ADVANCED RECEPTOR MODELING FOR SOURCE IDENTIFICATION AND APPORTIONMENT

Philip K. Hopke

Dept. of Chemical Engineering

Clarkson University

Clarkson University

OUTLINE

- Receptor Models
- Factor Analysis
- Positive Matrix Factorization
  - Theory and Application
- Potential Source Contribution Function
  - Theory and Application
- Advanced Factor Analysis Models
- Summary

BUT First!

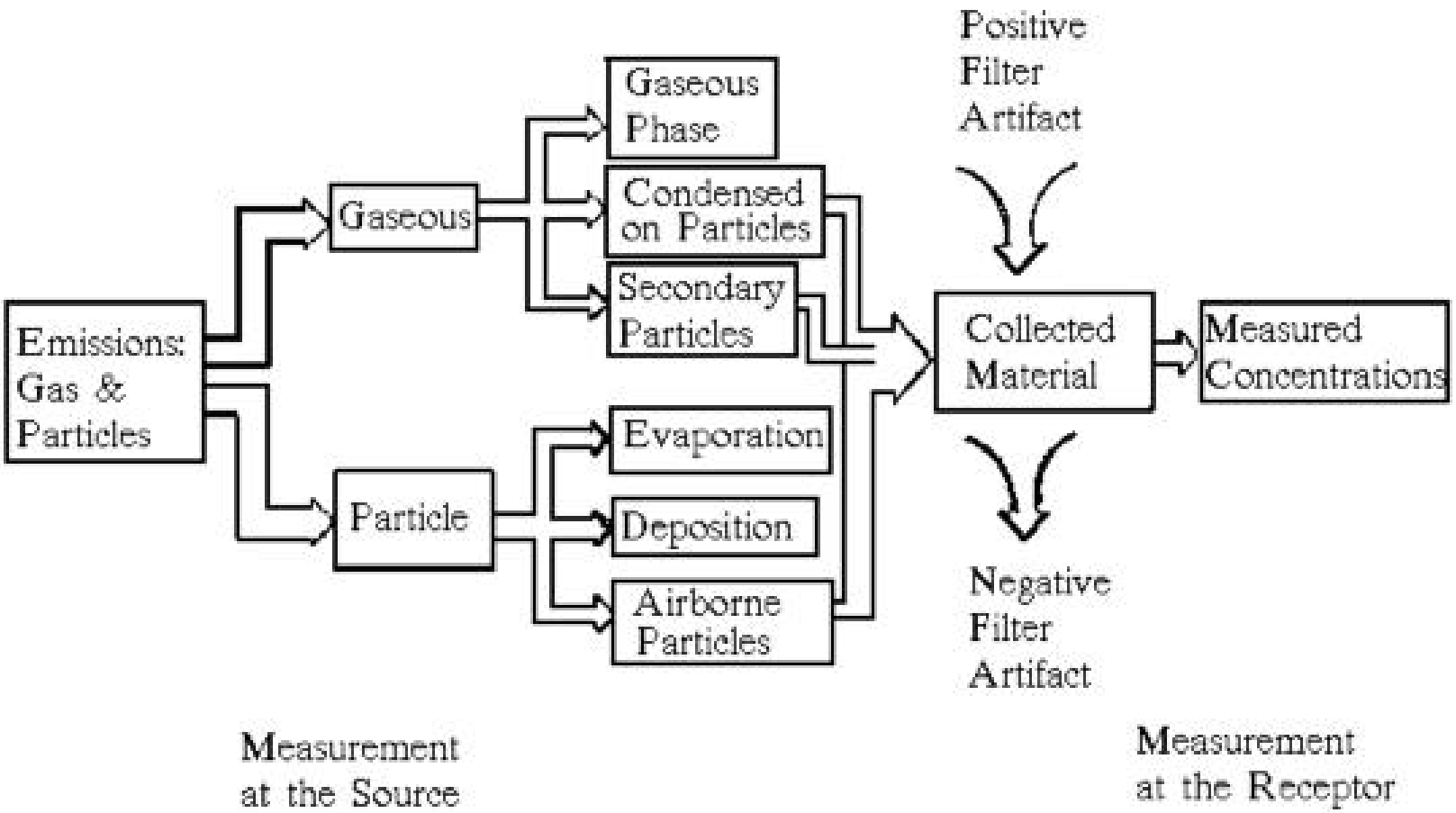
- We need to answer your first burning question:
- Where is Potsdam, NY?

BUT First!

MAPQUEST
0
100mi
100km
Chibougamau
Kapuskasing
Baie-Comeau
Timmins
Rouyn-Noranda
Val-D'or
Chicoutimi
Rimouski
Edmundston
Québec
Sault Ste. Marie
Sudbury
North Bay
Trois-Rivières
Fredericton
Ottawa
Montréal
Huntsville
Sherbrooke
St John
Cornwall
Owen Sound
Barrie
Peterborough
Montpelier
Augusta
Toronto
Yarmouth
Concord
Lansing
London
Buffalo
Syracuse
Albany
Portsmouth
Detroit
Boston
Erie
Hartford
Toledo
Cleveland
New Haven
Providence
Akron
New York
Pittsburgh
Harrisburg
Columbus
Philadelphia
Dayton
©2000 MapQuest.com, Inc.

Receptor Modeling

Receptor models are focused on the behavior of the ambient environment at the point of impact as opposed to the source-oriented models that focus on the transport, dilution, and transformations that begin at the source and follow the pollutants to the sampling or receptor site.


Positive
Filter
Artifact
Gaseous
Phase
Gaseous
Condensed
on Particles
Secondary
Particles
Emissions:
Gas &
Particles
Collected
Material
Measured
Concentrations
Evaporation
Particle
Deposition
Airborne
Particles
Negative
Filter
Artifact
Measurement
at the Source
Measurement
at the Receptor

Receptor Modeling

PRINCIPLE OF AEROSOL MASS BALANCE

The fundamental principle of receptor modeling is that mass conservation can be assumed and a mass balance analysis can be used to identify and apportion sources of airborne particulate matter in the atmosphere.

