6.5 QUALITY ASSURANCE AUDIT PROGRAM FOR SURFACE AND UPPER-AIR METEOROLOGICAL MEASUREMENTS IN THE SOUTH COAST AIR BASIN OF CALIFORNIA

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1. INTRODUCTION

The South Coast Air Quality Management District (SCAQMD) operates a large meteorological monitoring network to aid in forecasting air pollution episodes and to help analyze and model the meteorological processes that lead to elevated pollutant levels. In recent years, the network has undergone significant upgrades, including the addition of remote sensing instrumentation for upper-air measurements and the replacement of older mechanical sensors with newer sonic anemometers. Many of the improvements were related to enhanced monitoring requirements of the U.S. Environmental Protection Agency (EPA) Photochemical Assessment Monitoring Stations (PAMS) program. As part of the transition and upgrade process, an audit program was implemented to help understand the quality of the data obtained from the older instrumentation and what can be expected from the new sensors.

In addition to a variety of the more traditional sensors for wind, temperature, humidity, pressure, solar and UV radiation, the stations include three 915 MHz radar wind profilers with radio acoustic sounding systems (RASS), two sodars and twelve sonic anemometers. While this paper addresses the audit methods for each of the surface and upper-air remote sensors, it focuses primarily on techniques for the newer sonic anemometers and helps to establish some field procedures that are cost effective and efficient for the auditing of sonic wind systems. The procedures include the use of an audit data logging system with a compliment of certified sensors to audit station sensors that were not amenable to traditional simulated test atmospheres. Preliminary results of the audits are presented.

The audit program was initiated in September 2002 with initial audits of five surface stations. At the time of this paper preparation, the audit results have not been finalized. Nevertheless, the methods employed and preliminary findings from the field efforts in auditing these five stations are presented below.

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2. SCAQMD MONITORING NETWORK

The SCAQMD currently operates 35 air monitoring stations throughout the South Coast Air Basin in Southern California. Of these, 28 stations currently measure surface meteorology, with wind sensors at all locations, pressure sensors at 17, temperature and relative humidity sensors at 22, and solar and ultraviolet radiation sensors at eight. As part of the PAMS program, ozone photochemical precursors are measured at seven stations, along with all of the above meteorological sensors. In addition, three PAMS upper-air stations measure surface meteorology with tower-mounted sensors and profiles of wind and temperature with three Vaisala LAP®-3000 profilers and two AeroVironment Model 4000 MiniSodars. Siting of a fourth upper-air station in Orange County is pending. The SCAQMD meteorological network is shown in Figure 1.

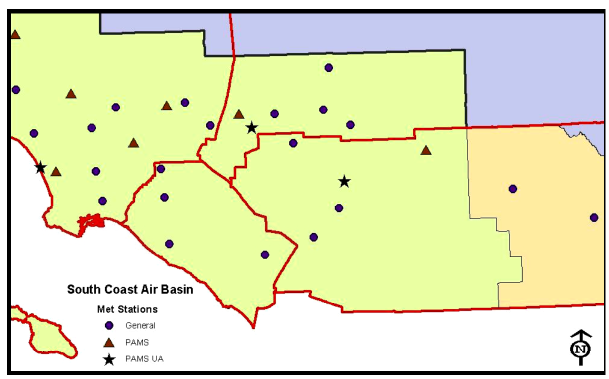

Figure 1. Map of the SCAQMD Meteorological Monitoring Network in the Southern California Counties of Los Angeles, Orange, San Bernardino and Riverside.

3. AUDIT METHODS

The meteorological monitoring network is operated by two different groups, one focusing on stations that measure surface air quality and meteorological variables, and a second that focuses on measurements of upper-air variables with surface stations to complete the vertical profile. For the first group, the sensor compliment was not amenable to audit methods that challenged the measurements with simulated atmospheres. For example, the temperature sensors could not be immersed in water baths, and the wind sensors audited were of the sonic variety that did not lend themselves to traditional rotational speed checks of the anemometers or aiming the "vane" in different directions. This group of sensors was the focus of the audits performed in September 2002.

