# The Value of Routine Site Visits in Managing and Maintaining Quality Data from the Oklahoma Mesonet

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(Manuscript submitted 22 March 2005, in final form 1 August 2005)



ABSTRACT

The Oklahoma Mesonet, jointly operated by the University of Oklahoma and Oklahoma State University, is a network of 116 environmental monitoring stations across Oklahoma. Technicians at the Oklahoma Mesonet perform three seasonal (i.e., spring, summer, and fall) maintenance passes annually. During each 3-month-long pass, a technician visits every Mesonet site. The Mesonet employs four technicians who each maintain the stations in a given quadrant of the state. The purpose of a maintenance pass is to 1) provide proactive vegetation maintenance, 2) perform sensor rotations, 3) clean and inspect sensors, 4) test the performance of sensors in the field, 5) standardize maintenance procedures at each site, 6) document the site characteristics with digital photographs, and 7) inspect the station's hardware. The Oklahoma Mesonet has learned that routine and standardized station maintenance has two unique benefits: 1) it allows personnel the ability to manage a large network efficiently, and 2) it provides users access to a multitude of station metadata.

## 1. Introduction

According to Brown and Hubbard (2001), *preventative* maintenance is the only effective maintenance program for an automated weather station network. They noted that it was essential to establish equipment rotation schedules based on manufacturers' recommendations, local network experience, and the experience of other networks. Changnon (1975) also noted the importance of at least annual or semiannual instrument maintenance (including calibrations, cleaning of sensors, and leveling) as an integral part of a successful network.

In the early 1990s, Meyer and Hubbard (1992) conducted a thorough survey of maintenance frequencies at nonfederal automated weather stations and networks. Of the 165 "networks" (i.e., groups consisting of one or more stations) that participated in their survey, they found that, in general, the fewer the number of sites in the network, the more frequent the maintenance interval. Some sites were maintained at least monthly, but it was common for even small networks to be maintained only once or twice per year. Despite the need for routine maintenance, Tucker (1997) identified that for networks across the western United States, sensor calibration schedules and site standards varied significantly.

Table 1 displays the frequency of routine maintenance during 2004 at several of the largest surface weather networks in the United States. The California Irrigation Management Information System (http://www.cimis.water.ca.gov) provides frequent station visits to keep the vegetation at their sites irrigated, fertilized, and mowed to a height of approximately 8 cm. The Climate Reference Network (CRN; NOAA 2003) of the National Oceanic and Atmospheric Administration (NOAA) relies on site hosts to provide monthly vegetation maintenance, as well as visual inspections of the sensors. More detailed sensor maintenance is performed annually by CRN personnel at their stations. Staff of the Automated Surface Observing System

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TABLE 1. Frequency of routine maintenance performed by a selection of federal and state networks.

| Network | No. of sites | Frequency of routine maintenance |
|---|---|---|
| AgriMet (P. Palmer 2004, personal communication) | 72 | Annual, in spring |
| ASOS (ASOS Program Office 1998) | 882 | 90 days* |
| California Irrigation Management Information System (CIMIS; wwwcimis.water.ca. gov2004) | 120 | 3–6 weeks |
| Climate Reference Network (NOAA 2003) | 59+ | 30 days** |
| Iowa Department of Transportation Road Weather Information System (maintenance contract available online at http://www.aurora-program.org) | 50 | Annual |
| Nebraska Automated Weather Data Network (G. Roebke 2004, personal communication) | 59 | Annual |
| Oklahoma Mesonet (Brock et al. 1995) | 116 | Spring, summer, and fall |
| Pennsylvania Department of Transportation Road Weather Information System (maintenance contract available online at http://www.aurora-program.org) | 49 | Annual |
| SNOTEL (J. Lea 2004, personal communication; G. Shaefer 2005, personal communication) | 706 | Approximately annual |
| West Texas Mesonet (Schroeder et al. 2005) | 40 | 60 days |

* Some tasks are performed every 90 days; other tasks are performed semiannually.
** Oversight by site host is performed every 30 days. Routine maintenance is performed by a technician on an annual basis.

(ASOS) network of NOAA's National Weather Service (NWS) perform preventative maintenance on a quarterly and semiannual basis. For ASOS, air temperature, dewpoint, rain, pressure, and wind sensors are inspected every 90 days. In addition, air temperature, dewpoint, and wind sensors are calibrated and tested semiannually (ASOS Program Office 1998). The West Texas Mesonet conducts site visits every 2 months to maintain vegetation and test sensors (Schroeder et al. 2005). The remaining networks in Table 1 perform vegetation and instrument maintenance approximately once per year. Most road weather networks (not shown in table) across the country provide only annual routine maintenance because their data are needed specifically during winter precipitation events. (See http://www.aurora-program.org/ for road weather maintenance contracts for many states.)

