Results of the Application of a New Laser Based Open-Path Spectrometer for the Measurement of Fugitive Emissions From Gas Processing Plants

Jim Bauer; John Tulip; Perry Kain; Murray Paulson; Jack Ondrack
Boreal Laser Inc.
#13, 51127 RR 255, Spruce Grove, Alberta, Canada T7Y 1A8

ABSTRACT

In this paper, we present results from field studies of the application of a new laser based spectrometer incorporated with real-time dispersion modeling techniques to measure fugitive emissions from gas processing facilities.

While open-path FTIR spectrometers can measure a variety of gaseous species, they suffer from the drawbacks of being large, expensive and of limited range. Also, uncertainty in results caused by spectral overlap has been a matter of concern to regulatory organizations. The laser spectrometer described in this paper is a small, portable device based on readily available telecommunications technology. The instrument is tuned to a specific absorption line for a specific gas (CH_4, H_2S, CO_2, HF, HCN, NH_3), and as a result is immune from line competition. Typical detection sensitivity of <1ppm over path lengths in excess of several hundred metres is observed.

In conjunction with this new laser spectrometer, a variety of dispersion modeling techniques are employed to estimate the fugitive emission rates from a gas processing plant. We have demonstrated the effectiveness of this method in field simulations and at actual operating natural gas facilities.

INTRODUCTION

Open-path spectrometers are now used to estimate the emission rates from industrial and agricultural sources. Traditional methods involved point monitoring at many discrete locations downwind from a suspected emission site (sampling tubes and or cans), or the characterization of the individual sources (stack monitors, "bagging" of valves , etc.). These methods are both tedious and costly when a large area is to be monitored.

Recently, several researchers have conducted field studies using open path spectrometers in conjunction with dispersion modeling software to estimate the emission rates from point, area and, volume sources. The following discussion outlines a protocol based on these investigations for a specific method of monitoring fugitive methane emissions.

Concept

The theory of open-path spectrometry is well developed. References to several papers outlining the practical issues involved are included at the end of this document. The ideas involved in Gaussian Plume Dispersion Modeling are also well established. The basic method considered here is the combination of the two tools to estimate the rate of emission of methane from a specific source.

The spectrometer used is an open-path instrument consisting of a laser head and a remote retroreflector which define the path (up to several hundred metres). This device is capable of measuring methane concentrations to below ambient levels (i.e.: on the order of 1 ppm).

The dispersion model under consideration is the EPA's most recent Industrial Source Complex Model (short term) ISCST3. This model was chosen because it is on the EPA's list of preferred models and it contains the EPA's default regulatory modeling options. It is also more capable of modeling complex source structures and has a better area integration routine than the PAL 2.0 (Point, Area, Line Source) model.

The basic premise of the protocol is to measure the path averaged concentrations of methane over a known path, down wind of the source being investigated. At the same time, meteorological information (wind speed and direction, temperature, pressure) is collected at the site. The data is time averaged, and then combined with the geographical layout of the actual source, to calculate a plume profile using the modeling software. The plume profile is then sampled at a location and direction corresponding to the actual measurement path. This calculated concentration distribution is then numerically integrated to provide the modeled path averaged concentration. The ratio of the modeled and measured concentrations are then used to estimate the actual emission rate. The proposed method can be summarized as follows:

1. Record meteorological data at the site under study.
2. Record path averaged methane concentrations at a location predominantly "down-wind" of the study site.
3. Use the meteorological data to compute a "model plume" using the EPA's ISCST3 model, normalized to an emission rate of one gram per second per square metre.
4. Calculate the modeled concentration along a path representative of the actual path.
5. Numerically integrate this concentration profile to obtain a *modeled* path averaged concentration.
6. Scale the model emission rate to coincide with the *measured* path averaged concentration.

FIELD TESTS

The purpose of these field tests was primarily to establish workable parameters and to provide a proof of concept under "real-life" conditions. Of main concern was the determination of averaging times which will provide acceptable data quality while at the same time be economical in terms of actual measurement duration. A pipeline riser located in a remote area free of significant obstacles was selected, and outfitted with a flowmeter and control valves. The flow rate was adjusted in order to determine the low end sensitivity of the method. The tests were performed over two days with quite different weather phenomenon to help characterize the method for a variety of wind speeds and temperatures.

