cause the data processor to overlook measurements. If measurements appear to be missing, check the FRMonitor logs for errors. Do not disconnect chambers from the multiplexer while it is actively running a measurement cycle, as this can cause the data processor to miss measurements, especially if the chamber was closed when removed.

14.3. Days Where Some Chambers Are Missing

If certain chambers (e.g., #1 or #2) are not sending data, this indicates either a communication issue between the multiplexer and analyzer or that the chambers were not connected. Verify that the FRMonitor software recognizes all connected chambers at startup using the “System Info” button. Disconnecting and reconnecting chambers during a measurement cycle can also cause communication errors.

14.4. N₂O Noise

N₂O measurements from the Picarro G2508 can be noisy at ambient concentrations. *TBD – document strategies for reducing N₂O noise (e.g., longer closure times, post-processing smoothing, data filtering thresholds). Contact Picarro technical support for recommendations.*

15. Appendix B: Open Questions

The following questions from previous deployments remain unresolved. Update this appendix as answers are obtained.

1. What is the difference between “dry,” “regular,” and “timed” data columns in the Data Logger setup tool?
2. What is “etalon temp” (listed under sensors in the data source)?
3. Recommendations for car-mounting the instrument? Is it acceptable to stack the multiplexer on top of the Picarro during transport?
4. Is there a way to turn on the computer without powering on the gas analyzer and vacuum?
5. What files need to be sent to the PI for reprocessing?
6. Should chamber offset (distance between the bottom of the chamber and the soil surface due to the collar) be measured for each chamber at each deployment?



Environmental Analysis Program

Pomona College
Biogeochemistry Laboratory

SOP-F505

Passive Air Samplers – Diffusion Tubes

Standard Operating Procedure

SOP Number	SOP-F505
Revision	0.2
Author(s)	Marc Los Huertos
Date	2026-06-26
Organization	EA Program, Pomona College

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1. Purpose

This procedure describes the deployment, retrieval, and documentation of passive (diffusion-based) air samplers for time-integrated measurement of gaseous air pollutants. Passive samplers require no pump or power supply: the target gas diffuses along a concentration gradient through a defined path length and is captured by a sorbent or reactive medium at the closed end of the tube. After a

known exposure period, the sampler is sealed, returned to the laboratory, and analyzed to determine the time-weighted average ambient concentration (Cape, 2009; Palmes et al., 1976).

Common target analytes include nitrogen dioxide (NO_2), ozone (O_3), sulfur dioxide (SO_2), ammonia (NH_3), and volatile organic compounds (VOCs). Passive samplers are widely used in spatial surveys and community-based exposure studies because they are inexpensive, silent, and require no electricity, making dense network deployments feasible (Vardoulakis et al., 2005; martin2014?).

Passive diffusion tubes are subject to known biases from wind speed, temperature, and tube geometry that must be understood and managed through quality control (Plaisance et al., 2004; Tang et al., 2001). When operated according to harmonized protocols and validated against active reference methods, passive samplers can provide data suitable for regulatory screening and spatial mapping (hafkenscheid2009?).

2. Scope

- **Applies to:** Deployment and retrieval of passive diffusion tube samplers (e.g., Palmes tubes for NO_2 , Ogawa badges for NO_2/O_3 , Radiello cartridges for VOCs/ NH_3) at EA Program field sites
- **Does not apply to:** Active (pump-based) gas sampling; passive PM samplers; low-cost electronic gas sensors; laboratory analysis of exposed samplers (handled by the analytical laboratory or per analyte-specific lab SOPs)
- **Location:** EA Program field deployment sites

3. Responsibilities

Role	Responsibility
PI / Field Lead	Approve sampling design, select sampler type and analytical lab
Trained Personnel	Deploy, retrieve, and document samplers
New Students	Complete training before independent deployment

4. Definitions

- **Passive (diffusion) sampler:** A device that collects a gaseous pollutant by molecular diffusion along a concentration gradient, without requiring a pump. The sampler relies on Fick's first law of diffusion to relate the mass of analyte captured to the ambient concentration over the exposure period (Palmes et al., 1976).
- **Palmes tube:** A cylindrical passive sampler (typically 7.1 cm long, 1.1 cm internal diameter) with a triethanolamine (TEA)-coated stainless steel grid at the closed end for NO_2 collection. Originally described by Palmes et al. (1976).
- **Ogawa badge:** A disk-shaped passive sampler with two collection pads separated by a diffusion barrier. Can be configured for NO_2 , O_3 , or SO_2 .

