7.4 THE VALUE OF A QUALITY ASSURANCE METEOROLOGIST

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1. INTRODUCTION

Automated software is a vital tool for quality assurance (QA) of the more than 1 million observations measured daily by the Oklahoma Mesonet. However, even the most carefully designed automated QA algorithms will miss some erroneous observations. Likewise, some of nature's most interesting meteorological phenomena result in data that fail many automated tests.

The QA meteorologist at the Oklahoma Mesonet employs numerous manual techniques to complement automated QA. The three primary techniques include: 1) examination of the automated QA results on a daily basis to investigate suspicious data, 2) evaluation of rainfall observations through comparison with radar data and double mass analysis, and 3) analysis of monthly statistics to detect sensor drift or bias. In addition to detecting problematic sensors, it is critical that the QA meteorologist trace the true start time of each problem so that appropriate data can be manually flagged as erroneous. Lastly, the QA meteorologist is responsible for communicating problems to, and coordinating with, appropriate field technicians to ensure proper resolution.

The role of QA meteorologists is also essential to climate networks. Over the past several years, climatologists at the Oklahoma Climatological Survey (OCS) have methodically investigated cooperative observer data for Oklahoma. Manual investigation revealed more than 2000 observations from the NCDC TD-3200 archive for Oklahoma that had been checked by automated routines but turned out to be in error when compared to original records or data from neighboring stations. A daily Top-20 list is one tool used by OCS to identify outliers for further review by the QA meteorologist.

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2. EXAMINATION OF AUTOMATED QA RESULTS

Each morning, the QA meteorologist receives an electronic report containing a summary of the problems detected by the automated QA software (auto-QA). The report contains information about sites, variables, and their respective auto-QA flags. Each problem is investigated so that data can be manually flagged back to the trace date (i.e., the true starting date/time of the problem) and a trouble ticket can be issued to Mesonet technicians. In some cases, the auto-QA flags are manually over-written if a mesoscale event caused good data to fail the automated tests (Fiebrich and Crawford 2001).

Table 1 shows an abridged auto-QA report from 11 June 2003. The first column in the report lists the names of stations with suspected data problems. The second column indicates the variable the auto-QA has flagged. The next seven columns specify the number of observations that were flagged from the following independent algorithms and the severity of the flag (Shafer et al. 2000; Fiebrich and Crawford 2001): range (R; failure), step (ST; warning), spatial (SP; suspect - warning), like-instrument (LI; suspect - warning), step-to-normal (STN), like-adjust-spatial (LAS), and spatial-adjust-like (SAL). The sensor-specific tests comprise the next six columns: soil moisture deltaT (SMD; suspect - warning), soil moisture step (SMS; warning), soil moisture freeze (SMF; suspect), soil moisture reference temperature (SMT; failure), barometer error (BAR), and battery voltage (BAT). The last column of the report lists the “final” auto-QA flag sorted by number of observations marked as suspect, warning or failure, respectively. These final automated flags are determined from a decision-making algorithm that logically compiles results from each of the independent tests.

The sample report in Table 1 depicts suspected data problems at three sites: Blackwell (BLAC), Erick (ERIC), and Fort Cobb (FTCB). At BLAC, the auto-QA flagged data from the soil moisture (FT05 and ST05 variables) and soil temperature sensors (TB05, TB10, TS05, TS10, and TS30 variables). The QA meteorologist traced the problems to a shared multiplexer and issued a trouble ticket. The subsurface data were

TABLE 1. Abridged report from the Mesonet's automated QA software on 11 Jun 2003.

SITE	VAR	ST R(F)	(W)	SP(S-W)	LI(S-W)	STN	LAS	SAL	SMD(SW)	SMS (W)	SMF (S)	SMT (F)	BAR	BAT	COMB(S-W-F)
BLAC	FT05	000	000	000-000	000-000	000	000	000	000-013	002	000	013	000	000	000-000-013
BLAC	ST05	000	000	000-000	000-000	000	000	000	000-013	002	000	013	000	000	000-000-013
BLAC	TB05	024	001	001-000	001-000	000	000	000	000-000	000	000	000	000	000	000-000-025
BLAC	TB10	024	000	000-000	001-000	000	000	001	000-000	000	000	000	000	000	000-000-024
BLAC	TS05	023	001	001-001	001-000	000	000	000	000-000	000	000	000	000	000	000-001-024
BLAC	TS10	024	000	000-000	001-000	000	000	001	000-000	000	000	000	000	000	000-000-024
BLAC	TS30	022	001	000-000	000-000	001	000	000	000-000	000	000	000	000	000	001-000-022
ERIC	TA15	000	000	002-005	000-000	000	004	000	000-000	000	000	000	000	000	004-002-000
ERIC	TAIR	000	000	002-005	000-000	000	004	000	000-000	000	000	000	000	000	004-002-000
FTCB	WS9M	000	000	000-001	000-001	000	000	000	000-000	000	000	000	000	000	000-000-001

TABLE 2. Monthly QA statistics for Mesonet variables. "Average" denotes the average of the 2100 UTC observations.