Routine site maintenance plays a key role in ensuring research-quality data from the Oklahoma Mesonet (http://www.mesonet.org), a network of 116 environmental monitoring stations. The Oklahoma Mesonet is operated jointly by the University of Oklahoma and Oklahoma State University (Brock et al. 1995). Figure 1 depicts a standard Mesonet tower and its associated instrumentation. Oklahoma Mesonet data are used by an ever-increasing variety of users, from emergency managers to K–12 students. Scientists input the data into numerical weather prediction models (Marshall et al. 2003; Dawson and Xue 2004) and agricultural models (Carlson et al. 2002; Grantham et al. 2002). NWS forecasters use Mesonet data to help compose short-term forecasts. Energy producers apply the data to predict both electrical energy load (Tribble 2003) and wind energy potential across the state of Oklahoma (Hughes et al. 2002). In addition, scientists analyze Oklahoma Mesonet data to further their research on land–air interactions (e.g., Illston et al. 2004; McPherson et al. 2004), unique or severe weather events (e.g., Fiebrich and Crawford 2001; Schultz et al. 2004), and public health or agricultural products (e.g., Rogers and Levetin 1998; Grantham et al. 2002).

As applications of both real-time and archived Oklahoma Mesonet data continue to grow, it is important that station integrity be consistent and ensured as much as financially possible. For this reason, the Oklahoma Mesonet has employed periodic, standardized site maintenance procedures since the spring of 2000. Technicians visit each station every spring, summer, and fall to perform preventative maintenance, rotate sensors, perform sensor tests, and document the site with digital photographs. These routine site visits are *in addition to* emergency visits to sites to repair problematic sensors or equipment. This article documents the key components that create the comprehensive maintenance plan of the Oklahoma Mesonet.

## 2. Maintenance frequency requirements of the Oklahoma Mesonet

The Oklahoma Mesonet's requirement for three seasonal visits to each station stems primarily from a need to perform vegetation maintenance during the growing season. Figure 2 depicts the average height of vegetation cut at each station between spring 2001 and fall 2004 (i.e., 12 passes at each site). At approximately 35% of the stations, technicians must cut more than 15 cm of vegetation during each visit. As expected, most of the stations with high vegetation growth are in the east-