Instrumentation

I - Gas Detector System
- Boreal Laser "GasFinder 1.0"
- Opticon 2" Hexagonal Retroreflector (3x Array)

II - Meteorological/Data Logging System
- Campbell Scientific CR10X datalogger
- Campbell Scientific #107 Temperature Probe
- R.M. Young 05103-10 Wind Monitor
- Vaisala PTB101 Barometric Pressure Sensor

III - Emission Control
- King 7700 Series Flowmeter

Experimental Procedure

The datalogger for day one was set to acquire weather and gas detector data on a 3 second sample rate, the data was then averaged on 15 second, 1 minute and 5 minute intervals.

Following an initial assessment of the prevailing winds, the meteorological station and gas detector were positioned to establish a path approximately 100m downwind of the source (path = 156m at 290°). After about five minutes the flow rate from the “leak” was set to 70 SCFM. This 5 minute delay was required to determine the background concentration of methane in this location. About 10 minutes into this initial release, the position of the retroreflector was changed to accommodate a shift in wind direction (path = 217m at 280°). The flow was maintained for a total of 40 minutes. The release was stopped for a period of about 15 minutes and a substantial decrease in the measured concentration was observed on the GasFinder instrument. The flow was then re-started. At this time however, due to the presence of fluid in the pipeline, the maximum available flow was approximately 40 SCFM. This reduced flow was maintained for about 30 minutes. The schedule for this first test is shown in Table 1.

A third location for the gas detector/ met. station was selected, again due to a shift in the direction of the wind (path = 207 at 285°). As the weather station and GasFinder were being repositioned, the liquid in the pipeline was removed. This location of the gas detector and weather station was maintained for the duration of the test. Unfortunately, the wind speed dropped below acceptable limits during the latter portion of this test. The schedule for test #2 is shown in Table 2.

On the second day of testing the same method as in test one was employed. However, as a result of the findings of the previous test, no 15 second data was acquired. The data logger was configured to acquire data on 3 second intervals and store averaged values every 1, 2, and 5 minutes. Due to predominantly east winds on day two, the weather station and gas detector were located to provide a path about 100m west of the leak site (path = 192m at 186°). The schedule for this test is shown in Table 3.

The data for the two tests was then downloaded to a laptop computer and the test apparatus disassembled and returned to Boreal Laser’s facilities.

The raw data from the datalogger was then reformatted to be input into the plume calculation program (EPA’s ISCST3 09/95). The meteorological data for each of the averaging periods were extracted for all measurement paths and passed to the ISC3 program. The results are described in detail in a following section.

Observations

The collected data is presented graphically in Figures 1 through 14.

Results

When input to the ISC3 program, the data shown above produce a “theoretical” plume for a source emitting at a normalized rate of 1g/sec. Figure 15 shows a typical modeled plume from day one, as viewed from above. The straight line represents the actual path as defined by the GasFinder / retroreflector pair (the laser and meteorological station are located at the origin (0,0)). The concentration along this path is modeled as shown in Figure 16. When integrated, the path averaged concentration under these conditions is calculated to be 56.4328ppmm.

Next, to obtain the estimated emission rate, this concentration is de-normalized with respect to the modeled emission rate of 1 g/sec. :

$$Q_{estimated} = Q_0 \times \left(CL_{measured} - CL_{ambient}\right) \Big/ CL_{ttheoretical} = 1 \;\; g/\sec \;\; \times \frac{1785-350}{56.4328} = 25.3 \;\; g/\sec$$

This value must then be converted to cubic feet per minute (CFM) to be consistent with the indicated flow rate. From the gas equation (PV = nRT) we can estimate the density of methane gas at a particular temperature and pressure:

$$\rho = \frac{nM}{V} = \frac{PM}{RT}$$

where

P = atmospheric pressure (mbar)
M = molecular weight of methane (16.043 g/mol)
T = temperature in K
R = 83.14 mbar litre K^{-1} mol^{-1} .

Finally, there are several factors affecting the actual amount of methane released as opposed to the amount indicated on the King 7700 Flowmeter.

