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Final Report: Final Design of the Ozone Monitoring Station

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Final Report: Final Design of the Ozone Monitoring Station

Ozone Monitoring Group

Travis Hansen

Rebecca King

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Engineering Design VIII, Spring 2001

Faculty Advisor: Dr. Diana Glawe

Special Project Advisor: Dr. Fred Loxsom

Project Administrator: Dr. J. Paul Giolma

May 1, 2001

Executive Summary:

The purpose of the ambient air pollution project is to implement a real-time dynamic and modular ozone monitoring system on the roof of the Marrs Mclean Science Building (MMS) at Trinity University. The ozone monitoring system consists of an ultraviolet radiation sensor, an ozone monitor, a nitrogen oxide analyzer, a wind speed and direction instrument, a temperature sensor, and a data acquisition system. The system satisfies requirements of the Environmental Protection Agency (EPA), the Texas Natural Resource Conservation Commission (TNRCC), Trinity University, and Dr. Fred Loxsom, the system end-user. The prototype design for this project was developed based on the requirements of all involved parties, and greatly influenced by cost and ease of implementation.

The final design includes the following components:

- Ozone Monitor - Dasibi 1008 AH
- Nitrogen Oxide Analyzer – Monitor Labs Model ML 9841A
- Ground-Based Ultraviolet Radiometer System - YES UVB-1
- Wind Instruments - Texas Electronics Inc. Model 2010/2011
- Thermistor- Texas Instruments Model 837
- Heat Tape/Temperature Controller – Thermolyne
- Teflon Air Intake Lines - Bevco
- Data Acquisition System (Detailed list in Section 5)
- Dell Pentium II 400 MHz Processor

The location of the system component was selected to accommodate the EPA requirements within the physical limits on the roof of the MMS building, which is the system location imposed by the system end-user, Dr. Fred Loxsom. The selected location of the meteorological instrumentation is above the surface of the roof and thus requires a 9.5-foot tall vertical support tower. The tower is made from ¾-inch 1040 carbon steel pipe and is anchored to a catwalk for structural support.

Condensation in the air sample lines connected to the ozone monitor and nitrogen oxide analyzer, which could corrupt the ozone and nitrogen oxide data, is prevented by the use of heat tape wrapped around the lines. The heat tape is maintained at an elevated temperature using a temperature controller. Pipe insulation as well as aluminum foil encases the heat tape and sample lines to increase conduction and minimize heat loss, respectively, in order to induce optimum performance.

The control system and the data acquisition system (DAQ) integrate multiple independent LabView modules to acquire, process, store, and transmit all relevant weather, ozone, and nitrogen oxide data. The end-user is able to control all instrumentation through one graphical interface module. This system runs on a computer already present in Dr. Loxsom's lab.

At the termination of the project, the following steps will need to be taken to make the station fully operational: the ozone monitoring station requires testing the instrumentation against standards to validate measurements, calibration of the temperature controller to determine the operational dial setting, and the final set-up for data transfer to the TNRCC main network, which may require integration of a data logger as well as a router into the system.

Abstract:

The final design for the ozone monitoring system focuses on instrumentation, structural support, avoiding condensation in the air sample lines, and data acquisition.

The final design includes the following instrumentation:

- Ozone Monitor - Dasibi 1008 AH
- Nitrogen Oxide Analyzer – Monitor Labs Model ML 9841A
- Ground-based Ultraviolet Radiometer System - YES UVB-1
- Wind Instruments - Texas Electronics Inc. Model 2010/2011
- Thermistor - Texas Instruments Model 837
- Heat Tape/Temperature Controller – Thermolyne
- Pentium II Computer running Windows 2000, with network card, data acquisition card, LabView v 5.1, and available serial, and PCMCIA ports. (All furnished by Dr. Loxsom from his weather laboratory)

The instrumentation is mounted on a tall tower constructed from 1040 carbon steel pipe that is anchored to an existing catwalk on the roof of the Marrs McLean Science Building (MMS) at Trinity University using U-bolts for support. Heat tape will be used to prevent condensation in the air sample lines. The Data Acquisition (DAQ)/Control system uses a 5 input channel data logger module to collect measurements, which is then integrated into the Graphical User Interface (GUI) module in LabView and will eventually be sent to the Texas Natural Resource Conservation Commission (TNRCC)/Alamo Area Council of Government (AACOG) main network. Currently, the ozone monitoring station has not been fully tested, and therefore, is not completely operational.

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1.0 Introduction:

The purpose of this project was to implement a real-time dynamic and modular ozone monitoring station on the roof of the Marrs McLean Science Building (MMS) at Trinity University. The system measures ambient air temperature, wind speed and direction, UV radiation, as well as ozone and nitrogen oxide concentrations. The information generated from this site will eventually be used by the Alamo Area Council of Government (AACOG) in the Community Calibration for Ozone Awareness project as well as by Dr. Fred Loxsom from Trinity University's Physics Department for his research. The system satisfies the requirements from the Environmental Protection Agency (EPA), the Texas Natural Resource Conservation Commission (TNRCC), Trinity University, and Dr. Fred Loxsom, the end-user. The prototype and final design for this project was developed based on the requirements of all involved parties, and greatly influenced by cost and ease of implementation.

2.0 Instrumentation:

The Trinity University site will include ozone concentration, ultraviolet radiation, ambient air temperature, wind speed and wind direction and nitrogen oxide (NOx) measurements.

2.1 Ozone Monitor

The ozone measurements are taken using an ozone monitor is on loan from Texas Natural Resource Conservation Commission (TNRCC). The instrument is the Dasibi 1008 AH built by Dasibi Environmental Corporation. The ozone-monitoring instrument uses ultra-violet (UV) light to determine the concentration of ozone in the air sample. Since ozone absorbs UV light, the instrument measures UV absorption, which is directly proportional to the concentration of ozone in the sample.

- The UV light source is a 254 nm emission line from a mercury discharge lamp.
- The minimum detectable level of ozone for this instrument is 1.0 part per million.
- The ambient operating temperature range of this instrument is about 10°C – 40°C. Some measurement interference occurs with the presence of gaseous hydrocarbons with strong absorption at 254 nm.

- The ozone monitor is able to measure ozone to within .001 part per million, as long as the ozone concentration of the air is above the minimum level.

Some measurement interference occurs with the presence of gaseous hydrocarbons with strong absorption at 254 nm. The cost of the ozone calibration equipment is about $4000. The calibrator cost is beyond the budget for this project, so the instrument will be calibrated quarterly by the Alamo Area Council of Governments (AACOG) to ensure quality performance.

2.2 Ultraviolet Radiometer

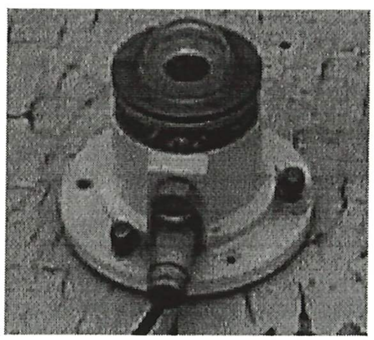

Figure 2.2: *Ultraviolet Radiometer*

The ultraviolet measurements are obtained using a Yankee Environmental Systems (YES) UVB-1 Ground-based Ultraviolet Radiometer System that has been provided by Dr. Loxsom from the Trinity Physics Department. The YES UVB-1 was chosen because it has a single channel output and would be easier to impliment into the system. The YES UVB-1 radiometer is designed to measure irradiance from 280 to 320 nm with a calibration coefficient of 1.80 $W/m^2/V$. The region of the UV-B spectrum that strongly affects the atmospheric ozone concentration is around 305 nm, which is within the instrument's range. Ideally, the ultraviolet measurement should be taken without shadows during daylight hours so the radiometer was placed to the South of the other instruments at a distance of 4 feet to prevent shadowing. Dr Loxsom has established the requirement that the ultraviolet sensor must be in direct sunlight during the time from 1 hour after dawn to 1 hour before dusk. This was accomplished be eliminating all obstructions around the UV instrument. The ultraviolet instrument was calibrated by Yankee Environmental Systems Inc. on January 16, 2001 and is operational. The Yankee Environmental Systems Inc recommends that the instrument be calibrated on a yearly basis for accurate measurements.

2.3 Wind Speed and Direction Instruments

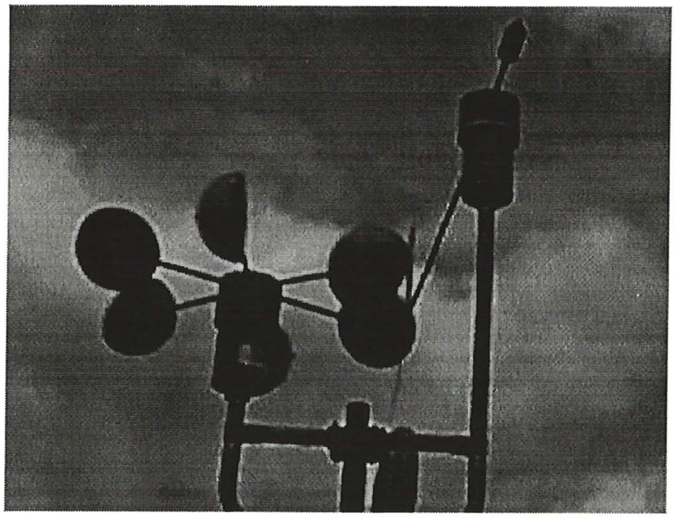

Figure 2.3.1: *Wind Speed and Wind Direction Instruments*

The wind speed and wind direction instruments were provided by the Trinity Physics department. The instruments were manufactured by the Texas Electronics Inc. The wind direction instrument is a Model Number 2010 and the wind speed instrument is Model Number 2011. The wind direction instrument is accurate to within the required 0.5 degrees and the wind speed instrument is accurate to within the required 1 mile per hour. The wind instruments have been calibrated and are in use in the testing station.

In addition to the accuracy requirements there were also requirements concerning the position of the instruments. The obstructions on the roof of MMS could cause reading problems. An obstruction is anything that is higher than the sensor for the measuring device, in an urban area the biggest concern is surrounding buildings. Structures that are higher than the sampling station for the measuring device could influence the wind speed and wind direction measurements. The air flow and mixing pattern around the sampling location could influence the measurement by changing the wind flow, so that the measurement is not representative of the areas true air flow. The Figure 2.3-2 shows the effect of a building or other obstruction on the air flow.

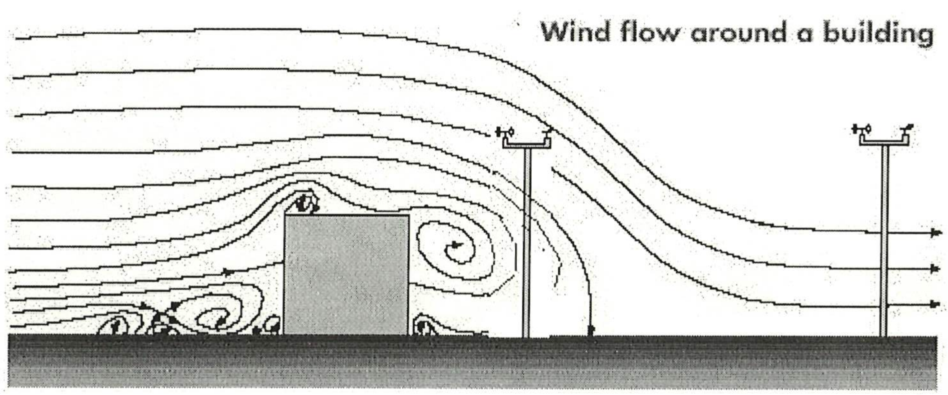

Figure 2.3.2: *Air Flow Around A Building*[1]

The instruments are located on the roof of the MMS building such that the distance from any obstruction is over 6 times the height difference between the obstruction and the ozone sensor (Section 3 provides details of wind instrument and tower placement).