- **Radiello cartridge:** A radial-symmetry passive sampler with a cylindrical diffusive body surrounding a sorbent cartridge. Used for VOCs (Carbograph sorbent), NH_3 (acid-coated), and other gases.
- **Uptake rate:** The rate at which the target analyte diffuses into the sampler, determined by the diffusion coefficient of the gas, the cross-sectional area, and the path length. Published uptake rates are specific to each sampler-analyte combination and are used to convert captured mass to ambient concentration.
- **Time-weighted average (TWA):** The mean ambient concentration over the exposure period, calculated from the total mass captured and the exposure duration.
- **Shortening ratio:** The effective reduction in diffusion path length caused by wind-induced turbulence at the open end of a Palmes tube, which increases the uptake rate and causes overestimation of ambient concentration in windy conditions (Tang et al., 2001).
- **Field blank:** A sampler transported to the site, briefly opened and re-sealed without exposure, then returned to the lab. Field blank analyte mass quantifies contamination from handling, storage, and transport.
- **Triethanolamine (TEA):** A viscous organic amine used as the absorbent medium for NO_2 in Palmes tubes. TEA reacts with NO_2 to form nitrite, which is subsequently analyzed by the Griess colorimetric reaction.
- **Fick's first law:** The principle that the flux of a gas through a still-air column is proportional to the concentration gradient and the diffusion coefficient:

$$J = D \times \frac{A}{L} \times C$$

where J = flux (mass/time), D = diffusion coefficient, A = cross-sectional area, L = path length, and C = ambient concentration (Palmes et al., 1976).

5. Safety and Hazards

Hazards

- **Chemical:** Some sorbent media (e.g., triethanolamine for NO_2) are mild irritants. Handle prepared tubes with gloves and avoid skin contact with the open end.
- **Traffic:** Many monitoring locations are near roadways. Wear a high-visibility vest and follow [SOP-F001](#) traffic safety procedures.
- **Height:** Mounting samplers on poles or structures may require ladder work. Follow standard ladder safety.

5.1. Required PPE

- ☐ Nitrile gloves (when handling samplers)
- ☐ Closed-toed shoes
- ☐ High-visibility vest (if near roadways)
- ☐ Sun protection

6. Equipment and Materials

Item	Notes
Passive samplers (type matched to target analyte; see Section 7.1)	Pre-prepared by analytical lab or in-house
Protective rain shelters (inverted cup or tube shelter)	Shields the open end from rain and direct sunlight while allowing airflow
Mounting clips, zip ties, or cable ties	For attaching shelters and tubes to poles, posts, or structures
Airtight storage containers or bags	For transporting unexposed and exposed samplers
Cooler with ice packs (for heat-sensitive sorbents)	Maintain at 4 C during transport if required
GPS unit	Per SOP-F006
Field notebook and deployment log	For recording dates, times, and site conditions
Permanent marker (Sharpie)	For labeling tubes

7. Procedure

7.1. Sampler Selection

Select the sampler type based on the target analyte and exposure period:

Target Analyte	Sampler Type	Typical Exposure	Analytical Method
NO ₂	Palmes diffusion tube (TEA-coated grids)	1–4 weeks	Spectrophotometry (Griess reaction)
NO ₂ / O ₃	Ogawa passive sampler	1–2 weeks	Spectrophotometry
NH ₃	Radiello cartridge or acid-coated filter	1–4 weeks	Spectrophotometry or IC
VOCs (BTEX)	Radiello cartridge (Carbograph sorbent) or 3M OVM badge	1–4 weeks	GC-MS (thermal desorption)
SO ₂	Impregnated filter or Radiello cartridge	1–4 weeks	Ion chromatography

Note

The analytical laboratory typically prepares and supplies the samplers, pre-loaded with the appropriate sorbent. Confirm sampler type, handling instructions, and shipping requirements with the lab before each deployment.