The audit methods that will be used for the upper-air sensors are described in EPA (2000). The radar wind profilers and RASS systems will be performance audited using a combination of rawinsondes and tethered sounding balloons (Baxter 2002). The MiniSodars will be audited using both simulated winds generated by an Acoustic Pulse Transponder (Baxter 1995) as well as comparison to independent wind measurements. As part of the audit process, the sites will also be evaluated for their suitability to make the respective measurements. For example, the background noise level in the operating spectrum of the sodars is measured to assess the impact of the noise on the measurements. Additionally, photo documentation of the site and sodar or radar beam pointing directions is collected. As of the writing of this paper, the upper-air audits have yet to be conducted. These audits are anticipated in early 2003.

For the surface audits of the stations employing measurements that are not amenable to simulated atmospheres, a collocated transfer standard method of auditing was employed. EPA guidance (EPA 1995) describes various techniques for conducting collocated audits, and for the most part these methods were employed. For the sonic anemometer wind instrumentation some discussions are provided in this guidance document, but field implementation of the techniques is very limited. Additionally, there are standards for testing and evaluation of the performance of sonic systems (ASTM 2001), but the methods described would not be practical for field implementation. Using the above information, we developed and implemented various techniques for field audits such that a relatively quick review of all sensors could be performed in a cost-effective and timely manner. The focus was on the variables of wind speed and wind direction (from the sonic anemometer), temperature, relative humidity, pressure, solar radiation and UV radiation.

The core of the audit system was a Campbell Scientific CR21X data logger. To allow rapid deployment and retrieval of the package in the field, the sensor wiring was converted from the screw type panel mount to a standard 25-pin connector used for computers. The required channels on the data logger were assigned specific pins in the connecting cable and a seven-connector junction box was used as the main connector interface for all sensors. All numbered pins in the junction box were wired in parallel allowing a sensor to be plugged into any one of the seven connectors and be operational. The assignment of power, ground, excitation and signal lines was performed in the wiring of the pins in the cable for the individual sensors. The length of the main cable connection between the data logger and the interface was kept short to minimize electrical noise and ground loop problems associated with the distances from common ground connections. Figure 2 shows the data logger, interface junction box and cable connections with several sensors.

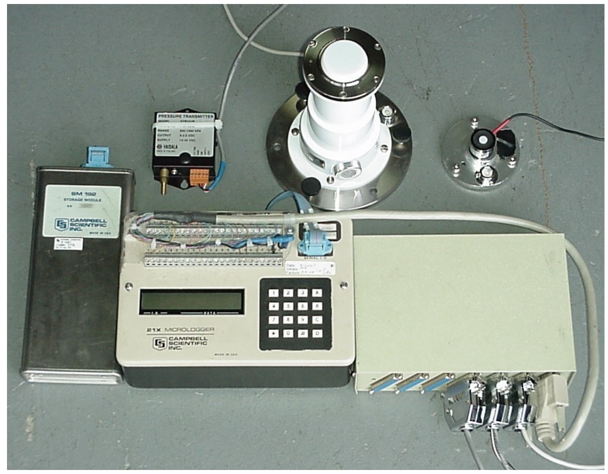

Figure 2. Data logging system with sensor interface/ junction box.

Prior to the start of the audit program the audit wind system was evaluated by collocation with a RM Young Model 81000 sonic anemometer. Data were collected over a 72-hour period and 5-minute horizontal scalar and vector averages of wind speed and wind direction were compared. The sampling height was less than ideal with the sensors approximately 4 meters above roof height and 1 meter apart. Figure 3 shows the sensor mounting. Scatter plots for the scalar wind speed and unit vector wind direction data sets for wind speeds greater than 1.0 ms^{-1}, as measured on the mechanical sensor, are shown in figures 4 and 5, respectively. The wind speed plot showed excellent agreement between the sensors with the sonic anemometer averaging wind speeds 0.04 ms^{-1} higher than the mechanical sensor. The standard deviation of the differences was 0.07 ms^{-1}. Wind direction differences averaged 6° with a standard deviation of 7°. These results were higher than what was found by Lockhart (1988) where he indicated the standard deviation of the differences for good agreement should be better than 2°. It is suspected that two factors caused this higher difference. The first is the shorter time duration (5 minutes versus Lockhart's 20 minutes) and the less than ideal siting, which would induce more turbulence over the rooftop. It should also be noted that a regression of the measurement pairs for wind direction is of little value since there were no wind directions less than 135° observed on the mechanical sensor.

As of September 2002, field audits had been conducted on five stations within a three-day period. To aid in the efficiency of the audits, up to two per day were conducted, one in the morning and one in the afternoon. For two of the audits, the system was allowed to collect data overnight providing a larger comparison database before it was moved to the next site. The field audit methods for each of the surface variables audited are described below.

