2.16 THE IMPACT OF UNIQUE METEOROLOGICAL PHENOMENA DETECTED BY THE OKLAHOMA MESONET ON AUTOMATED QUALITY CONTROL

Chris A. Fiebrich*
Oklahoma Climatological Survey, Norman, Oklahoma

1. INTRODUCTION

The Oklahoma Mesonet, funded and maintained by the State of Oklahoma, is an environmental monitoring network of 115 stations deployed across the state. Data from the Mesonet are quality assured by software and personnel at the central processing site in Norman, Oklahoma.

The task of manually inspecting each datum from 115 automated stations, each recording observations at 5-minute intervals, is insurmountable. Hence, automated quality assurance (QA) software is an essential tool.

For each datum, the Mesonet's automated software generates a QA flag that indicates the quality of each observation. However, some of nature's most interesting meteorological conditions provide data that fail many QA tests. As a result, some good observations are flagged as erroneous (Fiebrich and Crawford 2001).

The purpose of this manuscript is to illustrate how automated quality control procedures can fail when microscale phenomena are detected by meteorological observing networks. A remedy for this problem involves the use of a database to catalog unique meteorological events. The meteorological phenomena that create special problems for automated QA software that will be discussed include:

- Cold air pooling and "inversion poking";
- Mesohighs and mesolows;
- Heat bursts; and
- Microclimatic effects produced by variations in vegetation.

2. THE OKLAHOMA MESONET'S QUALITY ASSURANCE SYSTEM

The automated quality control performed on Mesonet data is one part of an extensive QA system. Together, four components compose the Mesonet's QA system: (1) laboratory calibration and testing, (2) on-site inter-comparison, (3) automated QA, and (4) manual QA. During laboratory calibration and testing, all sensors are calibrated in the Mesonet lab to validate or improve upon the calibrations sent from the instrument manufacturer. Next, through on-site inter-comparisons, instruments deployed to stations across the state are periodically compared (on average, once a year) to ensure accurate performance by the sensors. Automated QA software (described in more detail later in this section) evaluates the data received from remote stations. Finally, a meteorologist, trained in state-of-the-art QA procedures, reviews the suspicious observations detected by other components of the QA system. Human judgment is added to complement the automated QA. For a complete description of the Mesonet's QA system, see Shafer et al. (2000).

2.1 Automated QA

The Mesonet's automated QA software consists of 5 tests: (1) range, (2) step, (3) persistence, (4) spatial, and (5) like-instrument. The software evaluates data calendar day by calendar day. At the end of the process, one of four QA flags is assigned (each with increasing severity) to each datum: (0) "good", (1) "suspect", (2) "warning", or (3) "failure". Such stratification allows the data user to decide the level of QA they prefer.

The range test determines if an observation lies within a predetermined range. The allowable ranges are based on sensor specifications and annual climate extremes in Oklahoma; each parameter has a unique set of limits. If a datum is observed outside of the allowable range, it is flagged with a failure flag.

The step test uses sequential observations to determine which data represent unrealistic "jumps" during the observation time interval for each parameter. Observations that exceed the maximum allowed step receive a warning flag.

The persistence test analyzes data on a calendar day basis to determine if any parameter underwent little or no variation. The persistence test compares the daily range of each parameter to a predetermined threshold. When the daily range of observations is less than or equal to the threshold value, all observations for that parameter receive a QA flag of warning for the day. All data are flagged as suspect when the range of values exceeds the minimum threshold, but the observed range is less than 1.5 times the minimum threshold.

The spatial test performs a Barnes objective analysis (Barnes 1964) for each parameter at each observation time. The analysis is repeated with each station successively excluded from the field being analyzed. For each analysis, an expected value, based on data from surrounding stations, is calculated for each site. The expected value is compared with the actual observation at that site. If the difference between the estimate and the observed value is greater than two times the standard deviation of the sample (known bad observations are excluded from the sample), the observation receives a suspect flag from the test. If the difference exceeds three times the standard deviation, a warning flag is issued. Minimum standard deviations are also established for each parameter so that during quiescent times, a good observation does not become

Corresponding author address: 100 E. Boyd, Suite 1210, Norman, OK 73019; chris@redrock.ocs.ou.edu

flagged due to a very small departure from its expected value.