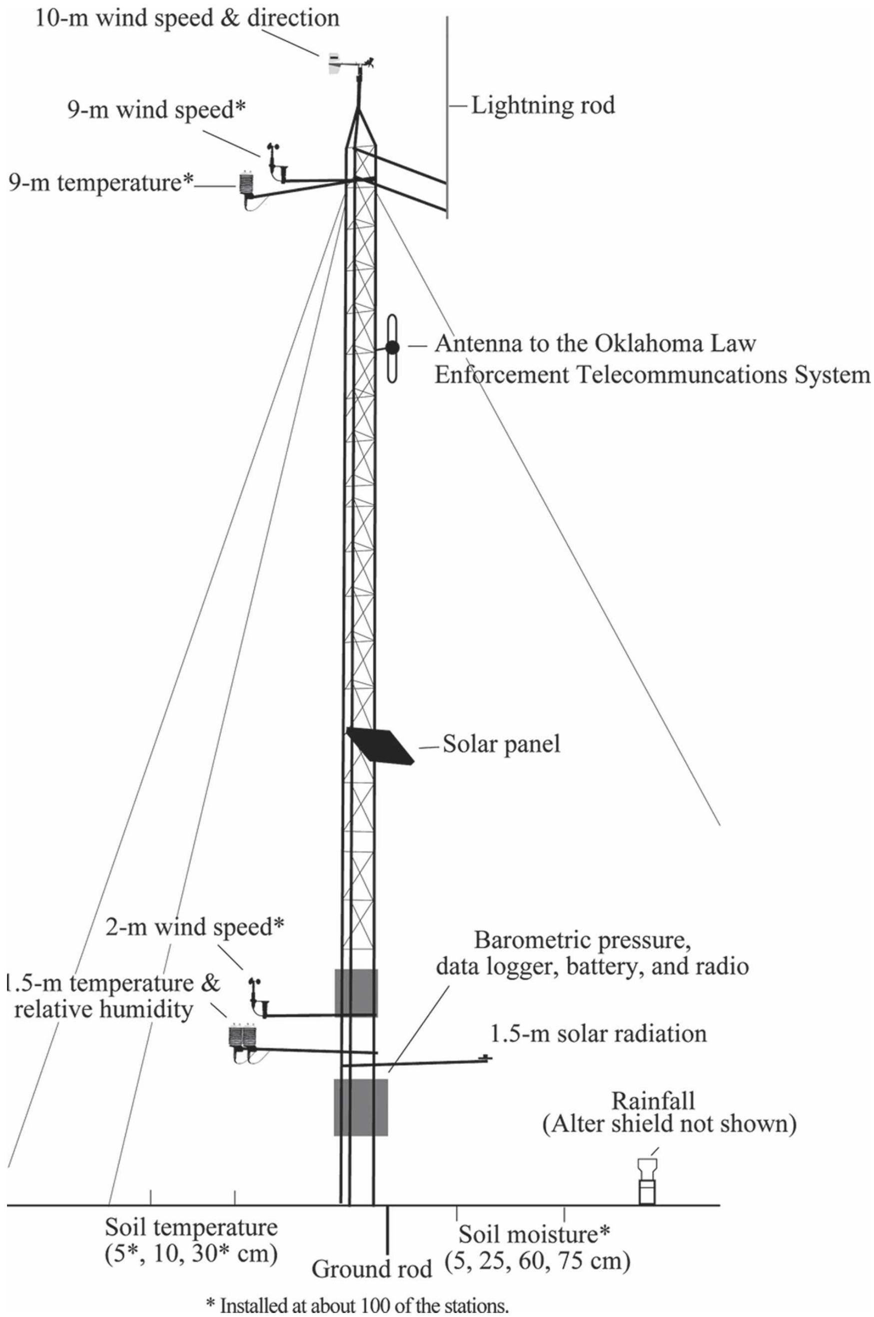


FIG. 1. Mesonet tower with standard equipment and instrumentation.



ern half of the state. [Annual precipitation ranges from 40 cm in western Oklahoma to 132 cm in eastern Oklahoma (Johnson and Duchon 1995).] The impact of tall vegetation on data quality can be significant. For example, tall grasses can shadow the pyranometer, prevent airflow through the radiation shield of the air temperature sensor, obstruct airflow for the 2-m cup anemometer, and block the rain gauge orifice.

Of equal importance, sensor cleaning, inspection, testing, and rotation are required frequently throughout the year. It is difficult to assess the value to data quality of performing these systematic tasks during the passes. Because the Oklahoma Mesonet is an operational network rather than a research network, the focus of its administrators is to disseminate the highest-quality data possible to real-time users. In practice, the more often sensors are cleaned and inspected, the better they will perform. Hence, for cost efficiencies, the

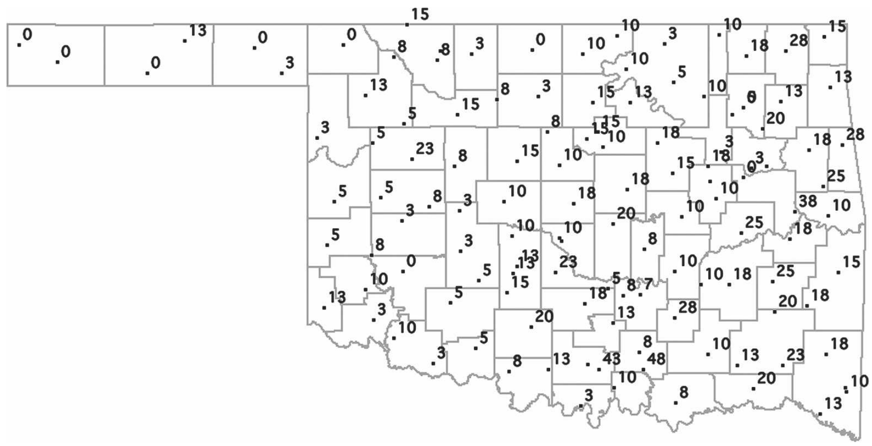

FIG. 2. Average height (cm) of vegetation cut at each Mesonet station during the spring, summer, and fall maintenance passes of 2001–04.

sensor tests and rotations are completed during the same site visit as that for vegetation maintenance.

Although the above reasons encourage frequent visits during the growing season, financial considerations constrain the frequency to no more than three routine visits annually. Four full-time technicians are required to visit all stations across the state during a 3-month period (i.e., the length of a seasonal maintenance pass). Ongoing annual costs of the maintenance visits include four salary lines, maintenance for four vehicles, replacement of one vehicle, and travel expenses. Note that emergency site visits (resulting from sensor biases, sensor failures, lightning strikes, or communication failures) add two to three more visits per site per year. Table 2 lists the maximum time allowed for a technician to resolve emergency site or sensor problems detected by the Mesonet's quality assurance system.

