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BAY AREA
AIR QUALITY
MANAGEMENT
DISTRICT

TECHNICAL SERVICES DIVISION

QUALITY ASSURANCE PROJECT PLAN

MET SOP 505

SOLAR RADIATION

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STANDARD OPERATING PROCEDURE
BAAQMD Technical Services Division

SOLAR RADIATION AUDIT PROCEDURES

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Introduction

Solar radiation is related to atmospheric stability and is commonly described in units of energy flux: Watts/meter² (W/m²), Langleys/minutes, Calories/centimeter²/minute (Cal/cm² min.) or Joules/centimeter² minute. The two common instruments for measuring solar radiation are pyranometer and net radiometers.

The pyranometer measures sun and sky radiation on a horizontal surface. Most pyranometers incorporate a thermopile sensor. However, a silicon photovoltaic cell can also be used. The net radiometer measures the difference between downward (solar) and upward (terrestrial) radiation. This sensor is based on the thermopile design.
The audit procedures described herein address pyranometer sensors. The audit sensor is either an Eppley Precision Spectral Pyranometer (Eppley PSP) with wavelength filtering hemispheres covering the thermopile, or a Licor LI-200 with a silicon photovoltaic cell. The Campbell 21X portable data logger is connected to the pyranometer to measure the output in millivolts. The output voltage will vary with the amount of radiation received.

The solar radiation audit is a collocated audit where the Eppley PSP or the Licor LI 200 values are compared to the station pyranometer values. EPA guidelines in the *Prevention of Significant Deterioration (PSD)* [1], and *Meteorological Monitoring Guidance for Regulatory Modeling Applications* [2] recommend an accuracy of ±5% agreement between the audit sensor and the station pyranometer values.

General Operating Procedures

The Eppley PSP is a multi-junction, wire-bound thermopile. The receiver is coated with a Parson's black lacquer. The sensor is supplied with a pair of removable, precision ground, Schott optical glass hemispheres. The clear (WG295 glass) hemisphere has

uniform transparency to radiation between 285 and 2800 nanometers. The sensor includes a spirit level, adjustable leveling screws, and a dessicator. The sensor has a cast bronze body with white enamel guard disk and is protected in a storage case when it is not in use. A calibration certificate to the World Radiation Reference is included with conversion factors for various units.

The Licor LI-200 features a silicon photovoltaic detector mounted in a fully cosine-corrected miniature head. Current output, which is directly proportional to solar radiation, is calibrated against an Eppley Precision Spectral Pyranometer (PSP) under natural daylight conditions in units of watts per square meter (W/m^{-2}). Under most conditions of natural daylight, the error is < 5%.

The spectral response of the LI-200 does not include the entire solar spectrum, so it must be used in the same lighting conditions as those under which it was calibrated. Therefore, the LI-200 should only be used to measure the daylight spectrum (400 to 1100 nm).

The Campbell 21X data logger has 12 channels for sensor inputs and 40 kilobytes of internal memory. The 21X data logger can be operated using battery power or alternating current (AC) via an adaptor. Data can be downloaded to a computer via the SC32A optically isolated RS-232 interface and the SC12 cable.

Audits are performed by connecting the electrical cable from the Eppley PSP or the Licor LI-200 to the 21X data logger. The Eppley PSP or the Licor LI-200 is positioned outside as close to the location of the station pyranometer as possible, in most cases the Eppley PSP or the Licor LI-200 is mounted on the same boom as the station pyranometer. If the station's pyranometer is dirty or wet, clean it with a lint-free soft cloth. The 21X data logger is turned on and the program is downloaded from a computer with Campbell Scientific software. Times are synchronized between the station logger clock and the Campbell 21X.

Flag 1 is set high during an audit to enable 5-minute data recording in memory. This method for performing an audit on solar radiation sensors will compare data in intervals of 5 minutes taken 4 times. This will allow a comparison of values over an extended time frame. Flag 1 is also used to indicate data recorded might be erroneous. EPA *Meteorological Monitoring Guidance for Regulatory Modeling Application* states that at least two 15-minute averaged periods of valid data are required to represent an hourly period. The Campbell Scientific CR10 datalogger is programmed to average all data recorded to memory within a given hour with as little as one data point (one data point is recorded per second). If there is not enough valid data for two 15-minute averaged periods, the data for the averaged hourly period must be deleted from the data bank.

Audit Equipment

Eppley PSP or Licor LI-200, associated electrical cable, and (carrying) case.
Computer with Campbell Scientific software and solar radiation program.
Campbell 21X data logger and flat head screw driver.

Solar Radiation Audit Worksheet (see attachments).

Collection

1. Cover the station's pyranometer with a black cover or similar to prevent any light from reaching the sensor. Wait at least 5 minutes for the readings to stabilize then record the values in the 'Zero Readings' section of the worksheet. Typically, the values would be between 0-1 W/m².

2. Position the Eppley PSP or the Licor LI-200 on a flat surface as near to the station's pyranometer as possible and, at the same height. In most cases there is a boom mounted to the tower with the station's pyranometer affixed to it. If the standard-pyranometer's mount can be affixed to the station's boom, then locate the Eppley PSP or the Licor LI-200 on the boom if possible. Do not locate it in areas where the Eppley PSP or the Licor LI-200 face will be shaded or where reflective surfaces are nearby. Also, do not block the light to the station pyranometer.