The like-instrument test compares the air temperatures at 1.5 m and 9 m at Mesonet sites equipped with temperature sensors at both levels. When the two sensor values differ by more than 10°C, the data are flagged as suspect. This threshold was determined by analyzing a climatology of extreme inversions detected within the depth of the Mesonet tower (Fiebrich and Crawford 1998). It is planned for the like-instrument test to expand and compare soil temperatures at varying levels and wind speeds at different heights.

A decision-making algorithm compiles the results of the five tests, and logically determines a final flag for each datum. The final QA flag may be increased or decreased in severity based on the results of the tests (Shafer et al. 2000).

2.2. The Quality of Parameters Table

Trained meteorologists track suspect and bad data detected by manual QA methods in a database termed the "quality of parameters" (qualparm) table. These observations, in many cases, include sensor problems not detected by the automated QA tests. Wind sensors with bad bearings or rain gauges with intermittently failing switches are two examples. Sensors that produce observations with small biases that, in turn, are identified by long-term manual QA represent another category of events added to the qualparm table.

The QA software compares the QA flags in the qualparm table with the flags from the automated QA tests. The most severe flag (either from the qualparm table or from the automated QA) is archived with each datum.

In the sections that follow, examples where the automated quality control procedures failed due to the occurrence of small-scale meteorological phenomena are discussed. These instances illustrate the importance of performing manual quality control in conjunction with the automated quality control procedures.

3. COLD AIR POOLING AND "INVERSION POKING"

Meteorological conditions sometimes create a very stable boundary layer across Oklahoma. When these conditions exist, strong low-level inversions may form overnight and create a wide range of surface air temperatures. Depending on local topography, a station may observe conditions that are suspiciously cool and moist or suspiciously warm and dry.

3.1 Case Study 1: Intense Radiational Cooling of 26 October 1999

Surface temperatures across the Mesonet on 26 October 1999 at 06:00 UTC (to convert to local standard time for Oklahoma, subtract 6 hours) are shown in Figure 1. In west central Oklahoma, Erick (ERIC) observed a temperature of 5.7°C, while the neighboring site at Cheyenne (CHEY) reported 15.6°C. Similarly, the Nowata (NOWA) site in northeast Oklahoma observed 4.3°C, while its neighbor at Skiatook (SKIA) reported 14.5°C. In addition to these two dramatic examples of large spatial temperature variations, countless sets of neighboring sites differ by 5°C on this map. Some of the variations can be attributed to in situ cooling, while others more closely correlate with differences in topography. With an average station spacing of only 30 km in the Oklahoma Mesonet, it is not surprising that the spatial QA test would erroneously flag many observations.

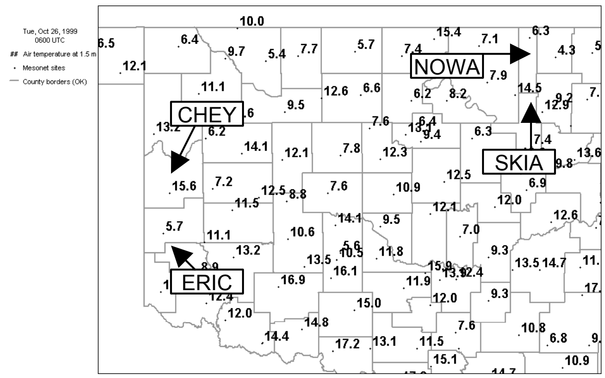


Fig. 1. Mesonet station plot of the surface temperature field (°C) across Oklahoma at 0600 UTC 26 Oct 1999. Radiational cooling caused large variations in temperature between many neighboring stations.

3.2 Case Study 2: A Comparison between Two Stations that Experienced Topographically-Induced Variations in Temperature

On the same day as in the previous case study, data from the Newkirk (NEWK) station in north central Oklahoma revealed that the site "poked" above the inversion layer (Fig. 2a). At 06:00 UTC, the expected air temperature at Newkirk (NEWK) was 7.3°C. However, NEWK observed an air temperature of 15.4°C. On almost any other occasion, this difference of 8.1°C (between the observed and expected air temperature) would indicate a problem thermistor. As a result, an automatic QA flag labeled the temperature data as suspect. Because NEWK is located at a higher elevation than are surrounding stations (Fig. 2b), NEWK remained in the well-mixed layer above the cold inversion.