Variable	Statistic
Air temperature at 1.5 m	Average; Difference between two 1.5 m sensors; Difference between 1.5 m and 9 m sensors
Air temperature at 9 m	Average
Rainfall	Monthly accumulation
Relative humidity	Average; Maximum observation during month
Dew point	Average
Solar Radiation	Average daily accumulation
Sea level pressure	Average
Wind speed at 10 m	Average; Difference between 10 m and 9 m sensors
Wind speed at 9 m	Average; Difference between 9 m and 2 m sensors
Wind speed at 2 m	Average
Wind direction at 10 m	Average
Bare soil temperature at 5 cm	Average; Difference between 5 cm and 10 cm sensors
Bare soil temperature at 10 cm	Average
Sod temperature at 5 cm	Average; Difference between 5 cm and 10 cm sensors
Sod temperature at 10 cm	Average; Difference between 10 cm and 30 cm sensors
Sod temperature at 30 cm	Average

manually flagged until the multiplexer was replaced. At ERIC, auto-QA flags were placed on the two 1.5 m air temperature sensors (TA15 and TAIR variables). Upon further investigation, it was determined that rain-cooled outflow caused the air temperature measurements at ERIC to fail the spatial test even though the data were valid. After this phenomenon was diagnosed, manual flags were entered into the QA database so that the auto-QA flags were removed from the data archive. At the final site listed (FTCB), a single auto-QA flag was placed on the 9 m wind data (WS9M). Evaluation of the data showed that the anemometer exhibited a starting threshold problem. The trace date of the problem was determined, the data were manually flagged, and a trouble ticket was issued.

A critical component of rigorous quality control is the accurate flagging of data from the true start time of the problem until the time the issue is resolved. A time series plot of the data from the two 1.5 m air temperature sensors (TAIR and TA15) at the Wister (WIST) site are shown in Figure 1. The auto-QA's like-instrument test detected a problem with the TA15 sensor on 15 June 2003. Closer manual inspection of the data showed that a slight bias developed in the TA15 data on 5 June 2003. Therefore, the TA15 data were manually flagged from 5 June 2003 until the sensor was replaced on 18 June 2003. In almost all cases, auto-QA at the Mesonet is successful in detecting instrument problems; however, manual QA is necessary to properly flag the exact period of erroneous observations.

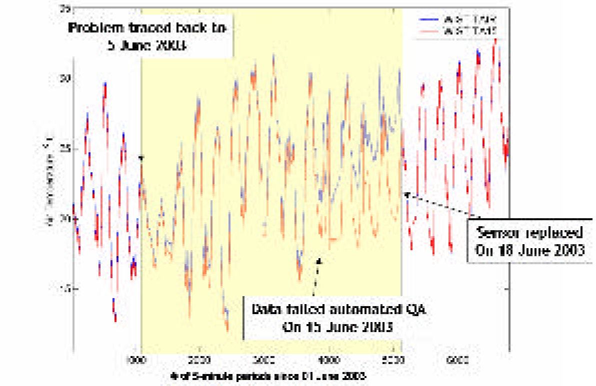


FIG. 1. Time series plot of the 5-minute air temperature (°C) from two independent sensors at the Wister, OK site for 1-23 June 2003. The shaded area indicates observations that were manually flagged as erroneous by the QA meteorologist.

3. EVALUATION OF RAINFALL DATA

Because of the high spatial variability of rainfall across Oklahoma, the quality assurance of rain data is performed manually. After each rain event, the QA meteorologist compares the rainfall observed from each Mesonet site to that estimated by the nearest NEXRAD radar. A map displaying Mesonet rain data with the radar-estimated rainfall for 7 August 2002 is shown in Figure 2. The Hectorville (HECT) site recorded no rain during this event; however, surrounding Mesonet sites received 25 to 61 mm (1.0 to 2.4 inches) of rain. Radar estimates of precipitation confirmed that the gauge at HECT had malfunctioned. Appropriate data were flagged and a trouble ticket was issued.

