

AmeriFlux Measurement Component Instrument Handbook

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Acronyms and Abbreviations

AMF	ARM Mobile Facility
AMC	AmeriFlux measurement component
ARM	Atmospheric Radiation Measurement
DOE	U.S. Department of Energy
ECOR	eddy correlation flux measurement system
LBNL	Lawrence Berkeley National Laboratory
NSA	North Slope of Alaska
OLI	Oliktok Point, Alaska
PAR	photosynthetically active radiation
QA	quality assurance
QC	quality control
SGP	Southern Great Plains
VWC	volumetric water content

Contents

Acronyms and Abbreviations	iii
1.0 Instrument Title	1
2.0 Mentor Contact Information.....	1
3.0 Instrument Description	1
3.1 Instrument/Measurements Theory.....	2
3.1.1 Soil Temperature and Volumetric Water Content Sensors	2
3.1.2 PAR Sensors.....	4
3.2 Sensor Installation	4
3.2.1 Soil Temperature and VWC Sensors.....	4
3.2.2 PAR Sensors.....	5
3.3 Calibration.....	5
3.3.1 VWC	5
3.3.2 PAR.....	6
4.0 Definitions and Relevant Information	6
4.1 Primary Variables.....	6
4.2 QC Bit Definitions	7
5.0 Citable References.....	8

Figures

1 Images of AMC systems tripods deployed at SGP (a), NSA (b), and OLI (c).....	2
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Tables

1 AMC system deployments.	1
2 Soil temperature and VWC sensor depths at each site, where deep sensors are 30 cm below the surface and shallow sensors are 10 cm below the surface vegetation layer.	4
3 VWC calibration method by site.	5

1.0 Instrument Title

AmeriFlux measurement component (AMC)

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3.0 Instrument Description

Three AMC systems were installed at the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) user facility observatories at the North Slope of Alaska (NSA) in Utqiagvik (formerly Barrow), Alaska in August 2012, the third ARM Mobile Facility (AMF3) deployment at Oliktok Point, Alaska (OLI) in September 2014, and at the Southern Great Plains (SGP) E39 site in Morrison, Oklahoma in April 2016.

Table 1. AMC system deployments.

Dates	Site
2012-08-08 to 2024-09-30	NSA
2014-09-11 to 2021-06-15	OLI
2016-04-04 to 2023-09-29	SGP

This in situ system consists of 12 combination soil temperature and volumetric water content (VWC) reflectometers and one set of upwelling and downwelling photosynthetically active radiation (PAR) sensors, all deployed within the fetch of the eddy correlation flux measurement system (ECOR) at each site. Soil temperature and VWC sensors placed at two depths (10 and 30 cm below the vegetation layer) at six locations (or microsites) allow soil property inhomogeneity to be monitored across a landscape.

The VWC sensors used at NSA are the Campbell Scientific CS650L and the sensors at OLI and SGP are the Campbell Scientific CS655 sensors. The two sensors are nearly identical in function, and vendor specifications are based on the CS650 unless otherwise stated.