In contrast to the NEWK site, Wister (WIST) frequently experiences cold air pooling. WIST recorded the second-lowest temperature in the state at 12:15 UTC on 4 November 1999 (Fig. 2c). WIST's elevation of 143 m makes it one of the lowest stations above sea level in the Mesonet (Fig. 2d). The valley location of WIST created undisturbed radiational cooling during the hours after sunset. Additional cooling via cold air drainage during the night contributed to a low temperature of -1.4°C, whereas many neighboring stations observed sunrise temperatures that were greater than 9.0°C.

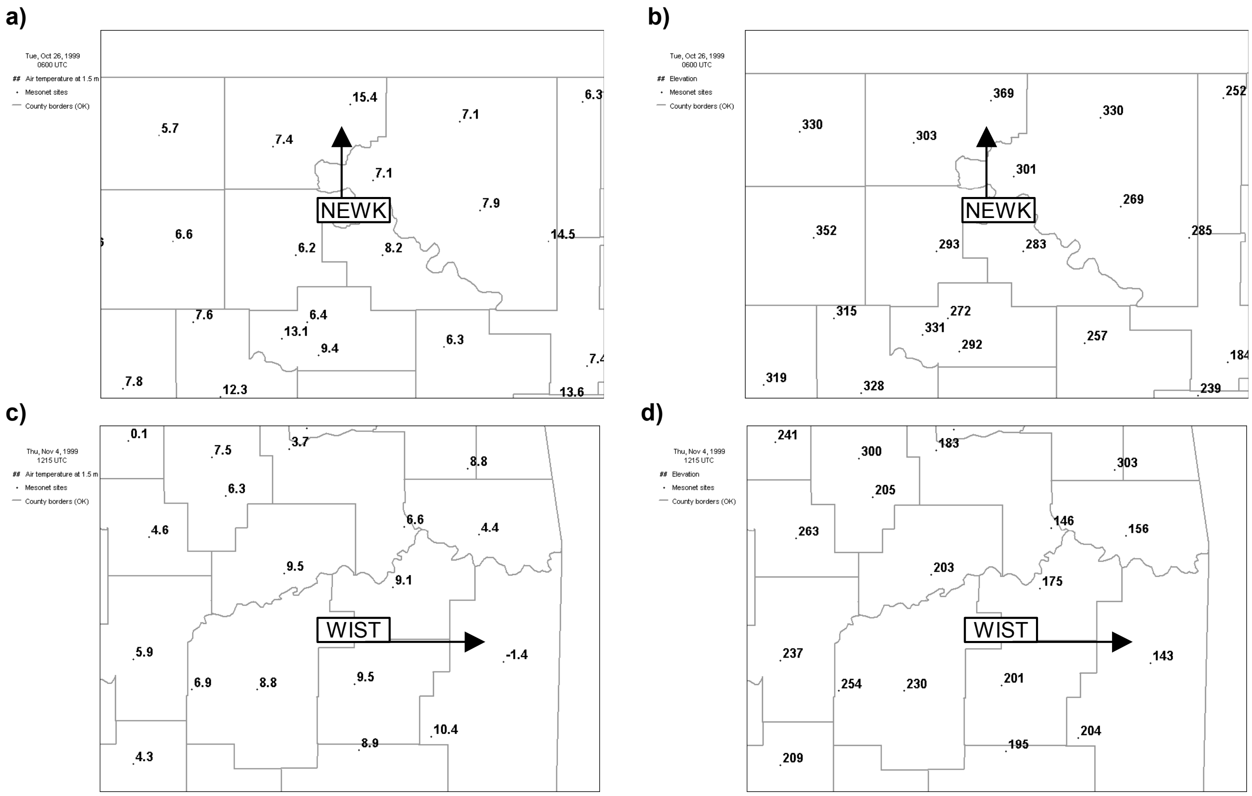


Fig. 2. (a) Mesonet station plot of the surface temperature field (°C) across northern Oklahoma at 0600 UTC 26 Oct 1999. The automated spatial QA flagged the NEWK observation as suspect due to the warm anomaly there. (b) As in (a) except the terrain elevation (m). (c) Mesonet station surface temperature field (°C) across eastern Oklahoma at 1215 UTC 4 Nov 1999. The WIST observations also received erroneous QA flags due to the cool anomaly there. (d) As in (c) except for terrain elevation (m).

