DEQ05-LAB-0031-TR

PRACTICAL ASSESSMENT OF THE OPEN PATH FOURIER TRANSFORM INFRARED (OP-FTIR) FOR AMBIENT AIR QUALITY MONITORING IN PORTLAND AND ALBANY OREGON

August and September 2003

Conducted By

The Oregon Department of Environmental Quality, Air Quality Monitoring

and

Arcadis Incorporated

Air Monitoring Manager: **Reviewed by:** Jeffrey M Smith **Date:** 1/20/05
Jeff Smith

QA Officer: **Reviewed by:** Paul McKay **Date:** 19-Jan 05
Paul McKay

AQ Planning Manager: **Reviewed by:** [illegible] **Date:** 2/25/05
Annette Liebe

DEQ05-LAB-0031-TR

State of Oregon
Department of
Environmental
Quality

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Report By: Anthony Barnack and Robert Jones

Referencing
Report on the Analysis of OP-FTIR Measurements Made in the Cities of Portland and Albany, Oregon – August to September 2003 by Dr. Robert Kagaan

September 2004

Introduction

The Ambient Air Quality Monitoring Section of the Oregon Department of Environmental Quality (ODEQ) Laboratory (The Lab) received an EPA special projects grant in late 2002 to operate an Open Path Fourier Transform Infrared (OP-FTIR) system for one month each in Portland and Albany, Oregon. The Lab's primary goal was to develop expertise and practical experience in the OP-FTIR technology and operation. Lab staff also wanted to ascertain the practicality and usefulness of the OP-FTIR as an ambient air toxics monitor. To accomplish this, airsheds needed to be monitored where ambient air toxics were thought to be present in measurable ambient concentrations.

A secondary goal of the project was to aid the ODEQ air quality regional offices by collecting data in areas of interest. Only the Portland and Salem offices were consulted for logistical reasons. The Lab and NW Regions decided on NW Portland because ongoing public interest in the air toxics in the neighborhood has created a demand for monitoring information. The Lab and the Salem office selected a site in Albany downwind of the major local industry and upwind of the residential area because it is the largest such industrial/residential interface in the Western Region's boundary.

The Lab contracted with Arcadis Consulting to lease the equipment, provide training, analyze the data, and supply a report. The Arcadis report discusses the results of the Portland and Albany monitoring, primarily addressing the secondary goal of this project. The purpose of this paper is to address the practicality and usefulness of the OP-FTIR. To fully answer this question both papers will have to be considered.

Methodology

Equipment

The Lab contracted with Arcadis Inc. to lease a RAM 2000 OP-FTIR with an integrated Climatronics Met system with wind direction and wind speed.

The RAM 2000 uses a single telescope to transmit and receive an infrared beam, which is returned via an orthogonal mirror (retroreflector) remotely positioned up to 500m away. The system measures mostly organic compounds as they are carried through the beam by wind or diffusion. The orthogonal mirror returns the beam in a concentrated ray to the RAM2000 telescope where it is deflected by a smaller mirror into the Fourier Transform detector (Figure 1).

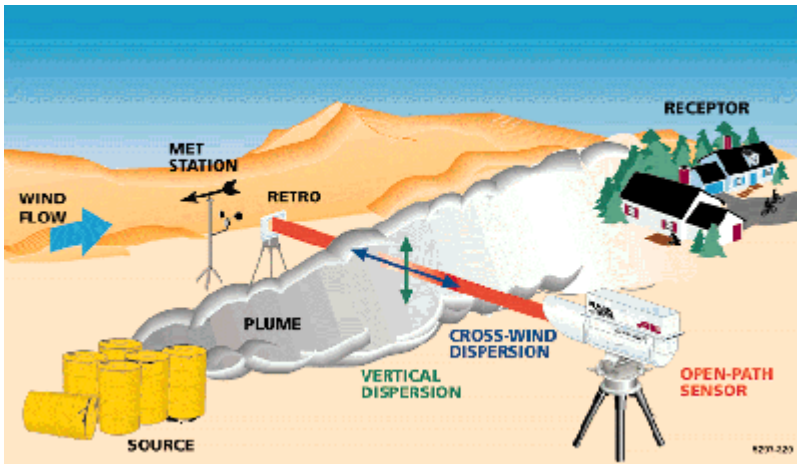


Figure 1. RAM2000 operation illustration. The telescope sends an infrared beam to a retroreflector mirror which concentrates the returned signal back to a detector in the telescope.

The OP-FTIR consists of a power supply, an infrared source, a black telescopic tube designed to create and focus an infrared beam, a retroreflector, a deflection mirror, a Fourier Transform detector, and a liquid nitrogen reservoir to cool the detector. Figure 2 pictures the main components. The OP-FTIR was connected to a computer via optical fiber cable. The OP-FTIR was run with RMM software version 3.5.2 furnished by AIL. The met system software was incorporated into the RMM software.

Figure 2. RAM2000 telescope and retroreflector.

The OP-FTIR was co-located with a Climatronics meteorology system containing wind speed and wind direction. Temperature was also included in the met system but we did not use it.

Siting

Requirements

The site requirements were:

a. Power (110VAC) with low electromagnetic interference (EMF). EMF causes noise in the detector and raises the minimum detection limit.
b. Stable surface. An unstable surface can result in vibrations which create detector noise and raise the minimum detection limit. An unstable surface can also cause the telescope to drift off of the retroreflector.
c. Protection from heat and rain.
d. Ventilation for equipment.
e. Reasonable access to the site.

The Lab sited the OP-FTIR at NW 24th and Wilson in NW Portland on the roof of Provvista, a grocery distributor. The retroreflector was located 322 meters (644 meters round trip) away on top of the Thurman House at 2537 NW Thurman Street. Provvista's building was a warehouse about 10 meters high. The Thurman House was a condominium complex about five stories high. The beam path was perpendicular and downwind of the NW Portland industrial area.

Figures 3a and 3b show the map overview of the sites and beam path. Figures 4a, 4b, & 4c shows photos of the telescope, retroreflector, the meteorology tower, and the beam path from telescope to retroreflector.

Figure 3a. General map showing monitoring area in NW Portland. The NW Portland industrial area is to the north and northwest of the site. The residential area is to the south.

Figure 2. Portland Map, Expanded in Vicinity of the Forest Park Neighborhood

Figure 3b. Expanded view of NW Portland OP-FTIR telescope and retroreflector sites and beam path.

4a. Telescope on Provvista Warehouse in NW Portland.

4b. Meteorology tower on Provvista Warehouse in NW Portland

Figure 4c. Beam Path from Telescope to Retroreflector in NW Portland. Retroreflector is located on the Thurman House and is indicated by the red arrow. The beam was below the wires.

In Albany we located the OP-FTIR at the Albany sewage treatment plant between the industrial area and residential area. The OP-FTIR beam path was completely within the plant boundaries, with the telescope mounted on the Chlorine building and the retroreflector mounted on the lab/office building. The beam path was close to the plants digester flame but upwind of the digester when the wind came from the industrial area to the north. The path was 190 meters. Figures 5a and 5b shows the map overview of the sites and the beam path. Figures 6a - e shows photos of the telescope, meteorological tower, retroreflector, beam path, and digester flame in Albany.

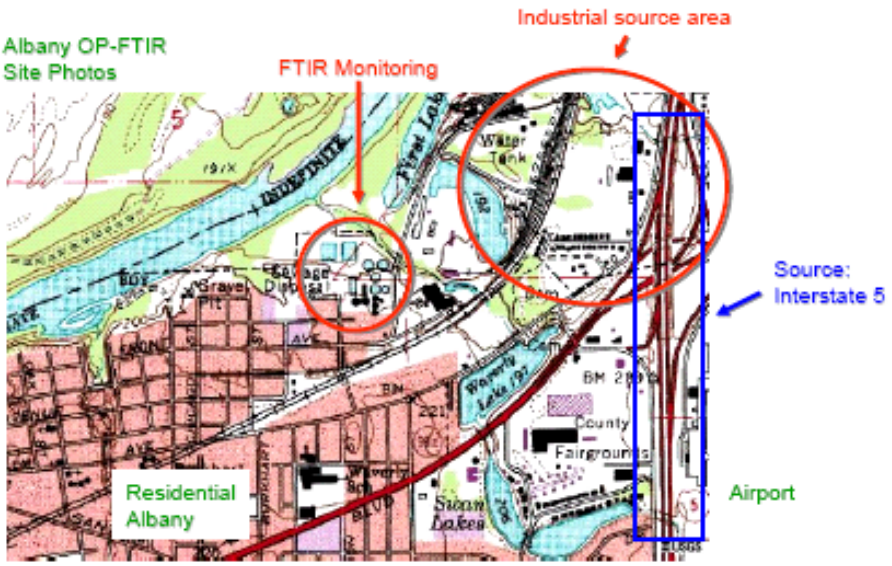


Figure 12. Map of the Measurement Site and Surrounding Areas in Albany

Figure 5a. A map of the north section of Albany, where the OP-FTIR was set up. Interstate 5 was to the east of the site, the industrial district was to the north and northeast, and the residential area was to the south and southwest.

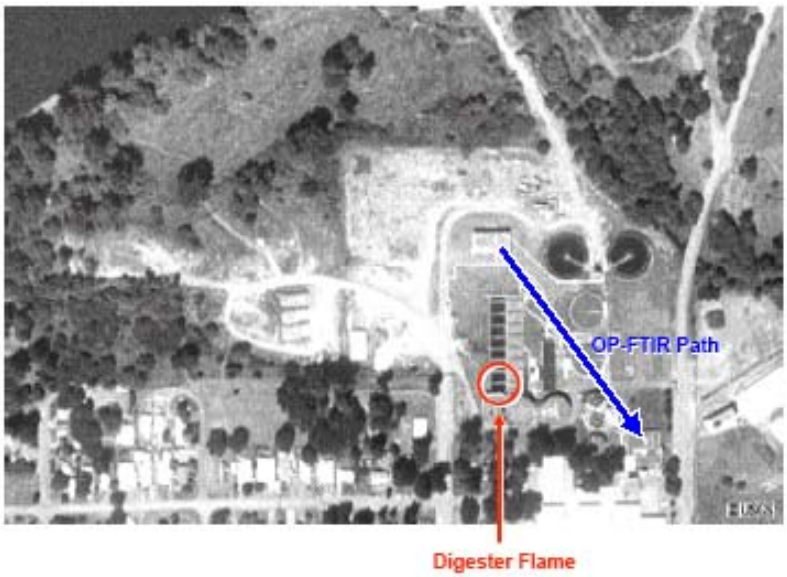


Figure 5b. Expanded map of the north section of Albany, where the OP-FTIR was set up.

Figure 6a. OP-FTIR telescope on the chlorine building, Albany Sewage Treatment Plant.

Figure 6b. Meteorology tower on chlorine building, Albany Sewage Treatment Plant.

Figure 6c. Retroreflector on the office/lab building, Albany Sewage Treatment Plant

Figure 6d. Beam path from the chlorine building, Albany Sewage Treatment Plant

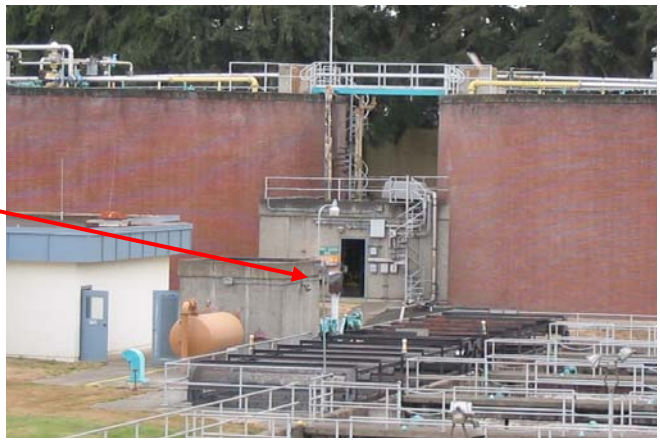


Figure 6e. Digester Flame to the SW of the Beam Path, Albany Sewage Treatment Plant

Operation and Maintenance

1. Liquid Nitrogen.
The basic RAM2000 OP-FTIR requires daily maintenance to refill the liquid nitrogen reservoir. Modified RAM2000s have liquid nitrogen dewers that feed into the reservoirs. The size of the dewer determines how many days the OP-FTIR operates without operator maintenance. More elaborate OP-FTIRs have cryogenic coolers which eliminate the need for liquid nitrogen.

