Modeling for VOCs Source Apportionment

Philip K. Hopke
Clarkson University
and
Consulting for Health, Air, Nature, & a Greener Environment, LLC
(CHANGE)

CHANGE
Consulting for Health, Air, Nature, & a Greener Environment, LLC
ENVIRONMENTAL SOLUTIONS. DELIVERED.

Outline

- Introduction
- Sampling and Analysis of VOCs
- Source Apportionment
  - Profiles Known
  - Profiles Unknown
- Summary

Introduction

- Why do VOCs matter?
  - Direct health effects
    - Acute – carbonyls and irritation responses
    - Chronic – PAHs and cancer
  - Drive atmospheric chemistry
    - Ozone formation
    - SOA formation

Introduction

- What VOCs matter?
  - PAHs
  - Reactive hydrocarbon compounds
    - Olefins including terpenes and isoprene
    - Aromatics like benzene, toluene, xylenes
    - Aliphatics to a lesser extent

Sampling and Analysis

- In the US, we have sites to look at the hydrocarbon compounds most related to ozone production.
- These are **Photochemical Assessment Monitoring Stations (PAMS)**
- They are described at http://www3.epa.gov/ttnamti1/pamsmain.html

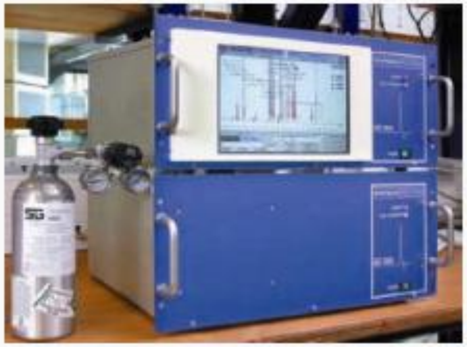
Sampling and Analysis

- Sampling
  - Semicontinuous in-situ sampling and analysis
    - Auto-GC
  - Integral samples
    - Canisters returned to the laboratory for sampling.

Sampling and Analysis

VOC Measurement Technologies

Canisters vs Auto-GCs



Canisters	Auto-GCs
•Data averaged over sampling period •Low capital cost •Continuing lab/shipping costs •Manually intensive •Canister "artifacts"	•Hourly data •Higher capital cost •Higher skill level required to run and analyze data •Difficulty resolving some compounds

Sampling and Analysis

Hydrocarbons		
Ethylene	3-Methylpentane	Styrene
Acetylene	2-Methyl-1-Pentene	o-Xylene
Ethane	n-hexane	n-Nonane
Propylene	Methylcyclopentane	Isopropylbenzene
Propane	2,4-dimethylpentane	n-Propylbenzene
Isobutane	Benzene	m-Ethyltoluene
1-Butene	Cyclohexane	p-Ethyltoluene
n-Butane	2-methylhexane	1,3,5-Trimethylbenzene
t-2-Butene	2,3-dimethylpentane	o-Ethyltoluene
c-2-Butene	3-methylhexane	1,2,4-trimethylbenzene
Isopentane	2,2,4-trimethylpentane	n-Decane
1-Pentene	n-Heptane	1,2,3-trimethylbenzene
n-Pentane	Methylcyclohexane	m-Diethylbenzene
Isoprene	2,3,4-trimethylpentane	p-Diethylbenzene
t-2-pentene	Toluene	n-Undecane
c-2-pentene	2-methylheptane	
2,2-Dimethylbutane	3-methylheptane	Carbonyls
Cyclopentane	n-Octane	Formaldehyde
2,3-dimethylbutane	Ethylbenzene	Acetone
2-methylpentane	m&p-Xylenes	Acetaldehyde

Which system is best for source apportionment?

- The auto-GC provides hourly data so 24 samples a day
- Canisters provide up to 8 3-hour samples a day, but most canister sites simply collect 2 per day (morning and afternoon) and miss the overnight hours.

In general, auto-GCs are highly preferred for source apportionment studies.

Apportionment Methods

- All of the apportionment methods work on the basis of a mass balance approach
- That is the concentrations we observe are additive contributions from a set of independent source types.
- Thus, we will do a mass balance analysis

Mass Balance

A mass balance equation can be written to account for all m chemical species in the n samples as contributions from p independent sources

$$x_{ij} = \sum_{k=1}^{p} g_{ik} f_{kj}$$

Where i = 1,…, n samples, j = 1,…, m species and k = 1,…, p sources

Receptor Modeling

- The question is then what is known *a priori* to solve this equation.

- Divide the problem into two classes
  - Source Profiles Known
  - Source Profiles Unknown

Receptor Modeling

- **SOURCES PROFILES KNOWN**
  - **Chemical Mass Balance**
  - **Multivariate Calibration Methods**
    - Partial Least Squares
    - Artificial Neural Networks
    - Simulated Annealing
    - Genetic Algorithm

Chemical Mass Balance Model

The mass balance equation can be rewritten as a regression problem where the profiles and the ambient concentrations are known.

$$x_j = \sum_{k=1}^{p} g_k f_{kj} + e_j$$

Where the equation is now written for one sample at a time.

Chemical Mass Balance

- The CMB model is then a regression problem. However, there are errors in both the dependent and independent variables so it is necessary to solve the problem using error models.
- The EPA has adopted the effective variance least-squares approach and incorporated it in CMB 8 that is available at www.epa.gov/ttn/SCRAM

Chemical Mass Balance

- The CMB model has been widely used for PM_{10} apportionment in the western US and for fine particle organic carbon apportionment based on specific organic species ("molecular markers") that have been identified in a series of source emissions by the late Glen Cass and his former students.

Chemical Mass Balance

- The key issue in the application of the CMB are knowing the profiles
- It is difficult and expensive to perform emissions sampling and very few sources have been examined. Thus, profiles may not be available for the specific source types needed.
- Very little is known with respect to the variability in composition in the profiles for a given source type.

Receptor Modeling

- SOURCES PROFILES UNKNOWN
  - Factor Analysis
    - Principal Components Analysis
    - Absolute Principal Components Analysis
    - SAFER/UNMIX
    - Positive Matrix Factorization

Factor Analysis

- We do not have time today to get into the details of these various approaches.
- One method has become the most widely used method because it has the ability to make more complete use of the data and what is known regarding the related measurement uncertainties.
- That method is Positive Matrix Factorization (PMF)

Positive Matrix Factorization

- Explicit least-squares approach to solving the factor analysis problem

- Individual data point weights

- Imposition of natural and other constraints, and

- Flexibility to build more complicated models

Positive Matrix Factorization

- The Objective Function, Q, is defined by

$$Q = \sum_{i=1}^{n} \sum_{j=1}^{m} \left[\frac{x_{ij} - \sum_{k=1}^{p} g_{ik} f_{kj}}{\sigma_{ij}} \right]^2$$

where σ_{ij} is an estimate of the uncertainty in x_{ij}

Positive Matrix Factorization

- The US EPA version of PMF (version 5) is available at https://www.epa.gov/air-research/positive-matrix-factorization-model-environmental-data-analyses

Positive Matrix Factorization

- There have been a number of application of PMF to VOC data. A good illustrative example is:
- Characteristics and source apportionment of VOCs measured in Shanghai, China, Changjie Cai, Fuhai Geng, Xuexi Tie, Qiong Yu, Junlin An, Atmospheric Environment 44 (2010) 5005 – 5014.

