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Measurement and Reporting Practices for Automatic Agricultural Weather Stations

Developed by the ASAE SW-244 Irrigation Management Subcommittee; approved by the ASAE Soil and Water Division Standards Committee April 2004; reaffirmed February 2009; revised April 2015.

Keywords: Meteorology, Weather

1 Purpose and Scope

1.1 Purpose: The purpose of this Engineering Practice is to establish minimum recommendations for measurement, reporting, siting, operation, maintenance, and data management procedures for automatic agricultural weather stations. Additionally, these recommended procedures are intended to assist in the planning of automatic agricultural weather station installation and operation.

1.2 Scope: This Engineering Practice applies to automatic weather stations installed individually, or as part of a network of stations, for the measurement and reporting of specific weather variables in agricultural environments. This Engineering Practice also addresses a recommended core set of measurements and general siting considerations for agricultural weather stations. It is recognized that special purpose agricultural weather stations may deviate from the recommendations herein, particularly with respect to sensor deployment and station siting conditions. This Engineering Practice does not specifically address these special purpose stations.

2 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies unless noted. For undated references, the latest approved edition of the referenced document (including any amendments) applies.

ASAE S526.2, Soil and Water Terminology

ASAE D271.2, Psychrometric Data

3 Definitions

For the purpose of this Engineering Practice only, the following definitions are defined herein. Additional terminology is defined in ASAE Standard S526, Soil and Water Terminology.

3.1 adiabatic lapse rate. The decrease in temperature of a parcel of air with height above the surface when lifted in elevation adiabatically, that is, without the addition or withdrawal of heat from the surrounding air. The adiabatic lapse rate of dry air is about 1°C/100 m.

3.2 anemometer: Instrument for measuring the speed of the wind.

3.3 atmospheric (barometric) pressure: The pressure exerted by the weight of air (dry air and water vapor mixture) above a given point.

3.4 automatic agricultural weather station: A stand-alone set of equipment designed to automatically measure and record agriculturally significant weather variables, as specified in clause 4, for agricultural purposes. The station is based on an electronic data logger and includes associated sensing devices, power supplies, environmental enclosures, and support structures, normally operated on a year-round basis at a fixed location and it may be part of a network of similar stations. It collects data at a specified sampling interval(s), stores intermediate measurements in memory, processes summary values at a specified reporting interval, and stores the summary values in memory. Finally, it incorporates some means of data telemetry for access to, or transfer of, summary values, typically on a near-real time basis, to a central location for more general processing, long-term storage and dissemination, or to alternative on-site exchangeable storage media.

3.5 climate day: A 24-hour period (e.g., midnight to midnight, 8 a.m. to 8 a.m., local standard time) for which a statistical summary of the measured weather values is prepared (means, maximums, minimums, totals, etc.)

3.6 data logger: An electronic, microprocessor-based device that can be programmed to make measurements of specific sensors, to process the measurements, and to store intermediate measurements and summary data values.

3.7 dew-point temperature: The temperature to which moist air at a specific barometric pressure, relative humidity, and temperature must be cooled to reach moisture saturation.

3.8 dry-bulb temperature: Ambient air temperature.

3.9 evaporation: The process by which a liquid changes into a gas.

3.10 fetch: The extent of homogeneous area surrounding a given point.

3.11 fully adjusted layer: Approximately the lowest 10% of the internal boundary layer that is in complete equilibrium with new surface boundary conditions caused by a transition in surface conditions.

3.12 internal boundary layer: The layer of air downwind of a transition in surface characteristics such as surface roughness; its thickness increases with distance downwind, or down fetch.

3.13 psychrometer: Instrument used to measure the water vapor content of the air by measuring the wet-bulb and dry-bulb temperature of the air.

3.14 radiation shield: A device used for housing air temperature sensors that reduces the temperature effects of radiation on the sensor.

3.15 resistance temperature detector: A length of pure metal (wire), carefully wound in a stress free form, that increases in resistance as the temperature of the metal (wire) increases.

3.16 sampling interval: The time interval between successive measurements of a sensor, or sensors, by a data logger.

3.17 saturation vapor pressure: The partial pressure exerted by water vapor when it is in equilibrium with a plane surface of pure water.

3.18 sensor: A device that provides a measurable signal output in response to a physical stimulus or variable.

3.19 soil heat flux: The flow of heat energy per unit cross-sectional area into, or out of, the soil.