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[1] Figure 2.3.2 was adapted from the Education and Weather (www.meto.govt.uk/sec2/pg3/awsmt.html)

2.4 Temperature Sensor

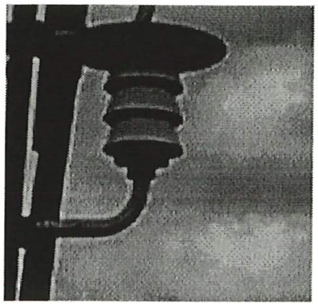

Figure 2.4: *Thermistor in Protective Shield*

The air temperature measurement is taken using a thermistor. The temperature measurement system is a Texas Instruments Inc. Model Number 837 provided by the Trinity Physice Department. The temperature system is accurate to within 0.5 degrees, which is within the 1-degree requirement. The thermistor is contained in a radiation shield that was also provided by the Trinity Physics Department. The thermistor was placed in a radiation shield to prevent solar radiation from interfering with the measurement. The temperature system has been calibrated and is operational. The thermistor and shield are mounted with the wind equipment on the roof of MMS on the tower. A potential problem was the convection from the surface of the building effecting the temperature measurement. This problem was solved by placing the thermistor at a height of 9.5 feet from the surface of the roof of MMS on the tower.

2.5 Nitrogen Oxide Analyzer

The nitrogen oxide (NOx) analyzer, sent to Trinity by the TNRCC, has been implemented in the ozone testing station. The instrument is a Monitor Labs Inc. Model ML 9841A Chemiluminescene-based nitrogen oxide analyzer. This instrument is designed to measure ambient levels of NO, NO_2 and NOx. NOx measurements are based on a reaction of the NO molecule with an internal source of ozone in an evacuated reaction cell, which results in the emission of light. The operating range for this instrument is from 0.05 to 1.0 parts per million. The device is a single channel instrument and has been successfully incorporated into the system.

2.7 Instrument Testing

The ozone monitor and the nitrogen oxide analyzer have not been calibrated yet and thus cannot be tested. These instruments will calibrated by the TNRCC. Operating instructions for each instrument are included in the "Trinity University Ozone Monitoring Users Manual" generated as a part of this project. The manual is attached.

3.0 Tower Design and Construction:

A tower was constructed to lift the meteorological instruments to an acceptable height above the MMS roof so that the wind speed and wind direction measurements would not be significantly influenced by air-flow obstructions such as Moody Engineering Building (MEB), Marrs McLean Science (MMS) elevator penthouse, and the surrounding trees. The UV sensor was placed in the proximity of the tower on an existing table. The ozone and NO sample lines were fastened to the tower in a separate conduit.

3.1 Tower Location and Height

As previously stated EPA standards require that wind speed and direction instruments be located such that the distance from any obstruction be at least six times the height difference between the obstruction and instruments. Also, since the tower had to support instruments that may require occasional maintenance, locating the tower near a catwalk was necessary. Based on all previously mentioned location constraints imposed on the tower location and elevation of instruments, Point B on Figure 3.1 was selected as the best location for a 9.5 ft tower. In addition the instrumentation was placed so that it affects the observatory view as little as possible. The construction of the tower provided for many options, all of which had advantages and disadvantages.

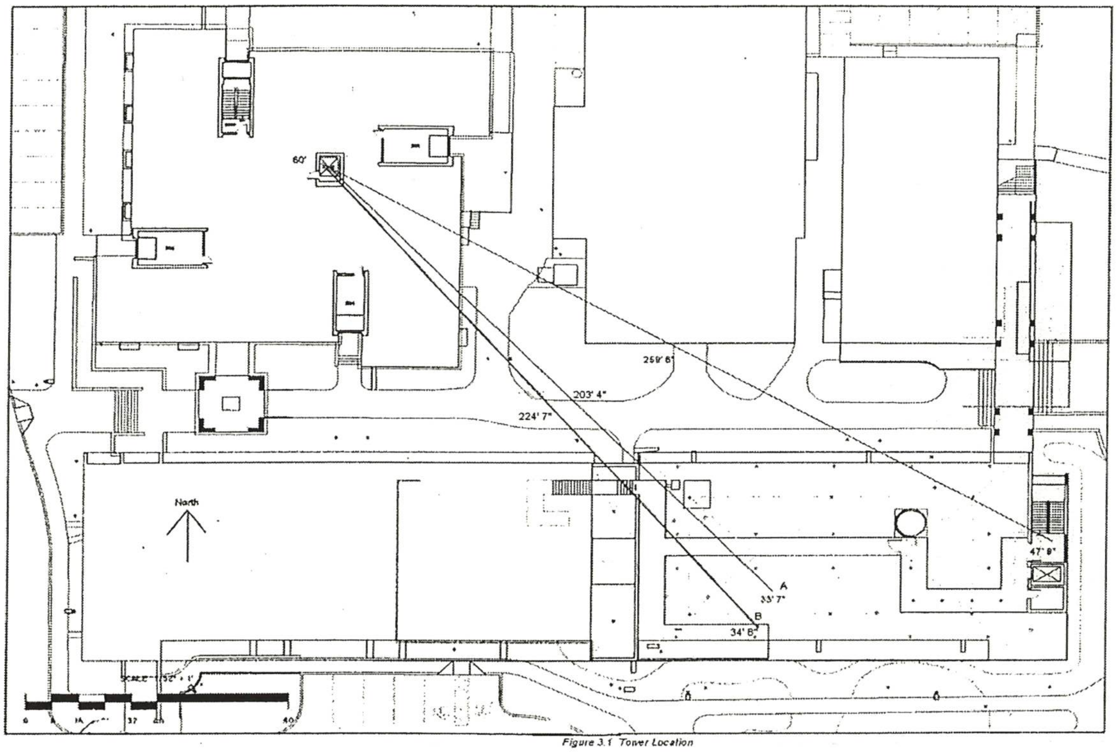

Figure 3.1: *Tower Location*

PVC, aluminum, and galvanized steel, were considered materials from which to build the new tower. PVC pipe was considered because of its high strength and low cost. However, PVC becomes very brittle and deteriorates when exposed to the outdoor elements for long periods of time. Due to this deterioration, PVC pipe may have failed structurally and was not used.

Metals are most widely used for load-carrying members in buildings, bridges, and a variety of consumer products. Aluminum and steel are used in many of the same applications. However, Aluminum is commonly used in applications that require a high strength-to-weight ratio and corrosion resistant material. Since aluminum is generally more expensive than steel, and weight is not a major concern in the tower design, steel is a more cost effective choice compared to aluminum. Furthermore by using galvanized steel, corrosion can be minimized.

3.2 Tower Attachment and Anchoring Methods:

Several methods were considered to secure the tower to the roof of the MMS building. These are: attaching a cable support system to the tower (Figure 3.2.1), connecting the tower to a metal plate and bolting the plate onto the roof (Figure 3.2.2) anchoring the tower into a concrete foundation (Figure 3.2.3), attaching the tower directly to the catwalk (Figure 3.2.4). The structural design of the tower must ensure that the tower is securely attached to the roof and that the instrumentation is mounted securely to the tower. John Greene, director of the Physical Plant at Trinity University, approved installation of a tower on the roof of the MMS building; however, he did not want the roof lining to be punctured in any way. This eliminated the cable support system and bolt support system from consideration, leaving the concrete foundation and catwalk system to be explored. This concrete foundation design was designed as a standalone assembly that would satisfy all requirements imposed on the tower. The pipe would be welded to a 1 foot by 1 foot square steel plate that is ¼" thick. This plate would then be imbedded into a 4" thick concrete slab 3 feet by 3 feet square. An inch and a half of the slab would be poured over a layer of chicken wire, used to strengthen the concrete, at which time the steel plate would be placed the remaining two and a half inches of concrete would then be poured over plate and existing concrete. The slab would weigh approximately 450 pounds using a density of 150 lbs/ft^3 for concrete. The pipe would reach a height of 9.5 feet as required.

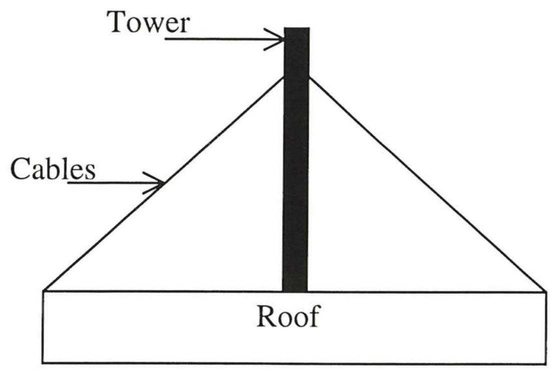

Figure 3.2.1: *Cable Support System*

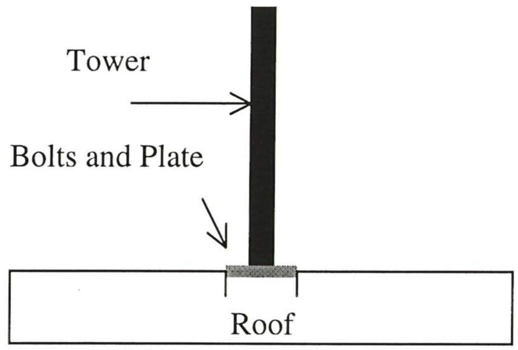

Figure 3.2.2: *Bolted Support System*

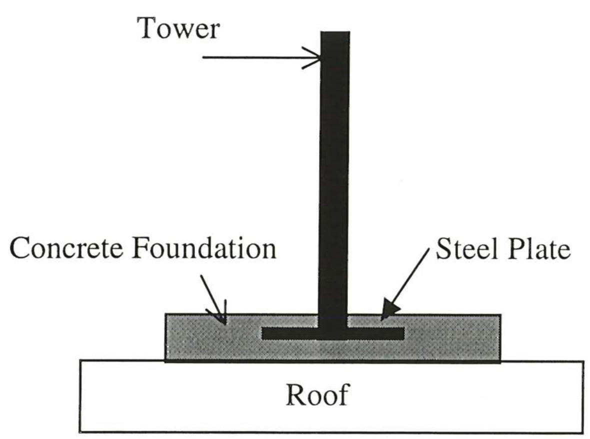

Figure 3.2.4: *Concrete Foundation System*

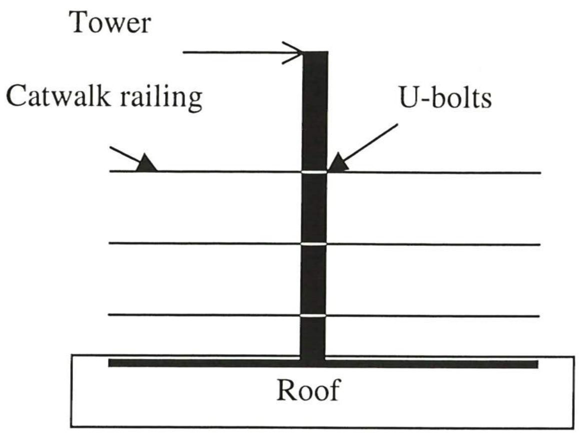

Figure 3.2.4: *Catwalk Mounting*

Since the tower would support instruments that may require occasional maintenance, and the weight of the concrete required to overcome any tilting that might occur was substantial (Appendix A). Dr. Loxsom the end user of the project requested the catwalk design be used.

3.3 Tower Testing

The tower was constructed from a ¾-inch 1040 carbon steel pipe with inner radius ¾-inch and outer radius $^{21}/_{20}$-inch. Mounting the tower directly to the catwalk would provide, easy access to the instruments on the tower and avoids the concerns about adding a concrete weight on the roof of the MMS building. The pipe would be attached to the railing of the catwalk using U-bolts. The catwalk is raised 13 inches above the roof's surface. An 8 feet 5 inch long pipe would successfully raise the instruments to the specified height of 9.5 feet above the roof's surface. The tower would be supported by the railing of the catwalk. The railing is 3 feet high so the total unsupported height of the tower is 5.5 feet.