Sampling and Analysis

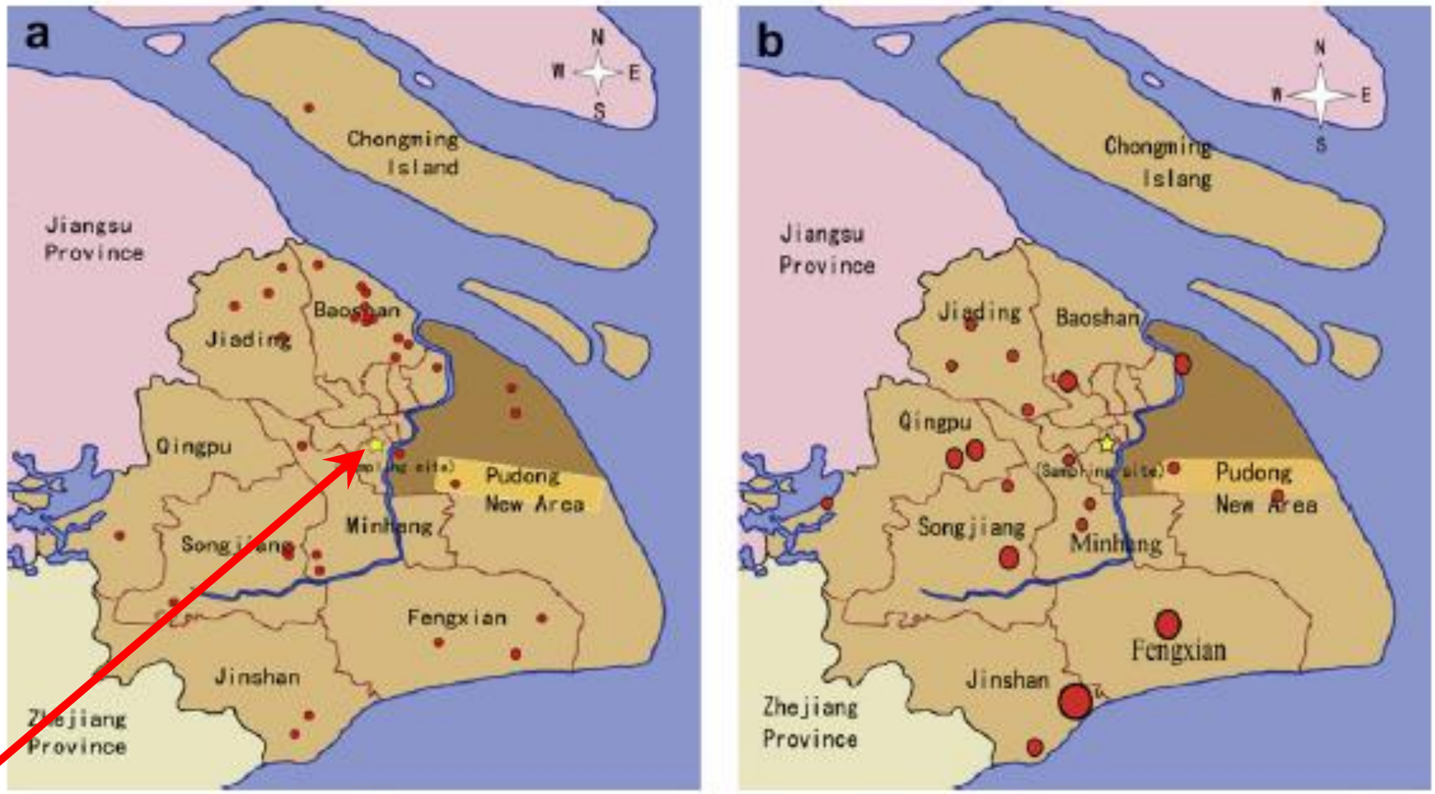


Fig. 1. Location of sampling site (yellow star) and the distribution of large smelter and steel factories (a) and large chemical industrial complex (b) in Shanghai.

Sampling and Analysis

- The sampling site is located at Xujiahui (XJH) commercial center of Shanghai
- VOCs were sampled at 6:00-9:00 for 3 h using a 6 L silonite canister with silonite valve (model 29-10622, Entech Instruments Inc., USA) from Jan. 2007 to Mar. 2010.
- To study the diurnal variations, VOCs were intensively measured (8 samples a day with a 3 h interval) from August 25 to September 20, 2009

Sampling and Analysis

- The sampling site is located at Xujiahui (XJH) commercial center of Shanghai
- VOCs were sampled at 6:00-9:00 for 3 h using a 6 L silonite canister with silonite valve (model 29-10622, Entech Instruments Inc., USA) from Jan. 2007 to Mar. 2010.
- To study the diurnal variations, VOCs were intensively measured (8 samples a day with a 3 h interval) from August 25 to September 20, 2009

Sampling and Analysis

- Gas samples were pre-processed using an Entech Model 7100 VOC pre-concentrator.
- Analyzed by gas chromatography with a mass-selective detector.
- Thirty-two compounds were available for the source apportionment study

Wind Data

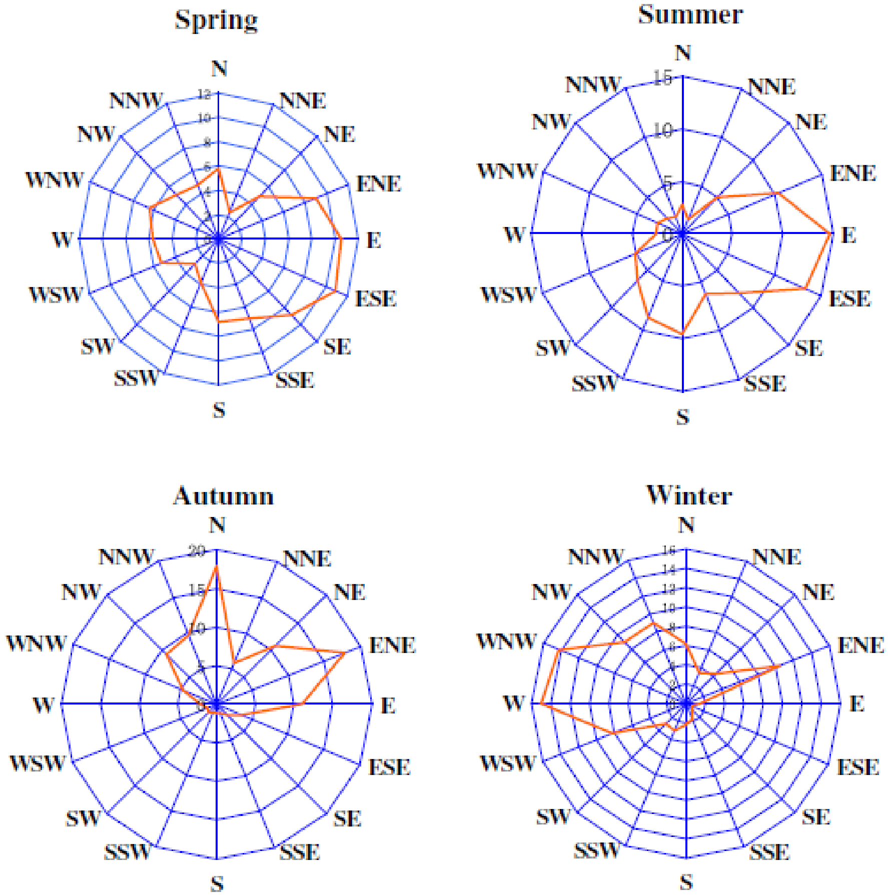


Fig. 2. The prevailing winds during different seasons in Shanghai.

Wind Data

- There are winds from different directions over the course of the year.
- This is helpful since now there are sources that are upwind and downwind at different times
- This variation provides a stronger basis for the PMF analysis.

PMF Details

- Using PMF, users need to choose a number of factors (p).
- The value of p is chosen based on several parameters, including:
  - the normalized sum of error squares in individual VOC concentrations (Q-value),
  - the normalized residual distributions for the individual VOC compounds, and
  - the physical interpretability of the derived source profiles

PMF Details

- Uncertainties need to assigned to each data value.
  - $U = \sqrt{(EF\ x\ conc)^2 + (MDL)^2}$ Conc > MDL
  - where EF represents an error fraction (EF = the percent uncertainty/100), and MDL represents the method detection limit.
- If the concentration is less than or equal to the MDL, the calculation is:
  - U = (5/6)*MDL Conc < MDL

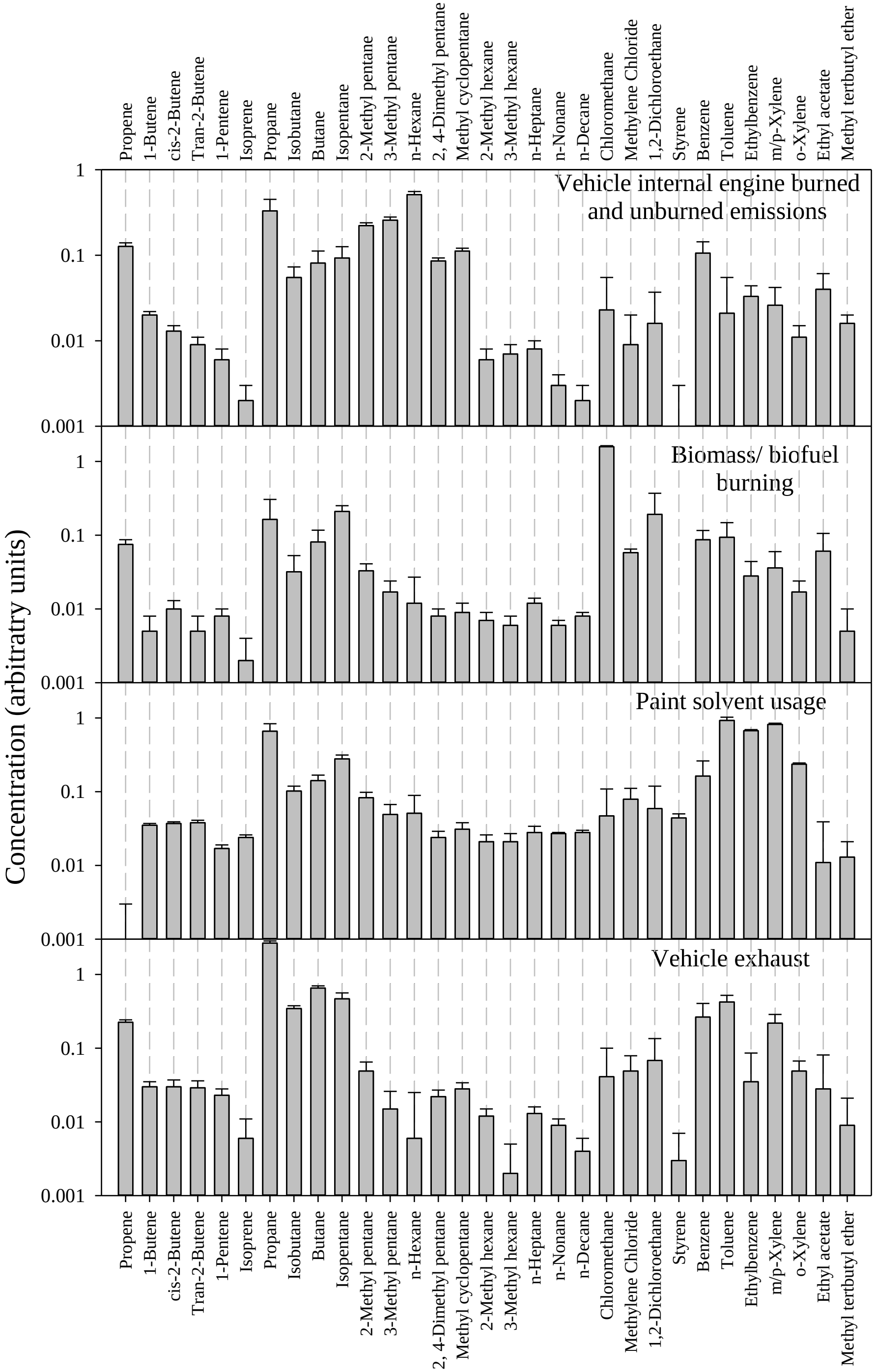
PMF Results

- Eight factors were selected according to the resulted stable Q values and interpretability of the resulting profiles.
- In order to better classify the automobile sources, three important components associated with vehicular emissions of VOCs were identified in this study, including vehicular exhaust (about 40%), fuel evaporation from tank (about 40%), and internal engine burned and unburned emissions from crankcase ventilation (about 20%).