3.20 solar radiation (irradiance) (direct, diffuse, global, longwave, net, shortwave): Direct solar radiation is the radiation coming from the solid angle of the sun's disc; irradiance is the property that is measured. Diffuse, or sky radiation, is downward, scattered and reflected solar radiation coming from the whole hemisphere. Global radiation is the sum of direct and diffuse solar radiation. Longwave radiation is the infrared energy emitted by the earth and the atmosphere. Net radiation is the sum of net shortwave radiation and net longwave radiation. Shortwave radiation is the radiant energy emitted from the sun at wavelengths less than 4 microns.

3.21 surface roughness: Aerodynamic roughness of a surface; a parameter affecting the downward transport of horizontal momentum from airflow to a surface.

3.22 telemetry: The transmission of data collected at a remote location to a central station, using one or more means of communication.

3.23 thermal stability: A concept describing the variation of temperature with elevation in the atmosphere. When the actual air temperature decreases with height above the surface at a rate greater than the dry adiabatic lapse rate (about 1° C/100 m), the atmosphere is unstable, the temperature is termed a lapse profile, air is buoyant, and turbulence or mixing is enhanced. When the actual air temperature decreases with height above the surface at a rate less than the dry adiabatic lapse rate, the atmosphere is stable, the temperature profile is termed an inversion, air tends to hold its position vertically, and turbulence or mixing is suppressed. When the actual air temperature profile equals the dry adiabatic lapse rate, the atmosphere is neutral.

3.24 thermistor: An electrical resistance device for measuring temperature that exhibits rapid and large changes in resistance for relatively small changes in temperature.

3.25 thermocouple: A device consisting of two dissimilar metals joined together at their end that produces a thermoelectric voltage proportional to the temperature difference between the two junctions.

3.26 time constant: The time required for an instrument to make a 63.2% adjustment to new environmental conditions, in which the measurement system is a linear, first-order, time-invariant, step function input. This percentage is equal to the quantity $(1 - 1/e)$ where e is the base of the natural logarithm, 2.7182.

3.27 vapor pressure (actual): The pressure exerted by the water vapor molecules in air at a given temperature.

3.28 wet-bulb temperature: The temperature to which moist air can be cooled adiabatically (without any gain or loss of heat) by evaporation.

3.29 wind speed: Horizontal movement of air in distance per unit time.

3.30 wind direction: The direction from which air is moving.

3.31 wind vane: Instrument used to indicate wind direction.

3.32 zero plane displacement: The mean level, or height, at which momentum is absorbed by individual elements on a surface, e.g., plant leaves.

4 Measurements

4.1 Variables

4.1.1 Core variables. The recommended core variable set to be measured on an agricultural weather station should include solar radiation, air temperature, relative humidity, wind speed, wind direction, and rainfall (total and intensity) (Table 1).

Table 1 – Core variable set, units, deployment heights, sampling intervals, and values reported for automatic agricultural weather stations

Variable	Derived Variables	Units	Deployment Height (m)	Sampling Interval (s)	Values Reported Each Hour
Solar radiation	–	W m ⁻²	[1]	≤ 10	average
Air temperature ^[2]	–	° C	1.5 to 3	≤ 60	average instantaneous max/min
	sat. vapor pressure	kPa	–	[3]	–
Relative humidity ^[2]	–	%	co-located with air temperature	≤ 60	average instantaneous max/min
	vapor pressure	kPa	–	[4]	average
	vapor pressure deficit	kPa	–	[4]	average
Wind speed ^[5]	–	m s ⁻¹	3	≤ 10	scalar mean maximum during interval and time of occurrence
Wind direction ^[6]	–	degrees	co-located with wind speed	≤ 10	unit vector or resultant mean magnitude and direction standard deviation
Rainfall ^[7]	–	mm h ⁻¹ [8]	≤ 10	[8]	total rate or intensity

Notes:

- 1) Deploy to avoid shading by and reflection from nearby objects. Practical considerations for height include ease of maintenance, i.e., routine cleaning and checking instrument level.
- 2) Supplemental data, which may be reported, are times of occurrence of maximum and minimum values.
- 3) Saturation vapor pressure is calculated with each sample of air temperature (see text for equation) and may be reported as supplemental data. See clause 4.1.2.1.
- 4) Vapor pressure and vapor pressure deficit are calculated with each sample of relative humidity and air temperature. Supplemental data that may be reported are times of occurrence of maximum and minimum values. See clauses 4.1.2.2 and 4.1.2.3.
- 5) See clause 4.1.2.4. WMO and OFCM standard is 3-second sampling rate for wind speed and direction, see clause 4.4. WMO standard height for wind measurements is 10 m.
- 6) Azimuth direction referenced to true North. See clause 4.1.2.4 for algorithms for calculating hourly mean wind direction (magnitude and direction) and standard deviation of wind direction from sampled values.
- 7) Liquid precipitation only.
- 8) Sampling is event driven for tipping bucket rain gauges. To obtain the rainfall rate or intensity, record the time of each tip for tipping bucket gauges; for weighing gauges, record the total weight and time for each 0.254 mm (0.01 in.) of rainfall to obtain both total rainfall and intensity. Hydrologists recommend a minimum sampling interval of 15 min; 1-min sampling intervals are often used.