Design calculations show that the pipe can support the weight of the meteorological instruments and withstand the forces due to a 75 mph wind and a 75 lb force exerted by an individual leaning on the tower during maintenance (Appendix A).

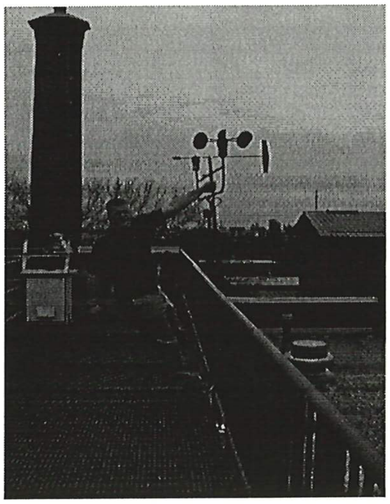

Figure 3.3: *Testing of Mounting System*

The group conducted a test on the tower that is currently on the roof of MMS to ensure that the tower will withstand the predicted forces. Travis Hansen, lead designer of the tower, pulled on the top of the temporary tower and found that there was only slight deflection as shown in Figure 3.3. The force that Travis applied to the tower is greater than any environmental forces and human influence that the tower is expected to encounter in its days on the roof of MMS.

4.0 Condensation:

4.1 Prevention of Condensation

When condensation occurs between the sample intake locations and the air monitors, the samples may no longer represent the actual ozone and nitrogen oxide levels in the vicinity of the sample intake. Condensation of the air sample in the sample line is only possible when the dew point of the air sample is above the temperature of the room in which the air monitoring devices are located. The dew point of the air sample depends on the local temperature and humidity of the surrounding environment so condensation is not as likely to occur during the winter as it is in the summer. The temperature of the room in which the ozone monitor and nitrogen oxide analyzer are located is approximately 70°F-80°F throughout the year. Therefore, condensation can occur in the air samples due to the temperature change the ambient air samples experience while traveling from the atmosphere to the air monitoring devices, which are located on the 3rd floor of the Marrs McLean Science Building. In order to prevent condensation from occurring in the sample lines, the system was designed to force the moisture in the air sample to remain in vapor form.

4.2 Proposed Analysis and Solutions

Several techniques for temperature control of the tubing were evaluated in terms of performance, ease of implementation, and cost. The standard procedure for EPA-controlled air monitoring stations is to insulate the portion of the tube that would experience a change in temperature in order to reduce the heat transfer between the tube and its surroundings. However, heat transfer analysis of the system configuration at Trinity University proved that insulation alone could not prevent condensation from occurring in the sample lines (Appendix B). Therefore, heat tape, which maintains the sample lines at an elevated temperature and therefore guarantees that condensation will not occur in the sample lines, has been wrapped around the air sample lines to prevent condensation in even the worst-case scenarios (i.e. extremely high temperature and humidity).

4.3 Heat Tape and Temperature Controller

A Thermolyne and Fibrox[2] manufactured flexible heating tape that has a heavy glass-braided yarn covering was selected to provide added electrical insulation. The heat tape is ½-inch wide and 10 feet in length. The heat tape requires a 120-volt power supply and is equipped with a connected plug, which allows it to be easily implemented into the system design, as well as lead wires that are securely joined to the end of the tape. An external temperature controller is required to maintain the operating temperature of the heat tape at the desired temperature of approximately 105°F. The controller selected is manufactured by Thermolyne and uses an on/off duty cycle input control with no feedback setting to specify temperature. Therefore, calibration of the temperature controller will be required to determine the relationship between the controller input settings and the resulting heat tape temperature. The temperature controller can be calibrated by measuring the steady-state temperature of the heat tape for each of the control settings in order to determine the dial setting that corresponds to the desired operating temperature.

4.4 Design of the Air Sample Line System

According to TNRCC affiliate Ken Rozacky the air sampling line connected to the air monitoring devices should be an inert material, specifically fluorinated ethylene propylene (fep) grade virgin Teflon with a ¼-inch outer diameter and a 3/16-inch inner diameter. Two 50-foot sample lines, one for the ozone monitor and one for the nitrogen oxide analyzer, run through a support conduit extending approximately 10 feet above the surface of the MMS roof. The openings of each tube, where samples of air are collected, are directed down towards the roof using a 90-degree elbow constraint to prevent rain from entering the sample tubes. Two ½ micron Whatman Teflon coated filters have been incorporated into the tubing system upstream of the air monitoring devices to remove particulates that could corrupt the accuracy of the measurements. In order to ensure that any condensate is removed from the sample prior to entrance into the air monitoring units, gravity-controlled water traps have been inserted into the air sample lines just upstream of both measurement devices. A removable plug has been incorporated into the water trap design (see Figure 4.1) so that the station operator can easily remove the collected moisture from the tubes.

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[2] VWR Scientific Products Catalog p. H786

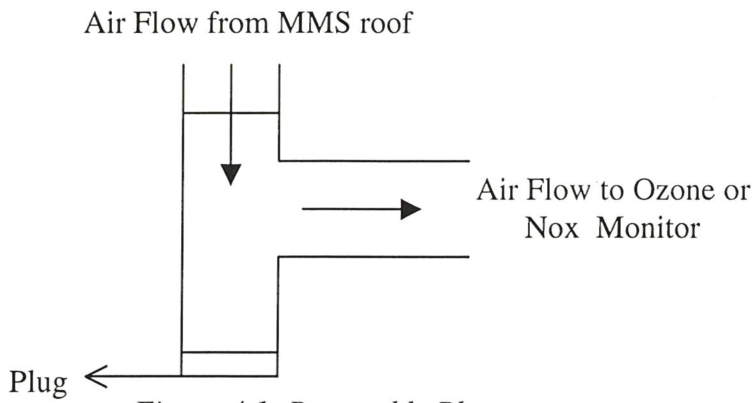


Figure 4.1: Removable Plug

As suggested by Dr. Michael Everest, Trinity Chemistry Professor, the heat tape is layered with aluminum foil to increase conduction along the sample line and then wrapped with pipe insulation to minimize heat loss to the environment (see Figure 4.2).

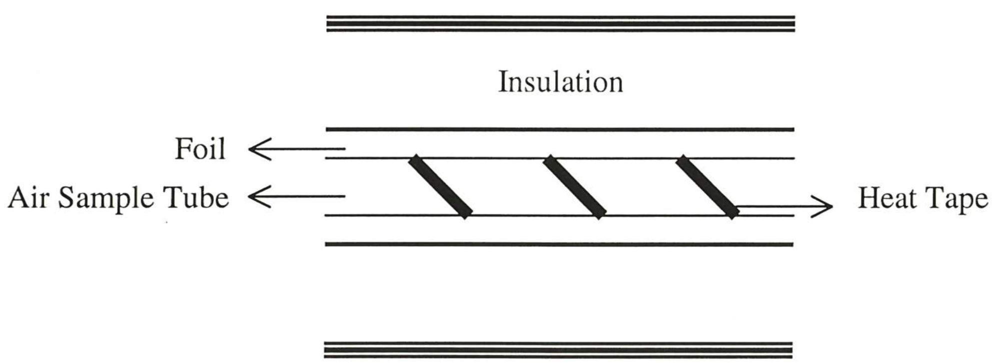


Figure 4.2: Tubing System
(cross-sectional view)

In order to minimize cost, both sample lines were wrapped with the same heat tape along the portions of the tubes that are exposed to the cool temperatures of the room. At the separation point, each line is wrapped only in pipe insulation, which is attached using duct tape adhesive, until the tubes enter the monitoring devices.

4.5 Recommended Operation of the Air Sample Line System

Using heat tape to warm the air sample lines will guarantee that condensation does not occur in the sample lines. However, during periods of low temperature and humidity, such as during the winter, it may be possible to turn off the power to the heat tape without incurring condensation in the lines. Incorporating gravity-controlled water traps into the air sample lines, just upstream of the ozone and nitrogen oxide monitors, will enable the device operator to test for condensation without risk of damaging equipment. The operator would simply turn off the power supply to the heat tape and monitor the water trap. If condensation occurs in the sample lines, water will accumulate in the water trap and the operator will know that power should be supplied to the heat tape to avoid condensation. Although the power consumption of the system has not been evaluated, the advantages of turning off the power supplied to the heat tape, when feasible, are to save energy as well as to reduce the number of active systems to be monitored and maintained during operation of the ozone monitoring station.

5.0 Data Acquisition System:

5.1 Design of the Data Acquisition/Control System (DAQ)

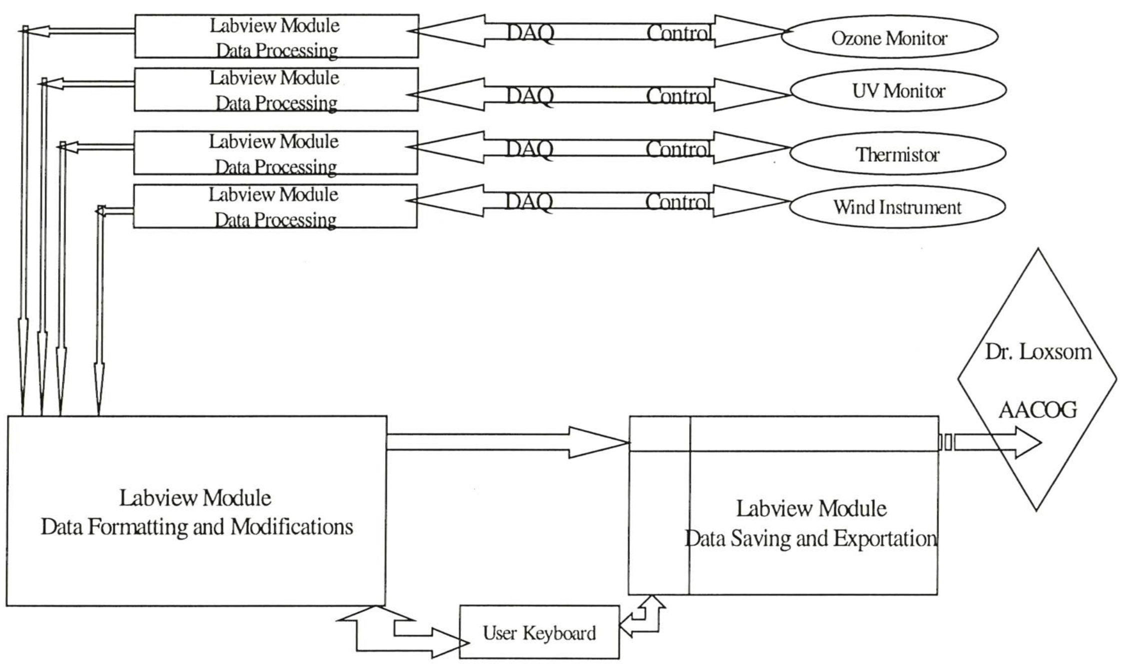


Figure 5.1: *LabView General Module Schematic*

The final design for the Ozone Monitoring DAQ System retains the functionality as indicated in the above block diagram. Through the course of the design project, the system has required numerous modifications to account for changes to the specifications and additional end-user modifications.

These modifications included the addition of the potential adaptability to work with the Campbell Scientific Data Logger (if chosen for use by Dr. Loxsom per TNRCC requirements), capacity for operation beyond the current level of 5 input channels and a digital display. These 5 channels are to receive data through the use of each channel's 2-terminal analog voltage (high voltage, and low/reference voltage) by means of standard signal wire supplied by the end-user Dr. Fred Loxsom.

The modifications also account for the need to sample data from the YES UVB-1 Radiometer, which had been chosen in mid-semester by Dr. Loxsom to replace the previously supplied Biospherical Instruments Radiometer.