2. Data Transfer.
Every two days the operator needs to close a file and restart a new file because the file size becomes too large to download to CD. With a DVD burner this requirement would be relaxed.

3. Beam Alignment
The operators should check the OP-FTIR alignment on the retroreflector daily until they can assure that it reliably holds its position. Realignment can be time consuming if the computer is located away from the FTIR because the signal voltage is shown on the computer and the adjustments are made on the telescope.

4. Mirror Cleaning
The retroreflector lenses and the mirror in the telescope should be cleaned with compressed air in an interval dependent upon the particulate fallout in the area. The mirrors and the retroreflector should not be cleaned with a cloth. The mirrors can easily be scratched and are very expensive.

Set up/Take down

The OP-FTIR was transported with a large pickup truck and took about one day to set up. The telescope weighs over one hundred pounds, is awkward, fragile, and extremely expensive. It took four people to transport it to the roof safely. The retroreflector is also heavy, awkward, fragile, and expensive. Two people can transport it. The rest of the equipment was handled by one to two people.

The set up consisted of:

a. Setting up the telescope tripod as level as possible.
b. Bolting the telescope onto the tripod.
c. Setting up the power supply with cable connections to the telescope.
d. Connecting the computer with a CD writer to the telescope. The computer had an optical board which communicated with the telescope using fiber optic cables. The length of the fiber optic cables determined where we located the computer relative to the telescope. The cables were six feet long so we had to keep the computer on the roof.
e. Setting up the retroreflector tripod as levels as possible.
f. Bolting the retroreflector to the tripod.

g. Visually aligning the retroreflector face perpendicular to the expected beam path. The beam was more accurately aligned by adjusting the telescope in step m.
h. Setting up the met tower with the wind direction and wind speed sensors.
i. Connecting the met system to the computer. The RMM companion met software was used to check the met readings.
j. Placing a canopy over the equipment to protect the electronics from rain, dust, and sun.
k. Placing fans in the tent to keep the temperature down.
l. Auditing the wind speed and wind direction.
m. Aligning the telescope with the retroreflector. This involved using a gun site to center on the retroreflector, then using the software to fine tune the beam to maximize the signal. Alignment was one of the last steps because the telescope jostled easily.
n. Running a background frame for comparison to later frames.
o. Starting a run using the RMM software.

Data review process

The software was programmed to track targeted compounds during the run. The meteorology was also tracked by the software. The ubiquitous Carbon monoxide was included as a target compound to provide immediate results to ensure the run was working properly soon after start up.

QA/QC

The wind speed was audited using a hand held wind speed monitor. The wind direction was audited by securing the wind vane at a known direction and comparing wind direction with a hand held compass.

As a check on the reasonableness of the data produced by the system, a VOC canister was run on five of the Portland sample days at the nearby 24th and Savior air toxics monitoring site.

Calibration

The OP-FTIR is calibrated at the factory but can be audited by placing a known gas under known concentration in a chamber in the telescope. This was not done during this project.

Discussion

Siting difficulties

Siting the OP-FTIR requires 100 to 500 meters of unobstructed path length. Finding an unobstructed view at street level, both near and perpendicular to the industrial area proved to be impossible in residential Northwest Portland. Buildings, trees, and other obstructions restricted the path length on every perpendicular street just downwind of the industrial area.

Roof top monitoring was the only alternative. Finding the requisite line of site at roof top level was also difficult, but not impossible. The requirements were a flat roof, an unobstructed view to another roof about 100 to 500 meters away, and a path length in close proximity to the industrial sources and perpendicular to the prevailing wind flow. Several possibilities were identified and evaluated. A line of site from Provvista Inc. at NW Wilson and 24th to the Thurman House on Thurman between 25th and 26th was the best option.

Getting permission to roof access was also problematic because we were limited to specific target buildings and many of the building owners did not want anyone on their roof. Others did not want to get involved in the air quality issues between the residential and industrial communities.

Once permission was granted to use a roof, a stable part of the roof that was in the beam path had to be located. Roof vibrations cause unsteady readings which raise the background noise level and raise the minimum detection limit. In residential areas most roofs are plywood with tar or composite tile so stable roofs are hard to find. The Provvista roof was unstable, so the telescope was located in the center of the building above the center beam for stability. The retroreflector was located near the edge of the Thurman House's roof for stability. The center of the Thurman House was not in the beam path.

Siting in Albany was simpler since the area just downwind of the industrial area was less densely populated. The OP-FTIR was located at the Albany sewage treatment plant with a path beam totally inside of the plant boundaries. The path was upwind (with a predominant wind direction from the north) of the sewage plant's digester afterburner. The telescope building was cement and very stable. The building the retroreflector sat on also had a very solid roof.

Siting the met tower at street level would have been very difficult because of obstructions. Siting on the roof tops was much simpler. The roof needed to be higher than other adjacent roofs and not surrounded by trees. Provvista was taller than roofs on three sides with no tall trees close by. There was a taller building on the west side so the met system was moved toward the east side of the Provvista roof. This required extra long communication and power cables. The Albany chlorine building was completely unobstructed and the met tower was easily sited.

The power at Provvista was very clean and contained no interference. The Albany site had EMF interference resulting in noisy spectra. The consultant complained that the spectral analysis was laborious. He was an expert and was able to extract the information out of the noise. A lesser analyst may have not been able to use the data.

Operation and Maintenance

The operation and maintenance of the OP-FTIR required daily visits to refill the liquid nitrogen reservoir. On hot days the liquid nitrogen would boil off in about 24 hours. During cool periods the liquid nitrogen could last 48 hours. There was no guarantee the liquid nitrogen would last 48 hours, so daily visits were required. When the liquid nitrogen is gone

the detector warms up and the background noise level obscures the ambient VOC levels. This happened once in Albany.

The data files grow to about 300 megabytes in 24 hours with one minute frames (measurement durations). The OP-FTIR computer system had a CD burner, as a result the file size was limited to no more than 700mbs. At a maximum, two days can be loaded on one CD. With a DVD burner a file of over two days could be created. The consultant preferred to analyze 24 hour runs regardless, so the CD writer was adequate.

Telescope realignment has to be done frequently if the roof is unstable. At Provvista with its tar on plywood roof, realignment had to be done daily. At Albany with its cement building realignment was not necessary. Obviously, cement roofs are preferred, but finding these types of stable buildings is not always possible. For stability, the best solution is to site the telescope on the ground, but this can lead to security and line of site issues.

Part of the maintenance of the telescope was to clean the mirrors. The mirrors dust up over time and the signal drops. The frequency of cleaning is site dependent. At Provvista the mirrors dusted up in two or three days and had to be cleaned when the signal dropped too low. In Albany the mirrors stayed relatively clean. Cleaning the mirrors has to be done with compressed air to prevent scratching. To help protect the mirrors a canopy should shelter the telescope and retroreflector. The retroreflector is gold plated and cost $28,000, so when possible more thorough cleaning should be done under controlled conditions in the lab.

The operation and maintenance of the OP-FTIR and met site took about 20 minutes to an hour per day depending on how much maintenance was performed. In 20 minutes the liquid nitrogen well could be refilled and the beam realign. During an hour visit the liquid nitrogen could be refilled, the beam realigned, the data copied, the recent VOC and met data checked for reasonableness, and the mirrors air cleaned. Travel time to Portland was about 20 minutes from the lab. Travel time to Albany was two hours round trip.

Data Review

Onsite review

The onsite data review was difficult and misleading. The screen was hard to see in the sunlight and the computer was difficult to use in the cramped conditions in the canopy. The software was easy to use but the positive hits from the RMM software's real time target compounds features proved to be inaccurate when the consultant performed the final analysis.

Comprehensive Review

The OP-FTIR forms a spectrum once a minute. Each spectrum had to be analyzed for changes in functional group peaks above background. Each compound has a different array of functional group peaks which gives it a unique spectra. The analyst needs to identify when a compound is present, then match the spectra with a library. The library often gives several possibilities so the analyst must select the most probable compound using their experience analyzing FTIR spectra. The quantity of the compound is discerned by

comparison to the background spectra. The analysis is much more complex than is described here and more can be learned from reading the Arcadis Report[1].

Analyzing OP-FTIR spectra is somewhat of an art form and requires considerable training; a chemistry background is helpful. Analysis by Air Quality Monitoring staff would require assistance from an organic chemist. The analysis can be done for target compounds or be done for unknowns. Looking for target compounds is easier and aided by the RMM software. Identifying unknowns is more difficult and more time consuming because relative functional group peak differences have to be analyzed frame by frame.

Targeted Compounds below Minimum Detection Limit (MDL)

ODEQ looked specifically for 19 target compounds in Portland and 16 in Albany. During this project only Chloroform was detected above the MDL with the OP- FTIR. These target compounds are in Table 1.

Table 1. Target Compounds analyzed for with OP-FTIR.

	Portland Target Compounds	Albany Target Compounds
1	Benzene	Benzene
2	Toluene	Toluene
3	p-Xylene	p-Xylene
4	m-Xylene	m-Xylene
5	o-Xylene	o-Xylene
6	Naphthalene	chlorobenzene
7	Phenol	1,1,1-trichloroethane
8	Carbon Tetrachloride	1,1,2-trichloroethane
9	Dichloromethane	1,3-butadiene
10	Formaldehyde	methyl mercaptan
11	Acetaldehyde	hydrogen fluoride
12	Acrolein	2-butanone
13	Styrene	methyl isobutyl ketone
14	Hydrogen Cyanide	phosgene
15	1,3 Butadiene	trichloroethene
16	1,2 Dibromoethane	tetrachloroethene
17	1,2 Dichloroethane	_
18	1,1 Dichloroethane	_
19	Chloroform	_

The OP-FTIR has high minimum detection limits (MDLs) because it has a short measurement time frame. This was confirmed by running a simultaneous 24 hour canister sampler a few blocks away. The canisters were collected at the DEQ site at NW24th and Savior on August 7, 13, 19, 25, and 31, 2003. Table 2 shows a comparison of 13 targeted compounds measured by canister versus the OP-FTIR spectral analysis data. All the target compounds except Chloroform were below MDLs using the OP-FTIR one minute frames. Chloroform only had one frame above the MDL (which is included in the unexpected compounds section for convenience).

For example, Benzene had a mean OP-FTIR MDL between 23 and 32 ppb on the five days the canister sample was also collected. The Benzene levels in the canister ranged from 0.13 to 0.37 ppb, well below the MDL for the OP-FTIR. However, because the canister sample was collected and averaged over 24 hours, any short duration, high concentrations of Benzene would have been smoothed out

In reality, the actual ambient air most likely fluctuated on both sides of the average canister concentration. Therefore, the only absolute is that the Benzene concentrations at any given time was below the MDL and averaged over 24 hours was two orders of magnitude below the MDL. The EPA health benchmarks for Benzene and 1,3 Butadiene were also included in Table 2 for comparison.

Figure 7 shows the average of the daily minimum, mean, and maximum MDLs for the targeted compounds from the Portland site. These statistics were compiled by first ascertaining the minimum, mean, and maximum one minute frame values for each day. The minimum, mean, and maximum values for the entire sampling period respectively were then averaged. Figure 8 shows a similar chart for data from Albany. The Albany MDLs are higher in part because of the EMF interference.

Table 2. Comparison of targeted compounds measured by 24 hour canister sampler at 24th and Savior vs. the OP-FTIR spectral analysis data on the same days.