Back Pressure (as indicated in the operating instructions for the meter): the correction factor is:

$$CF_{pressure} = \sqrt{\frac{14.7 + operating\ \ pressure\ (psi)}{14.7}}$$

Relative Density of CH4 - as indicated on the supplied "Gas Analysis of Well" the relative density is:

$$\rho_{rel} = 0.746$$

Percent CH4 in Flow - as indicated in the supplied "Gas Analysis of Well" the relative amount (mol%) of methane in the flow is:

$$C_{methane} = 0.80710$$

Therefore, the *actual* flow rate of methane for a given *indicated* flow rate would be given by:

$$F_{methane} = F_{indicated} \times C_{methane} \times {}^{CF_{pressure}}\!\big/_{\rho_{rel}}$$

Taking into account the above conversion factors, the estimated emission rates during the test are:
For Test #1 (approximately ½ hour each of 70 SCFM and 40 SCFM) using the 5 minute averaged data:

$Q_{est}|_{70}$= 63.5 CFM (-9%)
$Q_{est}|_{40}$= 43.2 CFM (+8%)

For Test #2 (5 minutes each 70 SCFM and 40 SCFM and 10 minutes 20 SCFM) using the 1 minute average data:

$Q_{est}|_{70}$= 65.2 CFM (-6%)
$Q_{est}|_{40}$= 49.3 CFM (+23%)
$Q_{est}|_{20}$= 15.5 CFM (-22%)

And, for test #3 (approximately 1 hour each of 8 SCFM and 4 SCFM and ½ hour of 2, 20, 40 SCFM), using the 5 minute average data:

$Q_{est}|_{8}$= 9.04 CFM (+13%)
$Q_{est}|_{4}$= 3.7 CFM (-8%)

$Q_{est}\,|_2$= 1.8 CFM (-6%)
$Q_{est}\,|_{20}$= 20.4 CFM (+2%)
$Q_{est}\,|_{40}$= 45.6 CFM (+14%)

Finally, since we have knowledge of the actual methane emission rate in this test (a luxury not available in a “real-life” situation), the ISC3 program was configured with the *actual* emission rates involved, and the measured path averaged concentration was compared to the theoretical as determined by the program. These results are presented in Figures 17, 18 and 19. As can be seen in these figures, the trends associated with the theoretical concentrations are quite closely followed by the measured concentrations. In the case of the 1 minute averaged data, there does appear to be a slight “lag” in the measured data, this effect is addressed in the next section.

DISCUSSION

These field tests helped to refine several important working parameters involved in using the proposed method to determine emission rates under “real world” circumstances. The importance of averaging time on the accuracy of the estimation was observed. For cases of averaging times less than 1 minute, the effect of the plume transport time became evident. That is to say; if the averaging time is less than the time typically required for the plume to reach the sensor path, there will of course be errors related to this delay. On the other hand, if the release time is short compared to the averaging time there will be insufficient data to give meaningful results. For the experiment on day one, the 15 second data was determined to be inappropriate in both tests since the transport time was on the order of 50 seconds (100m ÷ 2m/s). As a consequence no results for the 15 second averaging are reported. In Test #1, since the release times were in the range of ½ hour, data obtained with 5 minute averaging are used. In Test #2, the release times are 5 and 10 minutes in duration as such, 1 minute averaging is most appropriate.

As mentioned in a previous section, the variability of the wind played a role in reducing the amount of useable data available. For the low flow portion of Test #2 on day one, (flow rates ≤ 8 SCFM) the wind conditions degraded to the point of not being useful. Therefore, there are no results presented for flow rates less than 20 SCFM on this day. On day two, the wind velocities were significantly (2 - 3 times) higher.

A third finding of this study was the effect of plume rise on the accuracy of the estimation of emission rate. In the case of the artificial leak used in this field test, the methane is released from a relatively small point (the vents on the liquids collection truck), and as such the gas will experience some “buoyancy”. This would generally *not* be the case in the situation of many small dispersed leaks located over a larger area (as one would expect in a pumping station, battery or processing plant). For the experiment on day one, the release point was on the leeward side of the tanker truck and as such the plume would be fairly slow to disperse into the surrounding air. In order to compensate for this plume rise, an initial release height of 5m was chosen in the plume calculation program (this seems very reasonable given the height of the truck used and the magnitude of the day’s winds). On day two, the plume appeared to emanate from underneath the truck and as such, an initally high release height was not required. For the results shown above, the programmed release height was set to ground level. Again, the strong wind conditions may have played a role in the reduced estimated initial release height.