4. MESOHIGHS AND MESOLOWS

Mesohighs and mesolows are mesoscale perturbations in the surface pressure field. They generally are associated with convective precipitation. Mesohighs are usually centered along a convective line, whereas mesolows (or “wake lows”) are located on the trailing edge of precipitation (Haertel and Johnson 2000). Data from mesohighs and wake lows frequently fail the spatial test because these features are usually very small in scale.

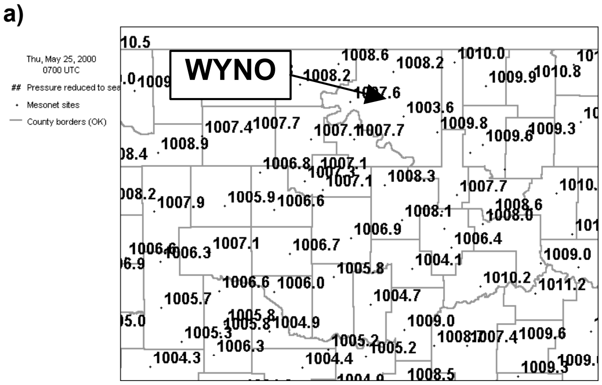
Mesohighs and mesolows occur during all months of the year in Oklahoma. At any given time when these features are underway, these mesoscale phenomena affect only one or two stations. Thus, the spatial test often places suspect or warning flags on the data from the station observing the pressure perturbation. As the pressure perturbation advances along with the convection, a second and third station is oftentimes impacted. In these situations, radar and rainfall data are helpful to diagnose when pressure observations have been inappropriately flagged by the automated QA. In addition, the occurrence of very strong winds at and near the site observing a suspicious pressure reading is a good indicator that the pressure anomaly is a real event.

4.1 Case Study 3: A Wake Low Event

A mesoscale convective system with an intense wake low caused a number of observations to be inappropriately flagged by the spatial QA on 25 May 2000. The first observations to be flagged were from Wynona (WYNO) in northeast Oklahoma at 07:00 UTC (Fig. 3a). The wake low was spatially small in scale, and caused the sea level pressure at WYNO to drop to 1003.6 mb; meanwhile stations immediately surrounding WYNO were 4.0 to 6.2 mb higher. The base reflectivity image from the Inola radar at 06:59 UTC indicated that WYNO was immediately west of a large area of convection (Fig. 3b). In addition to the small area of the wake low, a large, elongated mesohigh was located underneath the most intense convection in far eastern Oklahoma.

The wake low remained well defined as it drifted east-southeast along with the convection. The Skiatook (SKIA) station next observed the mesolow at 07:30 UTC with a similar pressure drop to 1003.2 mb (not shown). Thirty minutes later, the Claremore (CLAR) station observed a sea level pressure of 1003.6 mb as it was influenced by the mesolow at 08:00 UTC (not shown). In each instance, the wake low was observed to be on the west edge of the precipitation. Thus, the wake low of 25 May 2000 caused the pressure observations from WYNO, SKIA, and CLAR to receive a number of suspect and warning flags from the automated QA.

a)



b)

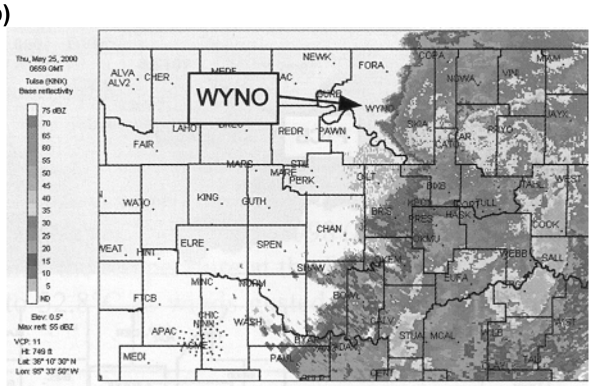
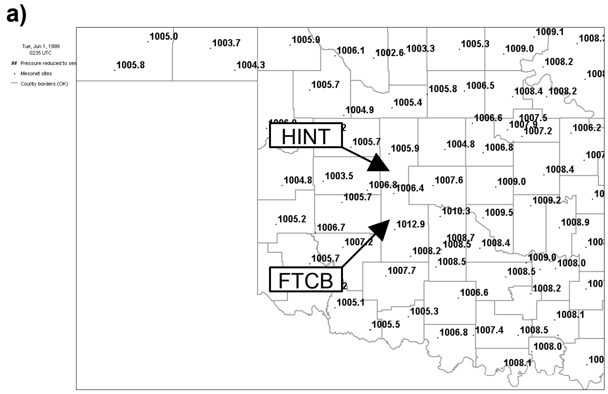