Figure 3. Sensor mounting for the testing and evaluation of the audit wind sensor against a sonic anemometer.

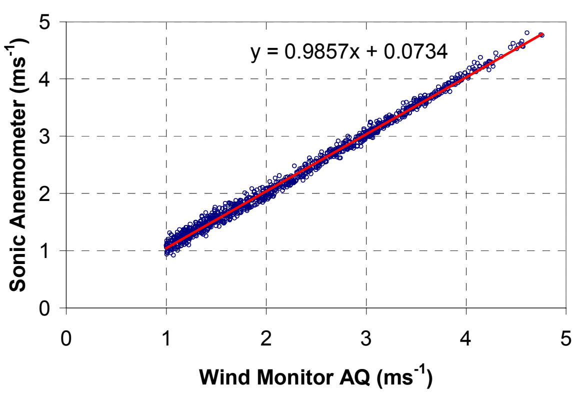

Figure 4. Wind speed plot showing the mechanical sensor (AQ) versus the sonic for wind speeds greater than 1 ms^{-1}.

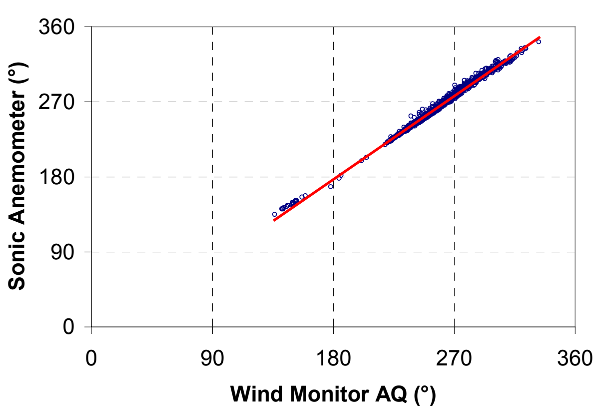

Figure 5. Wind direction plot showing the mechanical sensor (AQ) versus the sonic for wind speed greater than 1 ms^{-1}.

3.1 Wind Speed and Wind Direction

Even with the observed differences above, we decided the method would work for the first cut at audits of the sonic systems. The audits to be conducted would help evaluate the time duration required as well as provide much improved siting for the sensors. Our proposed criteria for evaluation of the sonic sensors are shown in Table 1. These criteria will be fine tuned as more data are collected.

Wind Variable	Average Difference	Standard Deviation of the Differences	Qualifications
Speed	±0.2 ms^{-1} + 5% of observed	0.2 ms^{-1}	Wind speeds greater than 1 ms^{-1}
Direction	±5°	2°	Wind speeds greater than 1 ms^{-1}

Table 1. Proposed audit criteria for the sonic systems.

The site sonic anemometer systems audited were not removed from the mounting tower during the audit process and all checks were conducted with the sensors in place. Each of the towers had movable carriages allowing the entire cross-arm and mounting assembly to be lowered from the measurement height to the surface. Prior to the lowering of the sensor, its orientation relative to true north was measured using either a solar method or alignment walked off using a hand-held GPS receiver. Both of these methods are described in Baxter (2001). Figure 6 shows the mounting of the audit system on the carriage structure. On one end of the audit boom was the wind sensor, the other end supported the temperature/ relative humidity sensor, adjacent to the site sensor.

Figure 6. Typical mounting of the audit sensors on the site tower.

A zero point with no wind flow around the sensor was then established using a simple box lined with "egg-crate" type foam to absorb acoustic signals. This type of enclosure is a simple version of what is recommended in ASTM (2001). To seal the box, additional foam was placed in the opening around the bottom and mounting mast. The response of the sensor was then observed over 5- to 10-minute periods and the wind speed and direction noted.

A collocated mechanical sensor (RM Young Wind Monitor AQ Model 05305) was then attached to the carriage on a separate cross-arm with the south facing direction of the sensor aligned down the cross-arm direction. Once mounted and raised to the normal measurement height, the cross-arm direction was measured and that direction was then used for the adjustment of the collected wind direction data to a true north alignment.