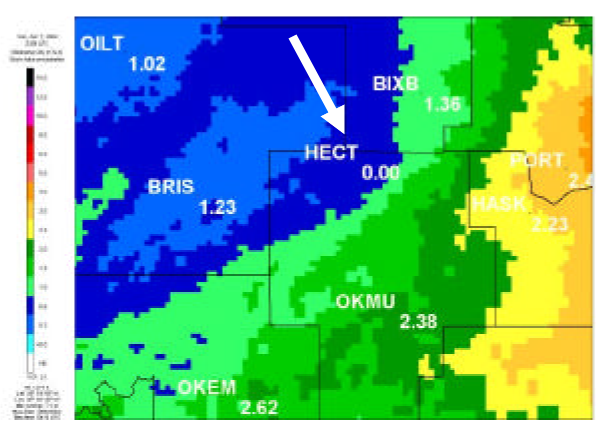


FIG. 2. Malfunctioning rain gauge at Hectorville (HECT) diagnosed by overlaying storm total precipitation from the Twin Lakes, OK radar at 2359 UTC 7 Aug 2002 with rainfall observations (inches) from Mesonet stations.

Subtle rain gauge problems can only be detected after long periods of data have been collected. Double mass analysis (Dingman 1994) is a useful tool to compare a site's accumulated rainfall to that of nearby sites. In Figure 3a, the upper left plot shows the accumulated rainfall at the Ada (ADAX) site in 1997. The remaining plots in Figure 3a compare the ADAX accumulated rainfall to that of five neighboring sites. It can be noted that although rainfall totals from individual rain events may differ from site to site, the double mass accumulations over several months follow a near 1:1 relationship. Figure 3b shows a similar analysis for the Antlers (ANTL) site. The double mass accumulations reveal that starting in February 1997, the ANTL rain gauge began to over-report. The problem was traced to the installation of a new gauge at the site in late January 1997; thus, the QA meteorologist flagged the ANTL rainfall data back to that time. ANTL is located in the southeastern part of Oklahoma where average annual rainfall ranges from 1016 to 1780 mm (40 to 70 inches) and radar coverage is limited. Therefore, double mass analysis is an extremely useful tool for ensuring quality rainfall data in this part of the state.

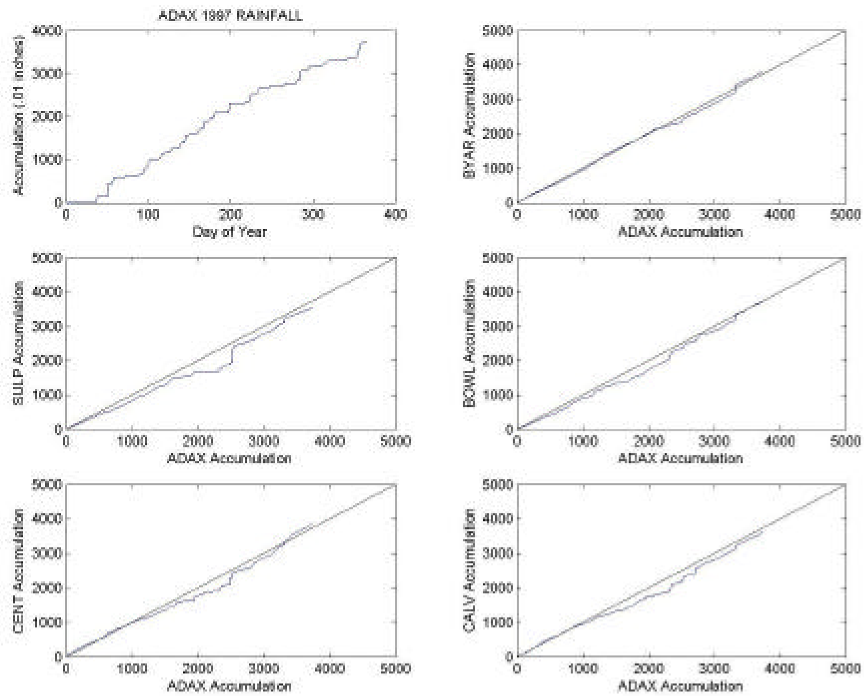
4. MONTHLY QUALITY ASSURANCE

Slight sensor biases and drift may not always be apparent by performing daily quality control. At the end of each month, the QA meteorologist analyzes monthly statistics of each variable and prepares a report that summarizes the health of the network.

Prior to performing the monthly analysis, missing data records are collected if possible (note: the number of uncollectible data records usually account for less than 0.5% of the Oklahoma Mesonet's data archive). Next, statistics (Table 2) are computed for each variable and evaluated by mapping the results.