Fig. 3. (a) Mesonet station plot of the sea level pressure field (mb) at 0700 UTC 25 May 2000. At this time, the spatial QA test began to flag the anomalously low pressure at WYNO. (b) Base reflectivity from the Inola radar at 0659 UTC 25 May 2000. Note that WYNO lies on the back edge of the precipitation.

4.2 *Case Study 4: A Mesohigh Event*

On 1 June 1999, a strong mesohigh developed under an intense convective storm in southwest Oklahoma. In 20 minutes, the sea level pressure at Fort Cobb (FTCB) rose 4.02 mb. Due to the small spatial scale of the intense mesohigh, the pressure data from FTCB were flagged as warning by the automated QA. Figure 4a depicts the sea level pressure field over southwest Oklahoma at 02:35 UTC. The FTCB pressure was 6.5 mb greater than that at the nearby Hinton (HINT) site located 40 km north. The base reflectivity from the Frederick, Oklahoma radar at the same time (Fig. 4b) depicted a large area of radar echoes which were 50-60 dBZ in intensity over FTCB. Downdrafts of cool air and almost 25 mm of rain in 20 minutes were observed during this mesohigh event at FTCB. Such ancillary information provided strong support that the pressure anomaly was a real event, despite the fact that the data were flagged as erroneous by the spatial test.

a)



b)

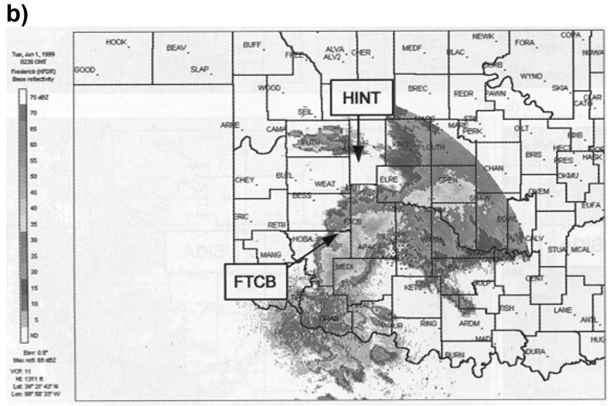


Fig. 4. (a) Mesonet station plot of the sea level pressure field (mb) at 0235 UTC 1 Jun 1999. The FTCB station was determined to be observing an intense mesohigh. (b) Base reflectivity from the Fredrerick radar at 0236 UTC 1 Jun 1999. Note that FTCB was located beneath a large area of radar echoes which were 50-60 dBZ in intensity.

5. HEATBURSTS

Heat bursts are mesoscale phenomena that usually occur in association with dying thunderstorms (Williams 1963). On occasion, heat bursts produce anomalously warm surface temperatures. Heat bursts have historically been difficult to detect due to their small spatial and temporal scale. However, the Oklahoma Mesonet has made it possible to observe these ‘rare’ phenomena on numerous occasions. Based upon more than 75 heat burst events detected within the Mesonet since 1994, the most dramatic heat bursts have occurred at night when temperatures sometimes rise higher than the afternoon maximum temperature.

When heat bursts occur in Oklahoma, they are usually detected by only a limited number of stations. Because of the small spatial scale of a heat burst, the observations from an event are often flagged as erroneous. Along with a temperature increase, sites that detect heat bursts usually witness a sharp decrease in relative humidity and a rapid increase in wind speed. These additional parameters plus radar data, when considered as a set, can lead to a more accurate determination of data quality than is produced by automated routines.