7.2. Pre-Deployment

1. Keep sealed samplers refrigerated (4 C) until deployment day unless the analytical lab specifies otherwise
2. Assign a unique ID to each sampler and record it in the deployment log
3. Designate at least 2 field blanks per batch: samplers that travel to the site, are briefly unsealed (less than 30 seconds), re-sealed, and returned to the lab with the exposed samplers

7.3. Deployment

1. At the monitoring location, mount the rain shelter at a height of 2–3 m above ground, away from walls (at least 1 m), exhaust vents, and vegetation canopy
2. Remove the sampler from its sealed container, note the date and time, and attach the open end downward inside the rain shelter
3. Secure the sampler with clips or zip ties
4. Record in the field notebook: site ID, sampler ID, deployment date/time, GPS coordinates, mounting height, distance to nearest road, weather conditions, and any potential sources nearby
5. Photograph the installed sampler for documentation

! Wind Exposure

Palmes tubes are sensitive to wind speed: turbulence at the open end of the tube effectively shortens the diffusion path, increasing the uptake rate and overestimating the ambient concentration by 10–30% at exposed sites (Plaisance et al., 2004; Tang et al., 2001). Rain shelters provide partial wind screening, but sheltered or recessed mounting locations should be avoided because they restrict airflow and cause underestimation. The harmonized EU protocol recommends mounting in locations with moderate, representative air exchange (hafkenscheid2009?).

7.4. Exposure Period

- The exposure period depends on the expected ambient concentration and the sampler's capacity. Follow the analytical lab's recommendation (typically 1–4 weeks for NO₂ Palmes tubes).
- Note any unusual events during the exposure period (wildfires, construction, power outages affecting nearby sources) in the field notebook.

7.5. Retrieval

1. Record the retrieval date and time in the field notebook
2. Remove the sampler from the shelter, immediately cap or seal it, and place in an airtight container or bag
3. Calculate the total exposure time in hours
4. Place sealed samplers in a cooler with ice packs for transport (if required by the analytical lab)

5. Retrieve and seal the field blanks in the same manner

7.6. Shipping to Analytical Laboratory

1. Pack sealed samplers securely with cushioning material in an insulated shipping container with ice packs (if heat-sensitive)
2. Include a chain of custody form listing all sampler IDs, site locations, deployment and retrieval dates/times, and total exposure hours
3. Ship via overnight courier or deliver in person to the analytical lab

7.7. Concentration Calculation

The analytical laboratory reports the mass of analyte captured on each sampler. The time-weighted average ambient concentration is calculated using Fick's first law (Palmer et al., 1976):

$$C = \frac{m}{D \times A/L \times t}$$

where:

- C = ambient concentration ($\mu\text{g}/\text{m}^3$ or ppb, after unit conversion)
- m = mass of analyte on the sampler (μg)
- D = molecular diffusion coefficient of the analyte in air (cm^2/s)
- A = cross-sectional area of the diffusion path (cm^2)
- L = length of the diffusion path (cm)
- t = exposure time (s)

Note

The analytical lab typically performs this calculation using published uptake rates for the specific sampler-analyte combination. Confirm which party is responsible for the calculation.

8. Quality Control

- Deploy at least 2 field blanks per batch (minimum 10% of total samplers). Field blank analyte mass should be below the method detection limit; if not, subtract the mean field blank mass from all samples.
- Deploy co-located duplicate samplers at 10% of sites. Duplicates should agree within 20% for NO_2 Palmer tubes (Cape, 2009). Duplicate agreement worse than 25% indicates handling problems or site-specific wind interference (Plaisance et al., 2004).
- If collocating with an active reference sampler (chemiluminescence NO_2 analyzer, UV O_3 analyzer), compare the passive sampler result with the reference average over the same period. Palmer tubes for NO_2 typically overestimate the reference by 10–30% at high-wind sites and underestimate at sheltered sites due to restricted airflow (Tang et al., 2001).

- Document any site disturbances (construction, shelter damage, vandalism) that could affect results.
- Archive field notebooks and chain of custody forms with the project data.

9. Waste Disposal

Waste Type	Disposal Method
Exposed Palmes tubes (TEA grids)	Return to analytical lab or dispose as chemical waste (TEA is a mild irritant)
Radiello cartridges (used)	Return to analytical lab
Rain shelters and mounting hardware	Clean and reuse

10. References

- Cape, J. N. (2009). The use of passive diffusion tubes for measuring concentrations of nitrogen dioxide in air. *Critical Reviews in Analytical Chemistry*, 39(4), 289–310. <https://doi.org/10.1080/10408340903001613>
- Palmes, E. D., Gunnison, A. F., DiMaggio, J., & Tomczyk, C. (1976). Personal sampler for nitrogen dioxide. *American Industrial Hygiene Association Journal*, 37(10), 570–577. <https://doi.org/10.1080/0002889768507522>
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- Vardoulakis, S., Gonzalez-Flesca, N., Fisher, B. E. A., & Pericleous, K. (2005). Spatial variability of air pollution in the vicinity of a permanent monitoring station in central England. *Atmospheric Environment*, 39(15), 2725–2736. <https://doi.org/10.1016/j.atmosenv.2004.05.067>