3.2 Other Meteorological Variables

While audit methods for temperature normally use a simulated atmosphere (multiple water baths), the sensors used throughout the network were not amenable to immersion. The sensor design integrated the relative humidity sensor into the temperature probe, and removal of the humidity sensor portion chanced damage to the instrument package. Additionally, the design of some of the temperature probes would not allow placement of a waterproof sheath around them and still have room for water immersion. As a result, the initial temperature audits used a collocation method with the audit system probe data logged on the audit data logger. The probe was placed in a naturally aspirated radiation shield adjacent to the site shield, which was also naturally aspirated. Prior to the audits, the audit probe was certified against a NIST traceable thermometer through multiple temperature water baths. This audit temperature sensor also had an integral humidity probe but the entire assembly could be placed in a waterproof sheath and immersed.

The remaining meteorological variables included relative humidity, solar radiation, UV radiation and pressure. Each of these variables was audited using the collocated method with all data logged on the audit data logger as 1- and 60-minute averages.

4. PRELIMINARY AUDIT FINDINGS

As of the writing of this paper the audits are still in the very early stages. Four upper-air audits have yet to be conducted and those audits will include surface stations of their own. Of the eight surface-only monitoring stations, five have been audited at this time. The presented audit findings below are not intended to provide numeric results, but instead to provide what has been learned from the development of the sonic wind system audit methods and the initial field applications of the developed audit system. Key preliminary findings are summarized below.

The results of the zero wind speed tests using the foam-lined box show an apparent offset in the wind speed of each of the sonic anemometers audited. The magnitude of the offset is less than 0.4 ms^{-1}. Comparisons of the reported wind speeds show very good agreement with little scatter between the two methods, but the offset seen in the zero response tests seems to be present in the upscale values. Whether this offset is due to an instrument or data system programming problem is being explored. Figure 7 shows the results from a typical audit showing this offset through the range of data collected. The data were collected as 1-minute scalar averages with the collection period including over 1000 measurements.

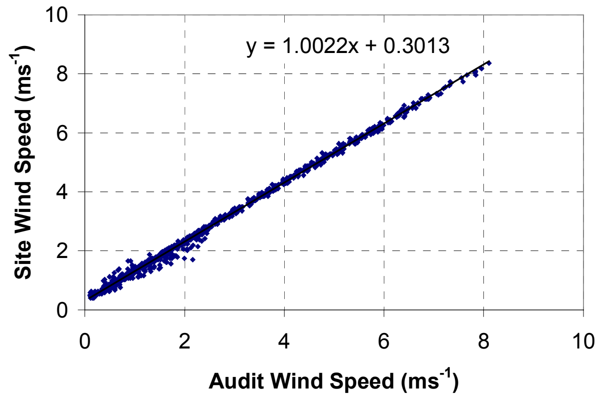

Figure 7. Wind speed audit of a sonic system showing an excellent correlation between the site and audit sensors, but with an offset in the sonic system of about 0.3 ms^{-1}.

Evaluations of the collocated wind direction data show mixed results. At one site, there is very good agreement between the scalar average wind directions (better than ±5°) for the 1-minute data compared. However, the results of the evaluation using the variance of the differences in direction shows a dependence on the wind direction. The worst agreement occurred with winds from a northerly direction. Further research into the problem revealed a calculation problem in either the sensor or the data system that produced differences upwards of 180° with audit reported wind directions within 30° of north. Figure 8 shows the plot for wind direction. This is a calculation problem that has plagued wind direction measurements for decades, and still seems to appear in some systems in use today. The reason for the calculation problem is being explored.

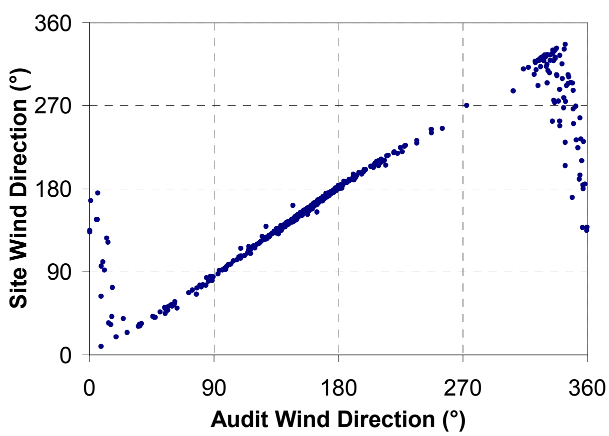

Figure 8. Wind direction audit of a sonic system showing a calculation problem with the north (zero) crossing.