5.1 Case Study 5: A Northwest Oklahoma Heat Burst

A localized heat burst occurred in northwest Oklahoma on 20 September 1998 (Fig. 5). On that morning, the temperature at the Buffalo site (BUFF) rose to 32.8°C as winds gusted to 23.6 m/s. These observations seemed inconsistent with nearby observations from stations in the area. As a result, the automated QA flagged the data as erroneous. Within 45 minutes, the heat burst dissipated, winds decreased, and the temperature decreased rapidly to 22.7°C. Associated with the initial temperature rise and gusty winds, a small decrease in pressure and a distinct decrease in dew point temperature were observed.

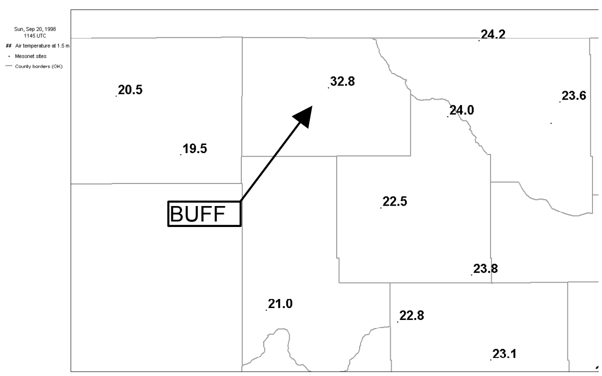


Fig. 5. Mesonet station plot of the air temperature field (°C) across northwest Oklahoma at 1145 UTC 20 Sep 1998. A heat burst is underway at the Buffalo (BUFF) station.

6. VEGETATION INFLUENCES ON MICROCLIMATES

The characteristics of vegetation in and around a meteorological observing station sometimes dramatically impact the observations of several meteorological parameters. The soil temperature, understandably, is sensitive to the characteristics of the soil. Darker soils naturally warm more than do light colored soils under similar conditions of solar radiation. In addition, the vegetation growing above the soil temperature sensors modulates the amount of insolation received by the soil; in effect, vegetation has a strong impact on the variability of soil temperature.

Likewise, the vegetation of surrounding land areas also influences the meteorological observations at a Mesonet site. A grove of trees on the eastern horizon may delay sunrise from a few minutes to an hour (as detected by the Mesonet's pyranometer). Moreover, an irrigated field upwind of a station can increase significantly the measured relative humidity. An extreme example of this influence occurs each winter as the wheat fields in western Oklahoma create a moist anomaly across a 6-7 county area. The higher relative humidity values observed result from abundant transpiration that occurs in the nearby wheat fields. The same agricultural fields have a surprisingly strong impact on air temperature observations in those counties (normally, Mesonet sites are much cooler).

6.1 Case Study 9: A Cooling Effect from an Agricultural Field

Each summer, a number of users express concern about a cool temperature anomaly at the Altus (ALTU) site in southwest Oklahoma. A snapshot of surface temperatures in that region at 23:00 UTC on 8 August 1998 is shown in Figure 6. Temperatures across the counties of southwest Oklahoma were nearly uniform at 38°C, except at ALTU which was 4°C cooler. This cool bias, however, is not always present. In fact, ALTU and nearby Tipton (TIPT) observed similar afternoon air temperatures on 7 August 1998 while the afternoon wind speed averaged less than 1.6 ms^{-1}. However, as average wind speeds exceeded 5 ms^{-1} on 8-9 August 1998, a cool bias at ALTU becomes apparent.

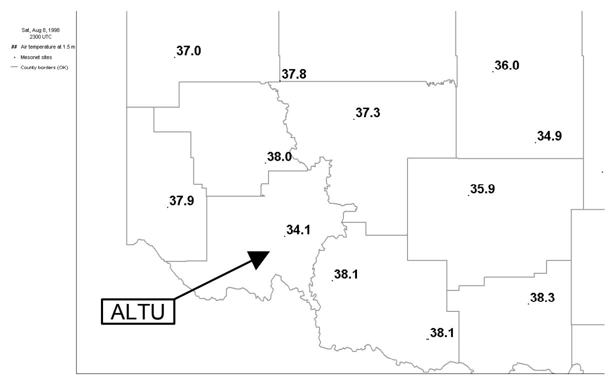


Fig. 6. Mesonet station plot of the air temperature field (°C) across southwest Oklahoma at 2300 UTC 8 Aug 1998. The Altus (ALTU) temperature appears to have a cool bias, but in fact, the cool anomaly is real and results from the influence of a large agricultural field upwind of the stie.