	1,1-Dichloroethane (ppbV)	1,2-Dibromoethane (EDB) (ppbV)	1,2-Dichloroethane (ppbV)	1,2-Dimethylbenzene (ppbV)	1,3-Butadiene (ppbV)	1,4/1,3-Dimethylbenzene (ppbV) vs. p-Xylene	1,4/1,3-Dimethylbenzene (ppbV) vs. m-Xylene	Benzene (ppbV)	Carbon Tetrachloride (ppbV)	Chloroform (ppbV)	Methylene Chloride (ppbV)	Styrene (ppbV)	Toluene (ppbV)
EPA Benchmarks					0.033			0.13					
08/07/2003													
Canister	<0.10	<0.10	<0.10	0.26	<0.10	0.65*		0.29	<0.10	<0.10	0.39	<0.10	1.1
OPFTIR min MDL	3.9	1.2	4.5	8.4	2.6	12	10	16	0.5	0.9	3.6	10	15
OPFTIR mean MDL	6.2	2.9	12	14	5.6	23	17	23	0.8	1.5	6.0	18	23
OPFTIR max MDL	14	18	96	32	17	88	36	50	2.2	3.6	15.0	44	72
08/13/2003													
Canister	<0.10	<0.10	<0.10	0.24	<0.10	0.66*		0.28	<0.10	<0.10	0.31	<0.10	1.2
OPFTIR min MDL	4.3	1.4	5.0	10	3.2	14	11	17	0.5	0.9	4.4	11	17
OPFTIR mean MDL	8.7	4.3	18	19	7.3	28	24	32	1.1	2.0	8.1	24	28
OPFTIR max MDL	29	28	140	40	18	78	46	110	3.0	4.4	20	72	64
08/19/2003													
Canister	<0.10	<0.10	<0.10	0.27	<0.10	0.71*		0.29	<0.10	<0.10	0.20	<0.10	1.0
OPFTIR min MDL	4.5	1.4	5.4	9.2	3.2	16	12	18	0.6	1.0	4.0	12	17
OPFTIR mean MDL	7.4	3.6	14	18	6.7	29	24	29	1.0	1.8	7.2	22	28
OPFTIR max MDL	15	34	130	68	16	152	80	51	2.4	3.6	14	50	140
08/25/2003													
Canister	<0.10	<0.10	<0.10	0.42	<0.10	1.1*		0.37	<0.10	<0.10	0.17	<0.10	1.3
OPFTIR min MDL	5.2	1.4	5.5	11	4.1	16	12	20	0.6	1.0	4.8	13	17
OPFTIR mean MDL	8.1	3.3	13	22	7.4	39	30	31	1.0	1.9	7.5	22	34
OPFTIR max MDL	23	7	45	48	18	164	80	66	2.8	4.4	15	60	96
08/31/2003													
Canister	<0.10	<0.10	<0.10	0.14	<0.10	0.32*		0.13	<0.10	<0.10	0.20	<0.10	0.61
OPFTIR min MDL	4.5	1.4	4.9	9.2	3.4	14	11	18	0.5	0.9	4.0	11	16
OPFTIR mean MDL	6.1	3.0	12	15	5.4	22	19	24	0.8	1.4	6.0	17	22
OPFTIR max MDL	11	8	37	36	15	50	42	59	1.6	3.0	11	40	48

*These compounds are not analyzed for separately in the canister sample.

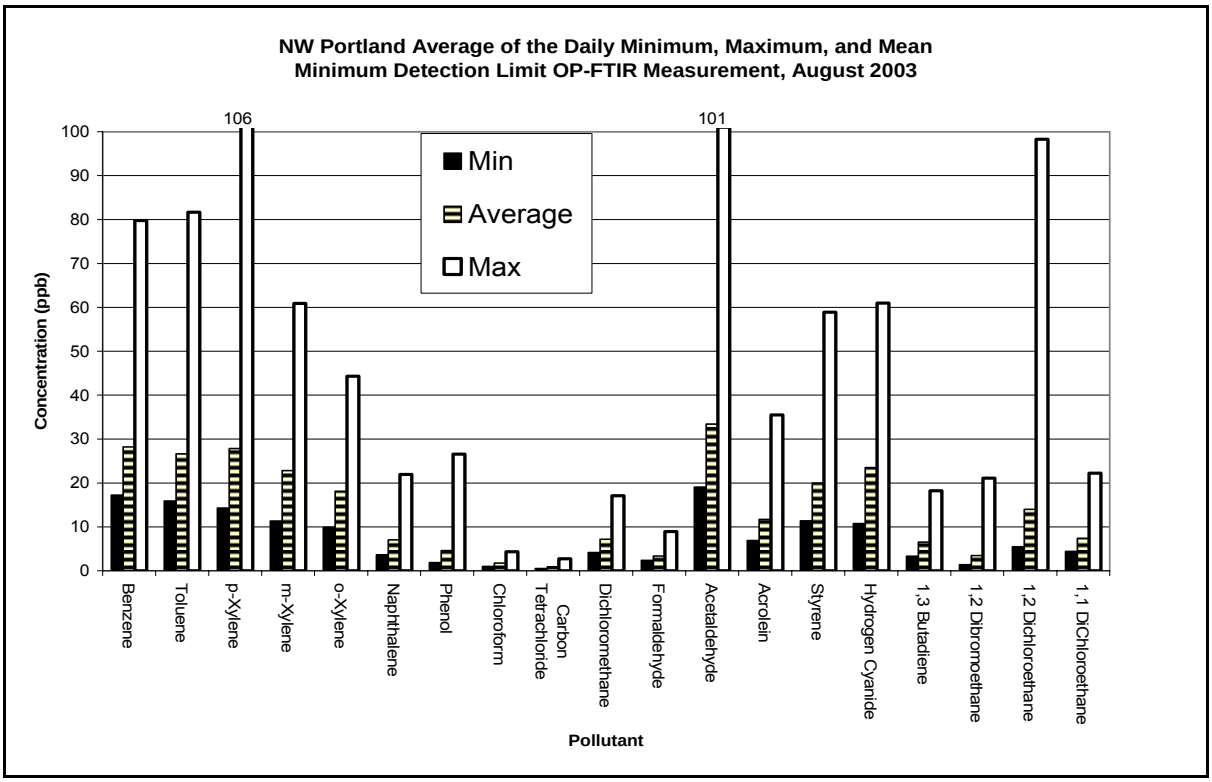


Figure 7. Average of daily minimum, mean, and maximum MDLs for NW Portland, August 4, 2003 through September 3, 2003.

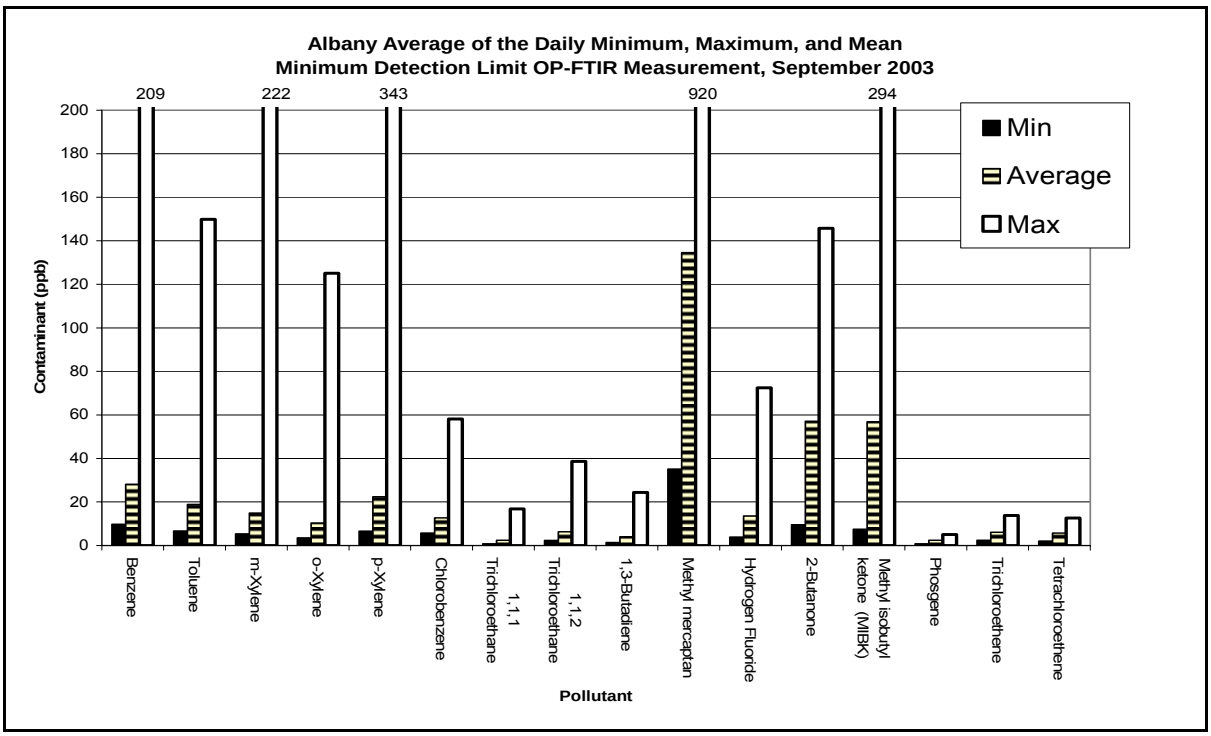


Figure 8. Average of daily minimum, mean, and maximum MDLs for Albany, September 8, 2003 to October 2, 2003. EMF interference may have contributed to raising the MDLs.

Unexpected Compound Analysis (Non-Targeted)

An analysis of non-targeted compounds was done to ascertain the ability of the OP-FTIR to determine unknowns. More detailed analysis of these compounds was included in this report because, aside from Chloroform, there was no data to analyze for the target compounds. Reviewing this data helped the lab assess the OP-FTIR's data analysis capabilities and visualize the usefulness of its presentation tools.

The OP-FTIR spectrum was analyzed for unexpected compounds and several were identified. In Portland 11 different compounds were detected and measured. Table 3 shows these compounds along with their number of detects, maximum, mean, and minimum concentrations. Chloroform's one measurable frame was also included in this table for convenience. The 3-σ values help the lab assess the reliability of the concentration determinations. The determinations that are much greater than the 3-σ values are more reliable than the values closer to 3-σ. Figures 9(a, b, c) and 10(a, b, c) illustrate the maximum and mean concentrations of these compounds. Figure 11(a, b, c) shows the number of one minute frames in which these unknowns were detected. For comparison, there are 1440 minutes in a day.
Note: The compounds are spread out into numerous tables for clarity. There is no specific grouping regime.

Table 3. Unexpected (Non-targeted) compounds detected in Portland.

		Number of detects	Min Conc. (ppb)	Max Conc. (ppb)	Mean Conc. (ppb)	Mean 3-σ
1	Ammonia	2712	0.78	14.9	2.66	0.77
2	Methanol	1081	2.1	19.8	5	1.6
3	Acetone	286	3.2	82	12.5	4.2
4	Propylene glycol methyl ether acetate	92	1.52	10.8	3.4	1.9
5	n-Butyl Acetetate	486	1.05	25.3	2.9	1.3
6	Iso-Butanol	310	1.7	30.8	6.6	1.6
7	1,1,1,2-Tetrafluoroethane	91	0.47	11.4	1.71	0.45
8	Chlorodifluoromethane	907	0.34	16.3	2.04	0.34
9	Tetrachloroethene	847	1.29	50.8	4.56	0.74
10	Isopropanol	2132	3.1	277.1	7.9	2.5
11	2-Butanone	54	7.6	49	17.8	5.4