The “high” calculated value for the 40 SCFM release is likely due to the presence of large amounts of fluids in the pipeline being used as the leak source. At the end of the 30 minute release, the flow meter indicated 50 SCFM (at the same pressure). Undoubtedly, the actual release rate was higher than 40 SCFM. The fluids in the line prevented any testing at higher flow rates. It was noted that the compressor facility that fed this pipeline was just coming back on line after a maintenance shut-down, this may have accounted for the high volumes of fluids present.

SUMMARY

Based on the forgoing results and discussion, one could conclude that the method outlined holds considerable promise. The observed errors of approximately ±10% in the case of the 5 minute averaged data and about ±25% for the 1 minute averaged data are very encouraging given the short measurement times involved.

ACKNOWLEDGEMENTS

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TABLES

Table 1 - Schedule for test #1

Time	Flow Condition
9:30	system ON
9:35	flow ON (70 SCFM/ 30psi)
10:12	flow OFF
10:31	flow ON (40 SCFM/33psi)
10:55	flow OFF

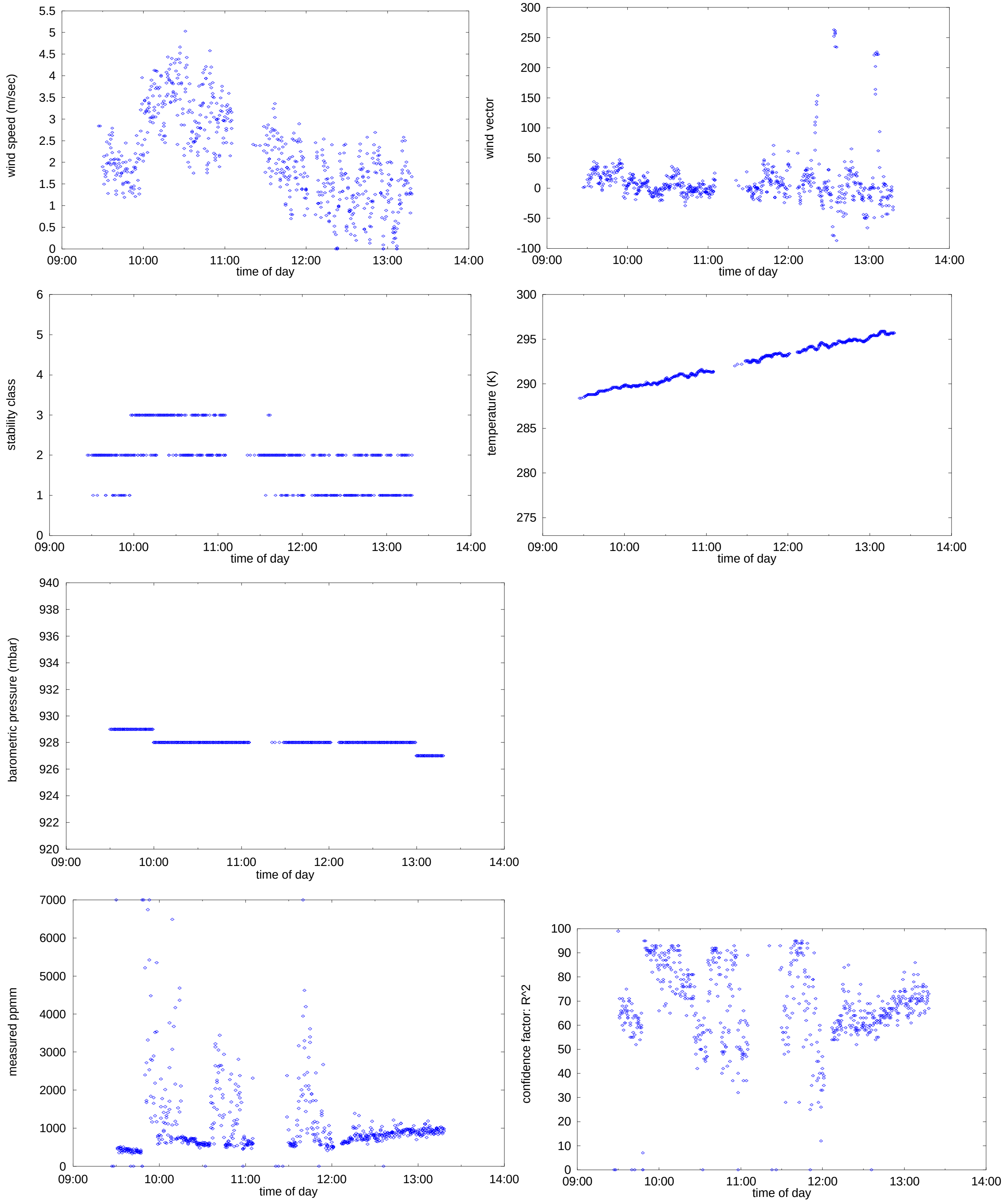
Table 2 - schedule for test #2

Time	Flow Condition
11:00	system moved
11:30	system ON (no flow)
11:34	flow ON (70 SCFM/26psi)
11:38	flow ON (40 SCFM/28psi)
11:43	flow ON (20 SCFM/29psi)
11:55	flow OFF (change flowmeter)
12:11	flow ON (8 SCFM/30psi)
12:21	flow ON (4 SCFM/30psi)
12:31	flow ON (2 SCFM/32psi)
13:05	flow OFF