Figure 4 shows the average 2100 UTC sod temperatures at 10 cm for May 2002 across southern Oklahoma. The 'cool spot' over Durant, OK (DURA) suggested that the 10 cm sensor had developed a low bias. Time series analysis of the sod temperatures verified that the sensor indeed had a 3 to 5 °C low bias compared to nearby sites and to the other sod temperatures (5 cm and 30 cm) at DURA. After determining the trace date, the QA meteorologist manually flagged the data and issued a trouble ticket to the appropriate Mesonet technician.

a)



b)

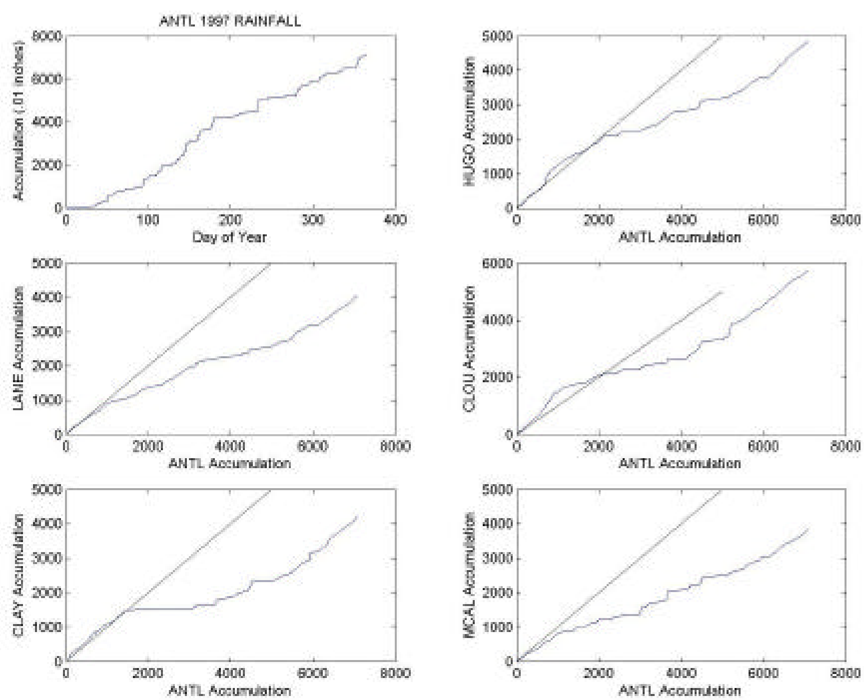


Fig. 3. (a) Double mass analyses for the Ada (ADAX) site for Jan 1997 through Dec 1997. Units of rainfall are in hundredths of inches. (b) As in (a) except for the Antlers (ANTL) site.

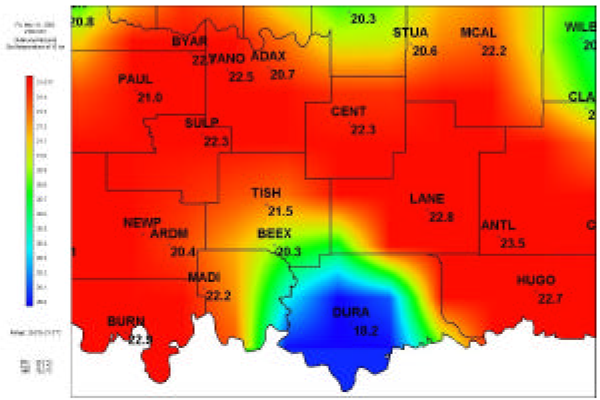


FIG. 4. Mesonet station plot of the average 2100 UTC sod temperature (°C) at 10 cm for May 2002.

5. OTHER MANUAL TECHNIQUES

This brief manuscript does not intend to fully describe every technique used by the QA meteorologist to ensure quality data. Time series analysis techniques are used frequently throughout the day to troubleshoot suspected problems. Thousands of digital photographs (Fiebrich et al. 2004) are archived and viewed each year to monitor vegetation and sensor conditions that may affect data quality. Special weather events (i.e., winter precipitation and severe weather) often warrant case studies to properly flag affected observations.

6. APPLICATIONS TO COOPERATIVE OBSERVER DATA

Detecting errors in other datasets requires vigilance on a par of that described here. However, when working with historical data sets, some of the techniques described thus far may not be available. For example, comparison between radar-estimated rainfall and in situ rainfall data is only possible in recent years. Other tests, designed to look at data on a monthly or longer scale, may detect biases and long-term errors, but fail to catch transient events. In addition, when working with cooperative observer data it is necessary to take into account the time-of-observation factor. Spatial techniques may not work on a day-to-day basis because even a few hours variance in observation time would quickly exceed allowable ranges of departures from estimated values.