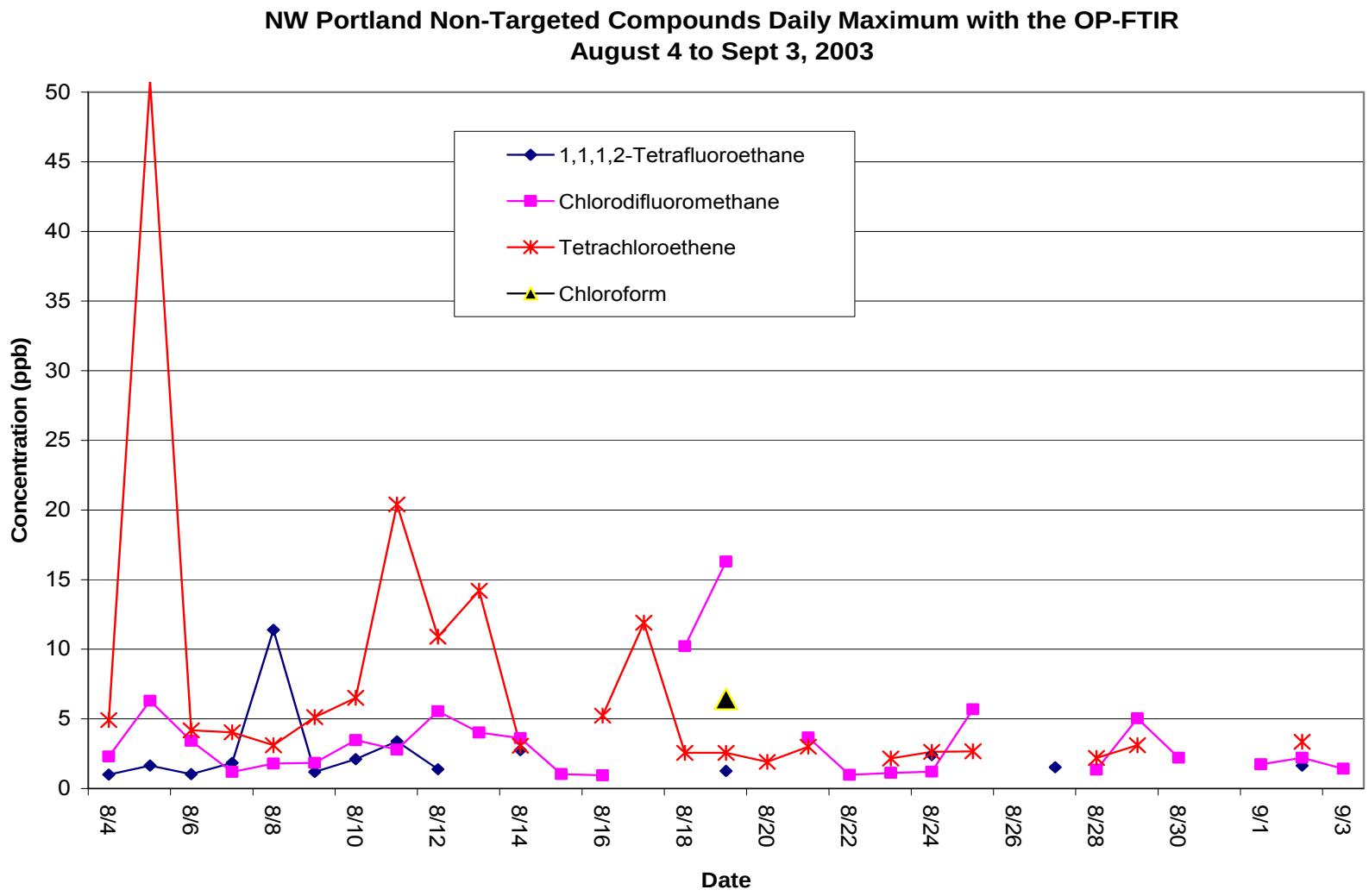


Figure 9a. Daily maximum OP-FTIR concentrations for 1,1,1,2 Tetrafluoroethane, Chlorodifluoroethane, Tetrachloroethene, and Chloroform for NW Portland, August 4, 2003 through September 3, 2003.

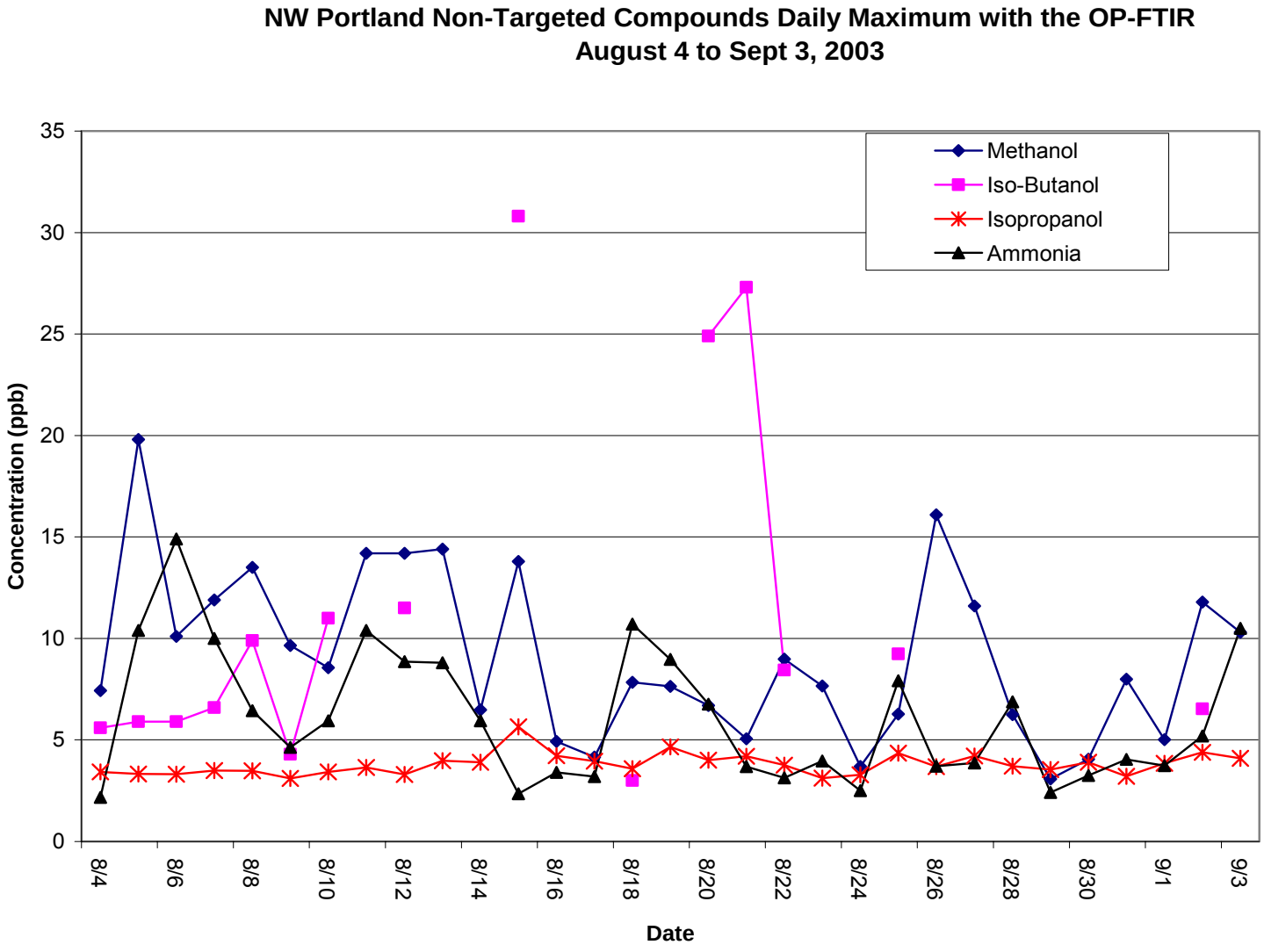


Figure 9b. Daily maximum OP-FTIR concentrations for Methanol, Iso-Butanol, Isopropanol, and Ammonia for NW Portland, August 4, 2003 through September 3, 2003.

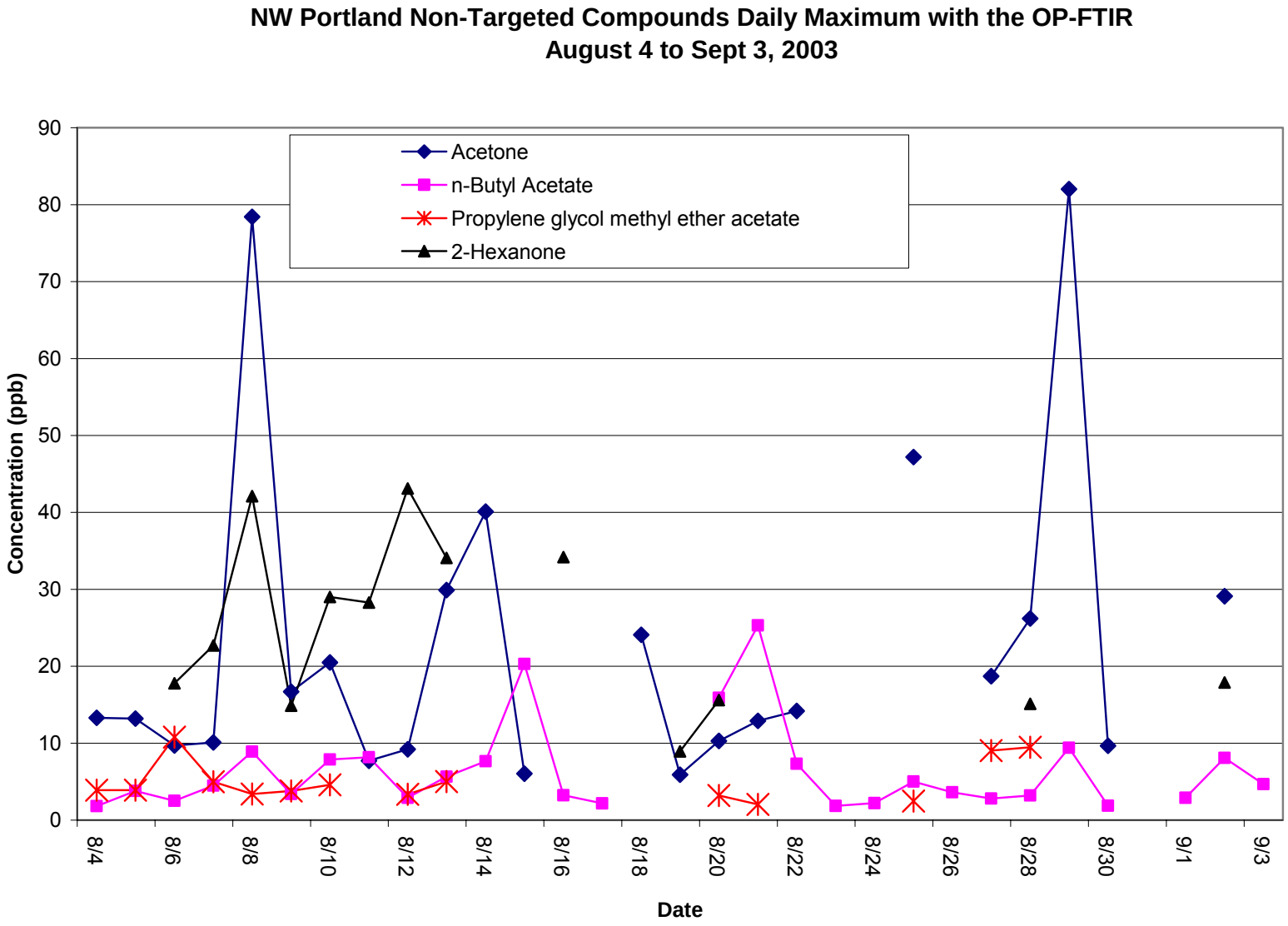


Figure 9c. Daily maximum OP-FTIR concentrations for Acetone, N-Butyl Acetate, Propylene glycol methyl ether acetate, and 2-Hexanone (MBK) for NW Portland, August 4, 2003 through September 3, 2003.