TABLE 2. Maximum time for Oklahoma Mesonet technician to resolve site or sensor problems.

| Measurement | Repair time |
|---|---|
| Air temperature at 1.5 m | 10 business days |
| Solar radiation | |
| Relative humidity | |
| Wind direction | |
| Wind speed at 10 m | |
| Pressure | |
| Rainfall | |
| Soil temperatures at 10 cm | |
| Air temperature at 9 m | 20 business days |
| Wind speed at 2 m | |
| Soil temperatures at 5 and 30 cm | |
| Soil moisture at 5, 25, and 60 cm | |
| Wind speeds at 4 and 9 m | 30 business days |
| Soil heat flux | |
| Skin temperature | |
| Net radiation | |
| Experimental observations | |

## a. Vegetation maintenance

Situated between the dry, high plains of New Mexico and the moist, forested hills of Arkansas, Oklahoma is home to diverse native vegetation. Short-grass and tall-grass prairies, savannah, and hardwood forests extend progressively from west to east across the state. Vegetation conditions have been shown to have a significant effect on both land surface physics (Marshall et al. 2003) and soil temperature measurements (Fiebrich and Crawford 2001). To minimize microscale influences on the measurements, the Mesonet's goal is to match the vegetation inside the station enclosure with the surrounding area as closely as possible. Meeting this goal has been a challenge. Rapid growth of vegetation in some areas can adversely affect some sensor measurements. In addition, grassfires and controlled burns occur regularly during spring, summer, and fall, and care must be taken to minimize fire damage to stations. Vegetation maintenance is particularly challenging when the surrounding land is heavily grazed.

From 1994 through 1998, subjective decisions by Mesonet field personnel resulted in a wide range of vegetation-height conditions across the network. Hence, in 1999, management decided to apply the same vegetation maintenance criteria to all stations. During each routine visit, vegetation must be cut and removed to match the height of surrounding vegetation, with a height limit of 45 cm. The technician also cuts a firebreak (maximum of 5 cm in height; Fig. 3) in a swath that extends from the tower base to the rain gauge. This firebreak helps protect equipment in the event of a

FIG. 3. Example of the vegetation cut for a firebreak around the rain gauge and instrument tower of the Oklahoma Mesonet.

wildfire and provides an access path for field personnel. While a technician is at a station, all data are automatically flagged as erroneous (via a datalogger enclosure door switch) in case maintenance activities compromise the quality of any of the observations.

### b. Sensor rotations

Oklahoma Mesonet personnel strive to replace sensors proactively (i.e., before they fail or exceed error specifications due to age) by following a sensor rotation schedule (Table 3). The rotation intervals are based on a combination of the Mesonet's experience with the failure rate of each sensor and the manufacturer's recommendation. A database tracks sensor residence times at every station, and when a sensor reaches its maximum residence time, it is replaced and returned to the Mesonet calibration facility. The three seasonal station visits provide an efficient schedule for routine sensor replacement.

In most cases, the Mesonet's rotation interval is longer than the manufacturer's recommendation. For instance, the manufacturer recommends a 24-month recalibration interval for the barometer, but the Mesonet's calibration tests rarely detect substantial drift in the sensor after 48 months of field use. The Mesonet's extensive quality assurance system (Shafer et al. 2000) allows for numerous real-time evaluations of sensor performance, and therefore most sensors with biases or drift usually are replaced with an unscheduled or emergency repair.

### c. Sensor cleaning and inspection

Nature provides an abundance of dust, debris, and insects across Oklahoma. These contaminants find their way into and onto many of the Mesonet's sensors (e.g., Table 4). Hence, technicians inspect and clean sensors during each routine site visit. Because climbing is required, technicians attend to the sensors at the 9- and 10-m levels only once per year



TABLE 3. Annual frequency of sensor failure experienced by Oklahoma Mesonet sites between January 2000 and June 2005, primary reason for rotation, manufacturer's recommended rotation interval, and Mesonet rotation schedule by instrument.

| Sensor | Measurement | Annual frequency of sensor failure | Primary reason for rotation | Manufacturer's recommended rotation interval (months) | Mesonet rotation interval (months) |
|---|---|---|---|---|---|
| Campbell Scientific HMP45C | Relative humidity | 8% | Sensor drift | 12 | 24 |
| Licor LI-200SZ Pyranometer | Solar radiation | 2% | Sensor drift | 30 (based on 2% drift per year) | 36 |
| RM Young Wind Monitor Direction Indicator | Wind direction at 10 m | 1% | Sensor wear | 48 | 60 |
| RM Young Wind Monitor Nose Cone | Wind speed at 10 m | 1% | Sensor wear | When noisy or starting threshold problem noticed | 48 |
| RM Young Wind Sentry | Wind speed at 2, 4, and 9 m | 4% | Sensor wear | When noisy or starting threshold problem noticed | 24 |
| Thermometrics Air Temperature Sensor | Air temperature at 1.5 and 9 m | 3% | Sensor testing | N/A [Brock et al. (1995) noted that thermistors have excellent stability of better than 0.1°C $yr^{-1}$] | 60 |
| Vaisala PTB 202/220 Barometer | Pressure | 2% | Sensor testing | 24 | 48 |