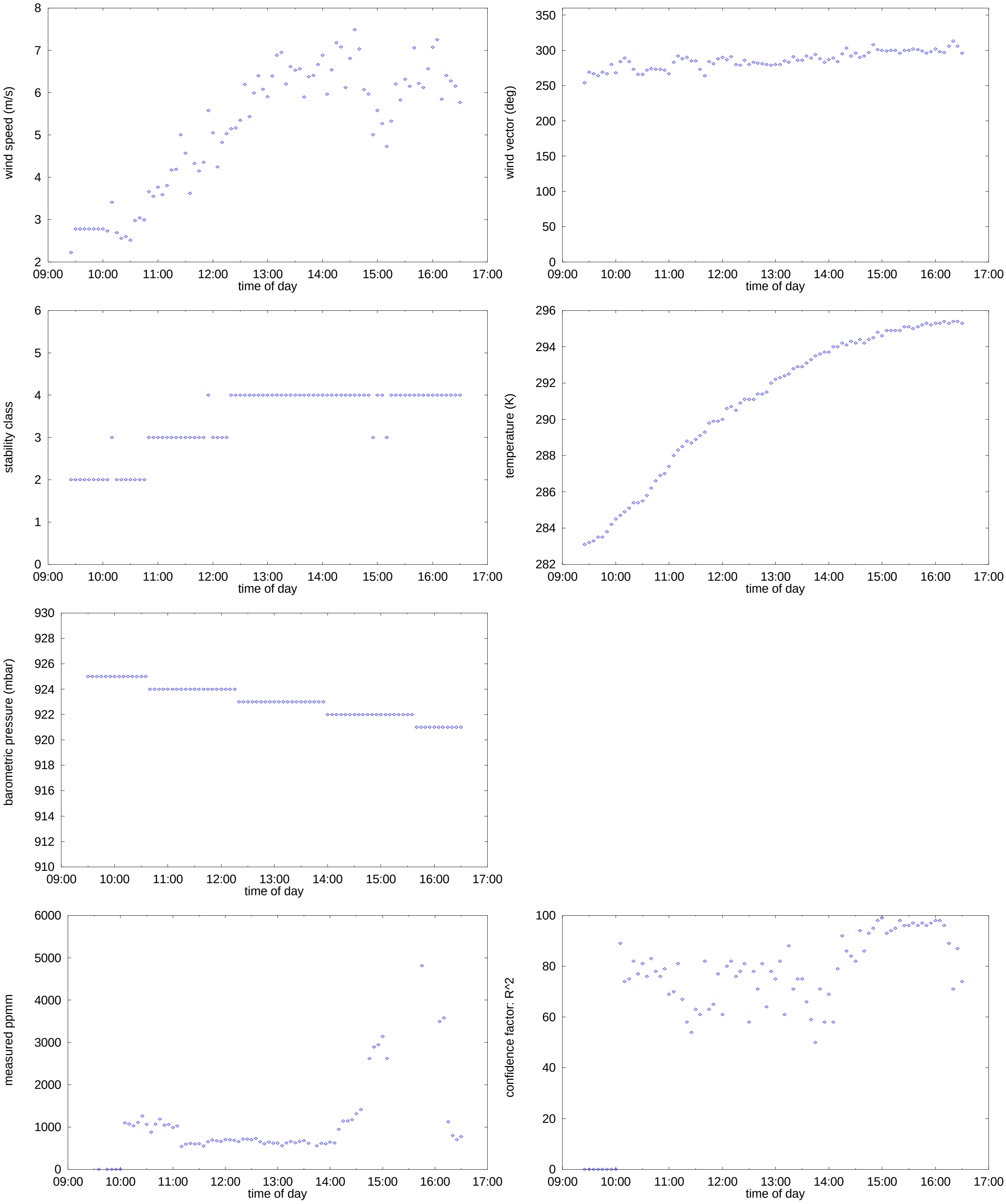
Table 3 - schedule for test #3

Time	Flow Condition
9:25	system ON
9:55	flow ON (8 SCFM/ 12psi)
11:00	flow OFF
11:30	flow ON (4 SCFM/ 9psi)
12:30	flow OFF
13:00	flow ON (2 SCFM/ 17psi)
13:30	flow OFF
14:00	flow ON (20 SCFM/ 2psi)
14:30	flow OFF (fluid in line)