PMF Results

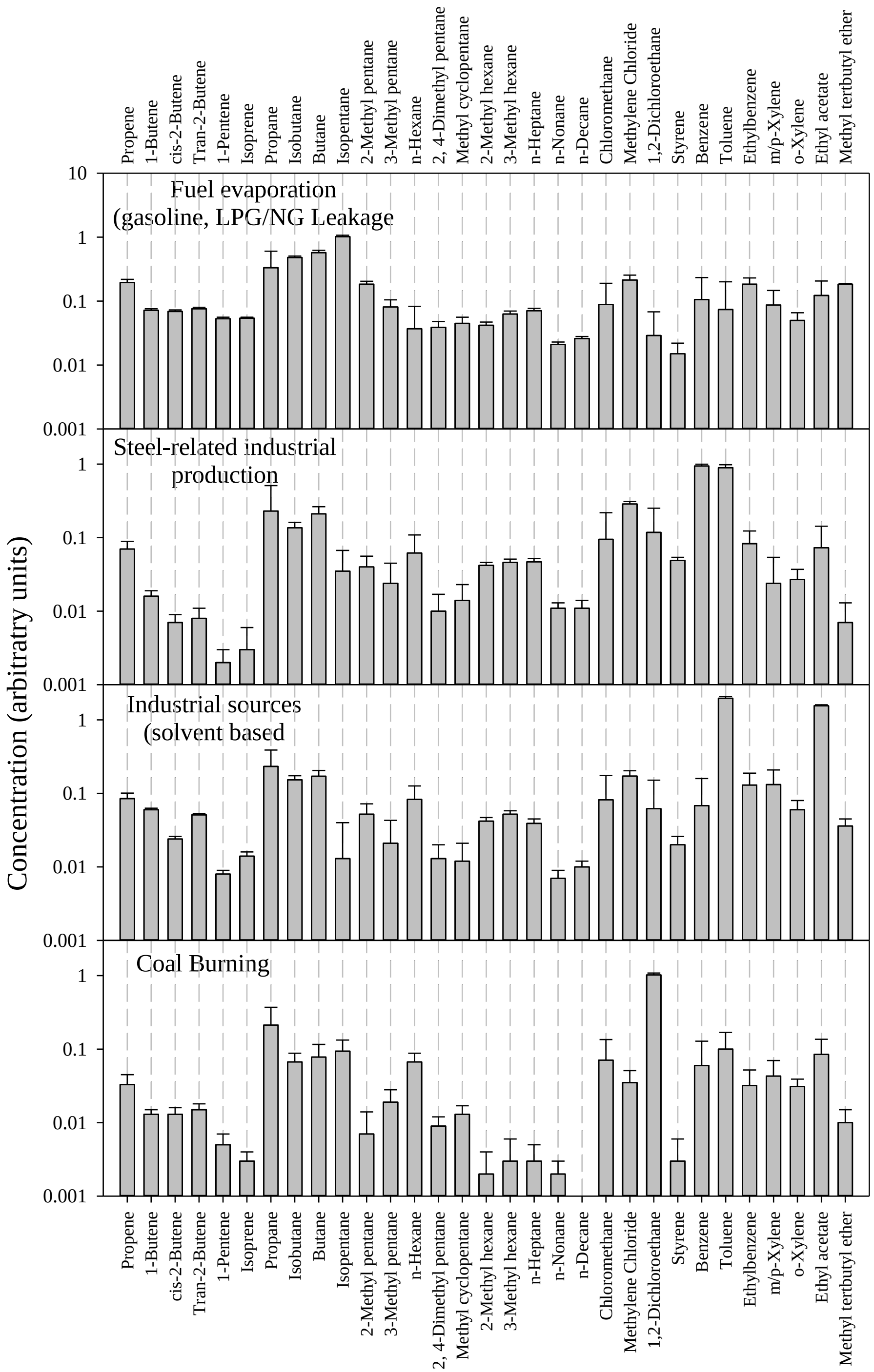
- The details of how the profiles were assigned to the various source types is described by Cai et al.
- There is no enough time now to discuss how each profile is attributed to a source type.

PMF Results



Vehicle internal engine burned and unburned emissions
Biomass/ biofuel burning
Paint solvent usage
Vehicle exhaust
Concentration (arbitratry units)
1
0.1
0.01
0.001
Propene
1-Butene
cis-2-Butene
Tran-2-Butene
1-Pentene
Isoprene
Propane
Isobutane
Butane
Isopentane
2-Methyl pentane
3-Methyl pentane
n-Hexane
2, 4-Dimethyl pentane
Methyl cyclopentane
2-Methyl hexane
3-Methyl hexane
n-Heptane
n-Nonane
n-Decane
Chloromethane
Methylene Chloride
1,2-Dichloroethane
Styrene
Benzene
Toluene
Ethylbenzene
m/p-Xylene
o-Xylene
Ethyl acetate
Methyl tertbutyl ether

PMF Results



Fuel evaporation (gasoline, LPG/NG Leakage
Steel-related industrial production
Industrial sources (solvent based
Coal Burning
Concentration (arbitratry units)
10
1
0.1
0.01
0.001
Propene
1-Butene
cis-2-Butene
Tran-2-Butene
1-Pentene
Isoprene
Propane
Isobutane
Butane
Isopentane
2-Methyl pentane
3-Methyl pentane
n-Hexane
2, 4-Dimethyl pentane
Methyl cyclopentane
2-Methyl hexane
3-Methyl hexane
n-Heptane
n-Nonane
n-Decane
Chloromethane
Methylene Chloride
1,2-Dichloroethane
Styrene
Benzene
Toluene
Ethylbenzene
m/p-Xylene
o-Xylene
Ethyl acetate
Methyl tertbutyl ether

PMF Results

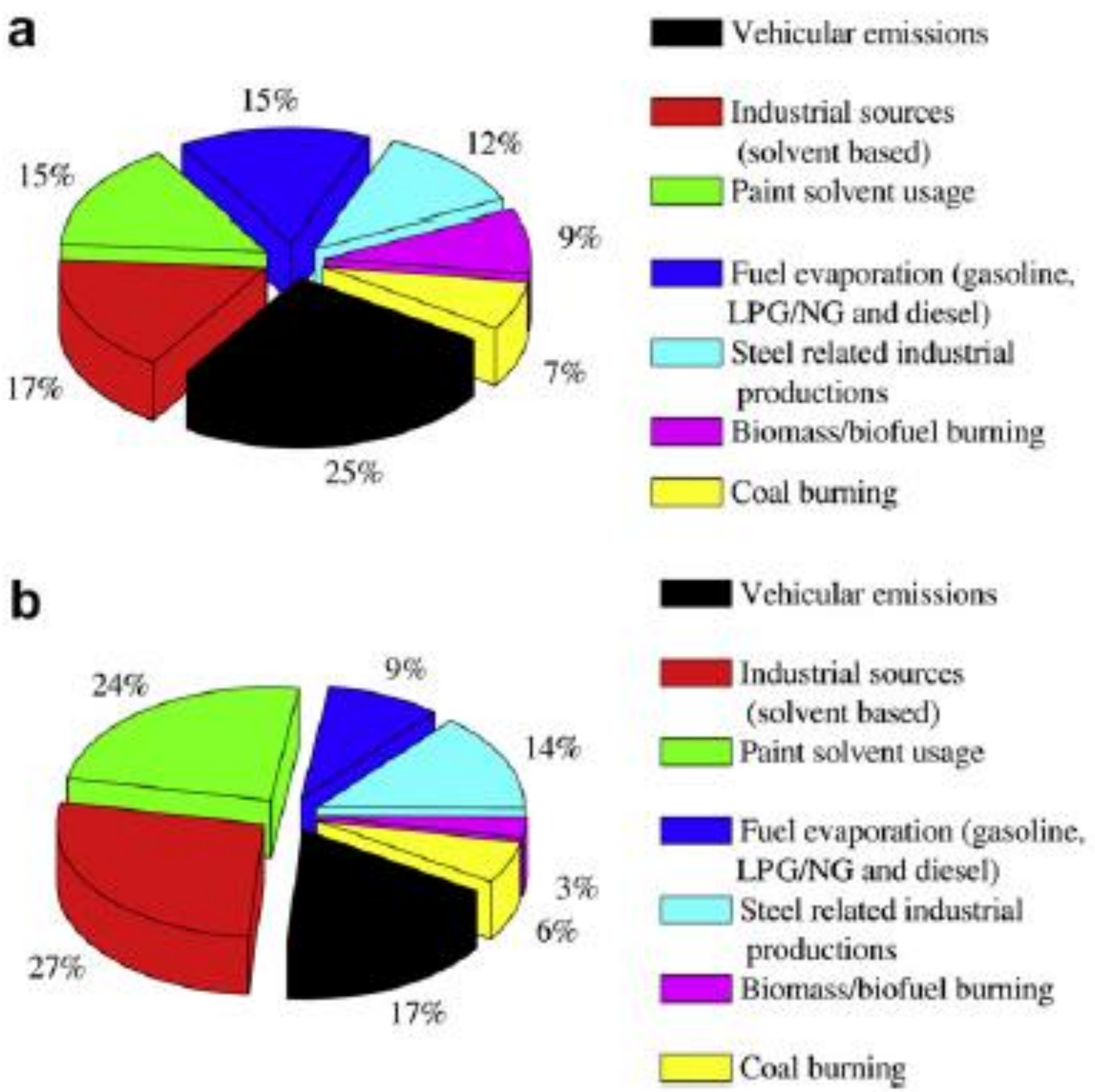


Fig. 6. a, Individual contributions of VOC sources to the measured VOC concentrations. b, Same to a, except for ozone formation potential.