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

MASS BALANCE

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

Mass Balance

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

MASS BALANCE

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

Mass Balance

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

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

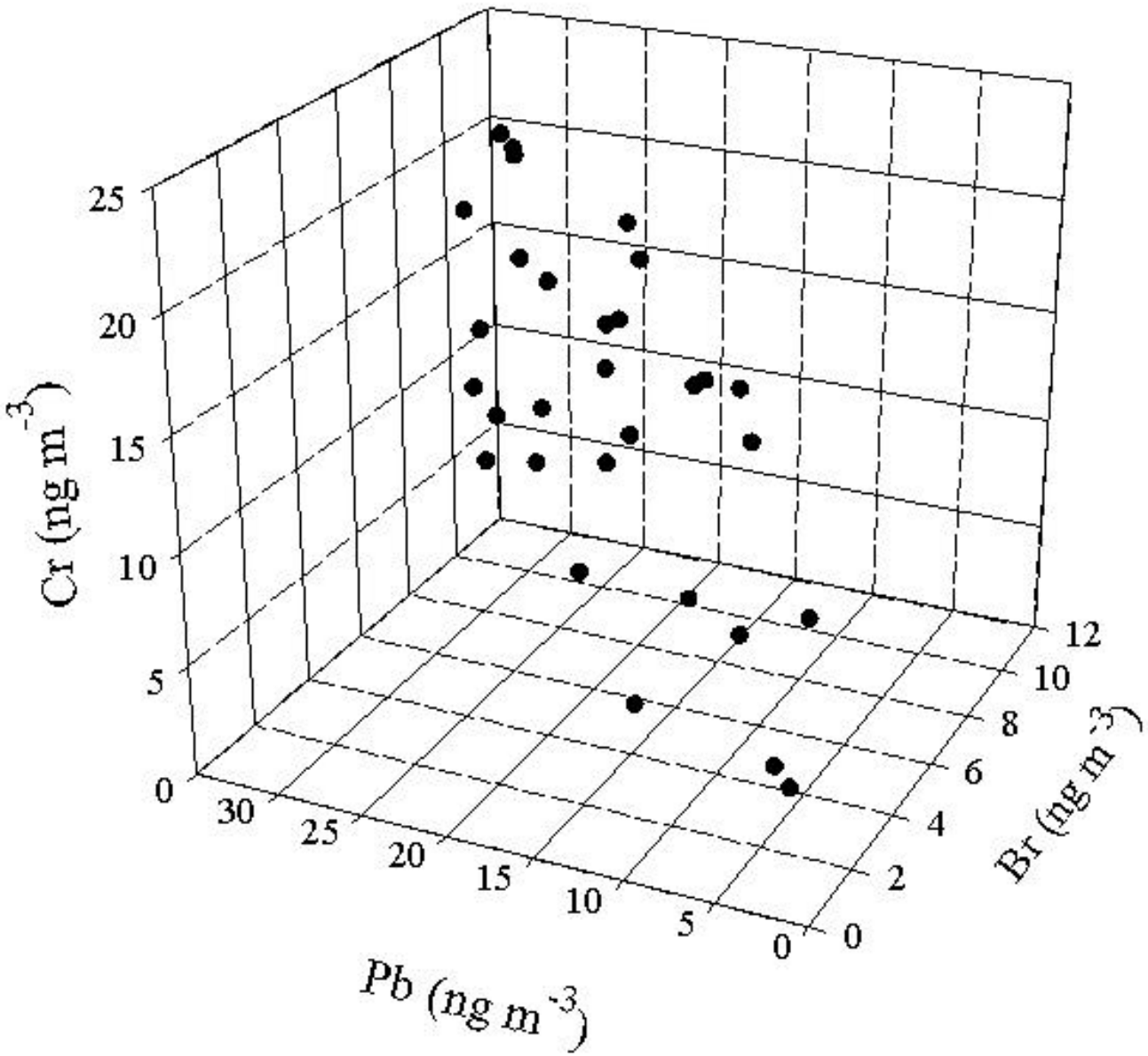
In a factor analysis, all we know are the ambient concentrations for a series of samples.

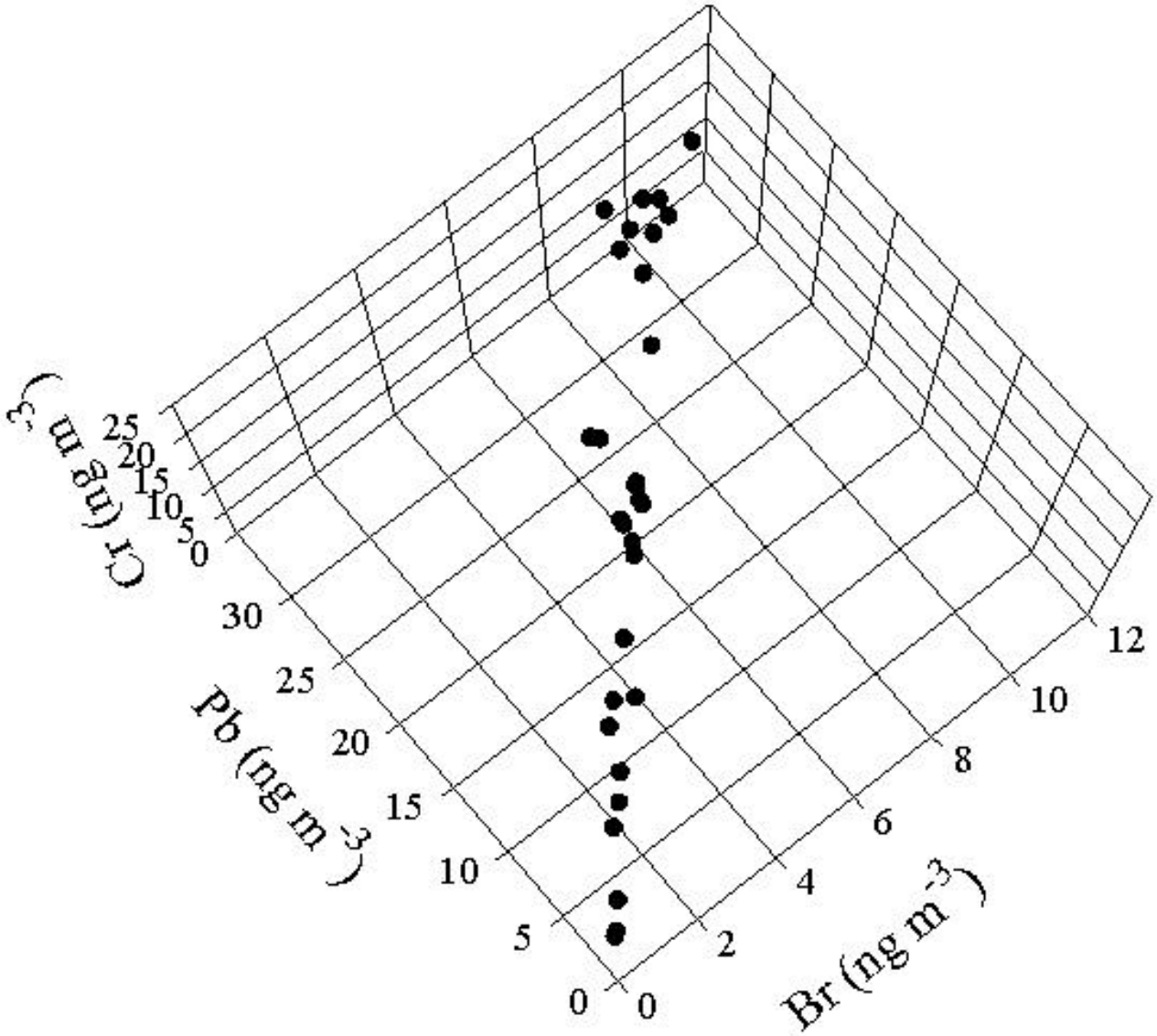
Mass Balance

The equation can be rewritten in matrix form as

$$X = GF$$

The question is then what information is available *a priori* in order to solve these equations. In general, good source profiles (F matrix) are not available and need to be derived from the data.