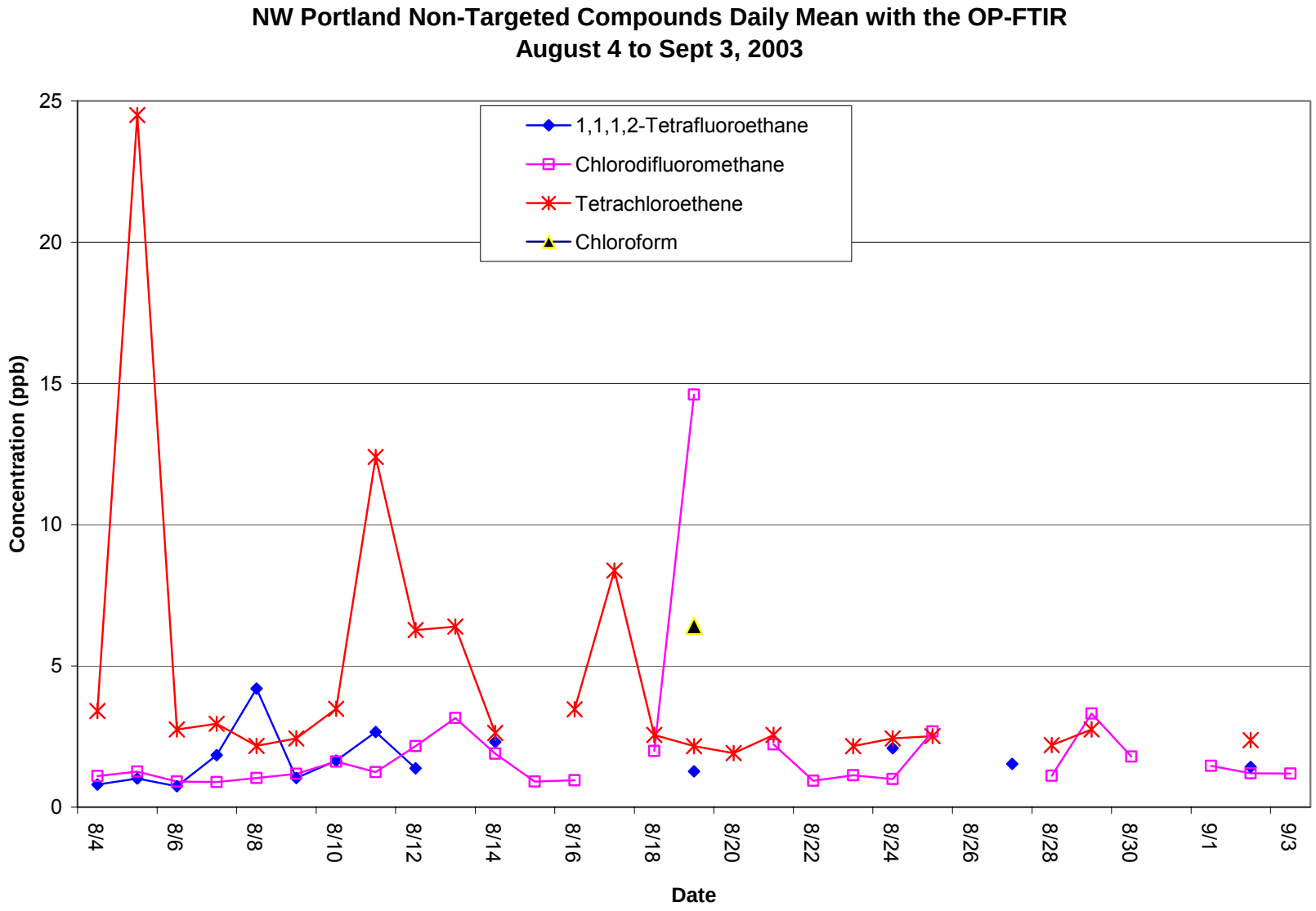


Figure 10a. Daily average OP-FTIR concentrations for NW Portland, August 4, 2003 through September 3, 2003.

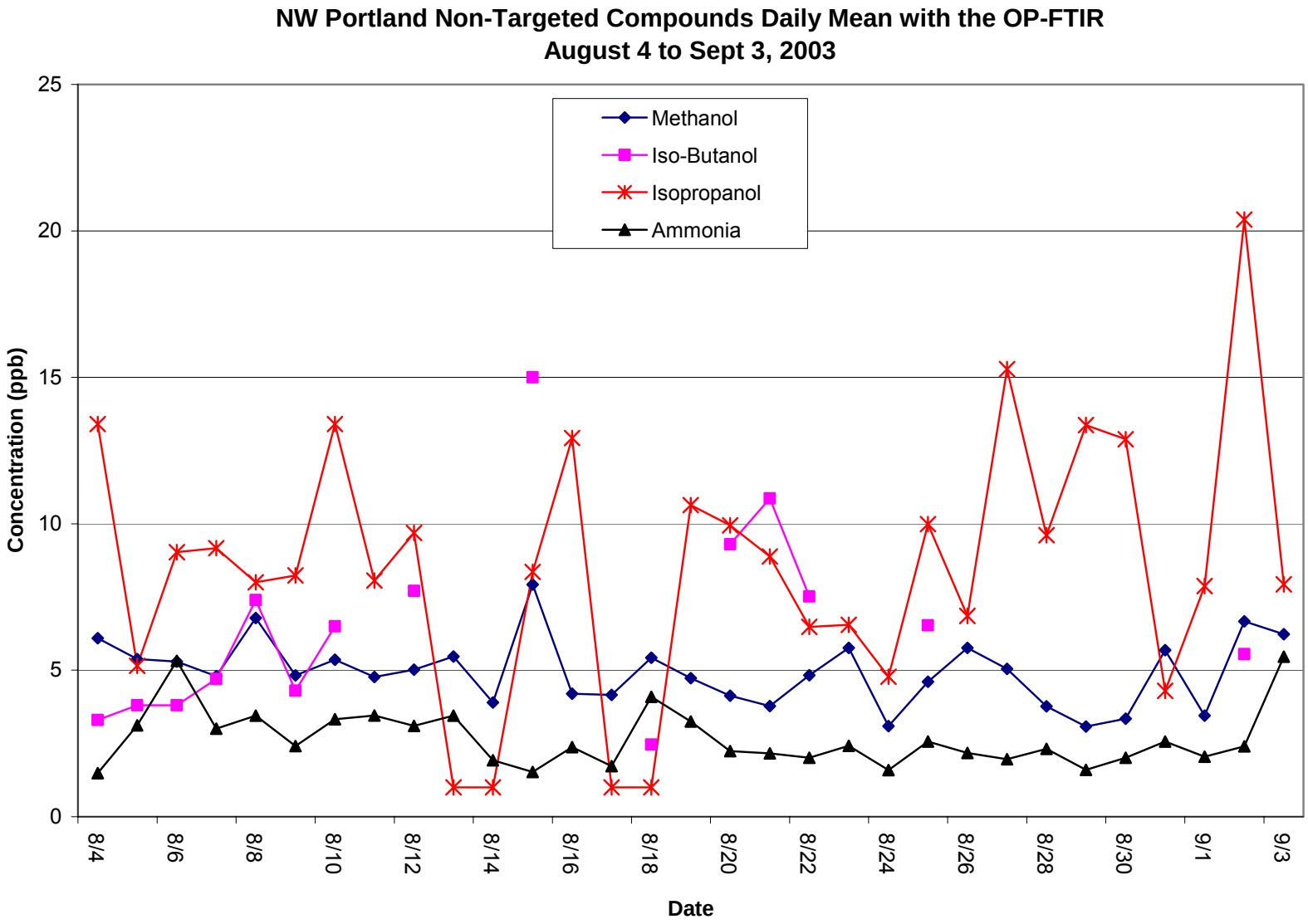


Figure 10b. Daily average OP-FTIR concentrations for NW Portland, August 4, 2003 through September 3, 2003.

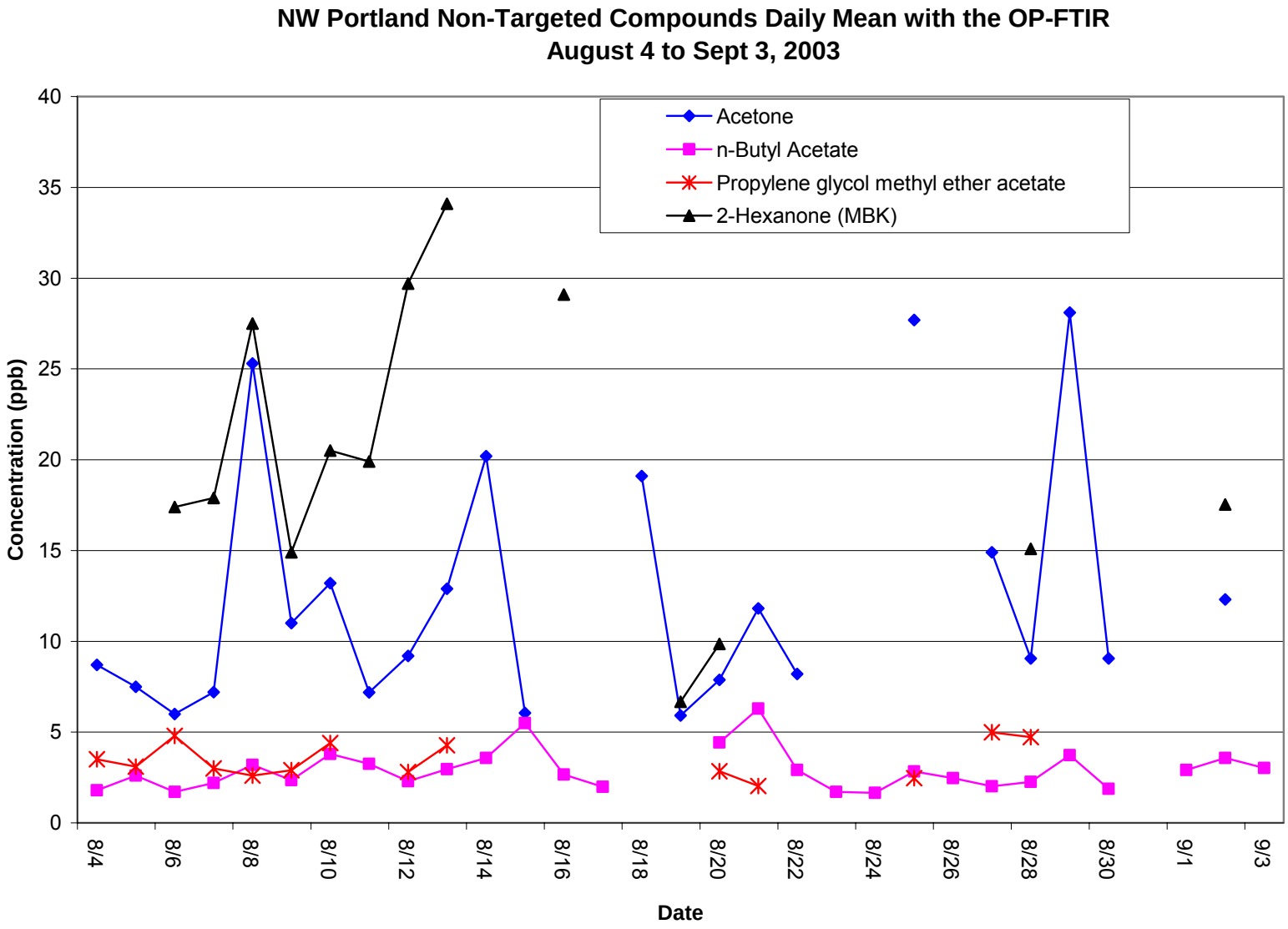


Figure 10c. Daily average OP-FTIR concentrations for NW Portland, August 4, 2003 through September 3, 2003.

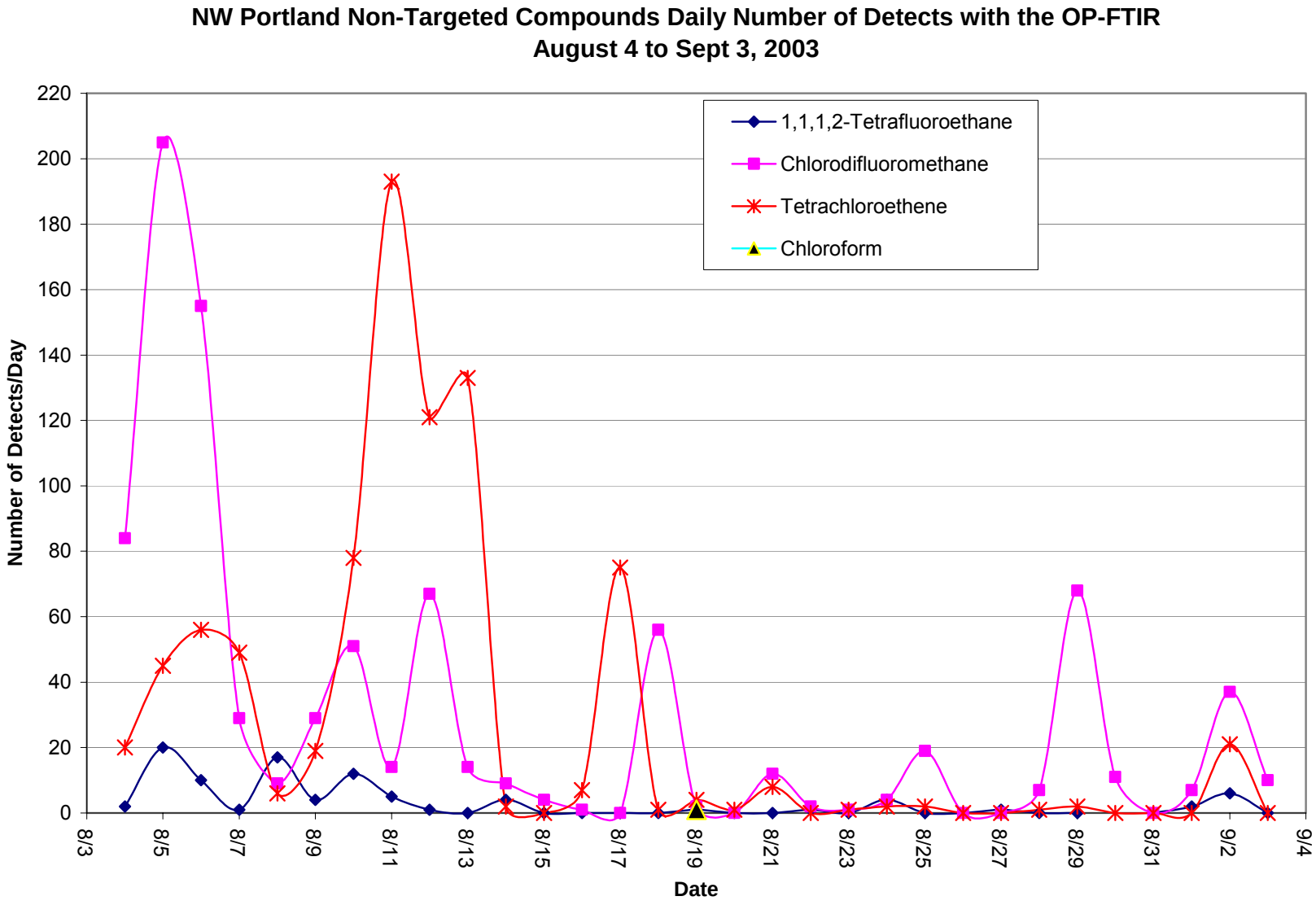


Figure 11a. Number of one minute time frames per day where a pollutant was detected by the OP-FTIR for NW Portland, August 4, 2003 through September 3, 2003.