Finally, of note with respect to modifications of the prototype design, the supplied ozone monitoring unit, Ozone Monitor Dasibi Environmental 1008-AH 6547, as previously expected, functions using a similar 2- voltage analog output signal, however features no input terminals for control functions. The unit must be controlled using its own control terminal, located on the front panel.

This DAQ hardware necessities of the Ozone Monitor System still required the following components:

- PC Computer Station
- PC Data Acquisition Card (as Data Logger usage is yet to be determined)
- PC Network Card
- PC Serial Port
- PC Data Storage Space (Backup/ Archive)
- Data Acquisition Card Software
- Programmable Control/ Processing Software (Labview)
- Internet Connection

The supplied PC unit was tested and verified operational. All necessary hardware and software have been acquired and installed in compliance with given specifications and requirements per Mr. Rick Hite and Dr. Fred Loxsom.

5.2 *DAQ System Graphical User Interface and Features*

The main features which a standard user or operator controls include:

- System On / Off

- System Data Sampling Time Interval
- System Data Saving
    - Data Save Path
    - Data Appending
- System External Communications
    - IP Address and Port Number of Host

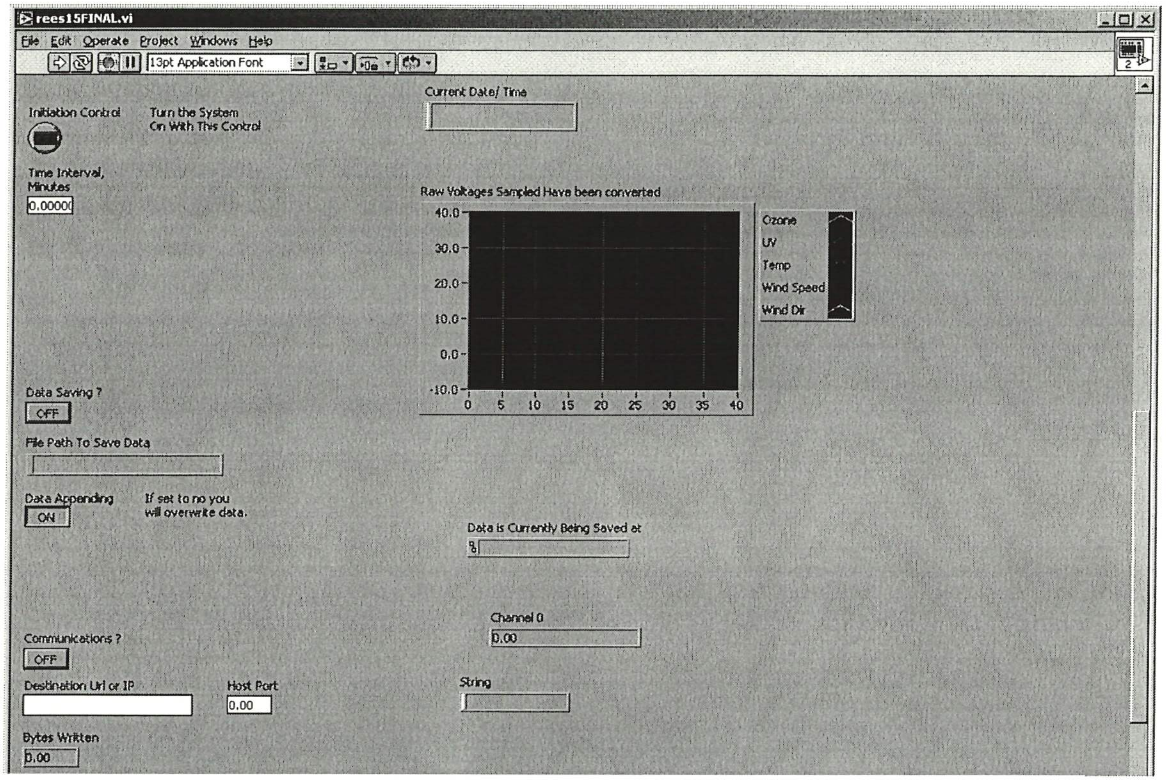


Figure 5.2 *LabView User Screen*

5.3 *DAQ System Program Theory Basics*

In order for the DAQ LabView Module to operate as mentioned above, the basic structure of the program was completed as follows. The entire System On / Off control is a digital input, controlled by the operator, set with default as 0 (off).

When the system is 'turned on', or 'initiated', Labview initializes a specific case structure module (a complex 2 setting while loop) for this setting that in turn operates all other features. If the system is in 'off' mode, LabView initializes an empty case structure which executes nothing, but keeps LabView running.

Inside of the 'on' case structure, there are numerous other sub-modules that operate in a synchronized, independent manner. The timing of the process executions is controlled by the user input of system sampling time (converted to milliseconds internally). When the specified time has elapsed, separate modules are initialed, as desired by the user through the GUI system screen. These modules include the processes for: accessing the current system date and time, converting raw voltages into meaningful measurements, data saving to a chosen path, data appending, opening communications with an external host computer, transmitting data to the external host computer, and returning the size of the string sent to the external host computer. The processes are arranged such that should an error occur in one process, the system remains running until the user disables it, rather than a total instantaneous system shut down.

5.4 *DAQ System Testing and Operations*

The overall system performance has been tested in several ways. Data sampling was verified using simulated signals from a Hewlett Packard 3311A Function Generator and measured with a Fluke 8050A Digital Multimeter. Calibration equations convert the sampled data correctly as verified using Microsoft Excel analysis of data saved.

Data Saving was verified. The sampled and converted data is properly stored in a .dat file named as the date of the session. Data is automatically appended to previously saved data file during the same day if multiple sessions are used, unless intentionally changed by operator or user. The format of the saved data is a tab delimited text file with standard spreadsheet string formatting. The time of the sampled data is also included in the data. At the proposed sampling time interval of 5 minutes, the system would save data at a rate of approximately 55 MB per year with continuous monitoring. Therefore, Disk storage space should not be an issue for a long period of time.

The connection to the TNRCC/AACOG network still requires separate testing, given that the officials representing these agencies have not supplied all necessary information concerning communications with their network system in a timely manner. The LabView code does include all necessary modules and requires simple test and verification of communications using a set of dummy data. The communications features of the LabView program include user notification of communication error, and a 'bytes transmitted' display for verification of full data string transmittal for each data set sampled. (Data strings are of consistent length, which the user can obtain on system) Further system operation help can be obtained by the user from a programmed online help manual, also available as a printed copy in the overall Ozone Monitor System Manual.

6.0 Project Scheduling and Costs

6.1 Gantt Chart

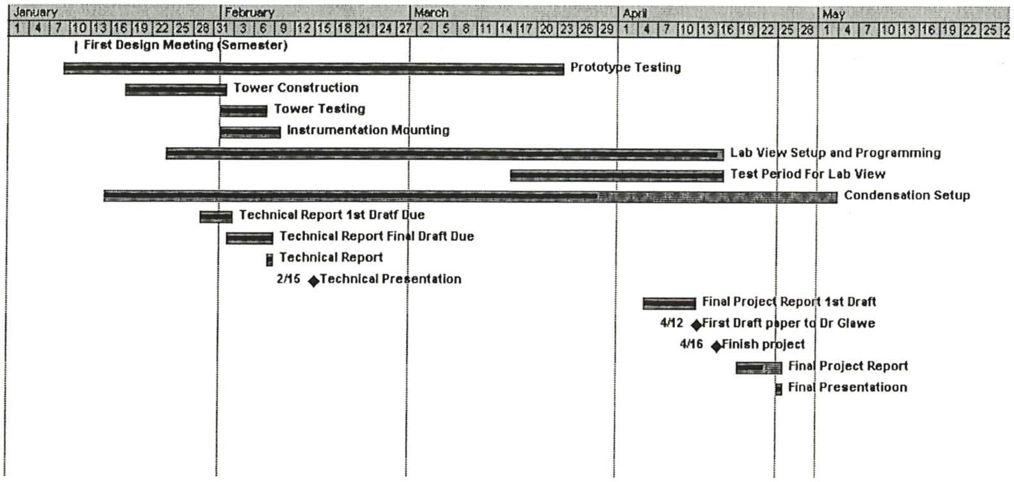


Figure 6.1 : Final Gantt Chart

6.2 Group Costs

Cost of Materials

Tower Supplies	$50
Power Supply Back-up (if needed)	$100
Teflon Tubing ¼" x 50'	$110
Thermolyne Heat Tape ½" x 10' (approx. 30' required)	$109
Thermolyne Temperature Controller	$130
Supplies and Materials	$144
Miscellaneous	$70
Real Costs	$713
Remaining Real Budget	$287

Appendix A: Tower Design Calculation

Design Calculations for Tower Height and Foundation Weight

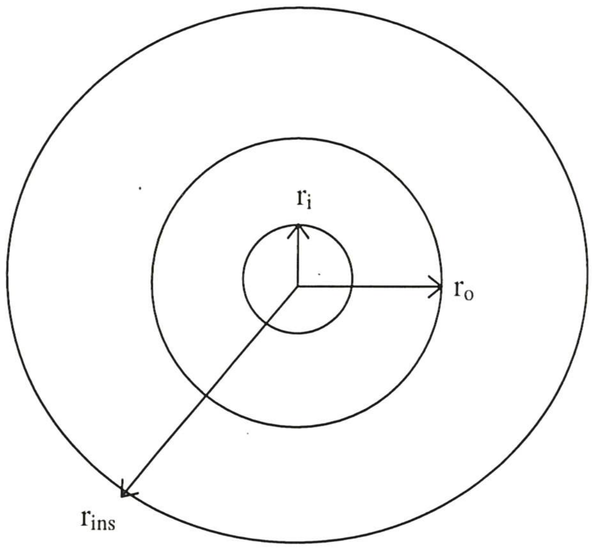
Max Winds	75mph	
Weight of Instruments	17.000lb	
Weight Top of Pole	2.500lb	ft
Weight of Main Pole	16.000lb	ft
Inner Diameter of Pole	0.750in.	0.063ft
Outer Diameter of Pole	1.050in.	0.088ft
Inner Radius	0.375in.	0.031ft^2
Outer Radius	0.525in.	0.044ft
Area pipe	0.424in^2	0.003ft
Pole Length	101.000in	8.417
Top pole Length	20.000in	1.667
Inertia	2.128E-06	
Area	0.146ft^2	
q	14.400lb/ft^2	
M	1.050	

Breaking

Tau	21629.109lb/ft^2
Tau	150.202psi
length	2.75
P	75
Weight if it is a 3 ft pad	400.2
Weight if it is a 4 ft pad	290.9
Density of Concrete	150lb/ft^3
3 ft Pad Thickness	3.56in
4ft Pad Thickness	1.45in

Appendix B: Required Insulation Thickness Analysis

Required Insulation Thickness Analysis:



- r_{ins1} is 1.59E-02 meters corresponding to an insulation thickness of 1.27E-02 meters
- r_{ins2} is 1.27E-02 meters corresponding to an insulation thickness of 9.52E-03 meters
- r_{ins3} is 2.22E-02 meters corresponding to an insulation thickness of 1.90E-02 meters

- System Parameters

  → T_{eflon} is the thermal conductivity of Teflon at 300K (≈ 0.35 W/(m*K))

  → k_{ins} is the thermal conductivity of insulation at 300K (≈ 3.61E-02 W/(m*K))

  → k_{air} is the thermal conductivity of air at 300K (≈ 0.026 W/(m*K))

  → L is the required/measured length of Teflon tube (≈ 6.34 meters)

  → r_i is the inner radius of the Teflon tube (≈ 2.38E-03 meters)

→ r_o is the outer radius of the Teflon tube (≈ 3.18E-03 meters)

→ T_{air} is the temperature of the air in the room (79°F ≈ 294K)