14:35	flow ON (40 SCFM/ 15psi)
15:00	flow OFF (flow - 50 SCFM)
15:55	flow ON (70 SCFM)
16:05	flow OFF (excessive fluids)

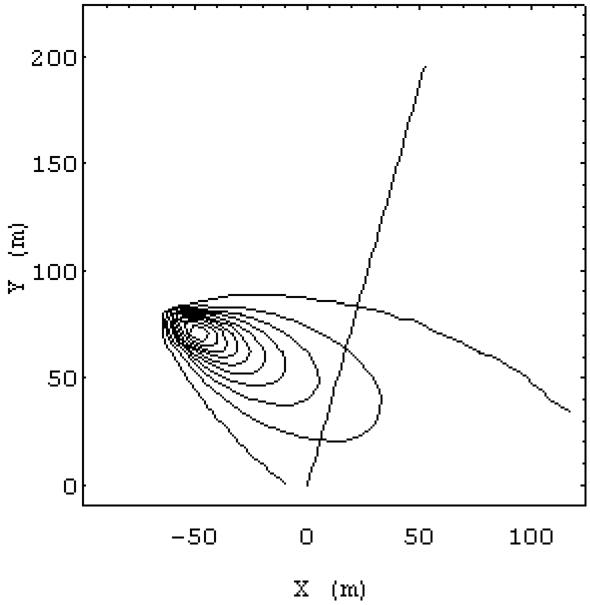
FIGURES



Figures 1 through 7. Meteorolgical and Gas Detector Data: Day One.



Figures 8 through 14. Meteorolgical and Gas Detector Data: Day Two.