Cr (ng m-3)
25
20
15
10
5
0
30
25
20
15
10
5
0
Pb (ng m-3)
0
2
4
6
8
10
12
Br (ng m-3)

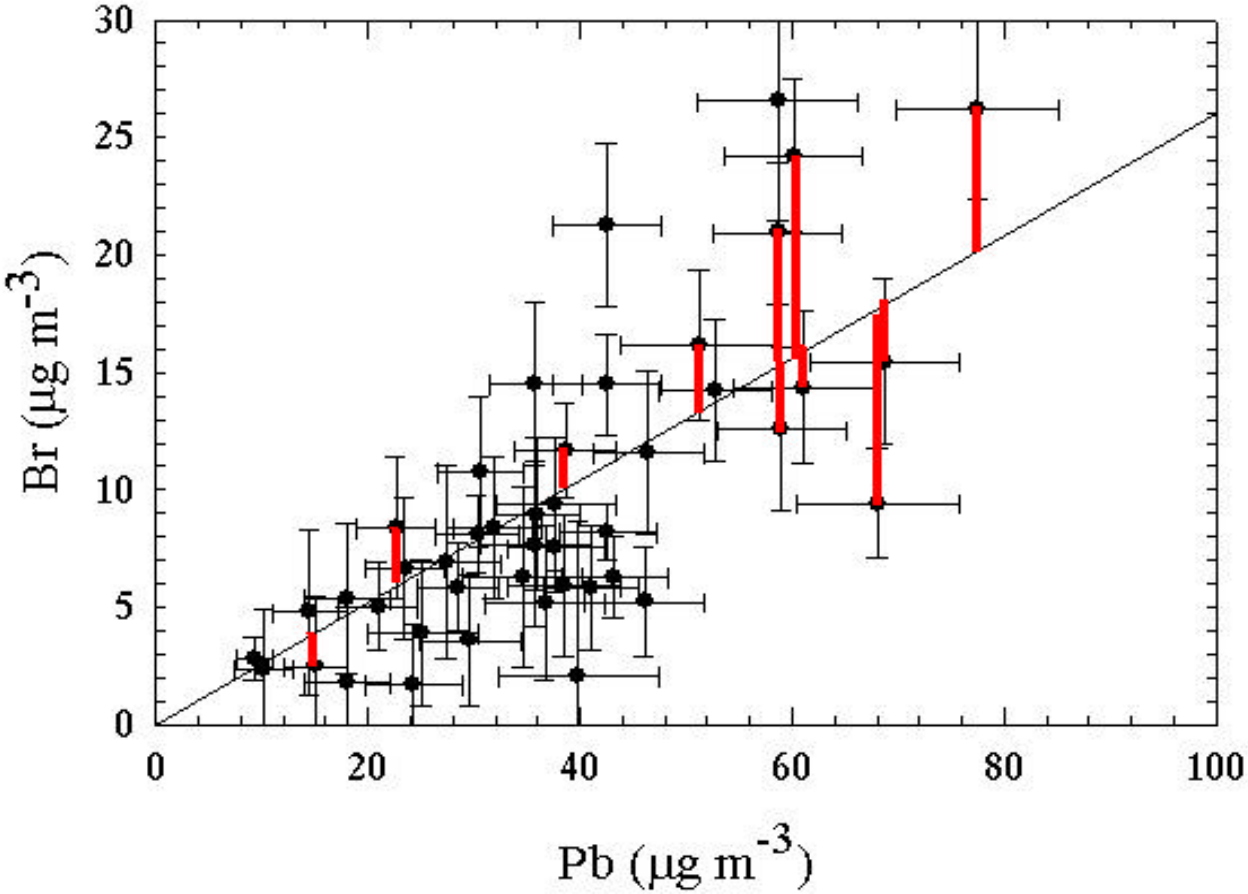

Cr (ng m-3)
25
20
15
10
5
0
Pb (ng m-3)
30
25
20
15
10
5
0
Br (ng m-3)
0
2
4
6
8
10
12

Factor Analysis

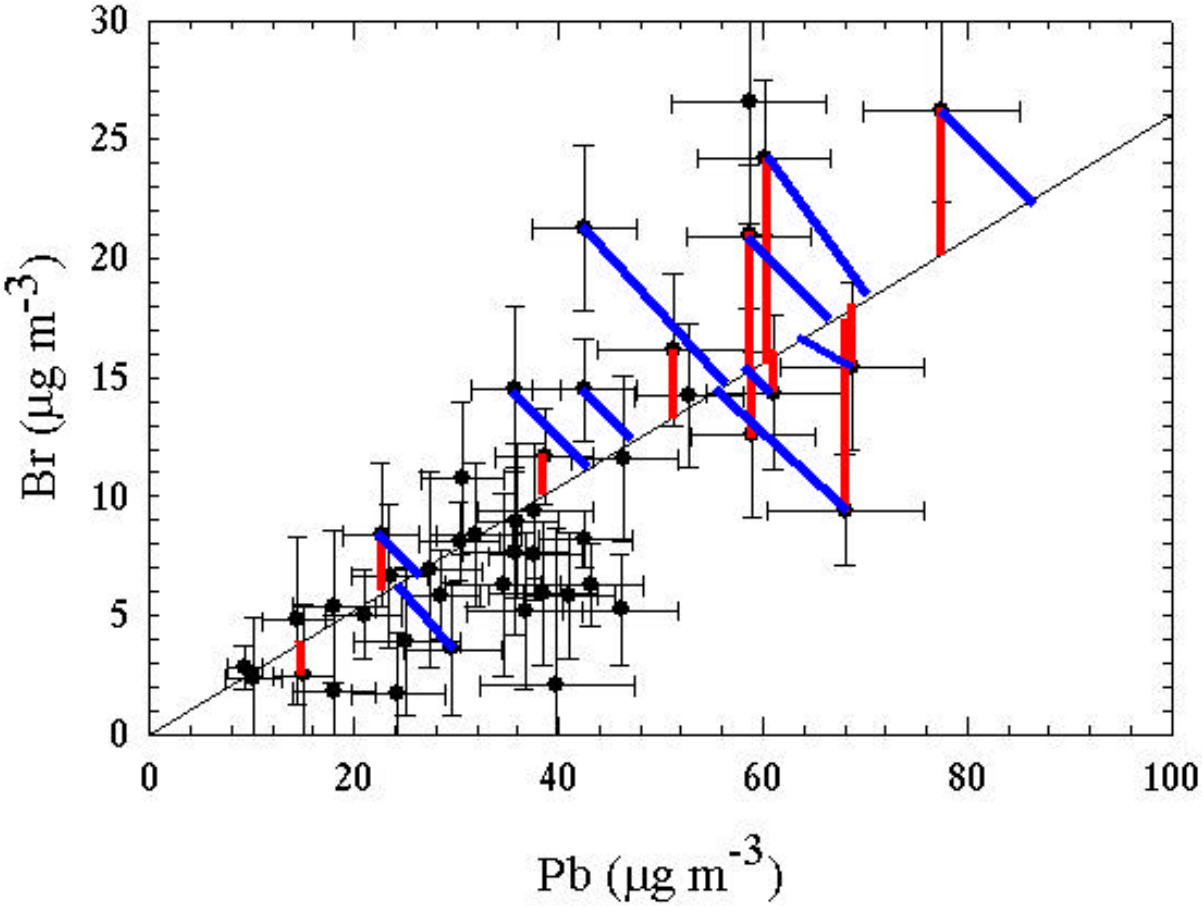
Most factor analysis has been based on an eigenvector analysis. In an eigenvector analysis, it can be shown [Lawson and Hanson, 1974; Malinowski, 1991] that the equation estimates **X** in the least-squares sense that it gives the lowest possible value for

$$\sum_{i=1}^{n}\sum_{j=1}^{m}\left(e_{ij}\right)^2 = \sum_{i=1}^{n}\sum_{j=1}^{m}\left(x_{ij} - \sum_{k=1}^{p} g_{ik} f_{kj}\right)^2$$