11. Related SOPs

SOP	Title	Relationship
F001	Field Safety	Required prerequisite
F502	Portable PM Sensors	Companion low-cost sensor SOP
F503	PM Filter Sampling	Active filter sampling companion
F504	Picarro GHG Analyzer	Companion field instrument
F510	Weather Monitoring	Wind data for interpreting bias

12. Training Record

Before deploying passive air samplers independently, personnel must:

1. Read this SOP and [SOP-F001](#) in full
2. Review the handling instructions provided by the analytical laboratory for the specific sampler type
3. Observe a trained operator demonstrate deployment and retrieval at one site
4. Deploy and retrieve samplers at one site under supervision, including field blank handling
5. Be signed off by the PI or field lead



Environmental Analysis Program

Pomona College
Biogeochemistry Laboratory

SOP-F506

Noise Level Monitoring

Standard Operating Procedure

SOP Number	SOP-F506
Revision	0.1
Author(s)	Marc Los Huertos
Date	2026-06-26
Organization	EA Program, Pomona College

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1. Purpose

This procedure describes field measurement and documentation of environmental noise levels using handheld sound level meters and logging dosimeters. Environmental noise is an increasingly recognized pollutant affecting human health (cardiovascular risk, sleep disturbance, cognitive impairment) and wildlife behavior (altered communication, habitat avoidance) (Barber et al., 2010; World Health Organization, 2018).

Noise monitoring in the EA Program supports community environmental assessments, transportation corridor studies, urban ecology research, and environmental justice analyses where noise disproportionately affects disadvantaged communities.

2. Scope

- **Applies to:** Outdoor environmental noise measurements (community noise, traffic noise, construction noise, natural soundscapes) using Type 1 or Type 2 integrating sound level meters and personal noise dosimeters
- **Does not apply to:** Occupational noise exposure assessment (governed by OSHA standards and conducted by campus EH&S); indoor building acoustics; underwater acoustics
- **Location:** All EA Program field sites

3. Responsibilities

Role	Responsibility
PI / Field Lead	Approve monitoring design, coordinate site access
Trained Personnel	Calibrate instruments, collect and document measurements
New Students	Complete training before independent monitoring

4. Definitions

- **A-weighting (dBA):** A frequency-weighting filter applied to sound level measurements that approximates the frequency-dependent sensitivity of the human ear; attenuates low and very high frequencies; the standard weighting for environmental and community noise assessments.
- **Calibrator:** A portable acoustic device that produces a reference tone of known sound pressure level (typically 94 dB or 114 dB at 1,000 Hz) used to verify sound level meter accuracy before and after each measurement session.
- **Day-night average sound level (L_{dn}):** A 24-hour energy-averaged sound level with a 10 dB penalty added to nighttime (10 pm–7 am) levels to account for increased sensitivity to noise during sleep; the primary US EPA regulatory descriptor for community noise exposure.
- **Equivalent continuous sound level (L_{eq}):** The steady-state sound level that would contain the same acoustic energy as the actual time-varying sound over a defined measurement period; the primary descriptor for environmental noise measurements; expressed in dB or dBA.
- **L_{max} / L_{min} :** The maximum and minimum instantaneous A-weighted sound levels measured during a monitoring period; used to characterize the range of noise events and identify peak exposures.
- **Percentile level (L_N):** The sound level exceeded for N% of the measurement period (e.g., L_{90} is the level exceeded 90% of the time); L_{90} approximates background noise; L_{10} approximates peak intrusive noise events.

- **Sound level meter:** An instrument that measures sound pressure level in decibels; classified as Type 1 (precision, laboratory and field) or Type 2 (general purpose); Type 1 meters are required for regulatory compliance measurements; both types are acceptable for research.
- **Sound pressure level (SPL):** A logarithmic measure of the effective pressure of a sound wave relative to a reference pressure of 20 μPa (the threshold of human hearing): $SPL = 20 \log_{10}(p/p_0)$; expressed in decibels (dB).
- **Windscreen:** A porous foam or fur cover placed over the microphone to reduce turbulent airflow noise caused by wind; required for all outdoor measurements to prevent wind-induced artifacts from contaminating sound level data.