Additional Methods

- With the higher time resolved data available from an auto-GC system, it is possible to use other methods to identify and apportion the VOCs to their sources.
- An example is the use of non-parametric regression by Henry et al. (Atmospheric Environment 36 (2002) 2237–2244) to identify several major sources of VOCs in Houston, TX.

Non-Parametric Regression

- This approach combines the concentration data for any given compound with the wind direction during the hour during which the concentration was measured.

Non-Parametric Regression

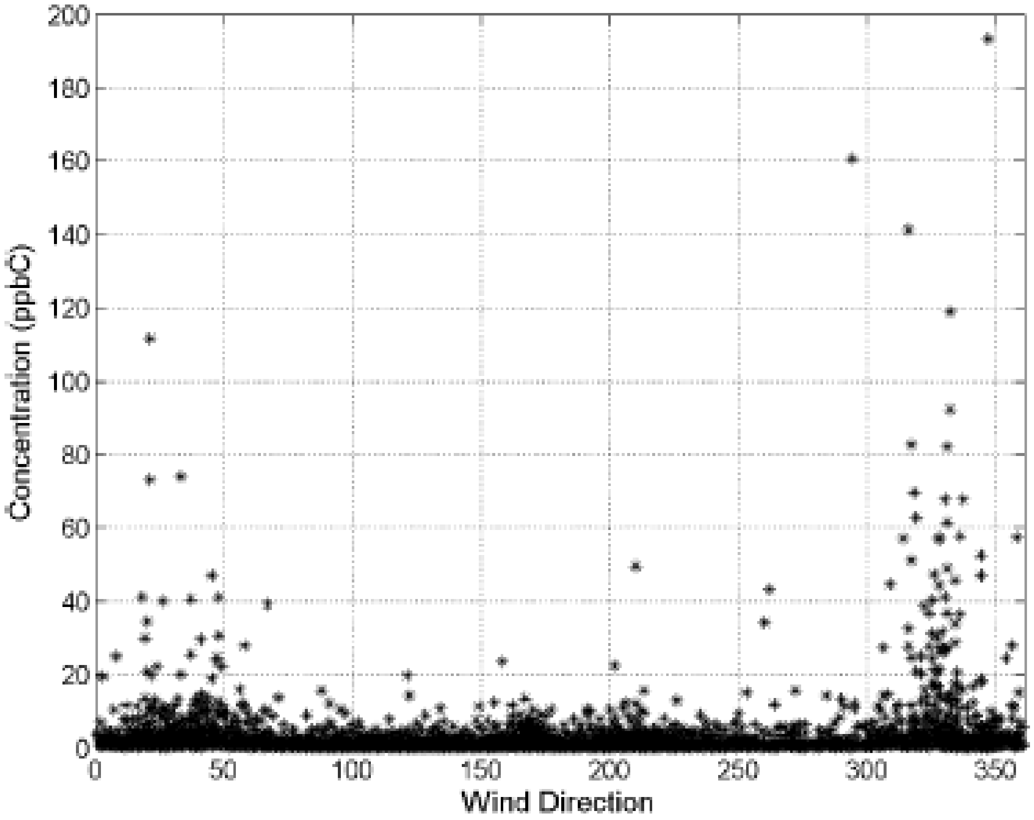


Fig. 1. Hourly cyclohexane measured at Deer Park during 1997 versus the azimuth of the wind direction.

Nonparametric regression (NPR)

- Analyzing source contribution vs wind direction.
- A regression model without parameters since it estimates expected value of concentration given wind direction.
- The average concentration over a sliding window of width *Δθ* centered at *θ*

$$\bar{C}(\theta, \Delta\theta) = \frac{\sum_{i=1}^{n} K((\theta - W_i)/\Delta\theta)\, C_i}{\sum_{i=1}^{n} K((\theta - W_i)/\Delta\theta)}$$

W_i: measured wind direction
C_i: measured concentration for the *i*th sample
n: total number of samples

- To give different weights to the measurements, a Gaussian kernel function, *K(x)*, is used and defined as

$$K(x) = \frac{1}{\sqrt{2\pi}} \exp(-0.5x^2)$$

Nonparametric regression (NPR)

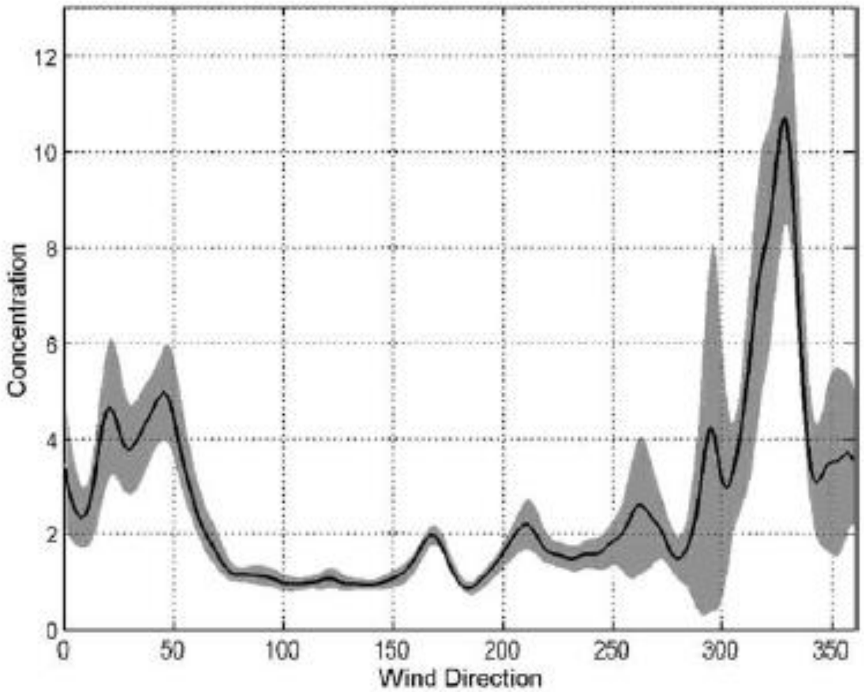


Fig. 4. Nonparametric regression of cyclohexane versus wind direction using a Gaussian kernel with a 10° FWHM. Data with wind speed < 1 mile/h are excluded. The gray region is the 95% confidence interval.

Nonparametric regression (NPR)

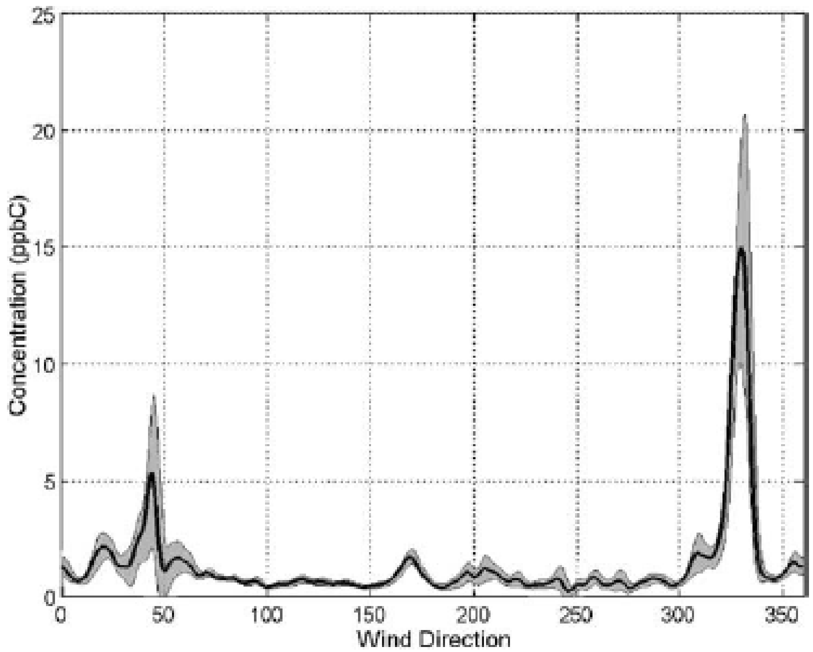


Fig. 6. Nonparametric regression of cyclohexane at Deer Park using a Gaussian kernel with a FWHM of 5. Data are restricted to periods with wind speed >6 miles/h (about 1 h travel time from the largest source to the site). The gray region is the 95% confidence interval.