→ T_s is the surface temperature of the insulation in the room (71°F≈295K)

- Flow Properties

  → m is the mass flow rate of the air sample (≈ 3.87E-05 kg/s)

    - $m = \rho_g * A_i * u_m$

  → u_m is the sampling rate of the ambient air (≈ 1.8712 m/s)

- Air Properties (at 300K)

  → α is the thermal diffusivity (≈ 2.25E-05 m^2/s)

  → β is the volumetric thermal expansion coefficient (≈ 3.33E-05 K^{-1})

  → ν is the kinematic viscosity (≈ 1.59E-05 m^2/s)

  → c_p is specific heat (≈ 1007 J/(kg*K))

  → Pr is the Prandtl number (≈ 0.707)

List of Equations:

- $u_m = \left(\frac{2L}{\min}\right)\left(\frac{0.001m^3}{1L}\right)\left(\frac{1}{1.7813935E-05m^2}\right)\left(\frac{1\min}{60\sec}\right)$

- $A_i = \frac{\pi D_i^2}{4} = 1.7813935E-05\,m^2$

- $\dot{m} = \rho * A_i * u_m$

- $\mathrm{Re}_D = \frac{4\dot{m}}{2\pi r_i \mu}$

- $R_{teflon} = \dfrac{Ln\left(\frac{r_o}{r_i}\right)}{2\pi k_{teflon} L}$

- $h_i = \dfrac{Nu_{Di} k_{air}}{2r_i}$

- $SA_i = 2\pi r_i L$

- $R_{ins1} = \dfrac{Ln\left(\frac{r_{ins1}}{r_o}\right)}{2\pi k_{ins} L}$

- $h_{o1} = \dfrac{Nu_{Do1} k_{air}}{2r_{ins1}}$

- $Nu_{Do1} = \left\{0.6 + \left[\dfrac{0.387 * Ra_{D1}^{\frac{1}{6}}}{\left(1 + \left(\frac{0.559}{\Pr}\right)^{\frac{9}{16}}\right)^{\frac{8}{27}}}\right]\right\}^2$

- $Ra_{D1} = \dfrac{9.81\beta(T_s - T_{air})(2r_{ins1})^3}{\alpha \upsilon}$

- $SA_{o1} = 2\pi r_{ins1} L$

- $R_{ins2} = \dfrac{Ln\left(\frac{r_{ins2}}{r_o}\right)}{2\pi k_{ins} L}$

- $h_{o2} = \dfrac{Nu_{Do2} k_{air}}{2r_{ins2}}$

- $$Nu_{Do2} = \left\{ 0.6 + \left[\frac{0.387 * Ra_{D2}^{\frac{1}{6}}}{\left(1 + \left(0.559/\Pr\right)^{\frac{9}{16}}\right)^{\frac{8}{27}}} \right] \right\}^2$$

- $$Ra_{D2} = \frac{9.81\beta(T_s - T_{air})(2r_{ins2})^3}{\alpha\upsilon}$$

- $$SA_{o2} = 2\pi r_{ins2} L$$

- $$R_{ins3} = \frac{Ln\left(r_{ins3}/r_o\right)}{2\pi k_{ins} L}$$

- $$h_{o3} = \frac{Nu_{Do3} k_{air}}{2r_{ins3}}$$

- $$Nu_{Do3} = \left\{ 0.6 + \left[\frac{0.387 * Ra_{D3}^{\frac{1}{6}}}{\left(1 + \left(0.559/\Pr\right)^{\frac{9}{16}}\right)^{\frac{8}{27}}} \right] \right\}^2$$

$$Ra_{D3} = \frac{9.81\beta(T_s - T_{air})(2r_{ins3})^3}{\alpha\upsilon}$$

- $$SA_{o3} = 2\pi r_{ins3} L$$

- $$R_{TOT1} = R_{teflon} + R_{ins1} + \frac{1}{h_{o1} SA_{o1}} + \frac{1}{h_i SA_i}$$

- $$R_{TOT2} = R_{teflon} + R_{ins2} + \frac{1}{h_{o2} SA_{o2}} + \frac{1}{h_i SA_i}$$

- $R_{TOT3} = R_{teflon} + R_{ins3} + \frac{1}{h_{o3} SA_{o3}} + \frac{1}{h_i SA_i}$

- $T_{m,o1} = T_{air} - \left[(T_{air} - T_{m,i}) \exp\left({-1}/{\dot{m} c_p R_{TOT1}} \right) \right]$

- $T_{m,o2} = T_{air} - \left[(T_{air} - T_{m,i}) \exp\left({-1}/{\dot{m} c_p R_{TOT2}} \right) \right]$

- $T_{m,o3} = T_{air} - \left[(T_{air} - T_{m,i}) \exp\left({-1}/{\dot{m} c_p R_{TOT3}} \right) \right]$

- $\Delta T_o = T_{air} - T_{m,o}$

- $\Delta T_i = T_{air} - T_{m,i}$

- $\Delta T_{lm} = \frac{\Delta T_o - \Delta T_i}{Ln\left({\Delta T_o}/{\Delta T_i} \right)}$

- $q_1 = \frac{\Delta T_{lm}}{R_{TOT1}} = \dot{m} c_p (T_{m,i} - T_{m,o1})$

- $q_2 = \frac{\Delta T_{lm}}{R_{TOT2}} = \dot{m} c_p (T_{m,i} - T_{m,o2})$

- $q_3 = \frac{\Delta T_{lm}}{R_{TOT3}} = \dot{m} c_p (T_{m,i} - T_{m,o3})$

Reynold's Number:

- $Re_D = \dfrac{\rho u_m D_i}{\mu}$

→ ρ is the density of air at ≈ 295K

- From Interpolation: ρ = 1.1882 kg/m^3

→ u_m is the velocity sampling rate of the pump

- $u_m = \left(\dfrac{2L}{\min}\right)\left(\dfrac{0.001m^3}{1L}\right)\left(\dfrac{1}{1.7813935E-05m^2}\right)\left(\dfrac{1\min}{60\sec}\right)$

  - $A_i = \dfrac{\pi D_i^2}{4} = 1.7813935E-05\ m^2$

- u_m = 1.87119428 m/sec

→ D_i is the inner diameter of the Teflon tube

- Known Dimension: D_i = 0.0047625 meters

→ μ is the viscosity of air at ≈ 295K

- From Interpolation: μ = 1.8173E-05 N*s/m^2

- Re_D is 582.66 < 2300 ⇒ Laminar Flow

Appendix C: MeteoStar LEADS Requirements

MeteoStar LEADS Requirements

1. Site Information

   The following information is needed (at a minimum) to initialize a new site.

   EPA site number – This is one of the primary keys necessary for data storage and retrieval in the MeteoStar LEADS system. The EPA site number consists of a two-digit code for the state (in this case it will be 48 for Texas); a three-digit code for the county the site is located in (in this case it will be 029 for Bexar County); and finally a four-digit site identifier. The four-digit site identifier will need to be coordinated through TNRCC. The TNRCC will register this EPA site number with the EPA and it must be unique for each site.

   CAMS number – CAMS stands for Continuous Air Monitoring Station. This is a three-digit number that is used in many reports and web pages when referring to a site. It is actually an identifier that is programmed into the dataloggers the TNRCC uses. The CAMS number must be unique at any point in time – it can be moved from site to site, but only one instance can be active at a time. The TNRCC will provide you with a CAMS number that does not conflict with other CAMS.

   Site name – A descriptive name for each site. This is used in reports and web pages. We will append the CAMS number to end of this. Examples include: Houston East C1; Ivanhoe C414; CPS/Trinity Pecan Valley C678. We generally try to put the city name in the description, but it is not necessary. There is a limit of 40 characters that can be displayed (in certain applications).

   Site location – The latitude and longitude of the site. This is required for plotting data on map backgrounds and is used by many of the MeteoStar LEADS tools for manipulating data over a region (such as ozone animations).

   Street address – The street address of the monitoring site.

   Site photos – These are optional, but of great use. There are nine standard photographs that the TNRCC uses. Prints or digital images can be used. If you provide digital photographs, we prefer to have them in JPEG format. We have web pages that will automatically display any photographs found and append pertinent site information to them. We use a standard naming convention for all our photographs that is described below. For an example of this, point your browser to the following URL: http://www.tnrcc.state.tx.us/cgi-bin/monops/site_photo?1

   Every site photo has the following name convention: cNNNv.jpg. Every file name begins with the letter "c". "NNN" is the CAMS number talked about above. "v" is the view shown in the picture and may be one or two characters. Every file name ends with ".jpg". The following describes the standard photos used for CAMS 1:

a. Overall site photo – Standard name: c001o.jpg. The view is designated by the letter "o" in the file name. This is an overall view of the site showing the entire shelter and external sensors.

b. Northwest photo – Standard name: c001nw.jpg. The view is designated by the letters "nw". This is a view towards the Northwest, usually taken from the top of the shelter. The purpose of this photo is to show the surrounding area.

c. North photo – Standard name: c001n.jpg. The view is designated by the letter "n". This is a view towards the North, usually taken from the top of the shelter. The purpose of this photo is to show the surrounding area.

d. Northeast photo – Standard name: c001ne.jpg. The view is designated by the letters "ne". This is a view towards the Northeast, usually taken from the top of the shelter. The purpose of this photo is to show the surrounding area.

e. East photo – Standard name: c001e.jpg. The view is designated by the letter "e". This is a view towards the East, usually taken from the top of the shelter. The purpose of this photo is to show the surrounding area.

f. Southeast photo – Standard name: c001se.jpg. The view is designated by the letters "se". This is a view towards the Southeast, usually taken from the top of the shelter. The purpose of this photo is to show the surrounding area.

g. South photo – Standard name: c001s.jpg. The view is designated by the letter "s". This is a view towards the South, usually taken from the top of the shelter. The purpose of this photo is to show the surrounding area.

h. Southwest photo – Standard name: c001sw.jpg. The view is designated by the letters "sw". This is a view towards the Southwest, usually taken from the top of the shelter. The purpose of this photo is to show the surrounding area.

i. West photo – Standard name: c001w.jpg. The view is designated by the letter "w". This is a view towards the West, usually taken from the top of the shelter. The purpose of this photo is to show the surrounding area.

2. Equipment

The following information about the installed equipment is required (at a minimum).

For each piece of monitoring equipment we need to know the manufacturer, the model number, and the EPA equivalency code (if applicable). Meteorological instruments do not have an equivalency code. Almost all commercial monitors (especially those that monitor criteria pollutants) will have an equivalency code. This is normally located on a manufacturer's tag attached to the monitor.

For each parameter measured, we need the EPA parameter number. This is a five-digit code that uniquely identifies a particular parameter. This is one of the primary keys necessary for data storage and retrieval in the MeteoStar LEADS system. The following tables list the parameters the TNRCC currently collects along with their EPA parameter numbers. Be advised that depending upon the instrument used or the way the machine is configured, the parameter number will be different. For example, PM-10 can be measured under either local conditions, or standard conditions (corrected for temperature and pressure). There are different parameter numbers for these two measurement methods.