5. Safety and Hazards

Hazards

- **Traffic:** Noise monitoring often occurs near roadways. Wear a high-visibility vest. Never stand in a travel lane.
- **Hearing:** If monitoring near very loud sources (e.g., active construction, aircraft operations above 85 dBA), wear hearing protection.
- **Personal safety:** Monitoring in urban areas may involve working alone or in unfamiliar neighborhoods. Work in pairs when possible and inform someone of your schedule and locations.

5.1. Required PPE

- ☐ High-visibility vest (near roadways)
- ☐ Hearing protection (if sustained levels exceed 85 dBA)
- ☐ Closed-toed shoes
- ☐ Sun protection

6. Equipment and Materials

Item	Notes
Integrating sound level meter (Type 1 or Type 2, IEC 61672)	With A-weighting and slow/fast time weighting
Acoustic calibrator (94 dB or 114 dB reference)	Matched to the microphone; calibrate before and after each session
Windscreen (foam cover for microphone)	Required for all outdoor measurements
Tripod with microphone mount	Position microphone at 1.2–1.5 m above ground
Noise dosimeter (optional)	For unattended time-integrated measurements
GPS unit or smartphone	For recording coordinates
Field notebook and noise monitoring data sheet	Record metadata and observations

Item	Notes
Stopwatch or timer	For timed measurement intervals
Camera	For photo-documenting site and source conditions
Spare batteries	For the meter and calibrator

7. Procedure

7.1. Pre-Field Calibration

1. In a quiet indoor location, attach the acoustic calibrator to the microphone and turn on the calibrator
2. Adjust the sound level meter reading to match the calibrator reference level (e.g., 94.0 dB) per the meter's calibration procedure
3. Record the calibration date, time, calibrator serial number, and meter reading in the field notebook
4. If the meter reading deviates from the reference by more than 0.5 dB, recalibrate or service the instrument

7.2. Site Setup

1. Select a measurement location that represents the receptor of interest (e.g., residential facade, park boundary, school playground)
2. Position the microphone on a tripod at 1.2–1.5 m above the ground, at least 3.5 m from any large reflecting surface (building wall, barrier, parked vehicle) to minimize reflections (Acoustics – Description, Measurement and Assessment of Environmental Noise – Part 2, 2017)
3. Orient the microphone toward the dominant noise source (or upward if the sound field is diffuse)
4. Attach the windscreen
5. Record: site ID, GPS coordinates, date, time, weather conditions (wind speed and direction, temperature), distance and bearing to the dominant source(s), ground cover, and any shielding

Important

Do not measure when wind speed exceeds 5 m/s (approximately 11 mph). Wind noise inflates readings even with a windscreen. Record the wind speed at the start and end of each measurement period.

7.3. Measurement Protocol

The following protocol collects standard community noise metrics. Adjust the duration and intervals to match the study design.

1. Set the meter to: A-weighting, fast time constant, and L_{eq} (equivalent continuous level) integration mode
2. Start the measurement and let it run for the designated period:
 - **Short-term survey:** 15 minutes per measurement location (the minimum recommended by most community noise standards)
 - **1-hour L_{eq} :** Run for 60 minutes if comparing to local noise ordinance limits
 - **Long-term (24-hour):** Use a dosimeter or logging meter; deploy and secure the instrument
3. During the measurement, note all significant noise events in the field notebook: vehicle pass-bys, aircraft overflights, dog barking, construction activity, etc. Record the time and estimated duration of each event.
4. At the end of the measurement period, record the following metrics from the meter display:
 - L_{eq} (equivalent continuous level)
 - L_{max} (maximum level)
 - L_{min} (minimum level)
 - L_{10} , L_{50} , L_{90} (statistical levels, if the meter computes them)
5. If the meter logs time-history data, download the file after the session

7.4. Post-Field Calibration Check

1. After the final measurement at the last site, re-check the calibration with the acoustic calibrator
2. Record the post-measurement calibration reading. If it differs from the pre-measurement value by more than 1.0 dB, flag all data from that session for review.