This cool anomaly can be explained by using site photos posted on the World Wide Web (http://okmesonet.ocs.ou.edu). A site photo from ALTU reveals a large irrigated cotton field surrounding most sides of the station. As surface air moved across the cotton fields toward the ALTU station, temperatures at the site were cooler (due to increased latent heat flux and decreased sensible heat flux) when compared with air temperature data from Tipton (20 km to the southeast). Despite the fact that the ALTU temperature data appeared suspect, in reality, the data were deemed to be quality observations.

In contrast to other case studies in this manuscript, the transient cool anomaly at ALTU has never been intense enough for the temperature data to fail the automated QA. A temperature difference of 6°C compared to surrounding sites would be necessary for the spatial test to suggest poor quality data. However, the ALTU observing site represents a good example of how land use affect meteorological observations and make quality control more difficult.

7. CATALOGING UNIQUE METEOROLOGICAL EVENTS IN THE QUALPARM TABLE

The cases of cold air pooling, “inversion poking”, mesohighs, mesolows, heat bursts, and variations in vegetation discussed in Section 3 through Section 6 illustrate instances when unique meteorological phenomena impacted the Mesonet’s automated quality control procedures. To combat these problems, the Mesonet plans to use its existing qualparm table to catalog the start and end times of events that created unwarranted QA flags by the automated tests.

The qualparm table represents a database that uses human intervention to flag data as erroneous regardless of results from the automated QA tests (Section 2b). It has been successfully used since 1996 to increase the severity of QA flags because trained personnel sometimes recognized erroneous data while automated routines did not. In the future, the qualparm table will also be used to *decrease* the severity of QA flags when real meteorological events are known to have occurred.

In addition to the QA flags of 0 through 3 (“good” through “failure”), two new levels of flags will be added. A flag of 5 would dictate that the final automated QA flag be reduced by 1 (i.e., a suspect QA flag would be decreased to good, or a warning QA flag would be decreased to suspect). A flag of 6 would dictate that the QA flag be reduced to 0 (i.e., the data should be deemed as good no matter what the automated QA determined.) These additional levels will allow a meteorologist to manually downgrade the severity of QA flags for a specific station at a specific time when appropriate, and allow more data to reach scientists without unwarranted flags.

8. CONCLUSIONS

To ensure quality data from a meteorological observing network, a well-designed quality control system is vital. Automated quality assurance software provides an efficient means to sift through large volumes of data and to flag observations that truly are erroneous. While employing algorithms to flag ‘bad’ data, it is difficult to avoid flagging data as erroneous when small-scale phenomena occur.

Data from many micro- and mesoscale meteorological events are difficult to quality control. For example, when the spatial test compares data acquired from close neighboring stations, perfectly good observations may differ enough to fail the test. Cold air pooling, “inversion poking”, mesohighs, mesolows, heat bursts, and variations in vegetation have all caused the spatial QA test used by the Oklahoma Mesonet to flag good data as erroneous.

Although not discussed in this manuscript, the step test, range test, and like-instrument test also have erroneously flagged good data. For instance, the hot, dry summer of 1998 created some soil temperatures in excess of the maximum range of 50°C used at that time. As air temperatures soared repeatedly above 40°C in 1998, it became obvious that flags from the range test for soil temperatures were unwarranted. That same summer, soil temperature observations occasionally failed the step test when rain fell on hot soils (> 50°C) and created rapid cooling.

The step test also ‘failed’ solar radiation data on occasions when bright sunshine sporadically broke through puffy cumulus clouds. Although rare, solar radiation has changed more than 800 Wm^{-2} between consecutive observations during mid-summer. Data collected during low-level temperature inversions that were unusually strong also have been flagged by the like-instrument test when temperature differences exceeded 10°C between 1.5 m and 9 m.

Despite these problems, the Oklahoma Mesonet has implemented a QA system that represents a compromise between having automated QA tests stringent enough to catch bad data, but relaxed enough to permit meteorological observations of real phenomena to be correctly flagged in the archives. Most importantly, the automated QA tests employed by the Oklahoma Mesonet are thought to be rigorous enough to ensure that research-quality data are collected on a routine basis. By cataloging the meteorological events that fail the automated QA in the qualparm table, even better quality assurance of Mesonet data will be accomplished.

9. REFERENCES

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