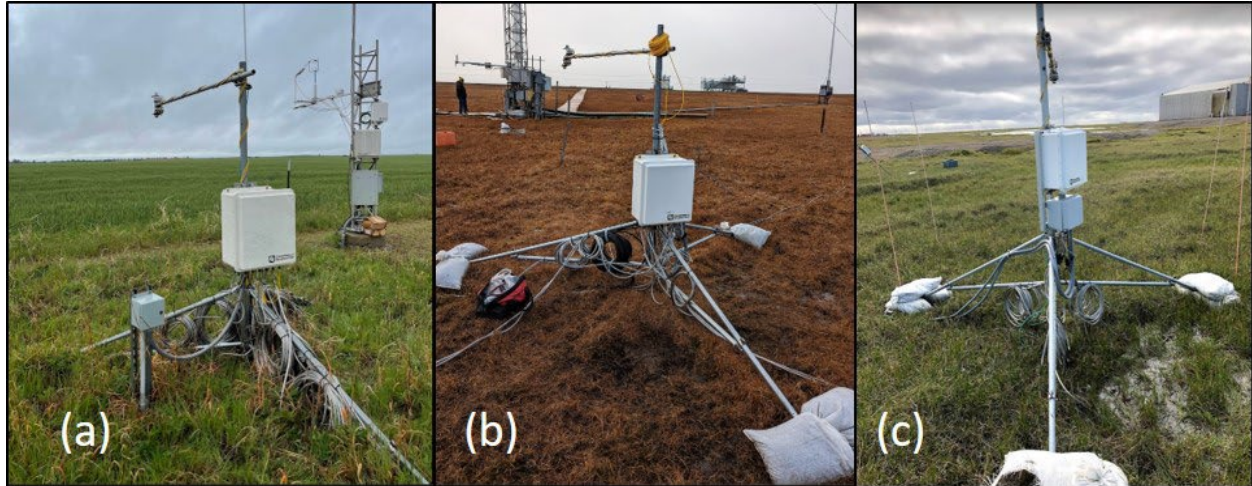


Figure 1. Images of AMC systems tripods deployed at SGP (a), NSA (b), and OLI (c). Images by ARM.

3.1 Instrument/Measurements Theory

3.1.1 Soil Temperature and Volumetric Water Content Sensors

Descriptions of this method were taken from Campbell Scientific *CS650 and CS655 Water Content Reflectometers Instruction Manual*.

For the water content measurement, a differential emitter-coupled logic oscillator on the circuit board is connected to the two parallel stainless-steel rods. The differentially driven rods form an open-ended transmission line in which the wave propagation velocity depends on the dielectric permittivity of the media surrounding the rods. An emitter-coupled logic oscillator state change is triggered by the return of a reflected signal from the end of one of the rods. The fundamental principle for the CS650 water content measurement is that the velocity of electromagnetic wave propagation along the probe rods depends on the dielectric permittivity of the material surrounding the rods. As water content increases, the propagation velocity decreases because of increasing dielectric permittivity. Therefore, the two-way travel time of the rod signal depends on water content; hence, the name water content reflectometer. Digital circuitry scales the high-speed oscillator output to an appropriate frequency for measurement by an onboard microprocessor. Increases in oscillation period resulting from signal attenuation are corrected using an electrical conductivity measurement. A calibration equation converts period and electrical

conductivity to bulk dielectric permittivity. The Topp equation or mentor defined soil-specific calibration is used to convert from permittivity to VWC.

The quality of soil water measurements, which apply electromagnetic fields to wave guides, is affected by soil electrical conductivity. The propagation of electromagnetic fields in the configuration of the CS650 instrument is predominantly affected by changing dielectric permittivity in response to changing water content, but it is also affected by electrical conductivity. Free ions in soil solution provide electrical conduction paths that result in attenuation of the signal applied to the waveguides. This attenuation reduces both the amplitude of the high-frequency signal on the probe rods and the bandwidth. The attenuation reduces oscillation frequency at a given water content because it takes longer to reach the oscillator trip threshold.

It is important to distinguish between soil bulk electrical conductivity and soil solution electrical conductivity. Soil solution electrical conductivity refers to the conductivity of the solution phase of soil. Soil solution electrical conductivity, σ_{solution} , can be determined in the laboratory using extraction methods to separate the solution from the solid and then measuring the electrical conductivity of the extracted solution.

The relationship between solution and bulk electrical conductivity can be described as follows (Rhoades et al. 1976):

$$\sigma_{\text{bulk}} = \sigma_{\text{solution}} \theta_v T + \sigma_{\text{solid}}$$

where σ_{bulk} is the electrical conductivity of the bulk soil, σ_{solution} is the soil solution, σ_{solid} is the solid constituents, θ_v is the VWC, and T is a soil-specific transmission coefficient intended to account for the tortuosity of the flow path as water content changes. Rhoades et al. (1989) published a form of this equation that accounts for both mobile and immobile water. This publication also discusses soil properties such as clay content and compaction related to operation of the CS650 instrument. The above equation is presented here to show the relationship between soil solution electrical conductivity and soil bulk electrical conductivity.