7.5. Data Recording

For each measurement, record on the data sheet:

- Site ID, GPS coordinates, date, start/end times
- Meter make, model, serial number
- Calibration readings (pre and post)
- Weather: wind speed/direction, temperature, sky conditions
- Source description and distance
- Measurement duration and metrics (L_{eq} , L_{max} , L_{min} , L_{10} , L_{50} , L_{90})
- Notable noise events and their times
- Observer name

8. Data Interpretation

Metric	Meaning
L_{eq}	Energy-averaged sound level over the measurement period; the single most important descriptor of community noise exposure
L_{max}	Highest instantaneous level recorded
L_{min}	Lowest instantaneous level recorded
L_{10}	Level exceeded 10% of the time (approximates “loud” events)
L_{50}	Median level
L_{90}	Level exceeded 90% of the time (approximates background or residual noise)
L_{dn}	Day-night average; L_{eq} with a 10 dB penalty applied to nighttime (10 PM–7 AM) hours

i Note

Community noise standards in California (Title 24, local general plans) typically set limits in terms of L_{dn} (CNEL) or L_{eq} for specific land use categories. A residential exterior standard of 60–65 dB L_{dn} is common.

9. Quality Control

- Calibrate before and after every measurement session; flag data if drift exceeds 1.0 dB
- Use the windscreen for all outdoor measurements
- Do not measure when wind speed exceeds 5 m/s
- Record all extraneous noise events so they can be identified in the time-history data
- For long-term deployments, perform a calibration check at each data retrieval visit
- Maintain a calibration and maintenance log for each meter

10. Waste Disposal

No waste is generated by noise monitoring. Dispose of used batteries per campus battery recycling procedures.

11. References

- Acoustics – Description, Measurement and Assessment of Environmental Noise – Part 2: Determination of Sound Pressure Levels, Pub. L. Nos. ISO 1996-2:2017 (2017).
- Barber, J. R., Crooks, K. R., & Fristrup, K. M. (2010). The costs of chronic noise exposure for terrestrial organisms. *Trends in Ecology and Evolution*, 25(3), 180–189. <https://doi.org/10.1016/j.tree.2009.08.002>
- World Health Organization. (2018). *Environmental noise guidelines for the European Region*. WHO Regional Office for Europe. <https://www.who.int/europe/publications/i/item/9789289053563>

12. Related SOPs

SOP	Title	Relationship
F001	Field Safety	Required prerequisite
F502	Portable PM Sensors	Companion air monitoring SOP
F505	Passive Air Samplers	Companion air monitoring SOP

13. Training Record

Before performing noise monitoring independently, personnel must:

1. Read this SOP and [SOP-F001](#) in full
2. Demonstrate proper calibration of the sound level meter
3. Perform a supervised 15-minute measurement at one site, including correct microphone positioning, windscreen use, event logging, and post-calibration check
4. Demonstrate ability to read and record L_{eq} , L_{max} , L_{min} , and statistical levels from the meter
5. Be signed off by the PI or field lead



Environmental Analysis Program

Pomona College
Biogeochemistry Laboratory

SOP-F510

Weather Monitoring and Field Meteorology

Standard Operating Procedure

SOP Number	SOP-F510
Revision	0.2
Author(s)	Marc Los Huertos
Date	2026-06-26
Organization	EA Program, Pomona College

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1. Purpose

This SOP describes procedures for recording weather and meteorological conditions during field activities. Documenting weather conditions at the time of sampling is essential for interpreting environmental data, identifying storm-driven events, establishing baseline climate conditions, and ensuring field safety. This SOP covers manual weather observations, use of portable weather instruments, and deployment of unattended data loggers for continuous monitoring (World Meteorological Organization, 2018).

2. Scope

- **Applies to:** All EA Program field activities where weather conditions may affect data interpretation, sample quality, or personnel safety; deployment and retrieval of portable weather stations and data loggers
- **Does not apply to:** Climate modeling or historical meteorological analysis; operation of fixed, permanently installed weather stations managed by other departments; air quality monitoring (see [SOP-F502](#))
- **Location:** All EA Program field sites

3. Responsibilities

Role	Responsibility
PI / Field Lead	Identify which weather variables are required for the project; approve deployment of data loggers
Trained Personnel	Record weather observations, deploy and retrieve loggers, download data
New Students	Complete training before independent use