3. Plug the electrical connector end of the cable into the Eppley PSP. The Licor LI-200 has its electrical cable pre-wired. Level the Eppley PSP or the Licor LI-200 by adjusting the leveling screws and center the bubble in the spirit level. Straighten the electrical cable so that it will reach the location of the 21X data logger.

4. Using a flat head screw driver, connect the black wire from the Eppley PSP to 1H and the clear wire to 1L. For a standard Licor LI-200, connect the black wire to 4H, the clear wire to 4L, and a jumper from 4L to ground. Standard LI-200's purchased from Licor generates current as a function of solar energy density. Connect a 1% 100 Ω resister rated at 10 PPM per degree C between 4H and 4L in order to generate a voltage at the logger input. For LI-200's purchased from Campbell Scientific, connect the red wire to 4H, the black wire to 4L, the white wire to analog ground, and the clear wire to ground. This unit already has a factory-installed in-line variable resistor so there is no need to connect a separate one externally.

5. Turn the 21X on by turning the toggle switch (located on the side of the logger) to the on position. Turn the computer on which has the program "Cal21x" in the LoggerNet software. Connect the RS-232 cable to the 21X and to the computer using the SC23A Optically Isolated Interface device. Select 21X under Station List. Click on "Connect". Select Cal21x as the program to be downloaded. If Download Successful appears, then the download was completed. Unplug the RS-232 cable.

6. The time in the 21X data logger must be synchronized with the station's CR10(X) data logger clock. To access the station's clock, connect one end of the RS-232 cable to the CR10(X) data logger and the other end to a Campbell CR10KD Keyboard Display. Press *0, then *5. The time should appear on the keyboard display. On the 21X data logger, press *0, then press *5, followed by the "A" button 3 times. This should allow you to change the time. Synchronize the 21X data logger clock to within one second of the station's CR10(X) data logger clock. Note the ending times on the audit form. Verify that the instantaneous solar values of the 21X and tower are relatively close.

7. After four 5-minute periods, collect and record data from the 21X and the station's CR10(X) datalogger. Data can be retrieved either directly from the 21X or the station's CR10(X) datalogger, or saved onto the laptop first then retrieve from the laptop.

   a. To retrieve data directly from the 21X or the station's CR10(X) datalogger, press *7A to access the first recorded data point in the first output array. Since we will usually want the *latest* recorded data, pressing B repeatedly will allow us to scroll through memory in *reverse* order of beginning with the last data point of the last output array. You may now scroll to and record the appropriate solar data point for each 5-minute period (Hint: data points can be easily found by scrolling back to the desired 5-minute ending time, then scrolling forward to the desired data point). On the 21X, *Eppley and Licor* are the first and fourth data points, respectively, after *ending time*. The order of data can be found in the file 21XCal.CSI in the laptop. On the CR10(X), solar is the third data point after ending time. Record the values onto the audit form (see attachment).

   b. To save data onto the laptop, connect the 21X datalogger to the laptop and download the data. Before opening the file that was downloaded, rename the file to the station's name. Open the file in Notepad or Excel and write down the values for the ending times on the audit form. Then connect the laptop to the station's CR10(X) datalogger. Download the data and then open this file. Write down the values from the station's pyranometer for the same ending times as the 21X on the audit form (see attachments).

8. Calculate the percent difference between the Eppley PSP or the Licor LI-200 (the standard) and the station's solar radiation sensor. Make sure to divide by the standard. District passing criteria is that the station solar radiation measurements be within ± 5% of the standard's measurements.

9. Disconnect the electrical cable from the 21X terminal block using the small flat head screw driver. Place the 21X in the carrying case. Disconnect the electrical cable from the Eppley PSP (the Licor LI-200's cable does not disconnect). Coil the cable and put back in the Eppley carrying case. Place the Eppley PSP or the Licor LI-200 back in the carrying case.

Audit Data Calculations

The Campbell 21X data logger requires a calibration multiplier in the program. The calibration multiplier is calculated from the calibration constant which is found on the Eppley PSP or the Licor LI-200 calibration certificate. The calibration constant is a result of a series of comparisons from a standard at either the Eppley Laboratory or from Licor. We have programmed the 21X data logger's input voltage range to ±15 mV which is optimal for these sensors. Consequently, we must convert the calibration constant to a multiplier that converts millivolts to watts meter^{-2}.

Eppley PSP
The Eppley PSP's calibration constant is given in microvolts per watts meter^{-2}. The calibration constant is converted to a multiplier, which changes millivolts to watts meter^{-2}. The multiplier is then inserted into a program that is downloaded to the Campbell 21X data logger.

Example:
Calibration constant = 9.62×10^{-6} V/watts meter^{-2}
9.62×10^{-6} V = watt meter^{-2}
1 mV = 1/ (9.62×10^{-3}) watts meter^{-2}
= 103.95 watts meter^{-2}

Thus, the calibration multiplier is 103.95.