Most expressions of soil electrical conductivity are given in terms of solution conductivity or electrical conductivity from extract because it is constant for a soil. Bulk electrical conductivity increases with water content so comparison of the electrical conductivity of different soils must be at the same water content.

The value reported by the CS650 is bulk electrical conductivity. This value is temperature dependent, changing by 2% per degree Celsius. To compensate for the effect of temperature, electrical conductivity readings may be converted to a standard temperature, such as 25°C, using the following equation:

$$EC_{25} = EC_T \div (1 + 0.023) \times (T_{\text{soil}} - 25)$$

where EC_{25} is the σ_{bulk} value at 25°C and EC_T is the σ_{bulk} value at soil temperature T_{soil} (°C).

3.1.2 PAR Sensors

The Kipp & Zonen PQS-1 PAR sensor irradiance is calculated using the output voltage values from the sensor.

$$E = U/S$$

where irradiance E ($\mu\text{mol}/\text{m}^2/\text{s}$) is the ratio of output voltage U (μV) read by the data logger and sensitivity S ($\mu\text{V}/\mu\text{mol}/\text{m}^2/\text{s}$) determined by the calibration of each sensor.

3.2 Sensor Installation

3.2.1 Soil Temperature and VWC Sensors

The sensors are installed horizontally, parallel to the earth surface, and underground. There are two sensors at each microsite, and a single pit is dug to place sensors at two depths. Pits 40 cm long by 15 cm wide by 33 cm deep are cut, and the earth is removed with care to maintain the shape and depth. The deeper sensor prongs are inserted horizontally along the long axis of the pit into the wall of the pit. Soil is replaced over the sensor until the depth of the shallower sensor is installed in the same way.

Each sensor cable was wrapped in stainless steel cable armor and sealed with electrical tape at each end to minimize damage from animals chewing through the cables.

Table 2. Soil temperature and VWC sensor depths at each site, where deep sensors are 30 cm below the surface and shallow sensors are 10 cm below the surface vegetation layer.

Sensor	NSA	OLI	SGP
1	shallow		deep
2	deep		shallow
3	shallow		deep
4	deep		shallow
5	shallow		deep
6	deep		shallow
7	shallow		deep
8	deep		shallow
9	shallow		deep
10	deep		shallow
11	shallow		deep
12	deep		shallow

3.2.2 PAR Sensors

Upward-facing and downward-facing sensors are identical models. Each sensor is mounted to an aluminum block that is mounted to the horizontal arm, which in turn is mounted to the tripod. The sensor cables are strain-relieved with zip ties or clamps along the arm all the way to the logger box.

The sensor arm is pointed directly south. The level bubble for the upward-facing sensor is used to level both sensors. At NSA the 40-meter tower causes an obstruction over an approximately one hour window throughout the spring and summer months of the year, and this is automatically flagged in the ingested data using the QC variables.

3.3 Calibration

3.3.1 VWC

The VWC sensors calibration use the same overall method of determining VWC values, but differ by site in which calibration is used to convert measurements of bulk permittivity to soil volumetric water content. The data from NSA and OLI sites use the manufacture-provided third-degree polynomial Topp equation, while data from SGP use the mentor-defined, soil-specific second-degree polynomial calibration performed by the Lawrence Berkeley National Laboratory (LBNL) AmeriFlux QA/QC Calibration Laboratory. Separate calibration coefficients were determined for shallow and deep sensors at SGP.

Table 3. VWC calibration method by site.

	NSA	OLI	SGP
Calibration Method	Topp	Topp	Mentor-defined
Polynomial Degree	3	3	2 for shallow 1 for deep

3.3.1.1 Topp Equation

Descriptions of this equation were taken from Campbell Scientific *CS650 and CS655 Water Content Reflectometers Instruction Manual*.

The relationship between dielectric permittivity and volumetric water content in mineral soils has been described by Topp et al. (1980) in an empirical fashion using a third-degree polynomial. With θ_v the volumetric water content and K_a the bulk dielectric permittivity of the soil, the equation presented by Topp et al. is

$$\theta_v = -5.3 \cdot 10^{-2} + 2.92 \cdot 10^{-2} K_a - 5.5 \cdot 10^{-4} K_a^2 + 4.3 \cdot 10^{-6} K_a^3$$

where θ_v represents volumetric water content and K_a is the soil bulk permittivity measured by the sensor.