EPA Number	Parameter Measured
10000	Mass Flow Controller
10001	Canister Pressure
10002	Canister Sample Port
10003	Oxidation Reduction Potential
10004	Battery Probe
10005	Fuel Cell Amperage
10006	Fuel Cell Voltage DC
10007	Fuel Cell Power
10008	Fuel Cell Efficiency
10010	Water Temperature
10078	Secchi Depth
10095	Specific Conductance
10100	Water Ammonium
10101	Water Nitrate
10102	Dissolved Oxygen Charge
10103	Water Chlorophyl A
10104	Water Turbidity
10300	Dissolved Oxygen
10301	Dissolved Oxygen %
10400	Water Ph
10480	Salinity
42101	Carbon Monoxide
42401	Sulfur Dioxide
42402	Hydrogen Sulfide
42600	NOy
42601	Nitric Oxide
42602	Nitrogen Dioxide
42603	Oxides of Nitrogen
43102	Total Non-Methane Organic Compounds
43201	Methane
44201	Ozone
61101	Wind Speed
61102	Wind Direction

61103	Resultant Wind Speed

EPA Number	Parameter Measured
61104	Resultant Wind Direction
61105	Maximum Wind Gust
61106	Standard Deviation of Horizontal Wind Direction
62101	Outdoor Temperature
62103	Dew Point Temperature
62107	Internal Station Temperature
62201	Relative Humidity
63101	Visibility
63301	Solar Radiation
63302	Ultraviolet Radiation
64101	Barometric Pressure
65102	Precipitation
81102	PM-10 (Standard Conditions)
85101	PM-10 (Local Conditions)
88101	PM-2.5 (Local Conditions)

For each parameter measured at a site, TNRCC will assign a unique Parameter Occurrence Code (POC). This allows you to measure multiple instances of a parameter at a site, say for instance co-located ozone monitors. The POC is a single-digit number from 1 to 9. For brand new sites, the POC will be 1 for each parameter. This is one of the primary keys necessary for data storage and retrieval in the MeteoStar LEADS system.

3. Data Format

The TNRCC collects data in five-minute increments. The datalogger used by TNRCC samples each instrument once a second and accumulates data for five-minutes before a sample record is stored on the datalogger. The datalogger keeps track of which records have been retrieved. Every 15 minutes, the datalogger is polled by a local (located in the same region) hub computer and any unsent records are requested. If the data transfer is successful, the records are marked as "sent" by the datalogger. The TNRCC uses telephones and satellite links to communicate with the monitoring sites.

The hub computers accumulate data from all the monitoring sites in a region. Software on the hub computers performs a preliminary scan of each data record and bundles the records for transmission to Austin. Data is transferred from the hub computers to Austin via ftp over the TNRCC statewide WAN. All of these computers are located behind the TNRCC firewall.

Once data reaches Austin, the MeteoStar LEADS pollution ingest software automatically rolls the five-minute averages into one-hour averages (or accumulations, or maxima, or etc. based on the particular parameter) and stores the data into a database for use by other applications. There are only two types of data in the MeteoStar LEADS system: five-minute data and one-hour data. All other averaging periods (30-minute, 3-hour, 8-hour, 24-hour, etc.) are derived externally by Perl scripts from either five-minute or one-hour data.

The TNRCC uses an automatic calibration system that is integrated with the datalogger. Periodically (at least twice a year) every pollution instrument is challenged by a five-point calibration procedure. Twice a week, either a three-point or a two-point span check challenges every pollution instrument. The three-point span check is used to collect precision data for the EPA.

The five-point calibration establishes a slope and intercept that converts millivolts to concentration for a particular instrument. The span checks can establish a new intercept (for controlling instrument drift) while keeping the previously established slope.

All pollution data is collected in volts and converted to engineering units (concentration) using a linear calibration curve. The slope and intercept of the calibration curves are automatically determined by the MeteoStar LEADS software. Each instrument has unique calibration information.

The following table shows what the MeteoStar LEADS software is expecting each parameter to be reported in (either volts or engineering units). This is critical for the correct interpretation of data. For all parameters reported in engineering units, the datalogger uses a user-specified calibration curve programmed into the datalogger to convert the measurement (or the instrument reports directly in engineering units).

Parameter Measured	Units
Mass Flow Controller	ml/min
Canister Pressure	psi
Canister Sample Port	none
Oxidation Reduction Potential	mv
Battery Probe	v
Fuel Cell Amperage	a
Fuel Cell Voltage DC	v
Fuel Cell Power	w
Fuel Cell Efficiency	%
Water Temperature	deg C
Secchi Depth	m
Specific Conductance	µS/cm
Water Ammonium	mg/l
Water Nitrate	mg/l
Dissolved Oxygen Charge	none
Water Chlorophyl A	mg/l
Water Turbidity	none
Dissolved Oxygen	mg/l
Dissolved Oxygen %	%
Water Ph	Ph

Salinity	PSS
Carbon Monoxide	v

Parameter Measured	Units
Sulfur Dioxide	v
Hydrogen Sulfide	v
NOy	v
Nitric Oxide	v
Nitrogen Dioxide	v
Oxides of Nitrogen	v
Total Non-Methane Organic Compounds	v
Methane	v
Ozone	v
Wind Speed	mi/hr
Wind Direction	deg
Resultant Wind Speed	mi/hr
Resultant Wind Direction	deg
Maximum Wind Gust	mi/hr
Standard Deviation of Horizontal Wind Direction	none
Outdoor Temperature	deg F
Dew Point Temperature	deg F
Internal Station Temperature	deg F
Relative Humidity	%
Visibility	mi
Solar Radiation	Ly/min
Ultraviolet Radiation	Ly/min
Barometric Pressure	mbar
Precipitation	in (cum)
PM-10 (Standard Conditions)	$\mu g/m^3$
PM-10 (Local Conditions)	$\mu g/m^3$
PM-2.5 (Local Conditions)	$\mu g/m^3$

The datalogger has an internal schedule that is used to trigger automatic calibrations and span checks by the gas calibrator. When the gas calibrator is performing either an instrument calibration or span check, it provides information to the datalogger that the datalogger in turn uses to attach a status flag to each data sample. These status flags are detected by the MeteoStar LEADS software and all calibrations or span checks are performed "in-line". By this we mean the software accumulates the entire calibration or span check and then performs QA/QC checks. If the calibration or span check passes, the new slope and/or intercept is applied to all data received subsequent to the calibration or span check.

The data records transmitted by the datalogger are comma-delimited ASCII files with the following format. This is one sample record from CAMS 1.

1,01/04/19,21:55:00,0,1,K,11.30,2,K,143.50,3,K,19.50,4,K,12.00,5,K,20.30,6,K,75.00,24,K,78.60,25,K,0.0976,28,K,0.0019,29,K,0.0130,30,K,0.0090,43,K,9.1096,70,K,80.20,50,K,0.0000,51,K,99000,

First field: "1" – Datalogger ID. This is the CAMS number described above. There can only be one instance of each CAMS number active at any time. The datalogger will only respond to commands addressed to its programmed ID.

Second field: "01/04/19" – Date. The date the sample was collected in YY/MM/DD format. Yes, we use two-digit years and no, we did not have a problem with Y2K.

Third field: "21:55:00" – Time. The time the sample was collected in HH:MM:SS format. Since we collect data in five-minute increments, any seconds that are not exactly "00" are an error condition. Samples must come in exact five-minute increments.

All TNRCC dataloggers operate on UTC. All data is stored in the MeteoStar LEADS database in UTC. All clocks in the system are synchronized from an atomic standard (we currently use the atomic clock at A&M). One of our computers in Austin fetches the current atomic time and this is then propagated throughout the system. The computer in Austin sets the time on each of the hub computers (we currently have 10 of these). The hub computers in turn set the time on each datalogger. The datalogger in turn sets the time on the automatic gas calibrator.

Fourth field: "0" – Error Word. This is a 32-bit word that the datalogger uses to report errors and other trigger conditions. Normally, the error word will be "0". Any other value must be interpreted. The error word is expressed as a hexadecimal number. If all 32 bits were set, the error word would be "FFFFFFFF". Bit numbering starts with the least-significant bit, BIT 0, at the right – BIT 31 is the leftmost bit. The table on the next page shows the interpretation of all 32 bits. The most important bit is the Power indicator bit – BIT 22. This is tied to the UPS and when set will cause the MeteoStar LEADS software to flag all data in the record as "PMA" – preventative maintenance mode. All other BITs are interpreted by support software and presented via various web pages. The DASIBI referenced in the table is the automatic gas calibrator – the datalogger must be able to communicate with the gas calibrator for calibrations and span checks to be flagged correctly.

Everything after the first four fields are "data triplets". A data triplet such as "1,K,11.30" consists of three values: the first is a channel number, in this case output channel 1; the second is a status flag – K indicates ambient data; the third field is the actual data value this will either be in volts or engineering units, depending upon the actual parameter being reported.

The output channel number is programmed in the datalogger. There are only two restrictions for reporting a parameter on an output channel: first, channels 50 and 51 are reserved for calibration and span check information – you cannot use these channels for anything else (and both these channels must be present in every data record); secondly, part of the site setup requires a mapping between channel numbers and actual parameters measured – you can report any parameter on any channel you like (except for 50 and 51) as long as you specify what that channel is actually reporting.

There can be up to 26 output channels (not counting channels 50 and 51) in any data record. This is driven by a restriction in our display software that currently only allows 28 parameters per site. This is normally not a problem, as most sites report only 10 to 15 parameters. If you have a site that reports more than 26 parameters, we will have to set up two or more separate sites – each of which will have a unique EPA site number and a unique datalogger ID.

The following table lists all the status flags that are expected in the data records. Any other status flags will result in the entire record being rejected.

Flag	**Meaning**	**Notes**
K	Ambient data	"Good" data
P	Equipment under maintenance	Manually set by the operator via the datalogger
Q	Quality audit	Manually set by auditors when they visit the station and perform periodic audits of the instruments
The following flags are used exclusively for calibrations, span checks, and troubleshooting		
M	80% of full scale value	Automatically set by the calibrator during calibrations or span checks or when manually commanded by an operator
R	60% of full scale value	Automatically set by the calibrator during calibrations or when manually commanded by an operator
S	40 % of full scale value	Automatically set by the calibrator during calibrations or when manually commanded by an operator
T	18% of full scale value	Automatically set by the calibrator during calibrations or span checks or when manually commanded by an operator
P	This is a calibration level that is different from the maintenance flag	Automatically set by the calibrator during calibrations or span checks on instruments like the hydrogen sulfide analyzer that have additional steps such as scrubber checks or converter checks – in order for this flag to be recognized, it must occur in the right place during a calibration or span check
Q	This is a calibration level that is different from the quality audit flag	Automatically set by the calibrator during calibrations or span checks on instruments like the hydrogen sulfide analyzer that have additional steps such as scrubber checks or converter checks – in order for this flag to be recognized, it must occur in the right place during a calibration or span check
G	Zero air level	Automatically set by the calibrator during calibrations or span checks or when manually commanded by an operator

The calibrator is programmed with various levels that correspond to different concentrations of challenge gas. A calibration or span check is a sequence of these different levels. There are standard sequences defined for all instruments that are calibrated.

If an output channel is flagged M, R, S, T, or G, (or the P or Q calibration flags) the system is in some type of calibration mode and there must be matching data in both channels 50 and 51. Channel 50 will contain the challenge concentration (in parts per million) reported by the calibrator. The status flag for Channel 50 will match the status

									3322	2222	2222	1111	1111	1100	0000	0000	**Updated 10/25/2000**
Record Status Value									1098	7654	3210	9876	5432	1098	7654	3210	
F	F	F	F	F	F	F	F		1111	1111	1111	1111	1111	1111	1111	1111	**Status Codes Flagged as Suspect**
							BIT	0								0001	Instrument System Reset
							BIT	1								0010	Real Time Clock Suspect
							BIT	2								0100	Data Logging Memory Initialized
							BIT	3								1000	Incomplete Data Capture
							BIT	4							0001		DASIBI Time Non-Response
							BIT	5							0010		DASIBI "dot 21" command Non-Response
							BIT	6							0100		DASIBI "dot 11" command Non-Response
							BIT	7							1000		Serial Pass-Thru Mode Entered
							BIT	8						0001			Failed Scheduler Command
							BIT	9						0010			BIT 9 RESERVED
							BIT	10						0100			Bit 10 RESERVED
							BIT	11						1000			Bit 11 RESERVED
							BIT	12					0001				Bit 12 RESERVED
							BIT	13					0010				Bit 13 RESERVED
							BIT	14					0100				Bit 14 RESERVED
							BIT	15					1000				Bit 15 RESERVED
							BIT	16				0001					TEOM M, T, or F Status
Aspirator Fan							BIT	17				0010					Temperature Indicator (Aspirator Fan)
CS-10 Sample							BIT	18				0100					CS-10 Sample in progress
Multi-can Sample							BIT	19				1000					Multi-can Sample in progress
							BIT	20			0001						TEOM X Status
							BIT	21			0010						Visibility Sensor Malfunction
ALL_SENSORS							BIT	22			0100						Power Indicator
							BIT	23			1000						Not Used
							BIT	24		0001							Bit 24 RESERVED
							BIT	25		0010							Bit 25 RESERVED
							BIT	26		0100							Bit 26 RESERVED
							BIT	27		1000							Bit 27 RESERVED
							BIT	28	0001								Bit 28 RESERVED
							BIT	29	0010								Bit 29 RESERVED
							BIT	30	0100								Bit 30 RESERVED
							BIT	31	1000								Bit 31 RESERVED

flag of the output channel being challenged. The status flag for Channel 51 will also match the status flag of the output channel being challenged.