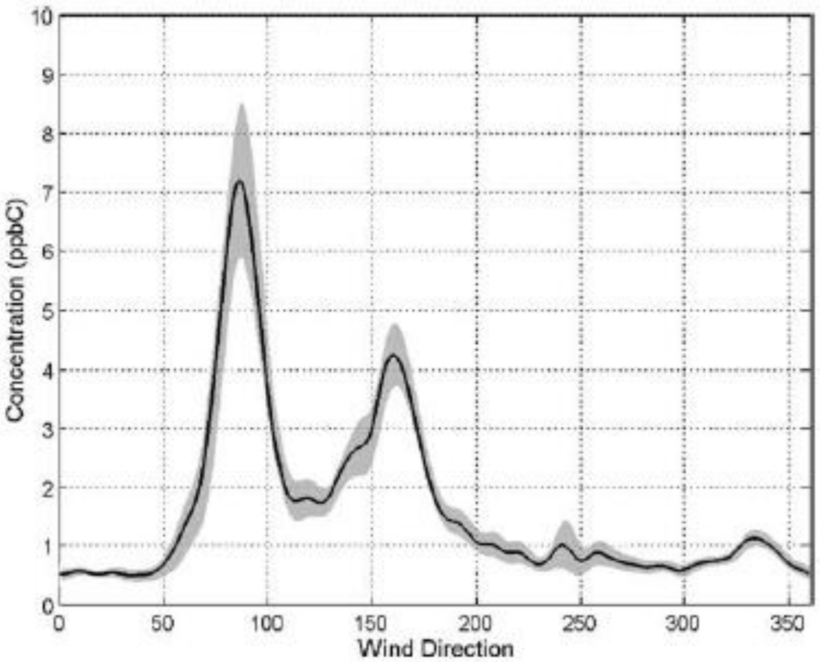


Fig. 7. Nonparametric regression of cyclohexane at Clinton Drive using a Gaussian kernel with a FWHM of 10. Data are restricted to periods with wind speed >5 miles/h (about 1 h travel time from the largest source to the site). The gray region is the 95% confidence interval.

Nonparametric regression (NPR)

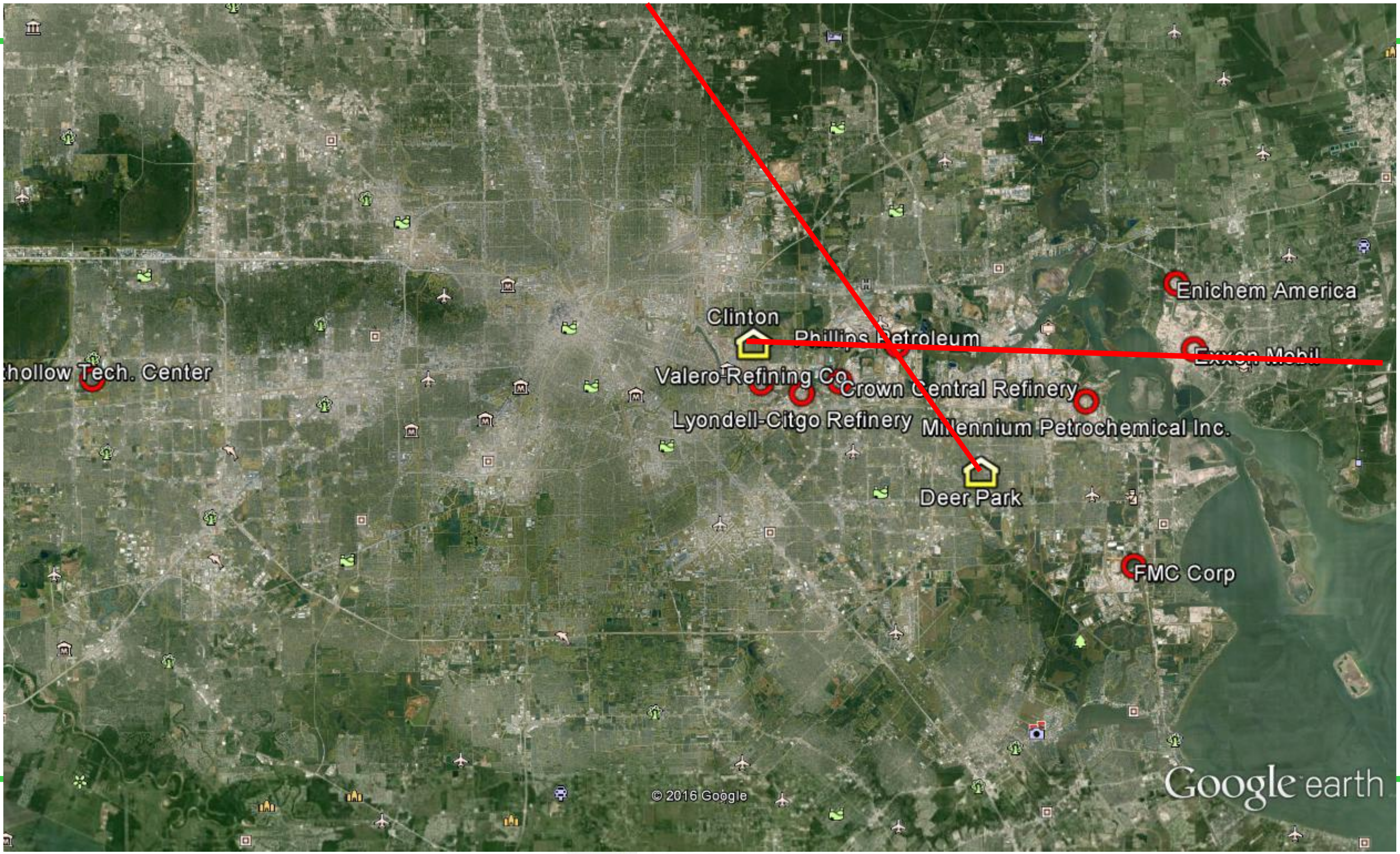
Table 1
Emissions of cyclohexane for 1997 in Harris Co., TX

Facility name	Release type	Total release (lbs/year)	Percent of total	Latitude	Longitude	Accuracy (m)	Deer Park		Clinton Drive	
							Azimuth	Distance (km)	Azimuth	Distance (km)
Phillips Petroleum Co.	STACK	167000	58.74	29.74167	95.17556	50	330.27	9.25	83.25	7.91
Phillips Petroleum Co.	FUGITIVE	33000	11.61	29.74167	95.17556	50	330.27	9.25	83.25	7.91
Exxonmobil Baytown Refinery	STACK	15282	5.38	29.73944	95.00694	80	56.33	14.05	88.33	24.15
Exxonmobil Baytown Refinery	FUGITIVE	3777	1.33	29.73944	95.00694	80	56.33	14.05	88.33	24.15
Enichem Americas Inc.	STACK	16402	5.77	29.77194	95.01694	11000	43.24	15.65	79.44	23.56
Lyondell-Citgo Refinery	FUGITIVE	8472	2.98	29.71806	95.23000	50	298.79	11.23	123.13	3.11
Lyondell-Citgo Refinery	STACK	7509	2.64	29.71806	95.23000	50	298.79	11.23	123.13	3.11
Shell Chemical	STACK	7000	2.46							
Valero Refining Co.	STACK	6628	2.33	29.72333	95.25306	20	296.43	13.48	161.34	1.17
Valero Refining Co.	FUGITIVE	2323	0.82	29.72333	95.25306	20	296.43	13.48	161.34	1.17
Westhollow Tech. Center	STACK	6365	2.24	29.725	95.63333	11000	277.34	49.19	268.63	36.36
Millennium Petrochemical Inc.	FUGITIVE	4360	1.53	29.71389	95.06833	80	49.40	7.60	96.72	18.34
Crown Central Refinery	FUGITIVE	3594	1.26	29.72389	95.20833	50	308.00	9.84	102.60	4.81
Fmc Corp.	FUGITIVE	2576	0.91	29.6325	95.04140	80	116.11	9.33	118.25	23.65
Total emissions		284288								

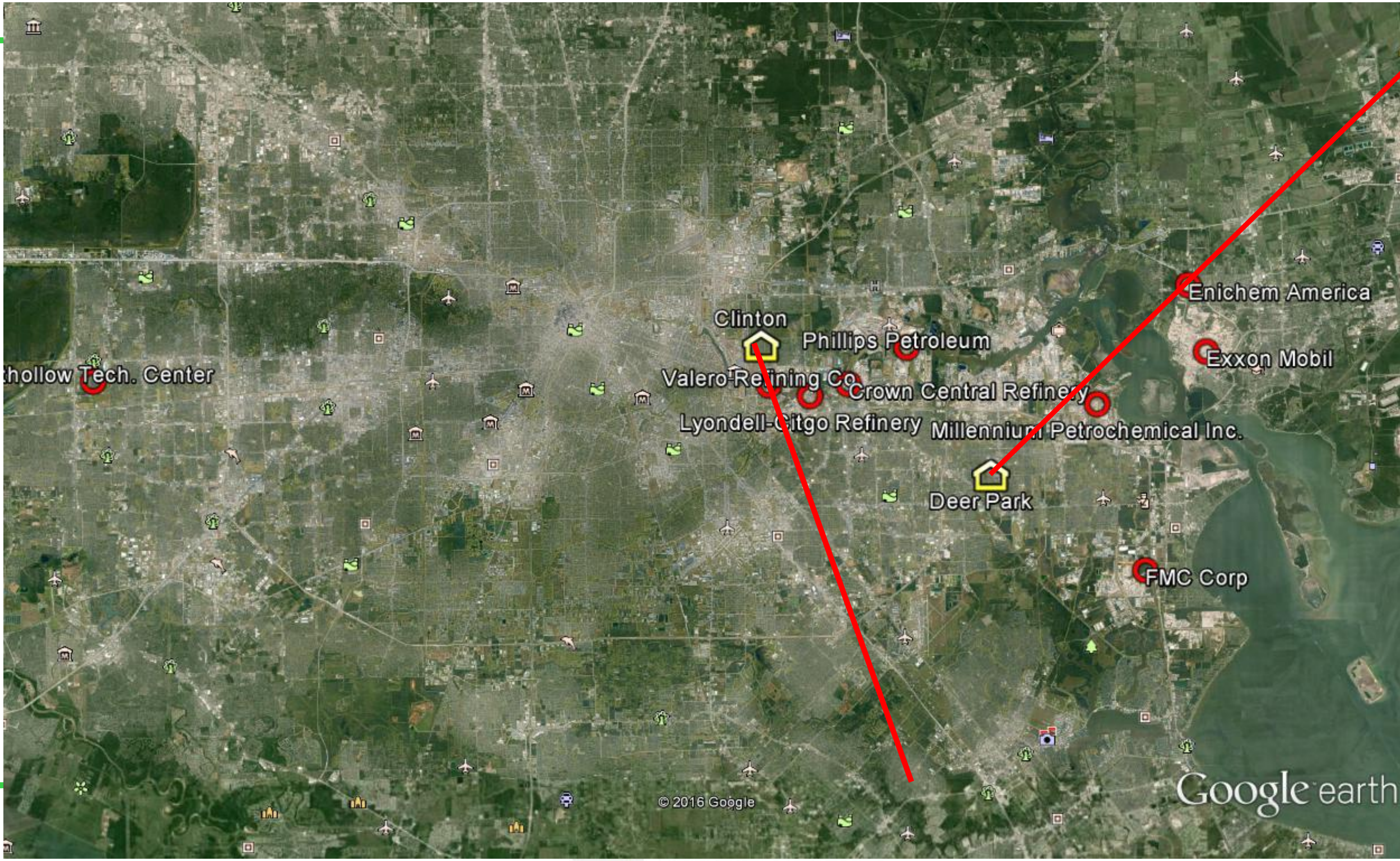
Nonparametric regression (NPR)