3.3.1.2 Mentor-Defined Calibration

For SGP volumetric water content, the mentors developed site-specific calibrations for the shallow and deep sensors. Calibrated data are available in b1-level data as vwc_#_corr, where # is the sensor number. Functions were derived from gravimetric laboratory measurements of water content of soil cores, which were collected on site and transported intact to LBNL. Cores were wetted to field capacity and then slowly dried over several weeks. Sensor permittivity (K_a) was related to corrected volumetric water content (vwc_corr) using the following function for shallow sensors:

$$\text{vwc_corr} = -0.0001951 * K_a^2 + 0.02226 * K_a - 0.02632,$$

and the following function for deep sensors:

$$\text{vwc_corr} = 0.01023 * K_a - 0.02273.$$

3.3.2 PAR

The PQS-1 sensor calibration is performed by the LBNL AmeriFlux QA/QC Calibration Laboratory. Sensors deployed are replaced every two years with sensors with updated calibration values, while removed sensors are sent back to the Calibration Laboratory and assigned new calibration values before redeployment. The calibration is a single multiplicative factor that converts sensor output in mV to solar radiation units of $\mu\text{mol}/\text{m}^2/\text{s}$.

4.0 Definitions and Relevant Information

The b1-level datastreams are:

nsaamcC1.b1
oliamcM1.b1
sgpamcE39.b1

4.1 Primary Variables

At the b1 level, the primary variable names are:

For NSA and OLI:

vwc_1
vwc_2
vwc_3
vwc_4
vwc_5
vwc_6
vwc_7
vwc_8
vwc_9
vwc_10
vwc_11

vwc_12
soil_temp_1
soil_temp_2
soil_temp_3
soil_temp_4
soil_temp_5
soil_temp_6
soil_temp_7
soil_temp_8
soil_temp_9
soil_temp_10
soil_temp_11
soil_temp_12
par_inc
par_ref

For SGP, the vwc_* variable names differ but soil_temp and par remain the same:

vwc_1_corr
vwc_2_corr
vwc_3_corr
vwc_4_corr
vwc_5_corr
vwc_6_corr
vwc_7_corr
vwc_8_corr
vwc_9_corr
vwc_10_corr
vwc_11_corr
vwc_12_corr

Note: The “best data” are those with qc_* values of 0.

4.2 QC Bit Definitions

QC definition for all qc variables corresponding to primary variables:

flag_method = "bit";
bit_1_description = "Value is equal to missing_value -9999."; 1
bit_2_description = "Value is less than the valid_min."; 2
bit_3_description = "Value is greater than the valid_max."; 4

Additional QC bit for PAR sensors at NSA:

bit_4_description = " Instrument shaded, solar position is within region defined by solar_obstruction_azimuth_range and solar_obstruction_elevation_range."; 8

5.0 Citable References

Rhoades, JD, PAC Raats, and RJ Prather. 1976. “Effects of liquid-phase electrical conductivity, water content, and surface conductivity on bulk soil electrical conductivity.” *Journal of the Soil Science Society of America* 40(5): 651–655, [doi:10.2136/sssaj1976.03615995004000050017x](https://doi.org/10.2136/sssaj1976.03615995004000050017x)

Rhoades, JD, NA Manteghi, PJ Shouse, and WJ Alves. 1989. “Soil electrical conductivity and soil salinity: New formulations and calibrations.” *Journal of the Soil Science Society of America* 53(2): 433–439, [doi:10.2136/sssaj1989.03615995005300020020x](https://doi.org/10.2136/sssaj1989.03615995005300020020x)

Topp, GC, JL Davis, and AP Annan. 1980. “Electromagnetic determination of soil water content: Measurements in coaxial transmission lines.” *Water Resources Research* 16(3): 574–582, [doi:10.1029/WR016i003p00574](https://doi.org/10.1029/WR016i003p00574)



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