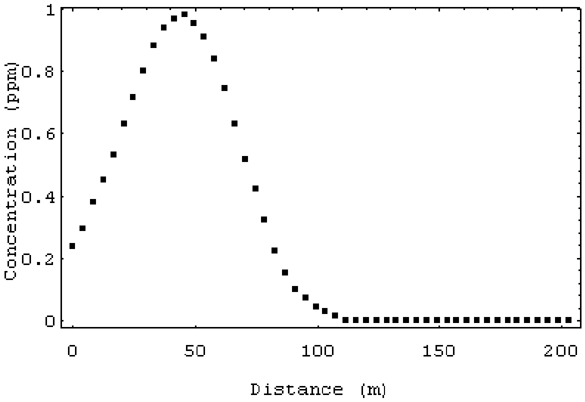


Figure 15. Modeled Plume. viewed from above

Figure 16. Modeled Concentration Along Path

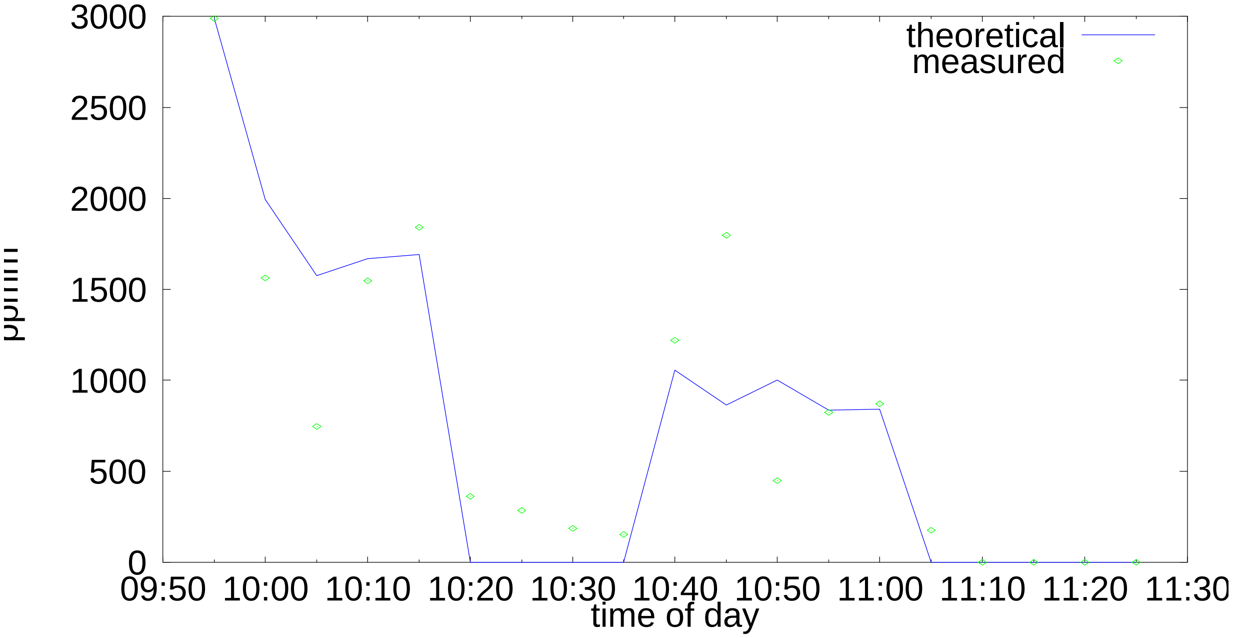


Figure 17. Comparison of Measured and Modeled Path-Averaged Concentration (test #1)