During a calibration or span check sequence, Channel 51 reports a 5-digit decimal number (ddddd). The first 2 digits are the current calibrator level number (00-99); the last 3 digits are the decimal representation of an 8-bit binary value, again the least significant bit is the rightmost bit.

BITs 0-2 are the concentration level being delivered by the calibrator

- 000 - ambient air
- 001 - G level concentration (0%)
- 010 - QA level 1 (10%)
- 011 - T level concentration (18%)
- 100 - QA level 2 (35%)
- 101 - S level concentration (40%)
- 110 - R level concentration (60%)
- 111 - M level concentration (80%)

BITSs 3-4 are unused

BIT 5 indicates converter power is on

BIT 6 is 1 to indicate a 3-point span check

BIT 7 is 1 to indicate a 5-point calibration

BIT 6 and BIT 7 set to 1 indicates a 2 point span check

Thus a value of 67167 in Channel 51 would be interpreted as sequence number 67 and the 167 decimal would convert to a binary value of 10100111.

BIT	7	6	5	4	3	2	1	0
Value	1	0	1	0	0	1	1	1

BITs 0-2 are all 1's which indicates that the calibrator is delivering the challenge gas at the M level (80%). BITs 3-4 are both 0. BIT 5 is 1 indicating the converter power is on. BIT 6 is 0 and BIT 7 is 1, which indicates a 5-point calibration is in progress.

The MeteoStar LEADS software ignores the sequence number part of Channel 51. The last 3 digits are used to determine what is going on with the calibrator. The processing software that detects the start of calibrations or span checks requires at least five minutes of ambient data measurement before a calibration or span check is started. The MeteoStar LEADS software will automatically flag the sample immediately (the number of samples flagged this way is configurable) following the calibration or span check. This allows the instrument time to settle back to ambient conditions.

The following is an actual ozone 5-point calibration that was performed at the monitoring site located in Clute (Brazoria county):

11,01/04/02,16:55:00,10000,1,K,17.20,2,K,185.50,3,K,11.70,4,K,17.60,5,K,25.70,6,K,74.90,24,K,87.30,25,K,0.0842,50,K,0.0000,51,K,99000,
11,01/04/02,17:00:00,10000,1,K,18.20,2,K,185.50,3,K,9.50,4,K,18.50,5,K,24.50,6,K,75.00,24,K,87.40,25,M,0.4815,50,M,0.3801,51,M,66135,
11,01/04/02,17:05:00,10000,1,K,15.80,2,K,186.20,3,K,10.40,4,K,16.00,5,K,27.00,6,K,75.50,24,K,87.50,25,M,0.7327,50,M,0.4001,51,M,66135,
11,01/04/02,17:10:00,10000,1,K,17.10,2,K,188.30,3,K,12.00,4,K,17.50,5,K,26.40,6,K,75.70,24,K,87.60,25,M,0.7467,50,M,0.4001,51,M,66135,
11,01/04/02,17:15:00,10000,1,K,18.80,2,K,188.60,3,K,12.20,4,K,19.20,5,K,29.70,6,K,75.30,24,K,87.80,25,M,0.7522,50,M,0.4001,51,M,66135,
11,01/04/02,17:20:00,10000,1,K,20.70,2,K,188.10,3,K,9.40,4,K,21.00,5,K,30.80,6,K,75.10,24,K,87.90,25,M,0.7572,50,M,0.4001,51,M,66135,
11,01/04/02,17:25:00,10000,1,K,17.40,2,K,190.60,3,K,11.90,4,K,17.70,5,K,31.20,6,K,75.80,24,K,88.10,25,M,0.7601,50,M,0.4001,51,M,66135,
11,01/04/02,17:30:00,10000,1,K,18.70,2,K,187.70,3,K,11.10,4,K,19.00,5,K,29.10,6,K,75.50,24,K,88.30,25,M,0.7621,50,M,0.4001,51,M,66135,
11,01/04/02,17:35:00,10000,1,K,21.00,2,K,186.40,3,K,7.90,4,K,21.20,5,K,27.90,6,K,75.00,24,K,88.40,25,R,0.6361,50,R,0.3051,51,R,65134,
11,01/04/02,17:40:00,10000,1,K,18.20,2,K,188.70,3,K,12.70,4,K,18.60,5,K,30.20,6,K,75.10,24,K,88.60,25,R,0.5763,50,R,0.3001,51,R,65134,
11,01/04/02,17:45:00,10000,1,K,17.70,2,K,193.70,3,K,12.50,4,K,18.10,5,K,27.00,6,K,75.50,24,K,88.70,25,R,0.5763,50,R,0.3001,51,R,65134,
11,01/04/02,17:50:00,10000,1,K,19.80,2,K,191.80,3,K,10.60,4,K,20.20,5,K,29.10,6,K,75.20,24,K,88.80,25,R,0.5765,50,R,0.3001,51,R,65134,
11,01/04/02,17:55:00,10000,1,K,17.10,2,K,193.30,3,K,12.80,4,K,17.50,5,K,24.20,6,K,75.50,24,K,89.00,25,R,0.5766,50,R,0.3001,51,R,65134,
11,01/04/02,18:00:00,10000,1,K,15.20,2,K,191.30,3,K,11.40,4,K,15.50,5,K,23.20,6,K,76.20,24,K,89.10,25,R,0.5778,50,R,0.3001,51,R,65134,
11,01/04/02,18:05:00,10000,1,K,16.20,2,K,188.60,3,K,11.90,4,K,16.60,5,K,25.70,6,K,76.00,24,K,89.30,25,R,0.5783,50,R,0.3001,51,R,65134,
11,01/04/02,18:10:00,10000,1,K,13.70,2,K,188.20,3,K,14.00,4,K,14.20,5,K,21.60,6,K,76.30,24,K,89.40,25,S,0.4494,50,S,0.2050,51,S,64133,
11,01/04/02,18:15:00,10000,1,K,16.80,2,K,189.70,3,K,12.40,4,K,17.20,5,K,27.80,6,K,75.90,24,K,89.50,25,S,0.3870,50,S,0.2000,51,S,64133,
11,01/04/02,18:20:00,10000,1,K,16.50,2,K,184.30,3,K,10.60,4,K,16.70,5,K,25.20,6,K,75.50,24,K,89.70,25,S,0.3874,50,S,0.2000,51,S,64133,
11,01/04/02,18:25:00,10000,1,K,17.40,2,K,191.40,3,K,10.40,4,K,17.70,5,K,26.30,6,K,75.60,24,K,89.80,25,S,0.3867,50,S,0.2000,51,S,64133,
11,01/04/02,18:30:00,10000,1,K,20.60,2,K,185.10,3,K,8.30,4,K,20.90,5,K,29.80,6,K,75.30,24,K,89.90,25,S,0.3865,50,S,0.2000,51,S,64133,
11,01/04/02,18:35:00,10000,1,K,18.90,2,K,188.80,3,K,8.20,4,K,19.00,5,K,27.00,6,K,75.00,24,K,90.10,25,S,0.3865,50,S,0.2000,51,S,64133,
11,01/04/02,18:40:00,10000,1,K,17.20,2,K,191.50,3,K,11.00,4,K,17.50,5,K,26.00,6,K,75.50,24,K,90.20,25,S,0.3864,50,S,0.2000,51,S,64133,
11,01/04/02,18:45:00,10000,1,K,17.10,2,K,190.80,3,K,12.50,4,K,17.50,5,K,25.40,6,K,75.90,24,K,90.30,25,T,0.2443,50,T,0.0956,51,T,62131,
11,01/04/02,18:50:00,10000,1,K,15.80,2,K,194.40,3,K,11.20,4,K,16.00,5,K,24.20,6,K,75.50,24,K,90.50,25,T,0.1760,50,T,0.0901,51,T,62131,
11,01/04/02,18:55:00,10000,1,K,14.70,2,K,188.40,3,K,10.30,4,K,15.00,5,K,22.30,6,K,75.80,24,K,90.60,25,T,0.1765,50,T,0.0901,51,T,62131,
11,01/04/02,19:00:00,10000,1,K,15.80,2,K,192.30,3,K,11.50,4,K,16.10,5,K,25.60,6,K,75.60,24,K,90.70,25,T,0.1762,50,T,0.0901,51,T,62131,
11,01/04/02,19:05:00,10000,1,K,17.40,2,K,189.30,3,K,11.30,4,K,17.80,5,K,25.20,6,K,75.10,24,K,90.80,25,T,0.1758,50,T,0.0901,51,T,62131,
11,01/04/02,19:10:00,10000,1,K,14.90,2,K,194.70,3,K,14.90,4,K,15.40,5,K,23.20,6,K,75.20,24,K,90.90,25,T,0.1752,50,T,0.0901,51,T,62131,
11,01/04/02,19:15:00,10000,1,K,14.00,2,K,191.00,3,K,11.60,4,K,14.30,5,K,20.20,6,K,75.40,24,K,91.10,25,T,0.1753,50,T,0.0901,51,T,62131,
11,01/04/02,19:20:00,10000,1,K,14.50,2,K,188.60,3,K,13.10,4,K,14.80,5,K,23.80,6,K,75.40,24,K,91.20,25,G,0.0508,50,G,0.0046,51,G,60129,
11,01/04/02,19:25:00,10000,1,K,18.40,2,K,186.30,3,K,9.50,4,K,18.70,5,K,28.20,6,K,75.40,24,K,91.30,25,G,0.0011,50,G,0.0000,51,G,60129,
11,01/04/02,19:30:00,10000,1,K,15.80,2,K,184.40,3,K,12.90,4,K,16.20,5,K,23.60,6,K,75.20,24,K,91.40,25,G,0.0009,50,G,0.0000,51,G,60129,
11,01/04/02,19:35:00,10000,1,K,16.50,2,K,181.50,3,K,9.50,4,K,16.70,5,K,24.50,6,K,75.10,24,K,91.50,25,G,0.0007,50,G,0.0000,51,G,60129,
11,01/04/02,19:40:00,10000,1,K,17.90,2,K,184.40,3,K,11.60,4,K,18.20,5,K,24.50,6,K,74.80,24,K,91.60,25,G,0.0005,50,G,0.0000,51,G,60129,
11,01/04/02,19:45:00,10000,1,K,17.00,2,K,184.90,3,K,11.10,4,K,17.30,5,K,26.10,6,K,75.00,24,K,91.70,25,G,0.0008,50,G,0.0000,51,G,60129,
11,01/04/02,19:50:00,10000,1,K,17.40,2,K,189.30,3,K,9.10,4,K,17.60,5,K,25.50,6,K,74.60,24,K,91.80,25,G,0.0005,50,G,0.0000,51,G,60129,
11,01/04/02,19:55:00,10000,1,K,13.60,2,K,187.10,3,K,10.50,4,K,13.80,5,K,22.30,6,K,75.00,24,K,91.80,25,K,0.0632,50,K,0.0000,51,K,99000,