FACTOR ANALYSIS



FACTOR ANALYSIS



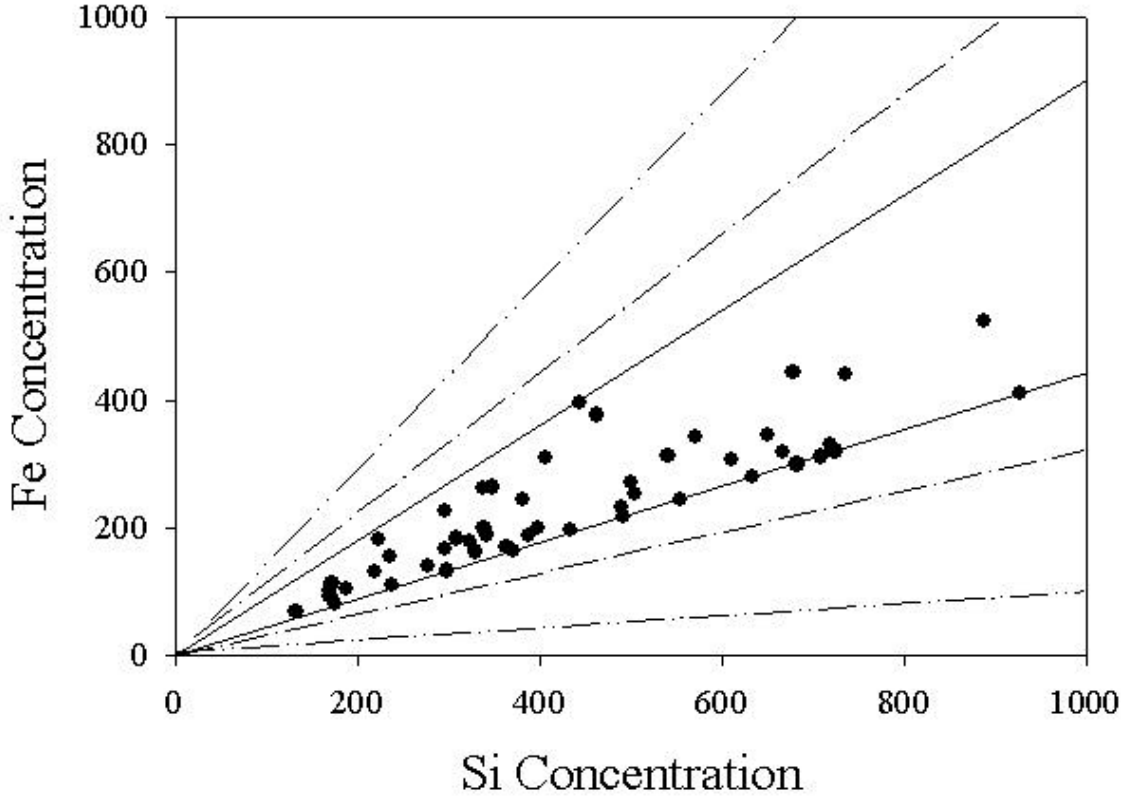
Factor Analysis

The problem can be solved, but it does not produce a **unique** solution. It is possible to include a transformation into the equation.

$$X=GTT^{-1}F$$

where T is one of the potential infinity of transformation matrices. This transformation is called a rotation and is generally included in order to produce factors that appear to be closer to physically real source profiles.

Factor Analysis



Positive Matrix Factorization

- 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

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

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

Positive Matrix Factorization

- The problem can be solved by several different programs developed by Pentti Paatero including PMF2 and ME. In PMF2, the constraints are imposed as soft constraints through a penalty function. In ME, hard constraints are imposed and the model can be much more complex.

Positive Matrix Factorization

- As an illustration of PMF2, the analysis of data from Underhill, VT will be presented.

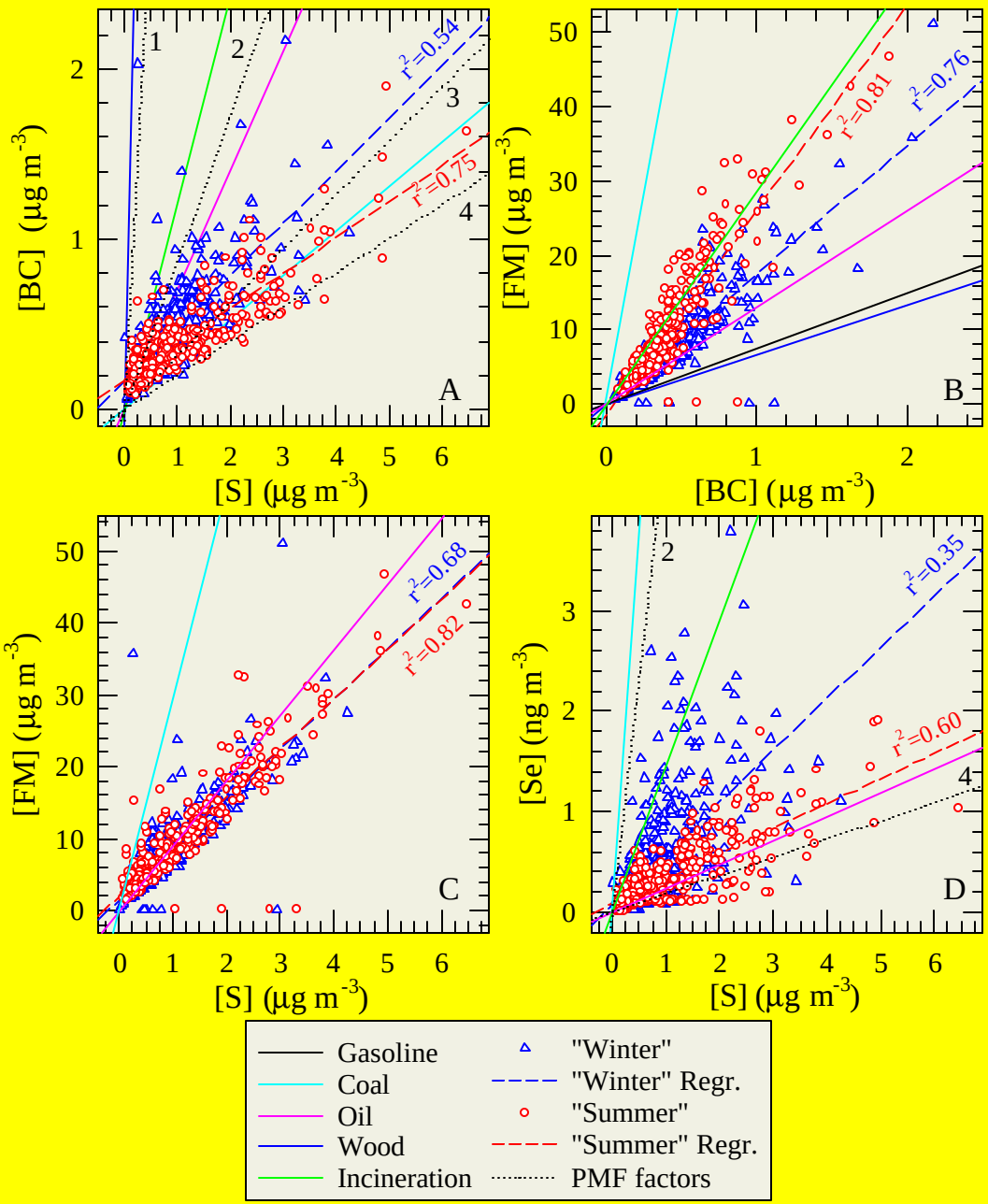
- Aerosol sampling in Underhill, Vermont (44.53 N, -72.86 W, 400 m elevation), was conducted between September 1988 and June 1995