TABLE 4. Annual frequency of environment-related problems experienced by Oklahoma Mesonet sensors between January 2000 and June 2005.

| Sensor type | Annual frequency of environment-related problems | Primary cause |
|---|---|---|
| Air temperature and relative humidity sensors | 3% | Mud daubers nests and spiderwebs encase the sensor. |
| Barometer | 1% | Spiders or other insects obstruct the barometer port. |
| Pyranometer | 1% | Bird droppings and other debris obscure the lens. |
| Rain gauge | 6% | Spiderwebs entangle the tipping buckets and debris obstructs the funnel opening. |

(Fig. 4) and follow tower-climbing procedures specified by the Occupational Safety and Health Administration (OSHA).

It is relatively common for insects to construct nests on the temperature and relative humidity sensors and shields. Fortunately, with three scheduled passes, the nests only become extensive enough to compromise the data at about 3% of the sites each year (Table 4). In addition, mold and dust accumulate on the shields, so they must be cleaned or replaced if needed. To inspect the wind sensors, both the cup and propeller anemometers are audibly checked for signs of worn bearings, which produce a noisy, grating sound. Springtime brings numerous dust storms and wind shifts across western Oklahoma, so radiation sensors must be cleaned and leveled.

During past winters, cycles of freeze and thaw have heaved 10% of the network's 5-cm bare soil temperature sensors above the ground. Likewise, during the spring and summer, wind and rain sometimes erode the soil over the bare soil temperature plot. Hence, technicians verify the depth of subsurface sensors and level the soil surface, if necessary, during each visit. Lastly, the technician removes all vegetation from the bare soil temperature plot and applies a soil sterilant, if required.

### *d. Rain gauge tests*

To verify the performance of the rain gauge, the field technician tests the gauge prior to any cleaning or other maintenance. During the test, the technician dispenses 1000 mL of water into the gauge. The number of bucket tips is recorded and compared to the expected number of tips (e.g., 50 ±5 tips for the Mesonet's gauges). [A similar method of checking rain gauge performance in the field is employed by ASOS (ASOS Program Office 1998).] After the initial drip test, the technician cleans and inspects the rain gauge (Fig. 5). Then, a second drip test is performed to determine if any changes in gauge performance occurred during the cleaning process. All drip test results are reported on the site pass form (to be discussed in section 3) and analyzed by the quality assurance meteorologist to assist in the assessment of data quality.

FIG. 4. An Oklahoma Mesonet technician inspects and cleans sensors at the 9-m level.

FIG. 5. An Oklahoma Mesonet technician cleans the rain gauge after the initial drip test.

FIG. 6. Portable reference system (center of picture) used by the Oklahoma Mesonet to verify field performance of various sensors. The system is mounted temporarily at the station during the site pass and records measurements of air temperature, relative humidity, solar radiation, and pressure while the technician completes maintenance activities.

### e. *Field sensor intercomparisons*

Oklahoma Mesonet personnel properly calibrate each sensor before deployment at a remote site (Shafer et al. 2000). However, instrument drift is a major cause of poor quality data (Hollinger and Peppler 1995). Thus, to examine sensor accuracy during a sensor's lifetime—a critical step to verifying data quality in the field (Brock and Richardson 2001)—Mesonet personnel have developed a portable system (Fig. 6) to perform standardized field comparisons. Observations from the air temperature, relative humidity, solar radiation, and pressure sensors are compared to calibrated reference sensors (Table 5). The system includes an integrated aspirator to provide homogeneous air volume for both the reference and station temperature and humidity sensors. Customized Palm OS software (PalmSource, Inc.) on a personal data assistant collects and analyzes these comparison observations. In addition to displaying comparison data for on-site evaluation, the software also generates a detailed report (see Table 6) for analysis by the quality assurance meteorologist. The system requires minimal interaction by field personnel and communicates automatically with the station datalogger when connected. The system is expandable so that other station sensors can be compared as needed.