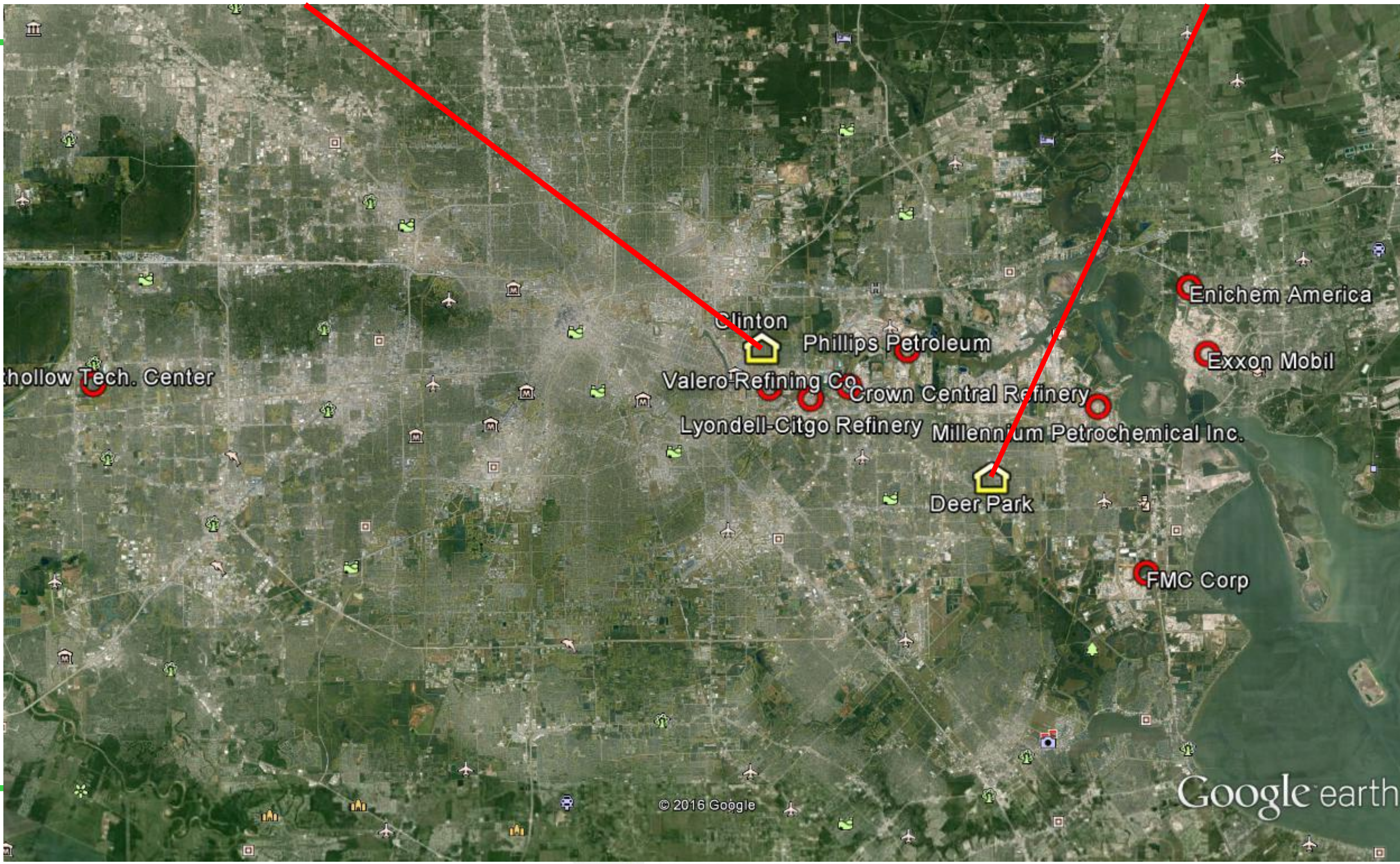
Table 2
Largest peaks in the nonparametric regression of cyclohexane on wind direction, Figs. 6 and 7

	Maximum	Deer Park		Maximum	Clinton Drive	
		Azimuth	Azimuth range		Azimuth	Azimuth range
Peak 1	14.953	329.12	325.64–332.68	7.197	86.43	80.56–92.76
Peak 2	5.391	43.72	40.68–46.96	4.251	160.04	153.90–166.21
Peak 3	2.197	21.60	15.51–25.01	1.147	332.63	326.37–340.20
Peak 4	1.775	168.89	165.87–171.44	1.027	240.95	235.12–248.86

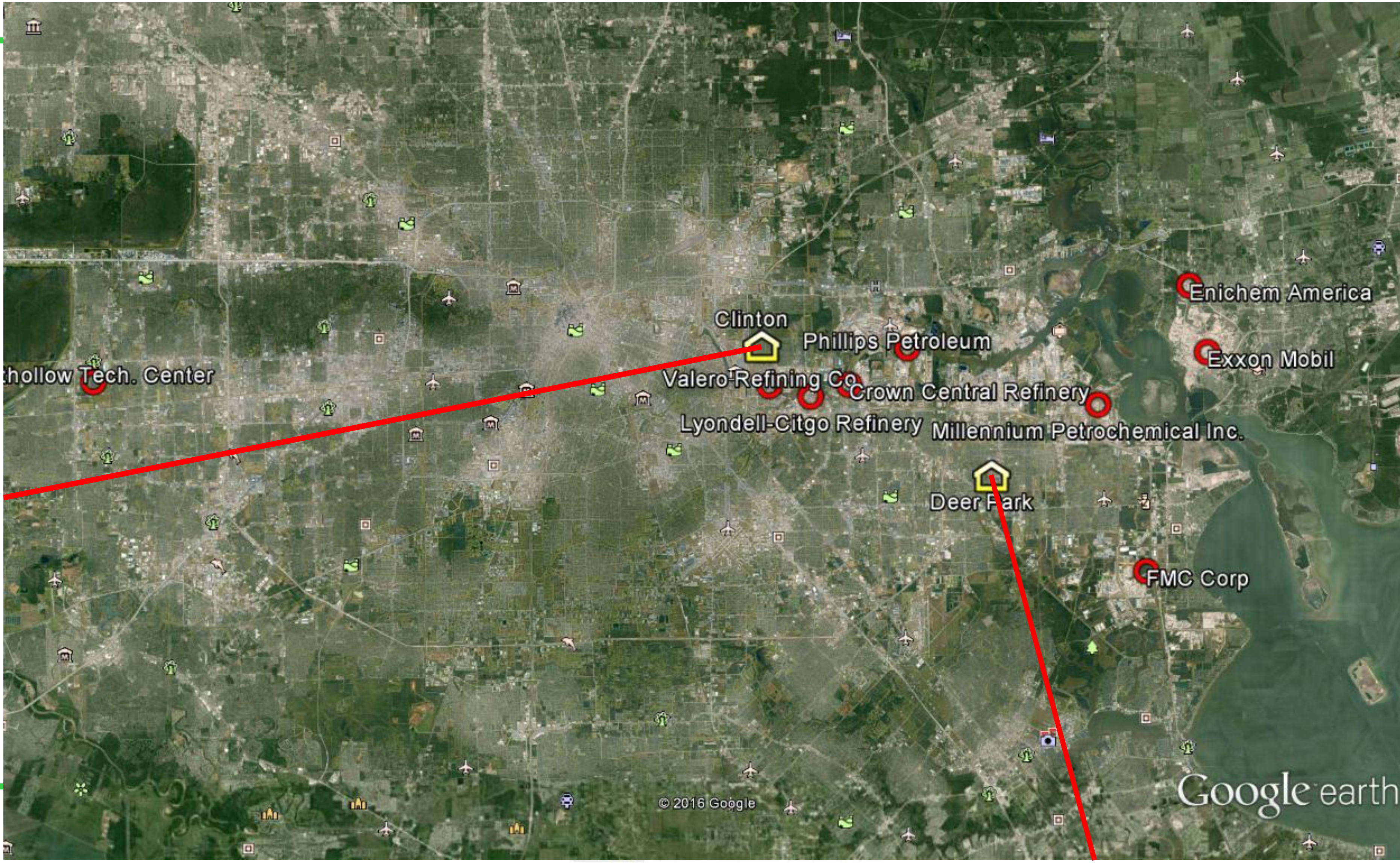


Enichem America
Clinton
Phillips Petroleum
Exxon Mobil
hollow Tech. Center
Valero Refining Co
Crown Central Refinery
Lyondell-Citgo Refinery
Millennium Petrochemical Inc.
Deer Park
FMC Corp
© 2016 Google
Google earth