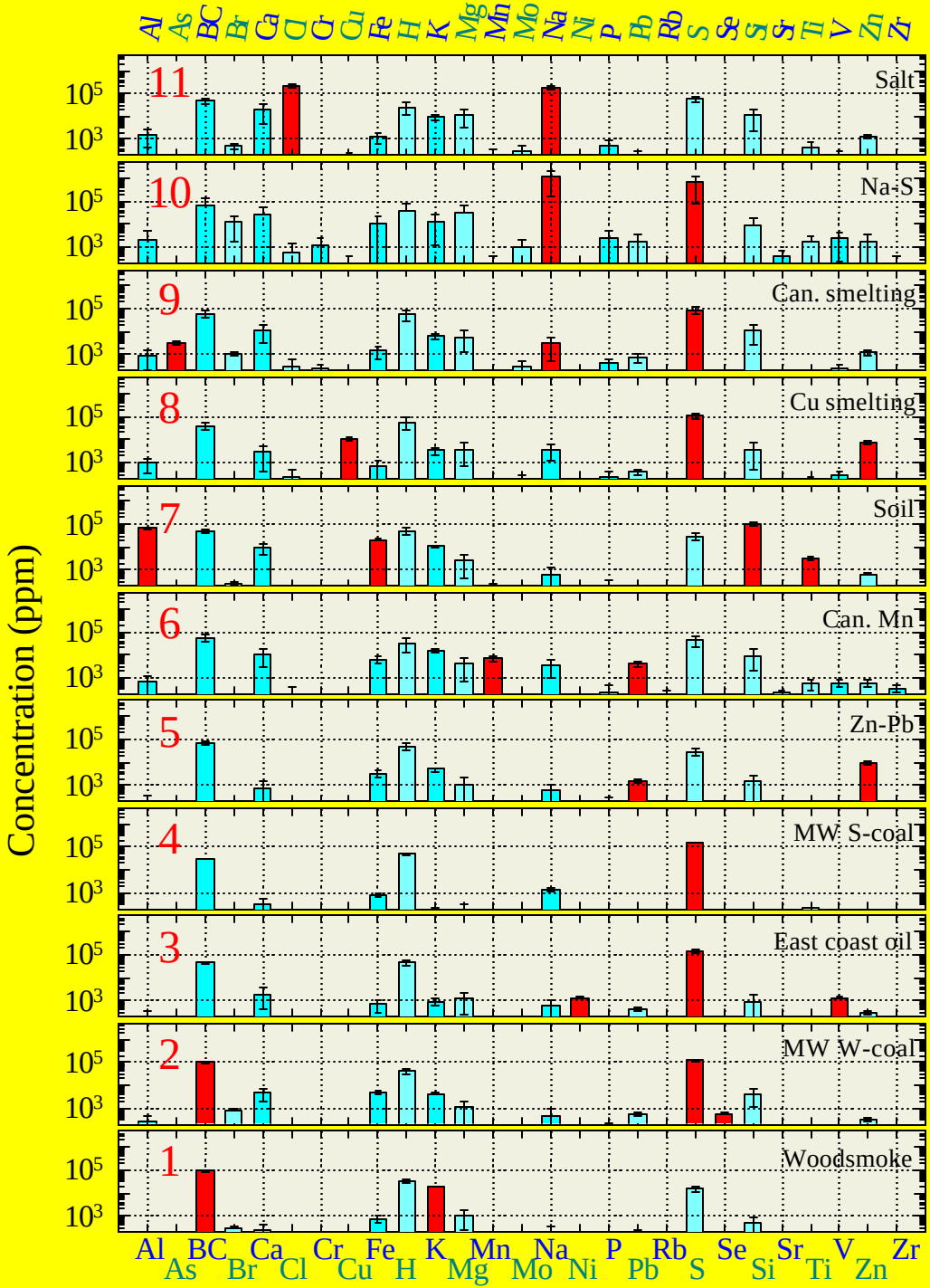
Positive Matrix Factorization

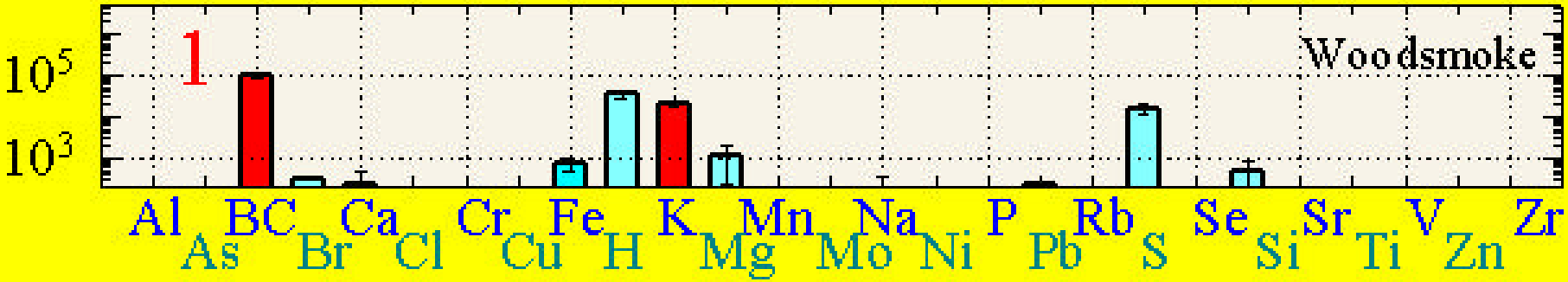
Filters were analyzed for mass (gravimetric), light absorption (B_{abs} - by laser integrating plate - LIPM), elemental hydrogen (by proton elastic scattering analysis - PESA), and elements from Na through Pb (initially by proton induced x-ray emission - PIXE, and starting June, 1992, by a combination of PIXE and x-ray fluorescence - XRF).