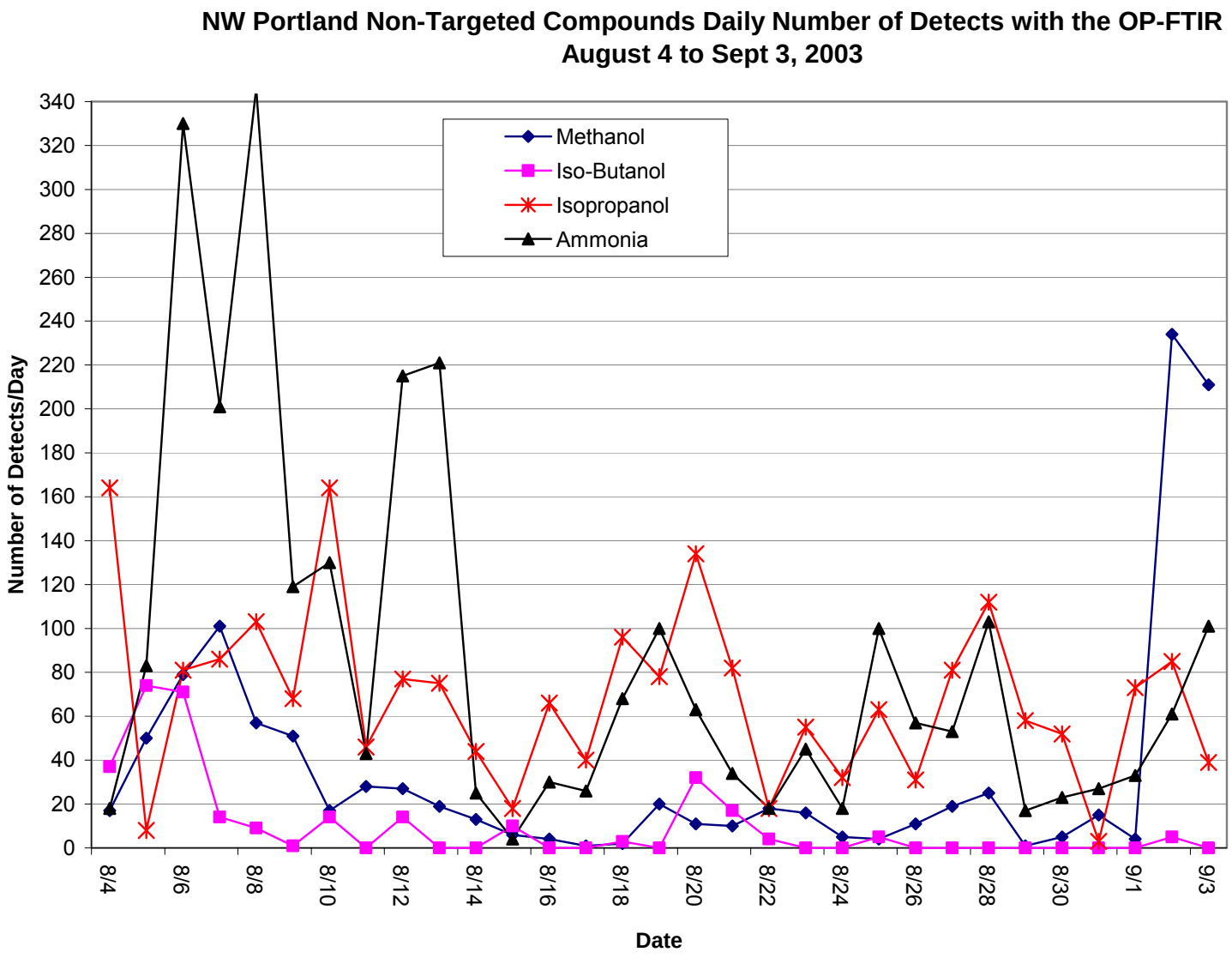


Figure 11b. Number of one minute time frames per day where a pollutant was detected by the OP-FTIR for NW Portland, August 4, 2003 through September 3, 2003.

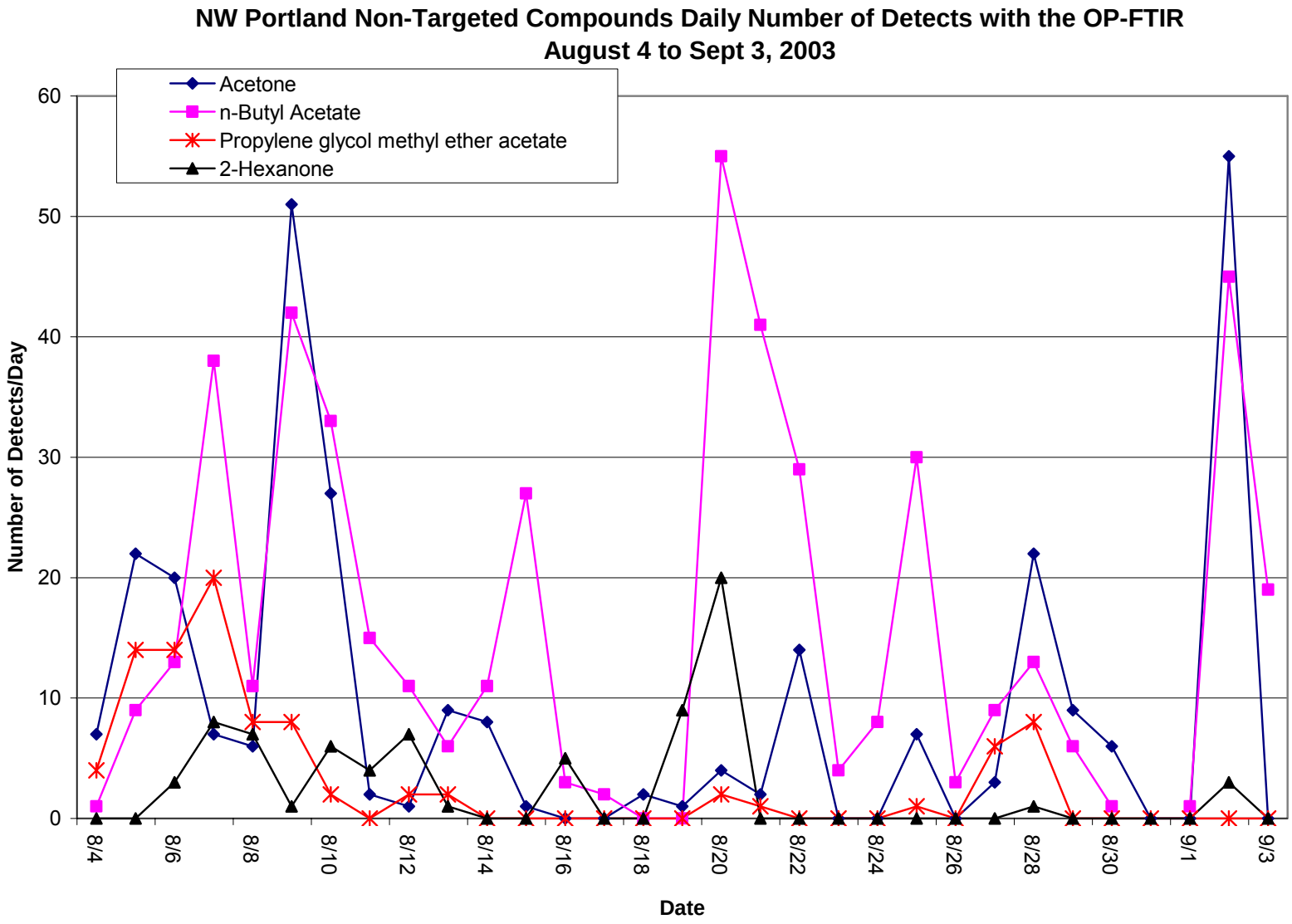


Figure 11c. Number of one minute time frames per day where a pollutant was detected by the OP-FTIR for NW Portland, August 4, 2003 through September 3, 2003.

The unexpected compounds measured in Albany are shown in Table 4 along with the number of detects and the minimum, mean, and maximum concentrations. The 3-σ values help assess the reliability of the concentration determinations. The determinations that are much greater than the 3-σ values are more reliable than the values closer to 3-σ.

Table 4. Unexpected (Non-targeted) compounds detected in Albany.

	Unexpected Compound	Number of detects	Min Conc. (ppb)	Max Conc. (ppb)	Mean Conc. (ppb)	Mean 3-σ
1	Ammonia	18903	0.44	68.5	4.89	0.76
2	Nitrous Oxide	23808	0.81	4080	37.5	3.8
3	Methane	24894	6.63	5760	373.3	35
4	Methanol	2171	1.25	9.79	3.68	2
5	Ethanol	3650	4.23	1280	40.6	3.8

Figures 12a and 12b and 13a and 13b display the daily maximum and daily average concentrations of these compounds. Figure 14 shows the number of one minute frames per day in which the pollutant was detected.

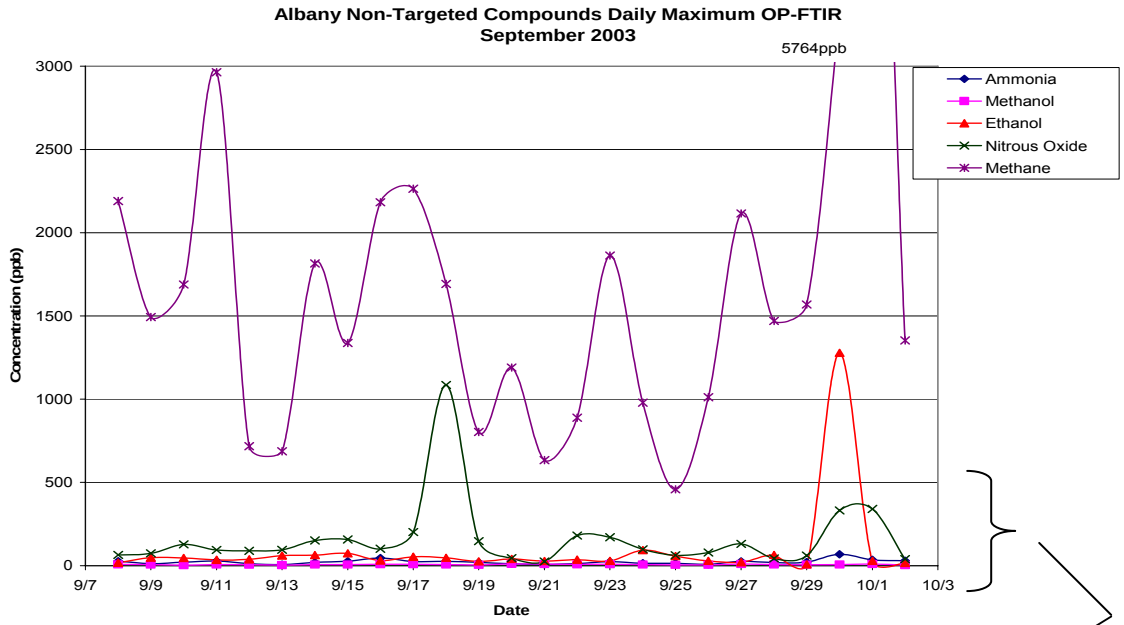


Figure 12a. Daily maximum OP-FTIR concentrations for Albany, September 8, 2003 through October 2, 2003.