Recognizing there is an error in the calculation of wind direction in the above sensor, we limited our evaluation of the differences at this site to wind direction comparisons when the audit sensor reported directions from 30° to 330°, to minimize the effect of the error on the statistical evaluation. Figure 9 shows the evaluation of the data from over 800 1-minute averages as a function of the wind speed. Both the average difference, and the standard deviation of the differences are plotted as a function of wind speed category. The wind speed category defines the threshold of wind direction values included in the calculation. For example, the values for average difference and standard deviation of the differences at 2 ms^{-1} includes all wind direction values when the audit wind speed was greater than 2 ms^{-1}. On the basis of these data, at an audit reported wind speed of 1 ms^{-1}, the average difference between the audit and site sensors was less than –0.5° and the standard deviation of the differences was just over 2°. It is suspected that with the correction of the north calculation problem, the reported standard deviations would improve.

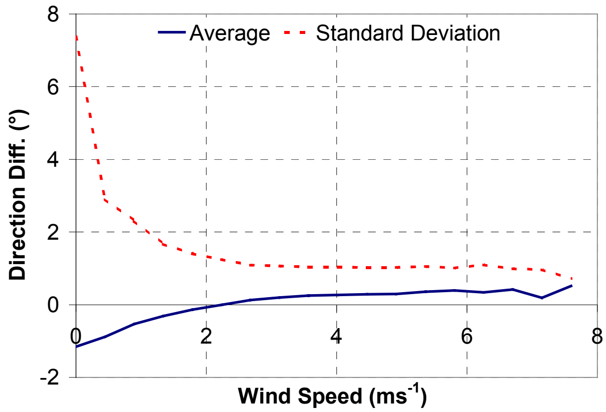

Figure 9. Calculation of the average of the differences and standard deviation of the differences as a function of wind speed for the sonic anemometer audit.

5. RECOMMENDATIONS

Much was learned in the preparation of the audit system and conducting the initial audits. The Collocated Transfer Standard (CTS) method of auditing will fulfill the goal of assessing the performance of site sensors, but usually involves a greater amount of time than is typically involved in an audit. The time is not so much in the field as in the analysis of the data collected. With future audits the procedures will become more routine and templates will be developed that will streamline the evaluation process. On the basis of our early results we have the following recommendations for audit programs that will be including sonic systems:

- For conducting the audits, an independent measurement system works well to assess the performance of the site sensors when auditing using artificial atmospheres is not possible. The developed system discussed here has provided very good results in the initial audits conducted. In particular, the performance audits of sonic wind systems can be conducted using shorter time interval data to collect enough data to perform a statistical comparison.
- The modular approach to the audit system proved reliable and efficient in the field for setup and operation. This allowed more than one audit to be conducted each day.
- For conducting multiple audits in a network, the scheduling of the audits can accommodate some sites where data are collected overnight to observe a broader range of conditions. This helps on a network-wide basis to overcome the limitation of the short duration of the “snapshot”, short-term CTS type audit.
- The comparison of the average differences for each variable audited provides a good measure of any bias in the data collected. Additionally, use of the variance of the differences can help identify potential problems with the calculations made in the data logger. As was observed during the initial audits, a problem was identified in the sensor/data logging system in the calculation of wind directions. This problem was not obvious in looking at the average differences alone.
- Collection of data in 1-minute averages provided adequate data to analyze the average differences. However, further research should be done to see if this short interval may introduce “noise” in the comparisons. The response time of the mechanical sensors is considerably longer than that of the sonic sensors. This recommended research may involve the averaging of the 1-minute data into longer intervals and then performing the comparisons to see if the statistical relationship has changed.
- Consideration should be given to the use of a “standard sonic anemometer” in place of the mechanical sensor. This would help reduce the effect of potential response time differences in the comparison of short time-interval data.
- Following the audits of all sensors, the data as a whole should be reviewed to assess the performance difference between the sonic systems audited and the mechanical sensor used in the audits. This mechanical sensor is considered typical of what is used in monitoring for meteorological data used in regulatory modeling but is in the process of being replaced by the sonic systems.
- The original wind speed and wind direction audit criteria proposed at the outset of the program proved to be fairly close to what was seen in the first set of data evaluated. However, more analyses are needed to identify criteria that are reasonable for field applications for a variety of sonic type sensors.

6. REFERENCES

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