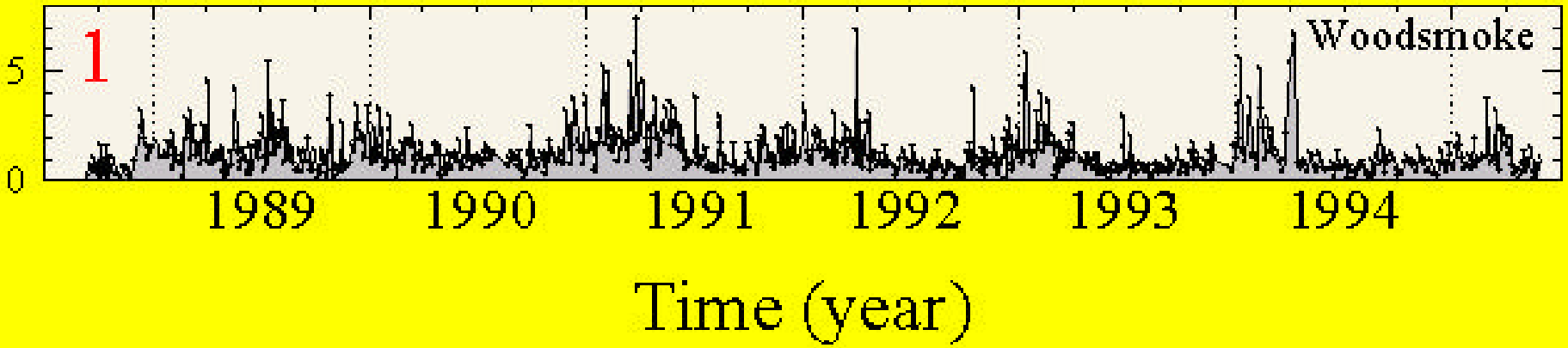
IMPROVE Data Analysis

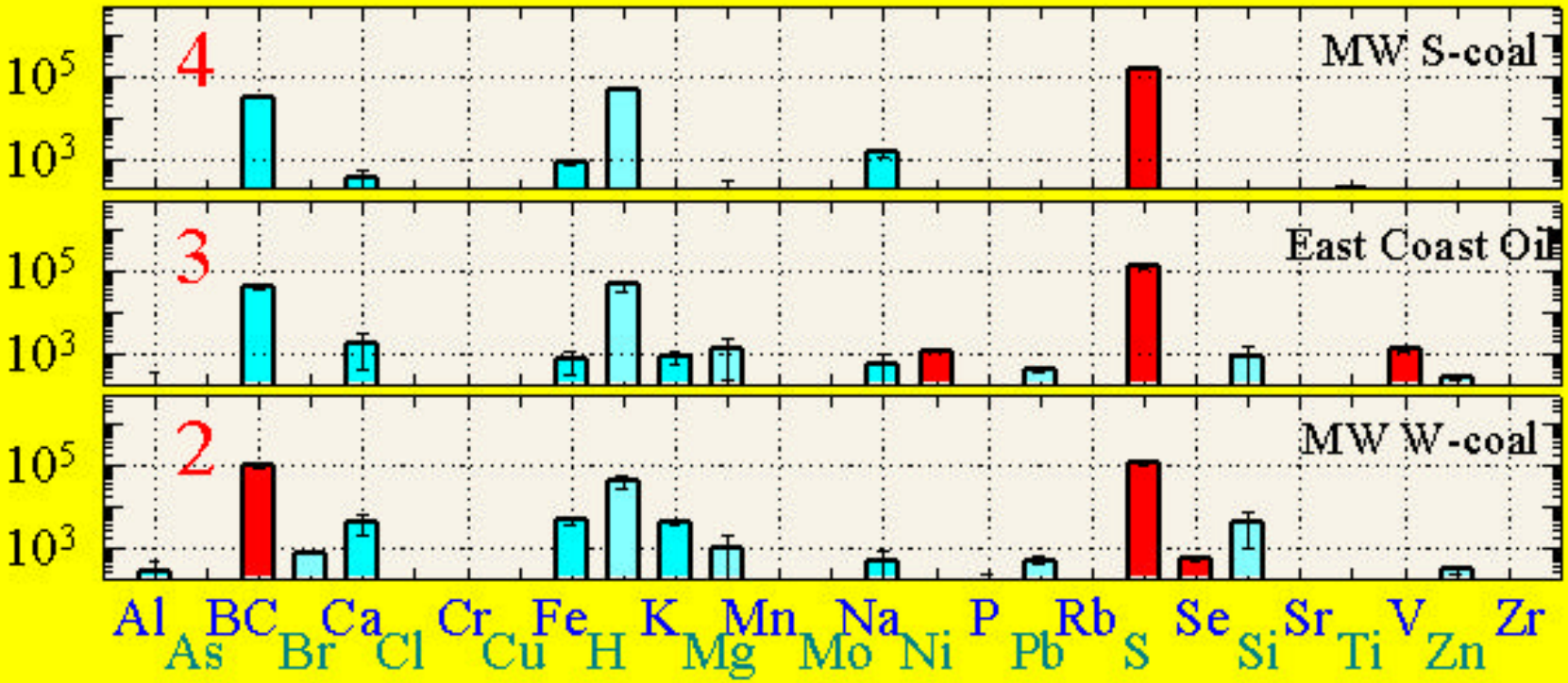
- Sources of Fine Particle Composition in the Northeastern US, X.H. Song, A.V. Polissar, and P.K. Hopke, *Atmospheric Environ.* 35:5277-5286 (2001).
- Atmospheric Aerosol over Vermont: Chemical Composition and Sources, A.V. Polissar, P.K. Hopke, and R.L. Poirot, *Environ. Sci. Technol.* 35: 4604-4621 (2001).

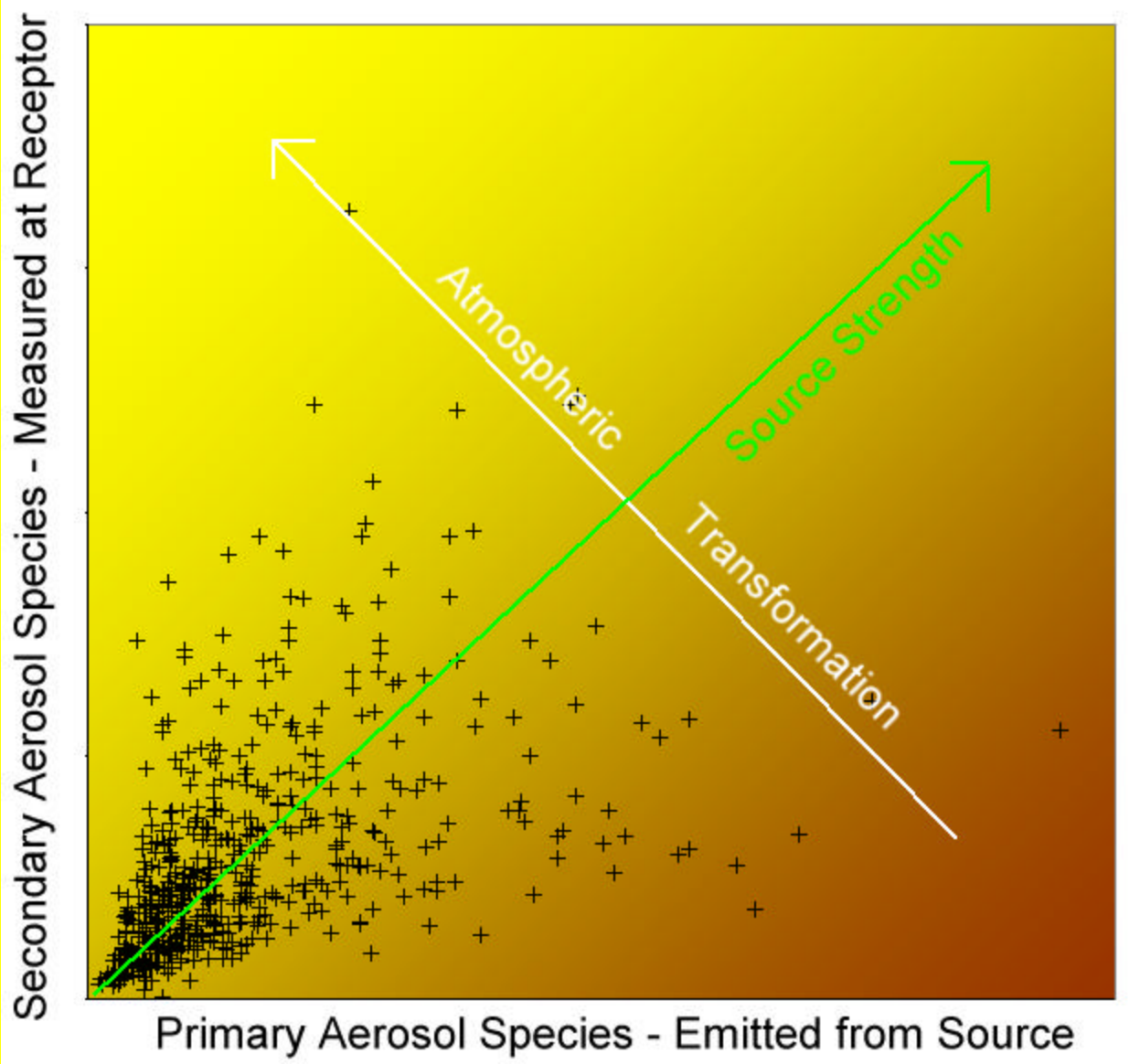

A
B
C
D
[BC] (µg m-3)
[FM] (µg m-3)
[Se] (ng m-3)
[S] (µg m-3)
r2=0.54
r2=0.75
r2=0.81
r2=0.76
r2=0.68
r2=0.82
r2=0.35
r2=0.60
1
2
3
4
Gasoline
Coal
Oil
Wood
Incineration
"Winter"
"Winter" Regr.
"Summer"
"Summer" Regr.
PMF factors