The in-field intercomparisons provide two distinct benefits: 1) they identify subtle sensor problems, and 2) they provide guidance for determining the true start time of data quality problems. The errors tolerated during the field sensor intercomparisons are listed in Table 5. These thresholds were based on approximately 350 field intercomparison tests completed at Oklahoma Mesonet sites. Using these thresholds during the 2004 site passes, 10 sensors were determined to have drifted out of tolerance. Those sensors included four relative humidity sensors, two pyranometers, and four air temperature sensors.

Even more important than on-site error identification, the intercomparison tests create a wealth of metadata and statistics for the quality assurance meteorologists of the Oklahoma Mesonet. When a new data quality problem is discovered by either automated or manual techniques (Martinez et al. 2004; Shafer et al. 2000), the intercomparison reports provide a baseline for helping to determine how far back to manually flag the data as erroneous. For instance, if one of the components of the Mesonet's quality assurance system identifies a 6% relative humidity bias at a station, the previous intercomparison reports from the station are used to determine whether the drift increased steadily with time or occurred abruptly.

## 3. Other benefits of routine maintenance

The three annual maintenance passes provide several other benefits to network maintenance and data quality of the Oklahoma Mesonet. These benefits include 1) standardized maintenance procedures at each station, 2) site pictures on numerous occasions throughout the year, and 3) thorough hardware inspections. Although these aspects alone do not mandate the maintenance frequency described in section 2, their inclusion in the Mesonet's seasonal passes adds a substantial contribution to station metadata and hardware integrity.

TABLE 5. Station and reference sensors used in field intercomparisons.

| Variable measured | Station sensor | Reference sensors (calibrated accuracy) | Error tolerated in the field |
|---|---|---|---|
| Air temperature | Thermometrics | 1) Rotronics Pt100 RTD (±0.1°C)<br>2) Thermometrics (±0.2°C) | ±0.5°C |
| Relative humidity | Vaisala HMP35C/45C | Rotronics MP 100H (±1% RH) | ±5% |
| Barometric pressure | Vaisala PTB 220 | Vaisala PTB 220 (±0.1 hPa) | ±0.2 mb |
| Solar radiation | Licor LI-200SZ | Licor LI-200SZ (±5%) | ±5% when solar radiation > 400 W $m^{-2}$ |

TABLE 6. Sample report detailing the comparisons of reference and station sensor observations at the Calvin (CALV) site on 20 Dec 2004. The "reference instrumentation" section lists the reference sensors and associated calibration coefficients used during the field intercomparisons.

Station: CALV; Technician: K. KESLER
Visit date: 20 Dec 2004; Start time: 19:42 UTC; Duration: 00:16
Reference Delta T abs avg: 0.06; Min: 0.00; Max: 0.10
Reference instrumentation
Datalogger: CR10X-TD 7714; Wiring panel 19954
RELH: Rotronic 90593; Poly: C0 = +0.1299, C1 = +0.9743, C2 = +0.0003
TAIR: Thermo 98065919; Poly: C0 = −0.0726, C1 = +0.9976, C2 = +0.0002
SRAD: Licor 45080; Poly: C0 = −4.0958, C1 = +70.346, C2 = +0.44802
PRES: Vaisala 513060; Poly: C0 = +0.0000, C1 = +1.0000, C2 = +0.0000

Air temperature (station minus reference) (°C)

| Time | Station obs | Error | Time | Station obs | Error |
|---|---|---|---|---|---|
| 1948 UTC | 21.68 | 0.23 | 1953 UTC | 21.30 | 0.09 |
| 1949 UTC | 21.43 | 0.18 | 1954 UTC | 21.25 | 0.09 |
| 1950 UTC | 21.43 | 0.17 | 1955 UTC | 21.30 | 0.04 |
| 1951 UTC | 21.33 | 0.16 | 1956 UTC | 21.31 | 0.06 |
| 1952 UTC | 21.54 | 0.16 | 1957 UTC | 21.40 | 0.08 |

Relative humidity (station minus reference) (% RH)

| Time | Station obs | Error | Time | Station obs | Error |
|---|---|---|---|---|---|
| 1948 UTC | 18.98 | −0.42 | 1953 UTC | 18.92 | −0.30 |
| 1949 UTC | 18.76 | −0.51 | 1954 UTC | 18.80 | −0.38 |
| 1950 UTC | 18.78 | −0.46 | 1955 UTC | 18.84 | −0.35 |
| 1951 UTC | 18.88 | −0.34 | 1956 UTC | 18.70 | −0.37 |
| 1952 UTC | 19.13 | −0.29 | 1957 UTC | 19.05 | −0.20 |