Clinton
Phillips Petroleum
Valero Refining Co
Crown Central Refinery
Lyondell-Citgo Refinery
Millennium Petrochemical Inc.
Enichem America
Exxon Mobil
Deer Park
FMC Corp
hollow Tech. Center
© 2016 Google
Google earth



Clinton
Phillips Petroleum
Enichem America
Exxon Mobil
hollow Tech. Center
Valero Refining Co
Crown Central Refinery
Lyondell-Citgo Refinery
Millennium Petrochemical Inc.
Deer Park
FMC Corp
© 2016 Google
Google earth



Enichem America
Clinton
Phillips Petroleum
Exxon Mobil
thollow Tech. Center
Valero Refining Co
Crown Central Refinery
Lyondell-Citgo Refinery
Millennium Petrochemical Inc.
Deer Park
FMC Corp
© 2016 Google
Google earth

Nonparametric regression (NPR)

Table 1
Emissions of cyclohexane for 1997 in Harris Co., TX

Facility name	Release type	Total release (lbs/year)	Percent of total	Latitude	Longitude	Accuracy (m)	Deer Park		Clinton Drive	
							Azimuth	Distance (km)	Azimuth	Distance (km)
Phillips Petroleum Co.	STACK	167000	58.74	29.74167	95.17556	50	330.27	9.25	83.25	7.91
Phillips Petroleum Co.	FUGITIVE	33000	11.61	29.74167	95.17556	50	330.27	9.25	83.25	7.91
Exxonmobil Baytown Refinery	STACK	15282	5.38	29.73944	95.00694	80	56.33	14.05	88.33	24.15
Exxonmobil Baytown Refinery	FUGITIVE	3777	1.33	29.73944	95.00694	80	56.33	14.05	88.33	24.15
Enichem Americas Inc.	STACK	16402	5.77	29.77194	95.01694	11000	43.24	15.65	79.44	23.56
Lyondell-Citgo Refinery	FUGITIVE	8472	2.98	29.71806	95.23000	50	298.79	11.23	123.13	3.11
Lyondell-Citgo Refinery	STACK	7509	2.64	29.71806	95.23000	50	298.79	11.23	123.13	3.11
Shell Chemical	STACK	7000	2.46							
Valero Refining Co.	STACK	6628	2.33	29.72333	95.25306	20	296.43	13.48	161.34	1.17
Valero Refining Co.	FUGITIVE	2323	0.82	29.72333	95.25306	20	296.43	13.48	161.34	1.17
Westhollow Tech. Center	STACK	6365	2.24	29.725	95.63333	11000	277.34	49.19	268.63	36.36
Millennium Petrochemical Inc.	FUGITIVE	4360	1.53	29.71389	95.06833	80	49.40	7.60	96.72	18.34
Crown Central Refinery	FUGITIVE	3594	1.26	29.72389	95.20833	50	308.00	9.84	102.60	4.81
Fmc Corp.	FUGITIVE	2576	0.91	29.6325	95.04140	80	116.11	9.33	118.25	23.65
Total emissions		284288								

Other Related Methods

- There are other related methods that could be similarly applied.
- Simplest is Conditional Probability Function (CPF) analysis (see Kim, E., and Hopke, P. K., 2004. Comparison between conditional probability function and nonparametric regression for fine particle source directions. *Atmospheric Environ.*, **38**: 4667-4673.)

Other Related Methods

- Henry, R., G.A. Norris, R. Vedantham, and J.R. Turner. 2009. Environ. Sci. Technol. 43:4090–4097 introduce an extension of NPR to include both wind direction and wind speed that they call Nonparametric Wind Regression Methodology.

Other Related Methods

- Vedantham, R., G. Norris, S.G. Brown, and P. Roberts. 2012. Atmos. Pollut. Res. 3:105–111 describe Sustained Wind Incidence Method (SWIM) further extends NPR and NWR.
- However, no publically available software is currently available to perform these analyses.
- The mathematics are provided in the papers, but it would need to be programmed.

Highly Time Resolved Data

- It can be seen that having hourly data as one gets from an auto-GC has significant advantages for both types of analyses.
  - It will provide better input to PMF
  - It will permit these wind analysis approaches that will provide both apportionment and directionality of the sources.

VOC Source Apportionment in China

- There have been a number of journal papers on apportionment of VOCs.
- A list is appended to this presentation.

Thank you for your attention!

Questions?

Papers on Source Apportionment

Ambient volatile organic compounds and their effect on ozone production in Wuhan, central China By: Lyu, X. P.; Chen, N.; Guo, H.; et al. SCIENCE OF THE TOTAL ENVIRONMENT   Volume: 541   Pages: 200-209   Published: JAN 15 2016

On-road emission characteristics of VOCs from light-duty gasoline vehicles in Beijing, China By: Cao, Xinyue; Yao, Zhiliang; Shen, Xianbao; et al. ATMOSPHERIC ENVIRONMENT   Volume: 124   Pages: 146-155   Part: B   Published: JAN 2016

Process-specific emission characteristics of volatile organic compounds (VOCs) from petrochemical facilities in the Yangtze River Delta, China By: Mo, Ziwei; Shao, Min; Lu, Sihua; et al. SCIENCE OF THE TOTAL ENVIRONMENT   Volume: 533   Pages: 422-431   Published: NOV 15 2015

Characterization of VOC sources in an urban area based on PTR-MS measurements and receptor modelling By: Stojic, A.; Stojic, S. Stanisic; Sostaric, A.; et al. ENVIRONMENTAL SCIENCE AND POLLUTION RESEARCH   Volume: 22   Issue: 17   Pages: 13137-13152   Published: SEP 2015

Vehicular volatile organic compounds losses due to refueling and diurnal process in China: 2010-2050 By: Yang, Xiaofan; Liu, Huan; Cue, Hongyang; et al. JOURNAL OF ENVIRONMENTAL SCIENCES   Volume: 33   Pages: 88-96   Published: JUL 1 2015

Emission and profile characteristic of volatile organic compounds emitted from coke production, iron smelt, heating station and power plant in Liaoning Province, China By: Shi, Jianwu; Deng, Hao; Bai, Zhipeng; et al. SCIENCE OF THE TOTAL ENVIRONMENT   Volume: 515   Pages: 101-108   Published: MAY 15 2015

Papers on Source Apportionment

Characterization and source apportionment of volatile organic compounds in urban and suburban Tianjin, China By: Han Meng; Lu Xueqiang; Zhao Chunsheng; et al. ADVANCES IN ATMOSPHERIC SCIENCES Volume: 32 Issue: 3 Pages: 439-444 Published: MAR 2015

Characterization of ambient volatile organic compounds and their sources in Beijing, before, during, and after Asia-Pacific Economic Cooperation China 2014 By: Li, J.; Xie, S. D.; Zeng, L. M.; et al. ATMOSPHERIC CHEMISTRY AND PHYSICS Volume: 15 Issue: 14 Pages: 7945-7959 Published: 2015

Do vehicular emissions dominate the source of C6-C8 aromatics in the megacity Shanghai of eastern China? By: Wang, Hongli; Wang, Qian; Chen, Jianmin; et al. JOURNAL OF ENVIRONMENTAL SCIENCES-CHINA Volume: 27 Pages: 290-297 Published: JAN 1 2015

Sources of C-2-C-4 alkenes, the most important ozone nonmethane hydrocarbon precursors in the Pearl River Delta region By: Zhang, Yanli; Wang, Xinming; Zhang, Zhou; et al. SCIENCE OF THE TOTAL ENVIRONMENT Volume: 502 Pages: 236-245 Published: JAN 1 2015

Characteristics and source apportionment of VOCs measured in an industrial area of Nanjing, Yangtze River Delta, China By: An, Junlin; Zhu, Bin; Wang, Honglei; et al. ATMOSPHERIC ENVIRONMENT Volume: 97 Special Issue: SI Pages: 206-214 Published: NOV 2014

Source apportionment of VOCs in a suburb of Nanjing, China, in autumn and winter By: Xia, Li; Cai, Changjie; Zhu, Bin; et al. JOURNAL OF ATMOSPHERIC CHEMISTRY Volume: 71 Issue: 3 Pages: 175-193 Published: SEP 2014

The characteristics, seasonal variation and source apportionment of VOCs at Gongga Mountain, China By: Zhang, Junke; Sun, Yang; Wu, Fangkun; et al. ATMOSPHERIC ENVIRONMENT Volume: 88 Pages: 297-305 Published: MAY 201

Papers on Source Apportionment

Contribution of VOC sources to photochemical ozone formation and its control policy implication in Hong Kong By: Ling, Z. H.; Guo, H. ENVIRONMENTAL SCIENCE & POLICY Volume: 38 Pages: 180-191 Published: APR 2014

Source Profiles and Chemical Reactivity of Volatile Organic Compounds from Solvent Use in Shanghai, China By: Wang, Hongli; Qiao, Yuezhen; Chen, Changhong; et al. AEROSOL AND AIR QUALITY RESEARCH Volume: 14 Issue: 1 Pages: 301-310 Published: FEB 2014