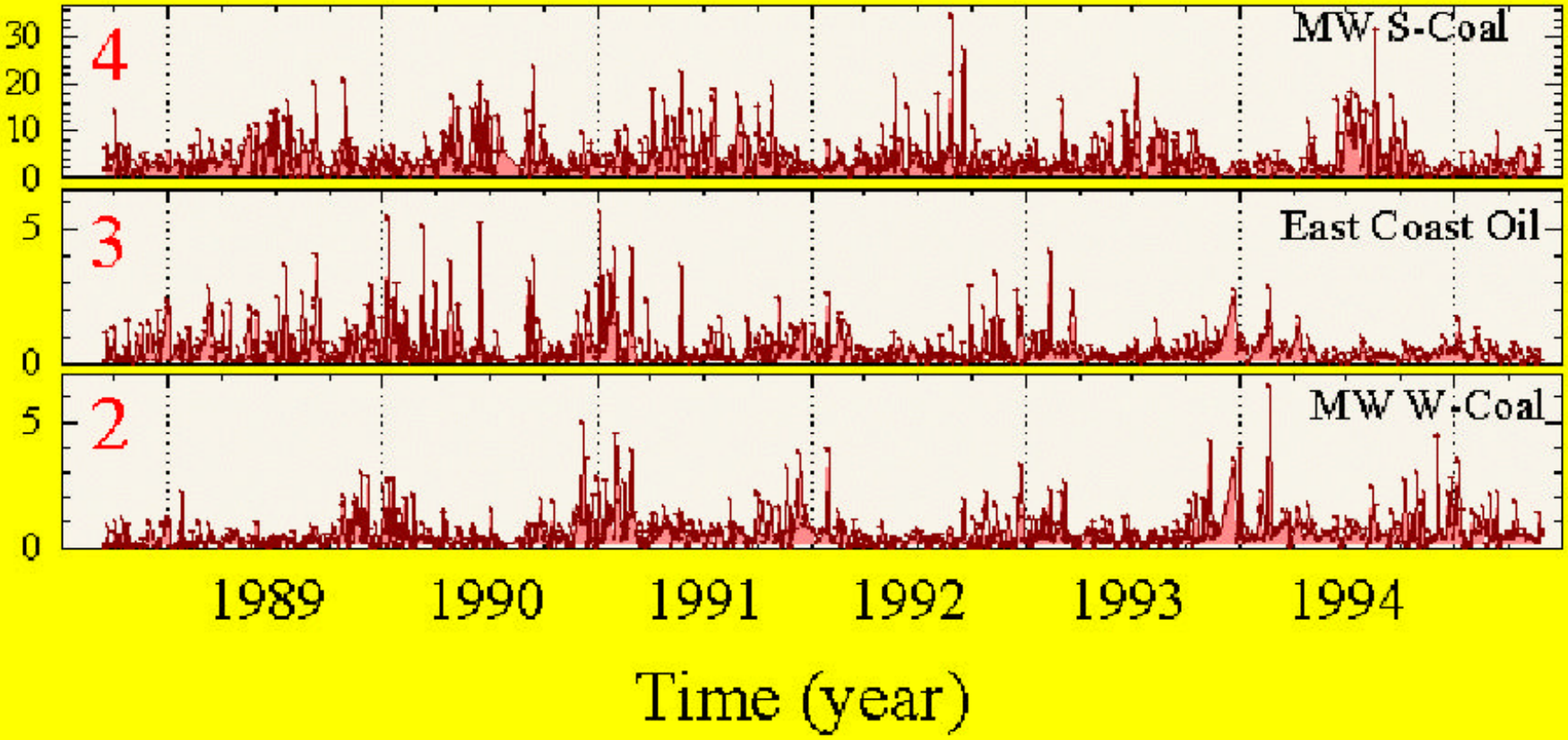

Concentration (ppm)
11 Salt
10 Na-S
9 Can. smelting
8 Cu smelting
7 Soil
6 Can. Mn
5 Zn-Pb
4 MW S-coal
3 East coast oil
2 MW W-coal
1 Woodsmoke
10^5
10^3
Al As BC Br Ca Cl Cr Cu Fe H K Mg Mn Mo Na Ni P Pb Rb S Se Si Sr Ti V Zn Zr