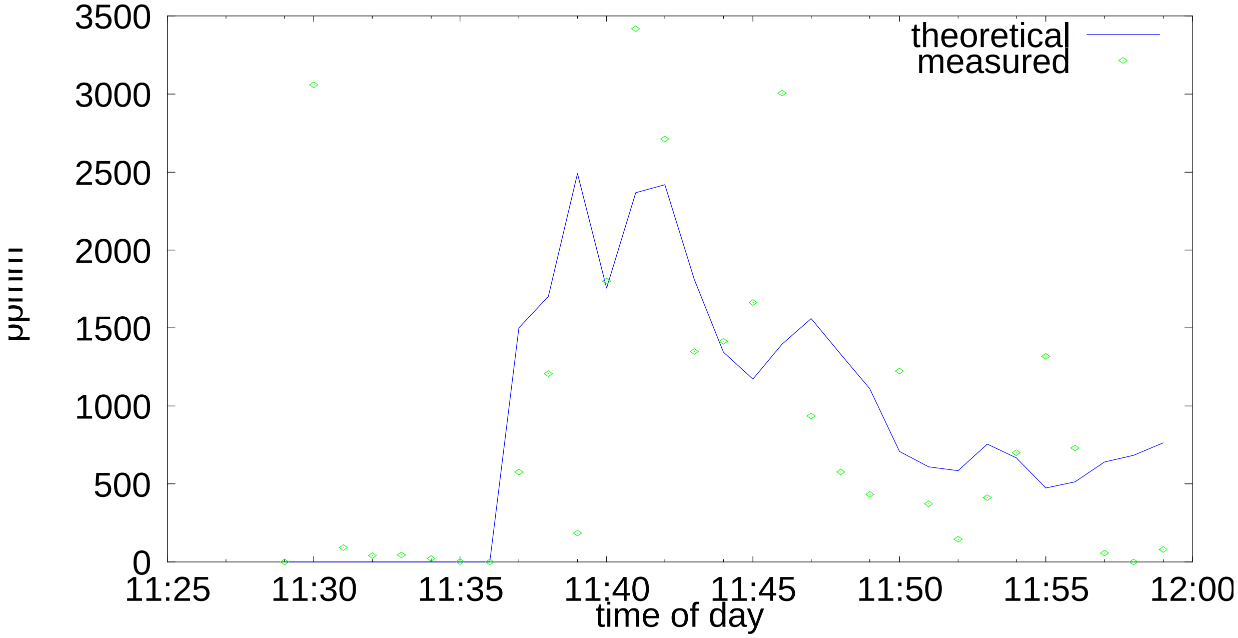


Figure 18. Comparison of Measured and Modeled Path-Averaged Concentration (test #2)

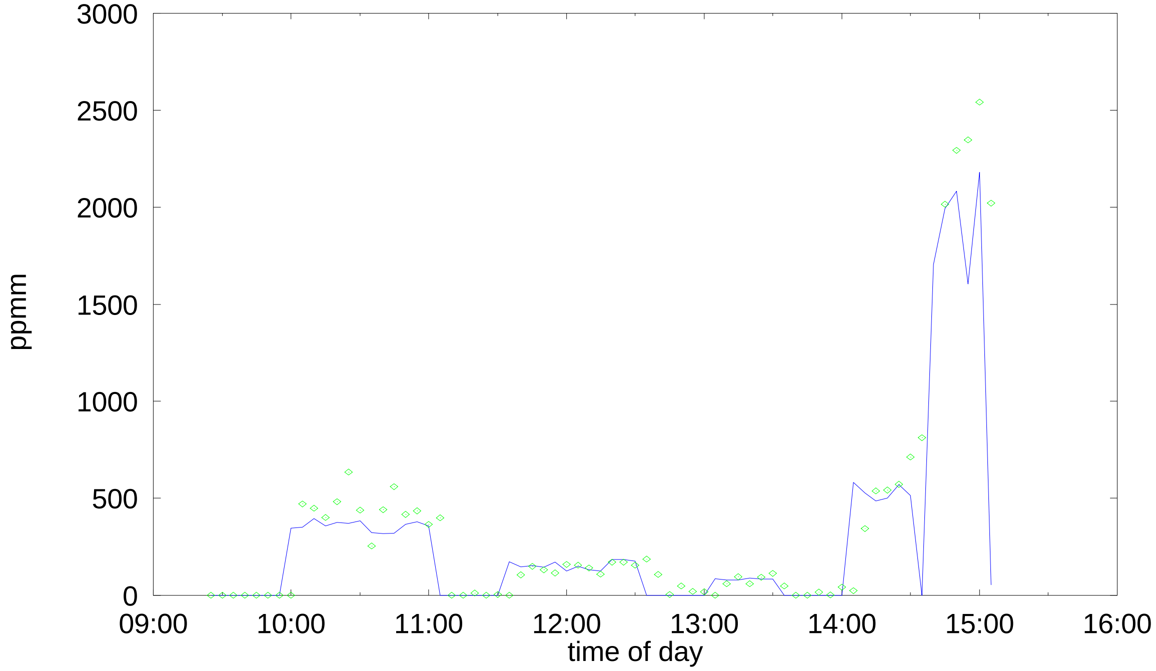


Figure 19. Comparison of Measured and Modeled Path-Averaged Concentration (test #3)