4. Definitions

- **Beaufort scale:** A standardized scale (0–12) relating wind speed to observable effects on land or water; allows wind speed estimation without instruments; developed by Admiral Beaufort in 1805 and adopted as the international standard by the WMO (World Meteorological Organization, 2018).
- **Cloud cover:** The fraction of the sky obscured by clouds, expressed in tenths (0–10) or oktas (0–8); recorded with each manual weather observation (World Meteorological Organization, 2018).
- **Dew point:** The temperature to which air must be cooled at constant pressure for condensation to occur; a direct measure of absolute humidity; can be derived from wet-bulb temperature measurements (World Meteorological Organization, 2018).
- **HOBOnnect:** The Onset smartphone app used to program and download data from Bluetooth-enabled MX-series HOBO loggers (Onset Computer Corporation, 2021).
- **Kestrel meter:** A handheld weather meter (Kestrel 3000 or similar) that simultaneously measures air temperature, relative humidity, wind speed, barometric pressure, and derived quantities (dew point, wet-bulb temperature, heat index); the standard portable weather instrument for EA Program field use.
- **Radiation shield:** A ventilated white housing that surrounds a temperature or humidity sensor to prevent direct solar radiation from inflating measured air temperatures; mandatory for any sensor exposed to sunlight (World Meteorological Organization, 2018).
- **Relative humidity (RH):** The ratio of actual water vapor pressure to saturation vapor pressure at the same temperature, expressed as a percentage; affects evapotranspiration,

dew deposition, and physical and biological processes at field sites (World Meteorological Organization, 2018).

- **Screen height:** The standard height of 1.5 m above ground level for air temperature and humidity measurements; specified by the WMO to ensure comparability between stations and with published meteorological data (World Meteorological Organization, 2018).
- **Sling psychrometer:** A pair of wet-bulb and dry-bulb thermometers mounted on a frame that is swung to ventilate the sensors; used to determine relative humidity from the wet-bulb depression; a reliable low-cost alternative to electronic sensors.
- **WMO (World Meteorological Organization):** The United Nations agency responsible for international meteorological and hydrological standards; its Guide to Meteorological Instruments and Methods of Observation (WMO-No. 8) is the authoritative reference for field measurement practice (World Meteorological Organization, 2018).

5. Safety and Hazards

Hazards

- **Lightning:** Cease all field activities and seek shelter in a vehicle or enclosed structure when lightning is observed. Wait at least 30 minutes after the last lightning strike before resuming.
- **Heat:** Southern California field sites can exceed 40 °C. Carry adequate water, take shade breaks, and monitor for heat-related illness.
- **Wind:** High winds can topple tripod-mounted instruments and create hazardous conditions near exposed ridgelines or water bodies.
- **Flooding:** Rapidly changing weather can cause flash flooding in Southern California canyons and channels. Monitor upstream conditions and have an evacuation route planned.

5.1. Required PPE

- ☐ Closed-toed shoes or field boots
- ☐ Sun protection (hat, sunscreen)

5.2. Emergency Procedures

Refer to [SOP-F001 Field Safety](#).

6. Equipment and Materials

Item	Notes
Kestrel 3000 or equivalent meter	For air temperature, RH, wind speed
Sling psychrometer	Backup for RH measurement

Item	Notes
Rain gauge (manual graduated cylinder)	For precipitation measurement
HOBO MX-series data logger	For unattended monitoring per SOP-F204
Radiation shield (RS3 or similar)	Required for any temperature sensor exposed to sunlight (World Meteorological Organization, 2018)
Compass	For wind direction measurement
Field notebook	Per SOP-F003

7. Procedure

7.1. Manual Weather Observations

Record weather conditions at the start and end of each field session, and at any time conditions change notably. Enter all observations in the field notebook per [SOP-F003](#) (World Meteorological Organization, 2018).

Variable	Method	Units
Air temperature	Kestrel, sling psychrometer, or digital thermometer at 1.5 m in shade	°C
Relative humidity	Kestrel or sling psychrometer	%
Wind speed	Kestrel or Beaufort scale estimate	m/s or Beaufort number
Wind direction	Compass bearing from which wind blows	degrees or cardinal direction
Cloud cover	Visual estimate	Tenths (0–10)
Cloud type	Identify dominant type	Name (cumulus, cirrus, etc.)
Precipitation	Observation and rain gauge	mm; note type (rain, drizzle, none)
Barometric pressure	Kestrel or smartphone app	hPa

Tip

If you do not have a weather instrument, still record qualitative observations. A note such as “clear sky, calm winds, warm” is far better than no record. Note the source of any online weather data (e.g., “NWS Ontario station, 08:00 reading”).