The following is an actual ozone 3-point span check that was performed at the monitoring site located in Clute (Brazoria county):

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11,01/04/18,06:55:00,10000,1,K,5.10,2,K,25.60,3,K,12.60,4,K,5.20,5,K,7.90,6,K,52.30,24,K,80.10,25,K,0.0339,50,K,0.0000,51,K,99000,
11,01/04/18,07:00:00,10000,1,K,5.20,2,K,16.10,3,K,18.60,4,K,5.40,5,K,7.80,6,K,52.20,24,K,80.00,25,M,0.4865,50,M,0.3801,51,M,66071,
11,01/04/18,07:05:00,10000,1,K,4.30,2,K,4.90,3,K,21.10,4,K,4.70,5,K,8.00,6,K,52.10,24,K,79.90,25,M,0.7370,50,M,0.4001,51,M,66071,
11,01/04/18,07:10:00,10000,1,K,5.20,2,K,8.30,3,K,18.60,4,K,5.50,5,K,8.90,6,K,52.10,24,K,79.80,25,M,0.7486,50,M,0.4001,51,M,66071,
11,01/04/18,07:15:00,10000,1,K,5.00,2,K,14.50,3,K,20.50,4,K,5.30,5,K,8.50,6,K,52.20,24,K,79.70,25,M,0.7573,50,M,0.4001,51,M,66071,
11,01/04/18,07:20:00,10000,1,K,5.30,2,K,12.80,3,K,21.90,4,K,5.70,5,K,8.80,6,K,52.40,24,K,79.70,25,M,0.7628,50,M,0.4001,51,M,66071,
11,01/04/18,07:25:00,10000,1,K,5.60,2,K,16.50,3,K,17.00,4,K,5.80,5,K,10.10,6,K,52.60,24,K,79.60,25,M,0.7657,50,M,0.4001,51,M,66071,
11,01/04/18,07:30:00,10000,1,K,6.00,2,K,18.20,3,K,18.50,4,K,6.40,5,K,9.50,6,K,52.60,24,K,79.50,25,M,0.7680,50,M,0.4001,51,M,66071,
11,01/04/18,07:35:00,10000,1,K,6.30,2,K,20.80,3,K,16.40,4,K,6.50,5,K,9.80,6,K,52.60,24,K,79.40,25,T,0.3768,50,T,0.1056,51,T,62067,
11,01/04/18,07:40:00,10000,1,K,5.10,2,K,21.80,3,K,16.70,4,K,5.30,5,K,8.60,6,K,52.60,24,K,79.40,25,T,0.1781,50,T,0.0901,51,T,62067,
11,01/04/18,07:45:00,10000,1,K,6.10,2,K,21.40,3,K,17.30,4,K,6.40,5,K,10.40,6,K,52.80,24,K,79.30,25,T,0.1778,50,T,0.0901,51,T,62067,
11,01/04/18,07:50:00,10000,1,K,6.30,2,K,30.50,3,K,13.90,4,K,6.50,5,K,10.60,6,K,52.90,24,K,79.20,25,T,0.1784,50,T,0.0901,51,T,62067,
11,01/04/18,07:55:00,10000,1,K,7.30,2,K,30.10,3,K,13.20,4,K,7.50,5,K,11.40,6,K,53.00,24,K,79.20,25,T,0.1786,50,T,0.0901,51,T,62067,
11,01/04/18,08:00:00,10000,1,K,6.70,2,K,28.60,3,K,12.40,4,K,6.90,5,K,11.10,6,K,53.20,24,K,79.10,25,T,0.1786,50,T,0.0901,51,T,62067,
11,01/04/18,08:05:00,10000,1,K,8.20,2,K,34.90,3,K,11.80,4,K,8.30,5,K,12.30,6,K,53.30,24,K,79.00,25,T,0.1786,50,T,0.0901,51,T,62067,
11,01/04/18,08:10:00,10000,1,K,6.30,2,K,33.60,3,K,12.60,4,K,6.40,5,K,9.00,6,K,53.30,24,K,79.00,25,G,0.0525,50,G,0.0046,51,G,60065,
11,01/04/18,08:15:00,10000,1,K,7.20,2,K,35.90,3,K,12.00,4,K,7.30,5,K,10.80,6,K,53.30,24,K,78.90,25,G,0.0022,50,G,0.0000,51,G,60065,
11,01/04/18,08:20:00,10000,1,K,7.20,2,K,32.80,3,K,13.60,4,K,7.40,5,K,11.00,6,K,53.50,24,K,78.90,25,G,0.0017,50,G,0.0000,51,G,60065,
11,01/04/18,08:25:00,10000,1,K,6.70,2,K,41.10,3,K,11.90,4,K,6.90,5,K,9.90,6,K,53.60,24,K,78.80,25,G,0.0016,50,G,0.0000,51,G,60065,
11,01/04/18,08:30:00,10000,1,K,8.10,2,K,34.50,3,K,12.10,4,K,8.30,5,K,11.40,6,K,53.70,24,K,78.80,25,G,0.0020,50,G,0.0000,51,G,60065,
11,01/04/18,08:35:00,10000,1,K,7.10,2,K,26.80,3,K,12.70,4,K,7.30,5,K,11.30,6,K,53.60,24,K,78.80,25,G,0.0020,50,G,0.0000,51,G,60065,
11,01/04/18,08:40:00,10000,1,K,7.00,2,K,34.40,3,K,12.80,4,K,7.20,5,K,12.20,6,K,53.60,24,K,78.70,25,G,0.0011,50,G,0.0000,51,G,60065,
11,01/04/18,08:45:00,10000,1,K,6.40,2,K,35.80,3,K,15.90,4,K,6.60,5,K,10.40,6,K,53.70,24,K,78.70,25,K,0.0318,50,K,0.0000,51,K,99000,
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4. Integrating Other Sites

The TNRCC has successfully integrated monitoring sites operated by other agencies. The preferred method is to replace existing station equipment with the datalogger, calibrator, modem, and valves used by the TNRCC. There is almost always some re-plumbing required in the station as well. Every agency that has had sites integrated this way has been very pleased.

The TNRCC provides data to the general public via web pages. This data is not sufficient to run and maintain a monitoring site. Internally, there are many web pages devoted to station performance, communications, problem monitoring, etc. When an outside agency is integrated into the TNRCC system, an ISDN link is established between the outside agency and the nearest TNRCC regional office. This provides full access behind the TNRCC firewall to all of these tools. The outside agency also gains access to all monitoring data collected by the TNRCC.

Since the TNRCC provides data in near real-time to the public, it is essential that any non-ambient data, especially high concentration challenges to the instruments, be flagged as such. With proper flagging, false alerts are avoided. Data that is flagged as non-ambient is not included in any of the alert mechanisms the TNRCC has developed and all the public will see is the flag, not the actual data.

The TNRCC uses Zeno 3200B dataloggers coupled with Dasibi 5008 automatic gas calibrators. We have had limited success integrating a Campbell datalogger with the system. The Campbell could not produce the data format the software was expecting so we had to write a translator program. The biggest problem we had was flagging data as non-ambient – there was no mechanism like the data triplets described above.

In order to gain the full benefits of the system, it is essential that any data stream coming in follow the same format and protocols the TNRCC has developed and refined over the last 6 years (the first MeteoStar LEADS sites were installed in December, 1994). At a minimum, any data that is not ambient must be flagged as such. To take advantage of the built-in quality assurance checks, the calibrations and span checks must follow the protocol and formats established by TNRCC.

Appendix D: TNRCC LEADS

TNRCC LEADS

The Lockheed Environmental Analysis and Display System (LEADS) grew out of Navy and Air Force weather programs at Lockheed Martin in Austin, TX. These products were developed over a fifteen-year period. In September 1997, Information Processing Systems (IPS) purchased the intellectual property rights for this family of products from Lockheed Martin.

In August 1994, TNRCC issued a purchase order to Lockheed Martin for LEADS with additional pollution sensor inputs. This system was a major overhaul of the existing TNRCC monitoring network and was designed to allow flexible monitoring network expansion and to provide analysis tools that were previously unavailable. The LEADS installed at TNRCC consists of two major portions, the integrated weather system and a point data collection system.

Integrated Weather Systems (LEADS). The LEADS software provides ingest of WMO formatted observations, WMO gridded fields and system-based sensors (e.g., NEXRAD, lightning systems, satellite ground stations, profilers, local numerical models, etc.). LEADS also provides a complete set of data manipulation and display tools which enables the system to superpose all data types and generate almost any weather product which can be imagined. All tools can be scripted, so the system can automatically generate user-defined products (e.g., by schedule or event). The TNRCC LEADS ingests data from the National Weather Service (NWS) in the form of surface and upper air observations, gridded forecast fields, high-resolution geo-stationary satellite imagery (visual and IR), and acoustic and radar profiler data. TNRCC does not employ the NEXRAD, lightning, or polar orbiting satellite interfaces.

Point Data Collection System (PDCS). These systems ingest data from mobile or stationary point sources (e.g., data valid at a specific latitude and longitude, elevation and time). The TNRCC PDCS is combined with the LEADS software to provide a complete system with local data collection fully integrated with WMO data and system-based sensors. The TNRCC PDCS collects local meteorological data as well as pollutant measurements.

The TNRCC PDCS begins with the data logger and calibrators installed in each monitoring station. As part of the LEADS purchase order, the old TNRCC data collection equipment was replaced with Zeno dataloggers and Dasibi automatic gas calibrators. The existing weather gear and monitors were kept as part of the PDCS. The meteorological sensor data is converted by the Zeno from voltages to engineering units. Pollutant data is stored by the Zeno in voltages for later conversion to engineering units.

Some special pollutant measuring equipment (such as Beta-gauges) are also converted by the Zeno to engineering units. Any parameter that requires calibration is stored as voltages in the Zeno.

A new data collection system was installed along with the new dataloggers and calibrators. This consists of modems at each of the monitoring stations. Each TNRCC Regional Office received a new UNIX workstation that is used to call each of the monitoring sites located in the region. The regional UNIX workstations are connected via the TNRCC wide-area-network (WAN). The collected data (meteorological and pollution) from the regional offices is moved over the WAN to a UNIX workstation located in the TNRCC offices in Austin where it is decoded and placed into a database. Multi-point calibrations and span checks are automatically detected in the data stream. The decoding software accumulates calibration and span information as the data streams in and then performs a series of quality assurance tests on the calibration or span check. Slopes and intercepts are calculated for the multi-point calibrations and are then applied to subsequent data collected. Failed calibrations or span checks will result in automatic data rejection.

The regional office workstations call each of the monitoring sites located in their regions every fifteen minutes. It takes approximately five to seven minutes for the data to be collected and sent upstream to Austin. Thus, data from across the state is available about twenty to twenty-five minutes after it is measured. This allows real-time monitoring of rising pollutant levels as well as real-time ozone action day forecasting.

Once pollution data is stored in the database, it is available immediately for display and analysis using the LEADS tools and other special tools (mostly web-based) designed specifically for TNRCC (product generation). Products range from tabular reports to ozone concentration animation loops. There are many interfaces available for pollution product generation. There is the LEADS weather interface that will integrate multiple data types (pollution data and NWS meteorological data). There is a Manual Validation interface that graphically displays pollution and meteorological data and allows validators to set or change data flagging codes and to recover data that has been automatically rejected.

There are literally hundreds of web pages available for viewing data. The web pages can be used to monitor overall system performance and health as well as viewing collected data. Web pages are being developed continuously as new ways of looking at data are thought up. Many of the web pages are available to the general public outside the TNRCC firewall. These publicly available web pages provide access to the data collected. All system performance related web pages are behind the firewall. The public web pages can be accessed at: http://www.tnrcc.state.tx.us/air/monops.

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