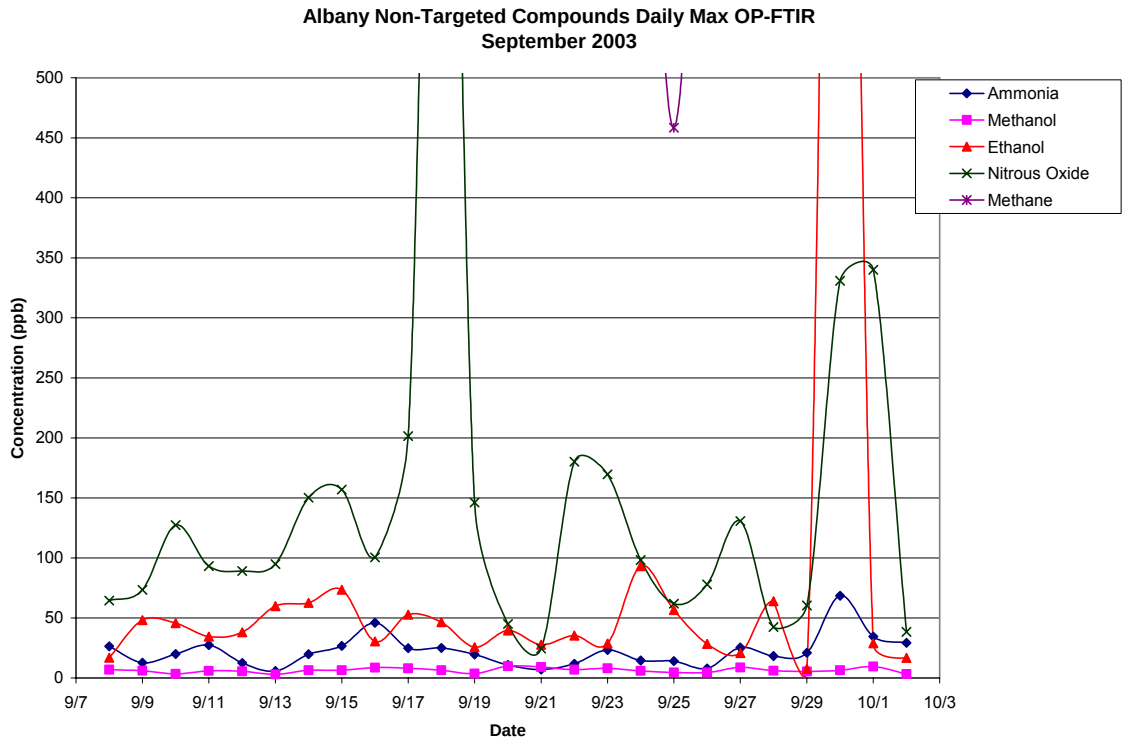


Figure 12b. Expanded view (lower portion of graph) of daily maximum OP-FTIR concentrations for Albany, September 8, 2003 through October 2, 2003.

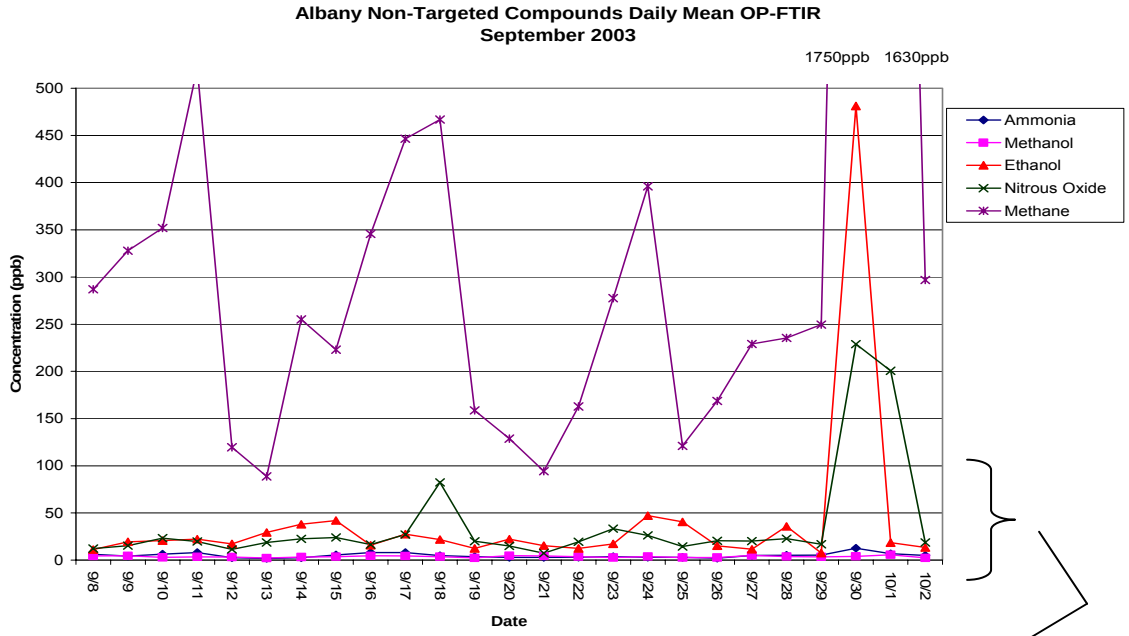


Figure 13a. Daily average OP-FTIR concentrations for Albany, September 8, 2003 through October 2, 2003

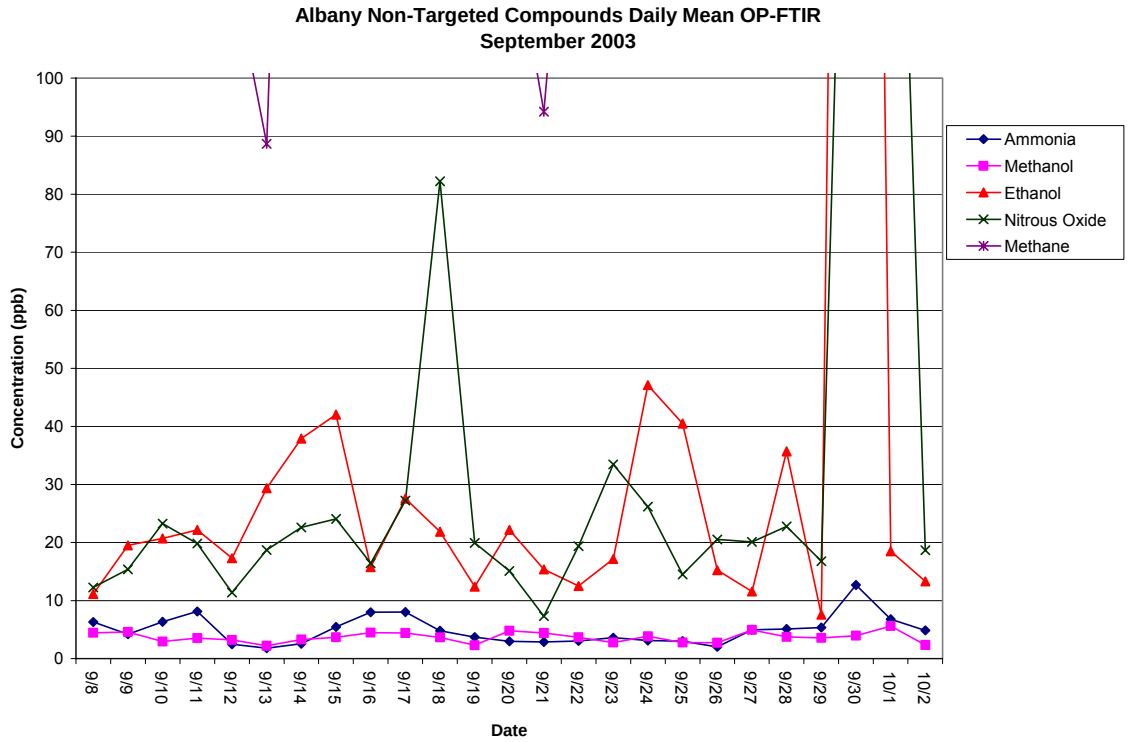


Figure 13b. Expanded view of daily average OP-FTIR concentrations for Albany, September 8, 2003 through October 2, 2003.

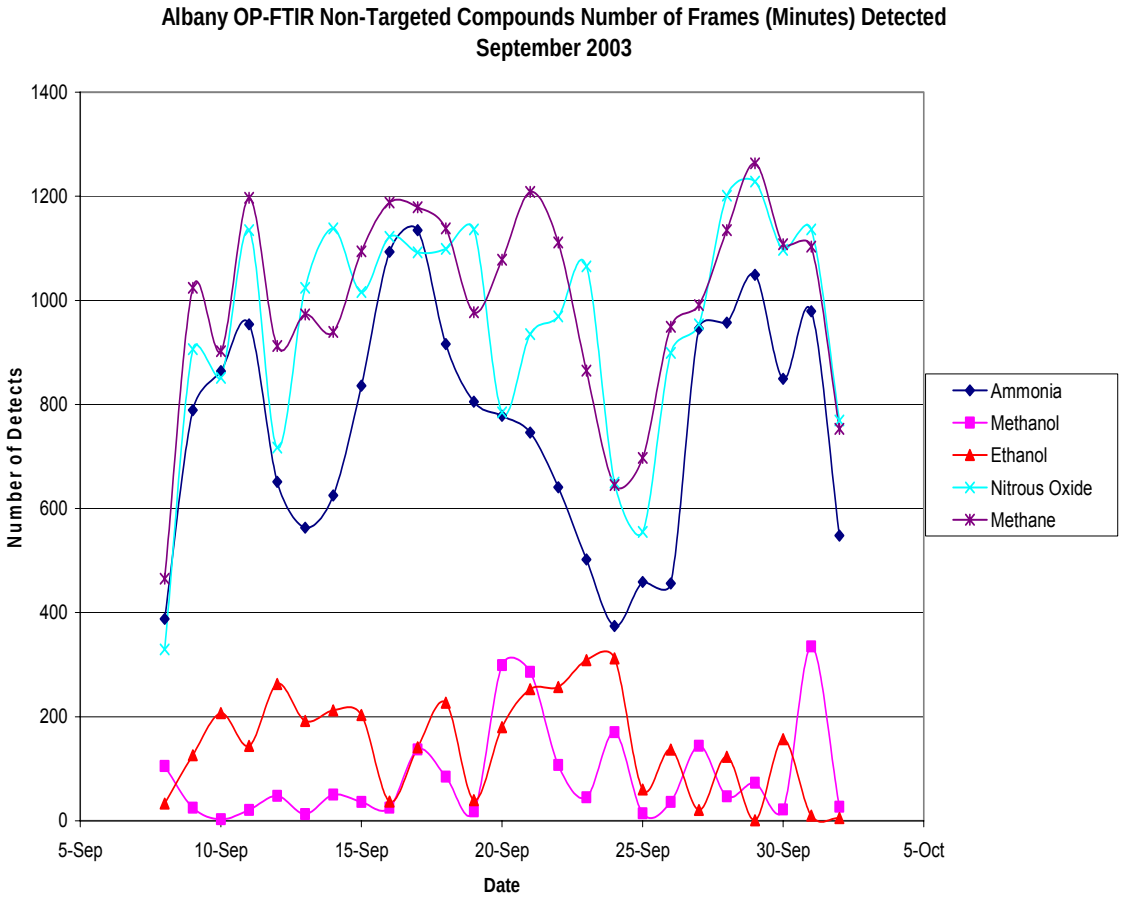
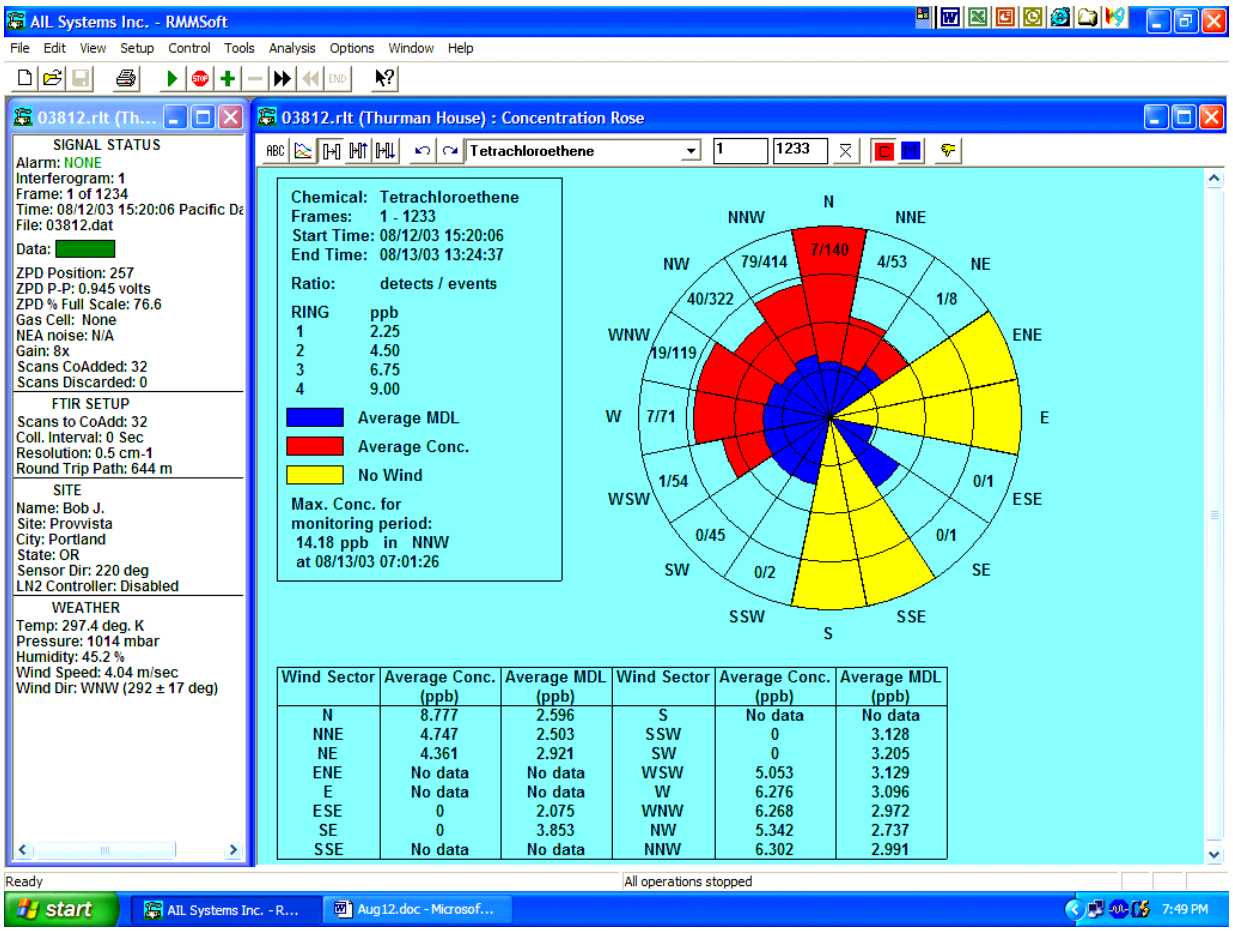