4.1.2 Derived variables. Variables derived from the core set of measured variables and applicable formulae for their derivation should include (see Table 1):

4.1.2.1 Saturation vapor pressure. Saturation vapor pressure should be calculated and logged with each sampling of air temperature and may be determined using an equation such as that of Tetens (1930) or Murray (1967):

$$e^o = \exp \left[\frac{16.78T - 117}{(T + 237.3)} \right]$$

Allen et al. (1994) give the Tetens (1930) equation as:

$$e^{\circ} = 0.611 \exp \left[\frac{17.27 T}{(T + 237.3)} \right]$$

and Allen et al. (1998) give the Tetens (1930) equation as:

$$e^{\circ} = 0.6108 \exp \left[\frac{17.27 T}{(T + 237.3)} \right]$$

where:

e° = saturation vapor pressure (kPa)

T = air temperature ($^{\circ}\text{C}$)

Lowe (1977) gives an equation for saturation vapor pressure as,

$$e^{\circ} = a_0 + T(a_1 + T(a_2 + T(a_3 + T(a_4 + T(a_5 + a_6 T))))))$$

where:

e° = saturation vapor pressure (kPa)

T = air temperature (K)

$$a_0 = 698.450\,529\,4$$

$$a_1 = -18.890\,393\,10$$

$$a_2 = 0.213\,335\,767\,5$$

$$a_3 = -1.288\,580\,973 \times 10^{-3}$$

$$a_4 = 4.393\,587\,233 \times 10^{-6}$$

$$a_5 = -8.023\,923\,082 \times 10^{-9}$$

$$a_6 = 6.136\,820\,929 \times 10^{-12}$$

Note that a different formula for saturation vapor pressure with respect to an ice surface should be used. The definition of relative humidity requires the use of saturation vapor pressure with respect to a water surface at all temperatures.

4.1.2.2 Actual vapor pressure. Actual vapor pressure of the air should be calculated and logged with each sampling of air temperature and relative humidity, and is determined by:

$$e_a = e^{\circ} (\text{RH}/100)$$

where:

e_a = actual air vapor pressure (kPa)

RH = relative humidity (%)

4.1.2.3 Vapor pressure deficit. Vapor pressure deficit should be calculated and logged with each sampling of air temperature and relative humidity, and computed using:

$$\text{VPD} = e^{\circ} - e_a \quad \text{or} \quad \text{VPD} = e^{\circ}(1 - \text{RH}/100)$$

where:

$$\text{VPD} = \text{vapor pressure deficit (kPa)}$$

4.1.2.4 Wind data reduction. Scalar mean wind speed, unit vector mean wind direction, resultant mean wind speed and direction, and standard deviation of wind direction may be computed using raw sampled data values in the following relationships:

$$W = \sum(w_i)/n$$

$$\theta_u = \tan^{-1}(w_x/w_y)$$

$$w_x = \sum(w_i \sin \theta_i)/n$$

$$w_y = \sum(w_i \cos \theta_i)/n$$

$$U = (w_x + w_y)^{0.5}$$

$$\theta_1 = \tan^{-1}(w_{x1}/w_{y1})$$

$$w_{x1} = \sum(\sin \theta_i)/n$$

$$w_{y1} = \sum(\cos \theta_i)/n$$

$$\sigma(\theta_u) = 81(1 - U/W)^{0.5}$$

$$\sigma(\theta_1) = \sin^{-1}(\epsilon)[1 + 0.1547 \epsilon^3]$$

$$\epsilon = [1 - (w_{x1}^2 + w_{y1}^2)]^{0.5}$$

where:

W = scalar mean horizontal wind speed (ms^{-1})

w_i = sampled wind speed data values (ms^{-1})

n = number of samples

θ_u = resultant mean wind vector direction (degrees)

w_x = speed weighted mean wind vector component in East-West direction

w_y = speed weighted mean wind vector component in North-South direction

θ_1 = sampled wind direction data values (degrees)

U = resultant mean wind vector magnitude (ms^{-1})

θ_1 = unit vector mean wind direction (degrees)

w_{x1} = mean unit vector component in East-West direction

w_{y1} = mean unit vector component in North-South direction