Licor LI-200 (Purchased From Licor)
The calibration constant for the Licor is given in microamps per 1000 watts meter^{-2}. Since the Licor LI-200 generates the output in microamps, a resistor is installed across the differential measurement (between 4H and 4L on the Campbell 21X logger) to convert the output to microvolts. The calibration constant is converted to a multiplier, which changes millivolts to watts meter^{-2}. The multiplier is then inserted into a program that is downloaded to the Campbell 21X data logger.

For our system, we are using a 1% 100 Ω resistor rated at 10 PPM per degree C. Using an ohm meter that is accurate to ± 0.1%, our 100 Ω resistor was found to be 99.5 Ω.

Example:
Calibration constant = 87.1×10^{-6} A/1000 watts meter^{-2}
87.1×10^{-6} A = 1000 watts meter^{-2}
(87.1μA x 99.5 Ω) = 1000 watts meter^{-2}
8.6665×10^{-6} V = 1000 watts meter^{-2}
1 mV = 1/ (8.6665×10^{-3}) watts meter^{-2}
= 115.39 watts meter^{-2}
Thus, the calibration multiplier is 115.39

Licor (Purchased From Campbell Scientific)
A Licor LI-200 purchased from Campbell Scientific has a variable resistor in the cable that converts the signal from current to voltage allowing the LI-200 to be measured directly by Campbell Scientific dataloggers. The pyranometer is calibrated at the Campbell Scientific factory, so that 1 mV is always equal to 200 watts meter^{-2}.

Thus, the calibration multiplier is 200.00

Preventative Maintenance

Before each audit, check that the clear outer glass hemisphere on the Eppley PSP or that the lens on the Licor LI-200, is clean. If it is not, wipe it clean with a damp, lint-free soft cloth. Be careful not to scratch the glass, as this will alter the transmission properties of the glass. If the internal surface of the outer hemisphere becomes coated with moisture, carefully remove the outer hemisphere on a dry day to expose it to the air for drying. The inside of the hemisphere should not be wiped unless smears are evident. The external surface of the inner hemisphere can be cleaned while the outer hemisphere is removed. The inner hemisphere can also be removed if moisture is evident on the inside surface. Be careful not to touch or damage the exposed thermopile when the inner hemisphere is removed. The desiccant visible in the side of the white pyranometer case (Eppley PSP) should be checked and changed, if necessary, before each audit (the color should be blue; pink or white indicates that the desiccant should be changed).

Calibration and Certification

The Eppley PSP and the Licor 200 sensor are returned to the factory for calibration and recertification every other year. Both companies provide a certification sheet with conversion factors.

Authors, Revisions, and Approvals

April 2005 (original version)
Author: David Beyer, Air Quality Instrument Specialist II
May 2006: 1st revision by Jiawei Toh, Air Quality Instrument Specialist I
August 2009: 2nd revision by Bill Trinh, Air Quality Instrument Specialist I
Approved: Dick Duker, Meteorology and Quality Assurance Manager

References

1. US Environmental Protection Agency. May 1987. Prevention of Significant Deterioration (PSD). EPA-450/4-87-007.

2. US Environmental Protection Agency. February 2000. Meteorological Monitoring Guidance for Regulatory Modeling Applications. EPA-454/R-99-005. http://www.epa.gov/scram001/guidance/met/mmgrma.pdf

Appendix

Solar Radiation Audit Forms

BAAQMD EPPLEY AUDIT RECORD

Site Name _____

Auditor _____

Date __/__/__ Start Time: _____(pst) End Time: _____(pst)

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SOLAR INSOLATION SENSOR

Sensor Mfg _____
Model No _____
Serial No _____
Sensor Ht _____

Last Calibration Date _____
Calibration Sensor Used: Eppley PSP (attach clear wire to 1H, black wire to 1L, and shield to ground)
Reference PSP Multiplier: _____

Is the glass dirty? No ☐ Yes ☐

Did you clean the glass? Yes ☐ I Forgot ☐

ZERO READING

Zero Readings

SOLAR READINGS

No.	PSP Sensor in W/m^2	Ending Time	Tower Sensor in W/m^2	Percent Difference
1				
2				
3				
4				

Tolerance: Within 5% Results: Pass/Fail

COMMENTS

BAAQMD LICOR AUDIT RECORD

Site Name _____

Auditor _____

Date __/__/__ Start Time: _____(pst) End Time: _____(pst)

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SOLAR INSOLATION SENSOR

Sensor Mfg _____
Model No _____
Serial No _____
Sensor Ht _____

Last Calibration Date _____
Calibration Sensor Used: Campbell Licor LI-200 (with in-line resistor)
(Wiring is Red to 4H, Black to 4L, White and Clear to Ground)
Reference Licor Multiplier : 200.00

Is the glass dirty? No ☐ Yes ☐
Did you clean the glass? Yes ☐ I Forgot ☐

ZERO READING

Zero Readings

SOLAR READINGS

No.	Licor Sensor in W/m^2	Ending Time	Tower Sensor in W/m^2	Percent Difference
1				
2				
3				
4				

Tolerance: Within 5%

Results: Pass/Fail