Figure 14. Number of one minute time frames per day in which a pollutant was detected by the OP-FTIR for Albany, September 8, 2003 through October 2, 2003. There are 1440 one minutes frames per day.

Meteorology Data Inclusion

One advantage of the OP-FTIR is that it provides one minute time frames with corresponding wind direction. This allows a snapshot of a contaminant plume's concentration and wind direction and allows for a more educated estimation as to its source. The frames can be compiled and put into a concentration rose. Figure 15 provides an example of this for Tetrachloroethene in Portland on August 12 and 13, 2003. The pollution rose displays the pollutant concentration, the wind directions, and the number of frames in which the compound was detected. The concentrations are represented by the rings with the inner most ring being ¼ the value of the outermost ring. The ratio of detects/events is indicated for each wind direction, where "detects" is the number of frames the pollutant is present from that wind direction, and "events" is the total number of frames measured from the indicated wind direction. The red shaded areas represent concentrations above the MDL, blue areas signify MDL measurements, and yellow areas show directions were there was no wind flow. The lower table also summarizes the wind direction, MDL, and concentration.



Wind Sector	Average Conc. (ppb)	Average MDL (ppb)	Wind Sector	Average Conc. (ppb)	Average MDL (ppb)
N	8.777	2.596	S	No data	No data
NNE	4.747	2.503	SSW	0	3.128
NE	4.361	2.921	SW	0	3.205
ENE	No data	No data	WSW	5.053	3.129
E	No data	No data	W	6.276	3.096
ESE	0	2.075	WNW	6.268	2.972
SE	0	3.853	NW	5.342	2.737
SSE	No data	No data	NNW	6.302	2.991

Figure 15. August 12 and 13, 2003 pollution rose for NW Portland.

The pollution rose graph in Figure 15 suggests that from August 12th 15:20 PDT to August 13th 13:24 PDT the predominant wind direction was from WNW to N. Most of the detects were from the NNW and NW. Table 5 Summarizes the percentage of detects/events for NNE to west under "% of Detects". The last column in the table contains a percentage calculated by dividing the percentage of detects for each wind direction by the total events between NNE and west. The second percentage is an attempt to normalize the detects for each wind direction within the range of interest. The pollution rose also gives concentrations which are highest from west to north with the highest average being detected from the north at 9 ppb.

Table 5. Percentage of detects of Tetrachloroethene per events measured for NNE to West in NW Portland on August 12 to August 13.

Wind Direction	% of Detects	Detects/Events	% of Detects all Events between ENE and W
NNE	8%	4/53	0%
N	5%	7/140	1%
NNW	19%	79/414	7%
NW	12%	40/322	4%
WNW	16%	19/119	2%
W	10%	7/71	1%

These parameters tell part of the story of the pollutant direction and concentration. What is missing is the wind speed and the time of day. The high concentrations from the north could have been transported from some distance or generated more locally dependent on wind speed. Also, with stagnant conditions the pollutants undergo less advective dispersion and will persist at higher concentrations. However, low wind speeds also tend to give sporadic wind directions. The wind rose in Figure 15 indicates that the vast majority of events were from the north so the wind speeds were likely high enough to keep the wind vane from sporadically spinning. Time of day is also critical for comparison to source activity. Fortunately, the raw data contains all the parameters in the pollution rose plus wind speed, time of day, and 3-Sigma (a statistical parameter that helps assess the reliability of the concentration determinations). Review of the raw data is necessary to complete the analysis.

When we analyzed this particular data range we see that the average wind speed of frames where concentrations were above 1 ppb was around 5mph. The highest values all occurred on the late evening of August 12th and the morning of August 13th with the maximum values present during the 0700 hour. The wind was predominantly from the NW. A visual representation of the raw data can be seen in Figure 16.

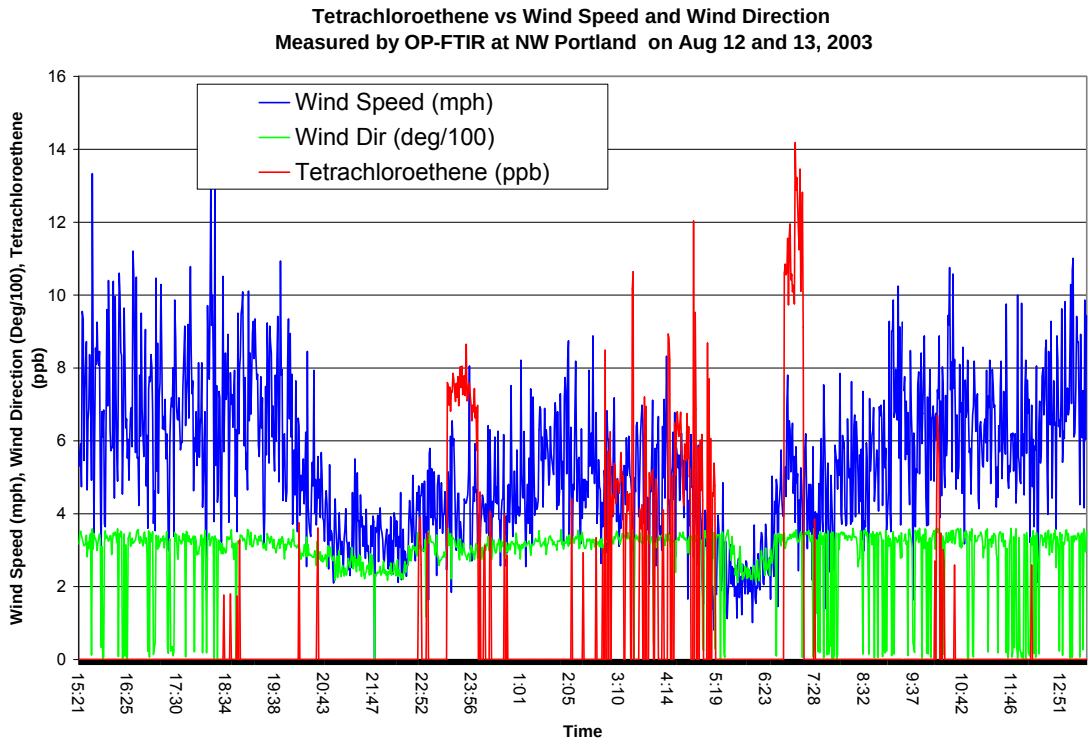


Figure 16. OP-FTIR Tetrachloroethene, wind speed, and wind direction for August 12 1521 PDT to August 13 1251 PDT, 2003. The Wind speed is in degrees/100 to place it on the same scale.

Quality Assurance

The quality assurance was performed on the meteorological system using a compass and wind speed sensor. The system audited well and was simple to use. The QA of the RAM2000 consisted of canister samples run for 24 hours in NW Portland on five days and compared to the OP-FTIR data as discussed above.

Conclusions:

The OP-FTIR has limited usefulness in measuring real time ambient organic air toxics because of its relatively high MDL when short time frames are measured. Using standard integrated canister sampling it was shown that most ambient air has organic air toxics below the OP-FTIR's MDLs. Better detection levels could be achieved if the time frames were lengthened, but important information indicating the plumes source would be lost.

The OP-FTIR may be useful for measuring suspected hotspots such as neighborhoods downwind of industrial areas. In these areas, suspected compounds can be targeted and at the very least shown not to exist in levels above the MDL. When a compound is present, the co-located met system and short measurement time frame indicate the

direction of its source. The OP-FTIR is also useful for measuring unsuspected (non-targeted) compounds that exist at high concentrations.

The best way to use this system is to lease it over a short period of time, during different seasons of the year. There are several reasons for this. First, the amount of data collected over one month with one minute time frames requires several months to evaluate. Second, emissions from industrial areas may be different at different times of the year. Also, collecting data for more than a month during the same season furnishes data of diminishing value.

Leasing this equipment and paying for analysis is the cheapest and most effective method of obtaining data. The OP-FTIR cost over $150K to purchase and around $200K with the co-located wind speed and wind direction sensors. The rental of this equipment with training and analysis provided was $38K for two months. The analysis of the data took Dr. Robert Kagaan, an expert consultant, months to complete. In Dr. Robert Kagaan's report he states there were over one million spectra to review. After training a chemist to interpret the data, one million spectra would have taken significant staff resources to analyze.

Finally, daily visits are necessary to keep the OP-FTIR operational. At best the OP-FTIR can be visited every other day. One hour per visit for site maintenance and the appropriate travel time must be included in any operational budget. The preliminary and final analysis of the data by DEQ staff also must be factored in. Preliminary analysis was two hours per week. Final analysis time beyond that of the consultant is dependent on the results but it can be extensive.

References:

1. Kagaan R., Barnack, A., Jones R., Hashmonay R, Report On The Analysis of OP-FTIR Measurements Made in the Cities of Portland and Albany Oregon – August to September 2003, Prepared by Arcadis G & M, Inc., Reference RN009010.0001.00002, April 2004.

2. Myers K., Kelly T., Lawrie C. Riggs K., Environmental Technology Verification Report, AIL Systems Inc. RAM 2000 Fourier Transform Infrared Open-Path Monitor, Prepared by ETV Advanced Monitoring Systems Center, Battelle, September 2000.