Barometric pressure (station minus reference) (mb)

| Time | Station obs | Error | Time | Station obs | Error |
|---|---|---|---|---|---|
| 1948 UTC | 975.36 | 0.07 | 1953 UTC | 975.35 | 0.13 |
| 1949 UTC | 975.24 | 0.03 | 1954 UTC | 975.34 | 0.14 |
| 1950 UTC | 975.35 | 0.10 | 1955 UTC | 975.33 | 0.11 |
| 1951 UTC | 975.19 | −0.05 | 1956 UTC | 975.19 | 0.11 |
| 1952 UTC | 975.44 | 0.09 | 1957 UTC | 975.25 | 0.03 |

Solar radiation (station minus reference) (% error)

Station pyranometer 45187; Coef = 94.4; installed: 19 Aug 2003

| Time | Station obs | Error | Time | Station obs | Error |
|---|---|---|---|---|---|
| 1948 UTC | 494.22 | 1.06 | 1953 UTC | 486.62 | 1.12 |
| 1949 UTC | 490.40 | 1.07 | 1954 UTC | 485.95 | 1.13 |
| 1950 UTC | 489.89 | 1.10 | 1955 UTC | 485.19 | 1.12 |
| 1951 UTC | 489.13 | 1.08 | 1956 UTC | 482.92 | 1.14 |
| 1952 UTC | 487.55 | 1.14 | 1957 UTC | 480.44 | 1.17 |

## a. Standardization

Many managers of surface observing networks have determined that systematic maintenance is enhanced significantly by using standard sensors and site configurations. In addition, maintenance procedures can be standardized easily when a sufficient number of technicians are available to visit all sites in a network during a short period of time (e.g., a season).

To standardize the maintenance passes for the Oklahoma Mesonet, a new site-pass form is created for each routine maintenance pass. The form outlines the maintenance objectives for that season, lists standard maintenance procedures, and notes special tasks that must be completed at each station. Special tasks may include upgrading specific equipment, verifying serial numbers, installing communications equipment at nearby base or repeater stations, checking licenses provided by the Federal Communications Commission, and performing radio interference tests. Upon completing a site visit, the technician submits the form to the quality assurance meteorologist for analysis and inclusion into the station's metadata file (Shafer et al. 2000; Martinez et al. 2004). An archive of the forms used for Oklahoma Mesonet site passes is available online (http://www.mesonet.org/sitepass).

## b. Digital photographs

Digital photographs are some of the most critical pieces of metadata obtained during a site visit. During each pass, the technician takes an average of 14 standard digital photos of each Oklahoma Mesonet station to document the condition of the site and its surroundings. Field personnel photograph the soil temperature

FIG. 7. One of 14 standard digital photographs taken during a site pass at an Oklahoma Mesonet station. The vegetation gauge (striped pole in foreground) indicates the height of the vegetation surrounding the station. The fence outlines a 10 m × 10 m plot, and the tower is centered within this square.

TABLE 7. The Oklahoma Mesonet's 10 principles for weather station metadata.