A temporally and spatially resolved validation of emission inventories by measurements of ambient volatile organic compounds in Beijing, China By: Wang, M.; Shao, M.; Chen, W.; et al. ATMOSPHERIC CHEMISTRY AND PHYSICS Volume: 14 Issue: 12 Pages: 5871-5891 Published: 2014

Species profiles and normalized reactivity of volatile organic compounds from gasoline evaporation in China By: Zhang, Yanli; Wang, Xinming; Zhang, Zhou; et al. ATMOSPHERIC ENVIRONMENT Volume: 79 Pages: 110-118 Published: NOV 2013

A new monitoring-simulation-source apportionment approach for investigating the vehicular emission contribution to the PM2.5 pollution in Beijing, China By: Cheng, Shuiyuan; Lang, Jianlei; Zhou, Ying; et al. ATMOSPHERIC ENVIRONMENT Volume: 79 Pages: 308-316 Published: NOV 2013

Evidence of coal combustion contribution to ambient VOCs during winter in Beijing By: Wang, Ming; Shao, Min; Lu, Si-Hua; et al. CHINESE CHEMICAL LETTERS Volume: 24 Issue: 9 Pages: 829-832 Published: SEP 2013

Papers on Source Apportionment

VOCs and OVOCs distribution and control policy implications in Pearl River Delta region, China By: Louie, Peter K. K.; Ho, Josephine W. K.; Tsang, Roy C. W.; et al. ATMOSPHERIC ENVIRONMENT Volume: 76 Special Issue: SI Pages: 125-135 Published: SEP 2013

Volatile organic compounds in the Pearl River Delta: Identification of source regions and recommendations for emission-oriented monitoring strategies By: Yuan, Zibing; Zhong, Liuju; Lau, Alexis Kai Hon; et al. ATMOSPHERIC ENVIRONMENT Volume: 76 Special Issue: SI Pages: 162-172 Published: SEP 2013

Industrial sector-based volatile organic compound (VOC) source profiles measured in manufacturing facilities in the Pearl River Delta, China By: Zheng, Junyu; Yu, Yufan; Mo, Ziwei; et al. SCIENCE OF THE TOTAL ENVIRONMENT Volume: 456 Pages: 127-136 Published: JUL 1 2013

Emission inventory of primary pollutants and chemical speciation in 2010 for the Yangtze River Delta region, China By: Fu, Xiao; Wang, Shuxiao; Zhao, Bin; et al. ATMOSPHERIC ENVIRONMENT Volume: 70 Pages: 39-50 Published: MAY 2013

Pollution characteristics of ambient volatile organic compounds (VOCs) in the southeast coastal cities of China By: Tong, Lei; Liao, Xu; Chen, Jinsheng; et al. ENVIRONMENTAL SCIENCE AND POLLUTION RESEARCH Volume: 20 Issue: 4 Pages: 2603-2615 Published: APR 2013

Relative contributions of secondary organic aerosol formation from toluene, xylenes, isoprene, and monoterpenes in Hong Kong and Guangzhou in the Pearl River Delta, China: an emission-based box modeling study By: Wang, Siyuan; Wu, Dongwei; Wang, Xin-Ming; et al. JOURNAL OF GEOPHYSICAL RESEARCH-ATMOSPHERES Volume: 118 Issue: 2 Pages: 507-519 Published: JAN 27 2013

Papers on Source Apportionment

A study on the trends of vehicular emissions in the Beijing-Tianjin-Hebei (BTH) region, China By: Lang, Jianlei; Cheng, Shuiyuan; Wei, Wei; et al. ATMOSPHERIC ENVIRONMENT Volume: 62 Pages: 605-614 Published: DEC 2012

Measurements of ambient hydrocarbons and carbonyls in the Pearl River Delta (PRD), China By: Yuan, Bin; Chen, Wentai; Shao, Min; et al. ATMOSPHERIC RESEARCH Volume: 116 Pages: 93-104 Published: OCT 15 2012

Characterizations of volatile organic compounds during high ozone episodes in Beijing, China By: An Jun-lin; Wang Yue-si; Wu Fang-kun; et al. ENVIRONMENTAL MONITORING AND ASSESSMENT Volume: 184 Issue: 4 Pages: 1879-1889 Published: APR 2012

Source apportionment of volatile organic compounds in Hong Kong homes By: Guo, H. BUILDING AND ENVIRONMENT Volume: 46 Issue: 11 Pages: 2280-2286 Published: NOV 2011

Sources of ambient volatile organic compounds and their contributions to photochemical ozone formation at a site in the Pearl River Delta, southern China By: Ling, Z. H.; Guo, H.; Cheng, H. R.; et al. ENVIRONMENTAL POLLUTION Volume: 159 Issue: 10 Pages: 2310-2319 Published: OCT 2011

Regional assessment of ambient volatile organic compounds from biopharmaceutical R&D complex By: Pan, Y.; Liu, Q.; Liu, F. F.; et al. SCIENCE OF THE TOTAL ENVIRONMENT Volume: 409 Issue: 20 Pages: 4289-4296 Published: SEP 15 2011

Papers on Source Apportionment

Characteristics and source apportionment of VOCs measured in Shanghai, China By: Cai, Changjie; Geng, Fuhai; Tie, Xuexi; et al. ATMOSPHERIC ENVIRONMENT Volume: 44 Issue: 38 Pages: 5005-5014 Published: DEC 2010

Source apportionment of ambient volatile organic compounds in Hong Kong By: Lau, Alexis Kai Hon; Yuan, Zibing; Yu, Jian Zhen; et al. SCIENCE OF THE TOTAL ENVIRONMENT Volume: 408 Issue: 19 Pages: 4138-4149 Published: SEP 1 2010

Characteristics of Ambient Volatile Organic Compounds (VOCs) Measured in Shanghai, China By: Cai, Chang-Jie; Geng, Fu-Hai; Tie, Xue-Xi; et al. SENSORS Volume: 10 Issue: 8 Pages: 7843-7862 Published: AUG 2010

Source profiles of volatile organic compounds associated with solvent use in Beijing, China By: Yuan, Bin; Shao, Min; Lu, Sihua; et al. ATMOSPHERIC ENVIRONMENT Volume: 44 Issue: 15 Pages: 1919-1926 Published: MAY 2010

Comparative study on indoor air quality in Japan and China: Characteristics of residential indoor and outdoor VOCs By: Ohura, Takeshi; Amagai, Takashi; Shen, Xueyou; et al. ATMOSPHERIC ENVIRONMENT Volume: 43 Issue: 40 Pages: 6352-6359 Published: DEC 2009

Speciated VOC Emission Inventory and Spatial Patterns of Ozone Formation Potential in the Pearl River Delta, China By: Zheng, Junyu; Shao, Min; Che, Wenwei; et al. ENVIRONMENTAL SCIENCE & TECHNOLOGY Volume: 43 Issue: 22 Pages: 8580-8586 Published: NOV 15 2009

Papers on Source Apportionment

Source analysis of volatile organic compounds by positive matrix factorization in urban and rural environments in Beijing By: Yuan, Zibing; Lau, Alexis Kai Hon; Shao, Min; et al. JOURNAL OF GEOPHYSICAL RESEARCH-ATMOSPHERES Volume: 114 Article Number: D00G15 Published: AUG 28 2009

Volatile organic compounds measured in summer in Beijing and their role in ground-level ozone formation By: Shao, Min; Lu, Sihua; Liu, Ying; et al. JOURNAL OF GEOPHYSICAL RESEARCH-ATMOSPHERES Volume: 114 Article Number: D00G06 Published: APR 4 2009

Comparison of receptor models for source apportionment of volatile organic compounds in Beijing, China By: Song, Yu; Dai, Wei; Shao, Min; et al. ENVIRONMENTAL POLLUTION Volume: 156 Issue: 1 Pages: 174-183 Published: NOV 1 2008

Source profiles of volatile organic compounds (VOCs) measured in China: Part I By: Liu, Ying; Shao, Min; Fu, Linlin; et al. ATMOSPHERIC ENVIRONMENT Volume: 42 Issue: 25 Pages: 6247-6260 Published: AUG 2008

Source apportionment of ambient volatile organic compounds in the Pearl River Delta, China: Part II By: Liu, Ying; Shao, Min; Lu, Sihua; et al. ATMOSPHERIC ENVIRONMENT Volume: 42 Issue: 25 Pages: 6261-6274 Published: AUG 2008

Source characteristics of volatile organic compounds during high ozone episodes in Hong Kong, Southern China By: Zhang, J.; Wang, T.; Chameides, W. L.; et al. ATMOSPHERIC CHEMISTRY AND PHYSICS Volume: 8 Issue: 16 Pages: 4983-4996 Published: 2008

Papers on Source Apportionment

Distributions and source apportionment of ambient volatile organic compounds in Beijing city, China By: Liu, Y; Shao, M; Zhang, J; et al. Conference: 2nd International Conference on Environmental Concerns Location: Xiamen, PEOPLES R CHINA Date: OCT 12-15, 2004 Sponsor(s): UN Environm Program; State Environm Protect Adm China; Xiamen Municipal JOURNAL OF ENVIRONMENTAL SCIENCE AND HEALTH PART A-TOXIC/HAZARDOUS SUBSTANCES & ENVIRONMENTAL ENGINEERING Volume: 40 Issue: 10 Pages: 1843-1860 Published: 2005

Source contributions to ambient VOCs and CO at a rural site in Eastern China By: Guo, H; Wang, T; Simpson, IJ; et al. ATMOSPHERIC ENVIRONMENT Volume: 38 Issue: 27 Pages: 4551-4560 Published: SEP 2004