7.2. Beaufort Wind Scale (Quick Reference)

Beaufort	Description	Speed (m/s)	Visual Indicator
0	Calm	< 0.3	Smoke rises vertically
1	Light air	0.3–1.5	Smoke drifts
2	Light breeze	1.6–3.3	Leaves rustle
3	Gentle breeze	3.4–5.4	Leaves and twigs in motion
4	Moderate breeze	5.5–7.9	Small branches move; dust rises
5	Fresh breeze	8.0–10.7	Small trees sway
6	Strong breeze	10.8–13.8	Large branches in motion

(World Meteorological Organization, 2018)

7.3. Deploying Portable Data Loggers

1. Select a deployment location representative of site conditions and unlikely to be disturbed by people, animals, or flooding.
2. Mount temperature and humidity loggers inside a radiation shield at 1.5 m above ground per WMO screen height standards (World Meteorological Organization, 2018). Secure to a tripod, post, or tree.
3. Mount rain gauges on a level surface with no overhead obstructions. The gauge orifice should be approximately 1 m above ground.
4. Program the logger using the HOBObconnect app or HOBOWare software per [SOP-F204](#) (Onset Computer Corporation, 2021):
 - Logging interval: typically 5 or 15 minutes
 - Start mode: delayed start
 - Time zone: Pacific Time
5. Record in the field notebook: logger serial number, GPS coordinates, deployment date and time, logging interval, sensor height.
6. Photograph the deployed logger with surrounding context.

7.4. Retrieving Data from Loggers

1. Connect to the logger via Bluetooth (HOBObconnect) or USB cable (Onset Computer Corporation, 2021).
2. Download the data and save using the naming convention: `YYYY-MM-DD_SiteID_LoggerSN_weather.csv`
3. Do not clear the logger memory until you have verified the file contains the expected date range.
4. Upload the raw data file to the project GitHub repository under `data/weather/` within 48 hours.

7.5. Using Online Weather Data

When on-site instruments are unavailable, supplement field observations with data from nearby weather stations. Preferred sources for Southern California:

Source	URL
NWS	https://www.weather.gov
MesoWest / SynopticData	https://synopticdata.com/mesowest
CIMIS	https://cimis.water.ca.gov
Weather Underground	https://www.wunderground.com

Record the station name, distance from field site, and retrieval date in the field notebook and data file metadata.

8. Quality Control

- Cross-check manually recorded air temperature against the nearest reliable weather station (NWS or CIMIS). Discrepancies greater than 3 °C at similar elevation and time should be investigated (World Meteorological Organization, 2018).
- Inspect data loggers for drift by deploying two loggers side by side for at least 24 hours once per year. Temperature readings should agree within 0.5 °C; humidity within 5%.
- Check rain gauge calibration at least once per year by pouring a known volume of water through the gauge and comparing the logged total to the expected value.
- Flag any suspicious data (e.g., sudden temperature jumps, constant humidity at 100% for days) during data review and note the issue in the project data log.

9. References

- World Meteorological Organization (2018)
- Onset Computer Corporation (2023)
- Onset Computer Corporation (2021)

Onset Computer Corporation. (2021). *HOBOWare user's guide*. https://www.onsetcomp.com/files/manual_pdfs/10246-K-MAN-HOBOWare.pdf

Onset Computer Corporation. (2023). *HOBO U23 Pro v2 external temperature data logger: User manual*. <https://www.onsetcomp.com/products/data-loggers/u23-004>

World Meteorological Organization. (2018). *Guide to meteorological instruments and methods of observation (WMO-no. 8)* (2018th ed.). World Meteorological Organization. <https://library.wmo.int/idurl/4/41650>

10. Related SOPs

SOP	Title	Relationship
F001	Field Safety	Lightning and heat safety
F003	Field Notebook Protocols	Weather recorded in notebook

SOP	Title	Relationship
F006	GPS and Site Navigation	Logger deployment coordinates
F204	HOBO Weather Station Deployment	Detailed logger procedures
F501	Air Temperature Monitoring	Dense sensor network SOP
L801	RStudio and GitHub	Data file version control

11. Training Record

Before recording weather observations or deploying loggers independently, personnel must:

1. Read this SOP in full
2. Demonstrate correct use of a sling psychrometer or Kestrel meter
3. Demonstrate logger programming, deployment, and data download during a supervised field visit
4. Be signed off by the PI or field lead