1) Station names. Assign a unique station name to each site. If a station moves, even as few as 100 m, assign a new name to the site to ensure an accurate climate record.
2) Station geographic information. Record lat and lon in decimal degrees, with precision to the fourth decimal. Record elevation in meters, with precision to the nearest meter. Record distance and direction from station to the nearest incorporated town in kilometers and 8-point compass direction (e.g., 2 km NNW of Cheyenne, OK). Record legal description of the station location (e.g., NE 1/4 of the SW 1/4 of Section 22, Township 4N, Range 6E, County of Pontotoc, State of OK). Record soil characteristics indicating % silt, % clay, and % loam for each site measuring soil moisture. Document the slope of the land, direction, and distance to nearby obstructions, the dominant vegetation type, land use, and accessibility conditions.
3) Landowner information. Obtain the name, address, phone number, and e-mail address of the station landowner at the time the site is surveyed. If the landowner does not live near the site property, establish a local contact person.
4) Sensor information. Record the serial number, vendor, manufacturer, model, cost, date purchased, date commissioned, date decommissioned, sampling interval, measurement interval, measurement unit, installation height, and location history of each sensor in an instrumentation database.
5) Calibration and coefficient information. Document the calibration characteristics of each sensor both before the sensor is deployed to the field and immediately after the sensor returns from the field. Thus, the data user will know how a particular sensor performed in the laboratory both before it was deployed and after it returned from the field. If a sensor requires calibration coefficients, those coefficients will be stored with the date calibrated since each sensor may have numerous coefficients throughout its lifetime.
6) Site visitation reports. Each time a station is visited, complete a site visitation report to document the date/time of the visit and the work performed at the site.
7) Station photographs. Take panoramic photographs every 5 yr. The picture naming convention is SITEIDYYYYMMDDPXX.JPG where: SITEID = unique site ID; YYYYMMDD = date picture was taken; and PXX = panoramic direction toward which picture is taken (i.e., PN_, PNE, PE_, PSE, PS_, PSW, PW_, PNW). Take additional station photographs during each routine maintenance visit. These photos document the height and condition of the vegetation inside and outside of the site enclosure upon arrival and departure of the site visit, the condition of the bare and sod soil plots, the footprint under the net radiometer, the condition of the soil heat flux plots, and the condition of the soil moisture plots. The naming convention is the same as for the panoramic photos, except that PXX is replaced with SPX = sod plot; BPX = bare plot; SSX = soil moisture plot; NFX = net radiometer footprint; HAX = soil heat flux plot; IHX = inside vegetation height; OH = outside vegetation height; and CH = close-up view of firebreak. In these cases, X = 1 for arrival photo, and X = 2 for departure photo.
8) Station trouble tickets. Document each sensor problem or sensor install at a site with a unique trouble ticket. Each trouble ticket clearly indicates the date/time (to the nearest minute) the action is traced to (so that appropriate data can be flagged), the sensor and data affected, the nature of the action (i.e., a new sensor installation, a sensor replacement, a repair to the sensor, or a sensor removal), the date/time (to the nearest minute) the fix occurred, and detailed comments about the action.
9) Field intercomparison reports. Record statistics describing the observed differences between station sensors and reference sensors on an intercomparison report. The report also lists the reference sensor serial numbers and coefficients used. The report clearly lists the date/time the intercomparison was performed. Whenever possible, the reference sensors are of different type and/or measurement interface to guard against systematic errors.
10) Quality control information. Document the list of automated tests for each variable, as well as the associated thresholds. A unique quality assurance flag, whether it be from an automated test or through manual quality control, is associated with each observation indicating whether the observation is considered "good," "suspect," "warning," or "failure" (Shafer et al. 2000; Fiebrich and Crawford 2001).

plots, soil moisture plots, soil heat flux plots, net radiometer footprint, full 10 m × 10 m site enclosure, and surrounding vegetation. The vegetation conditions are photographed both upon the technician's arrival and departure. Vegetation-height gauges, with alternating stripes every 10 cm, appear in appropriate photographs (Fig. 7). Each year, the Mesonet archives more than 4000 digital pictures to aid in the documentation of station histories.

### *c. Hardware inspections*

During each visit, the technician examines the tower hardware and power system, including the integrity of the tower and guy wires. The tower is leveled, if necessary, and the guy wire tension is adjusted. The technician performs a load test on the battery to verify its operation and uses a wire brush and solvent to remove any corrosion on the battery terminals. To ensure optimal operation, the solar panel is cleaned of debris. Because of the large seasonal range of temperatures experienced across Oklahoma, the technician tightens all screw terminal connections to guard against loosening due to thermal expansion and contraction. Finally, all electronics enclosures receive a fresh package of desiccant to minimize the datalogger's exposure to moisture.

## 4. Organizing the metadata

A Web site (http://www.mesonet.org/sitepass) organizes the metadata gathered during each pass for use by researchers and other data customers. The Web site provides links to the digital photographs, the technician's forms, and any unique findings from the pass. All data quality problems identified during the pass also are listed on the Web site. Metadata obtained from routine site visits assist Mesonet personnel to meet principles 6 through 9 of the Oklahoma Mesonet's "10 Principles for Weather Station Metadata" (Martinez et al. 2005; Table 7).

## 5. Summary

Routine site maintenance across a weather network is a critical component for obtaining high-quality measurements. For networks created for specific and limited applications, maintenance likely can be conducted annually. For networks that provide data for numerous applications (i.e., ranging from real-time data used by forecasters to archived data used by researchers), more frequent maintenance and site documentation are required. The Oklahoma Mesonet has demonstrated that routine and standardized site maintenance has two unique benefits: 1) it provides personnel the ability to manage a large network efficiently, and 2) it allows users to access a multitude of station metadata.

*Acknowledgments.* Continued funding for maintenance of the Oklahoma Mesonet is provided by the taxpayers of the State of Oklahoma through the Oklahoma State Regents for Higher Education. The authors thank James Kilby, Leslie Cain, Ken Meyers, Bill Wyatt, Thomas Smith, Janet Martinez, and Peter Hall for their professional assistance in maintaining the Oklahoma Mesonet. In addition, the authors thank the staff of the Oklahoma Climatological Survey, whose innovative work makes such projects possible. We also appreciate the guidance of the Oklahoma Mesonet Steering Committee and their commitment to excellence.

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