One technique used by climatologists at OCS is a subjective evaluation of daily top-20 lists (see excerpt in Table 3). Each day, a top-20 list of highest and lowest maximum and minimum temperatures, greatest daily precipitation, greatest daily snowfall, and greatest daily snow depth is automatically generated and e-mailed to staff climatologists. The data included in the lists includes NCDC TD-3200 and TD-3206 datasets. The top-20 lists provide a quick scan for outliers on a given date. In the example shown in Table 3, the 91-degree maximum temperature reading at Okmulgee looked suspicious. Subsequent comparison with original records, published in Climatological Data, revealed that the actual reported temperature was 53 degrees. In addition, the NCDC dataset had the minimum temperature for the date listed as missing; the original records revealed that a value of 44 degrees was appropriate.

In some cases, this technique reveals suspicious values that are shown to be accurate. For example, several stations reporting in the top-20 list for a given date lend validity to the NCDC observations. In the example shown in Table 3, the second station in the list was corroborated by another observation the same year. Similarly, observations for 2000, 1907, and 1980 showed up multiple times. It was not deemed necessary to further examine these observations. The list also indicates if observations in the dataset have been altered or flagged. In the example shown, the 79-degree reading at Ardmore in 2000 was edited by NCDC; in this case the series of observations for the month had been shifted by one day from what was reported.

In addition, during examination of some events, other values that were missing or removed by automated quality-assurance checks can be put back in, such as the minimum temperature for Okmulgee described previously. If a climatologist had not looked at the original records to validate the maximum temperature for that date, it is unlikely that the existing minimum temperature value would have been uncovered.

When errors are detected, such as in the case described above, an entry is made into a log file. The entry consists of the original dataset value, the corrected value, how the determination was made, and by whom. The log file is used to produce updated files which are used as the basis for OCS operations. In addition, errors are reported to dataset managers at NCDC, so that the values may be corrected in the original archive.

Daily listings of observations help put potential outliers in the context of other observations and make examining the historical

TABLE 3. Excerpt from the daily top-20 list for cooperative observer network maximum temperatures for January 13.

	Value	Data Flag	Obs. Time	Station Name	Climate Division	Year	Data File
1	91	-	(18)	Okmulgee Water Works	(CD 6)	1951	OK6670.dat
2	82	-	(99)	Hobart Municipal Airport	(CD 7)	1928	OK4204.dat
3	81	-	(7)	Marietta	(CD 8)	2000	OK5563.dat
4	80	-	(99)	Mcalester	(CD 6)	1907	OK5662.dat
5	80	-	(18)	Pauls Valley 4 WSW	(CD 8)	1928	OK6926.dat
6	79	N	(7)	Ardmore	(CD 8)	2000	OK0292.dat
7	79	-	(18)	Elk City	(CD 4)	1980	OK2849.dat
8	79	-	(18)	Erick	(CD 4)	1980	OK2944.dat
9	79	-	(7)	Madill	(CD 8)	2000	OK5468.dat
10	79	-	(99)	Meeker	(CD 5)	1907	OK5779.dat

records a manageable task. By checking these lists on a daily or weekly basis, the most egregious errors are removed from the data records. Iteration on an ongoing basis, sometimes over a period of years, can identify more outliers and at least improve the records of daily station extremes.

7. REFERENCES

Dingman, S. L., 1994: Precipitation. *Physical Hydrology*, R. McConnin, Ed., Macmillan, 108-110.

Fiebrich, C. A., and K. C. Crawford, 2001: The impact of unique meteorological phenomena detected by the Oklahoma Mesonet and ARS Micronet on automated quality control. *Bull. Amer. Meteor. Soc.*, **82**, 2173–2188.

____, D.L. Grimsley, and K.A. Kesler, 2004: The value of routine site visits in managing and maintaining quality data from the Oklahoma Mesonet. Preprints, *8th Symposium on Integrated Observing and Assimilation systems for Atmosphere, Oceans, and Land Surface*, Seattle, WA, Amer. Meteor. Soc.

Shafer, M.A., C.A. Fiebrich, D.S. Arndt, S.E. Fredrickson, and T.W. Hughes, 2000: Quality assurance procedures in the Oklahoma Mesonet. *J. Atmos. Oceanic Technol.*, **17**, 474-494.