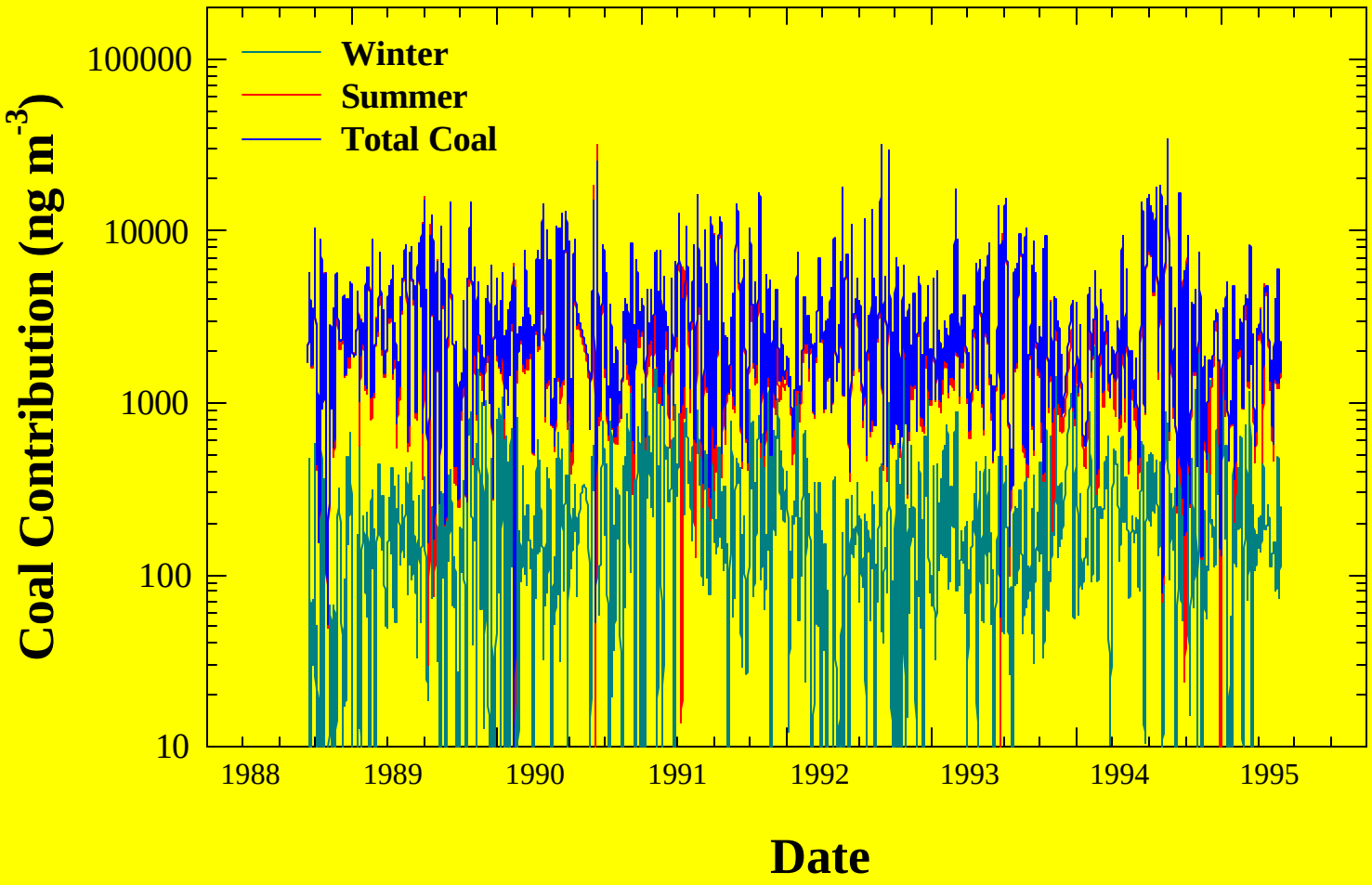

1
Woodsmoke
10^5
10^3
Al
As
BC
Br
Ca
Cl
Cr
Cu
Fe
H
K
Mg
Mn
Mo
Na
Ni
P
Pb
Rb
S
Se
Si
Sr
Ti
V
Zn
Zr

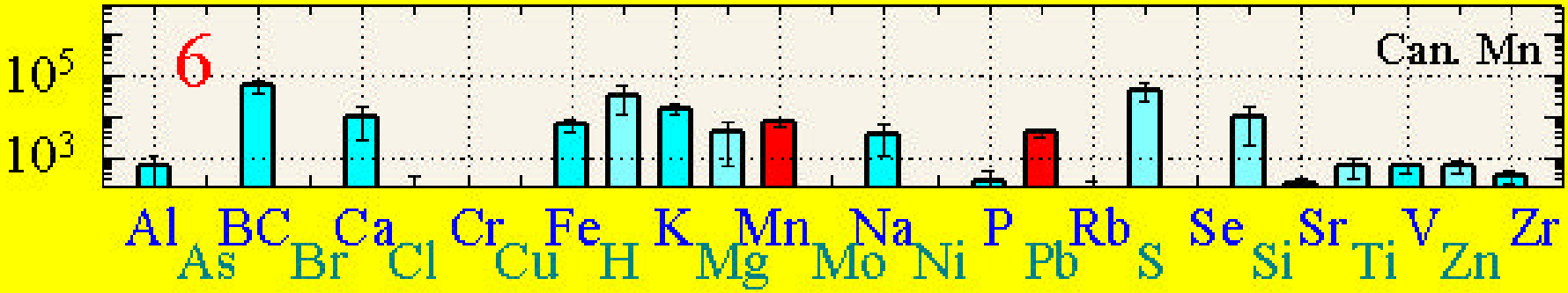

1
Woodsmoke
5
0
1989
1990
1991
1992
1993
1994
Time (year)

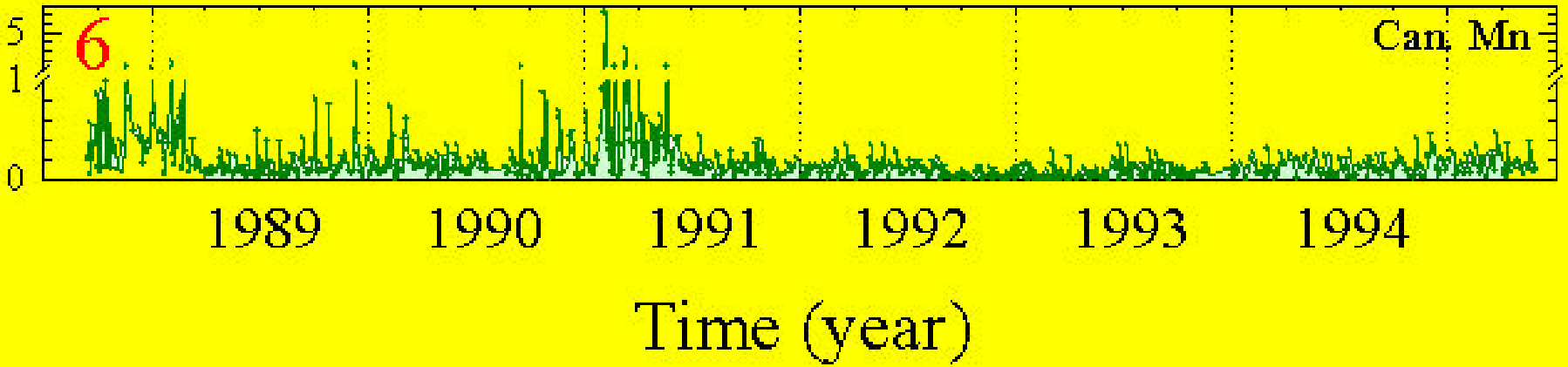

4
MW S-coal
3
East Coast Oil
2
MW W-coal
10^5
10^3
Al As BC Br Ca Cl Cr Cu Fe H K Mg Mn Mo Na Ni P Pb Rb S Se Si Sr Ti V Zn Zr

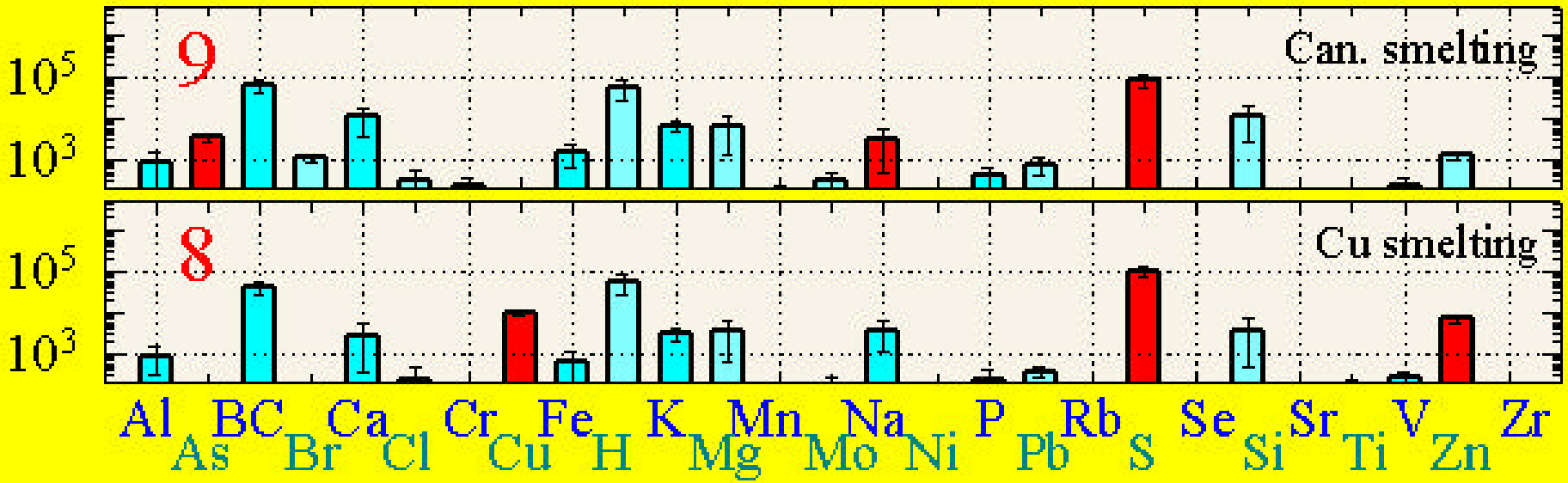

Secondary Aerosol Species - Measured at Receptor
Primary Aerosol Species - Emitted from Source
Atmospheric
Transformation
Source Strength

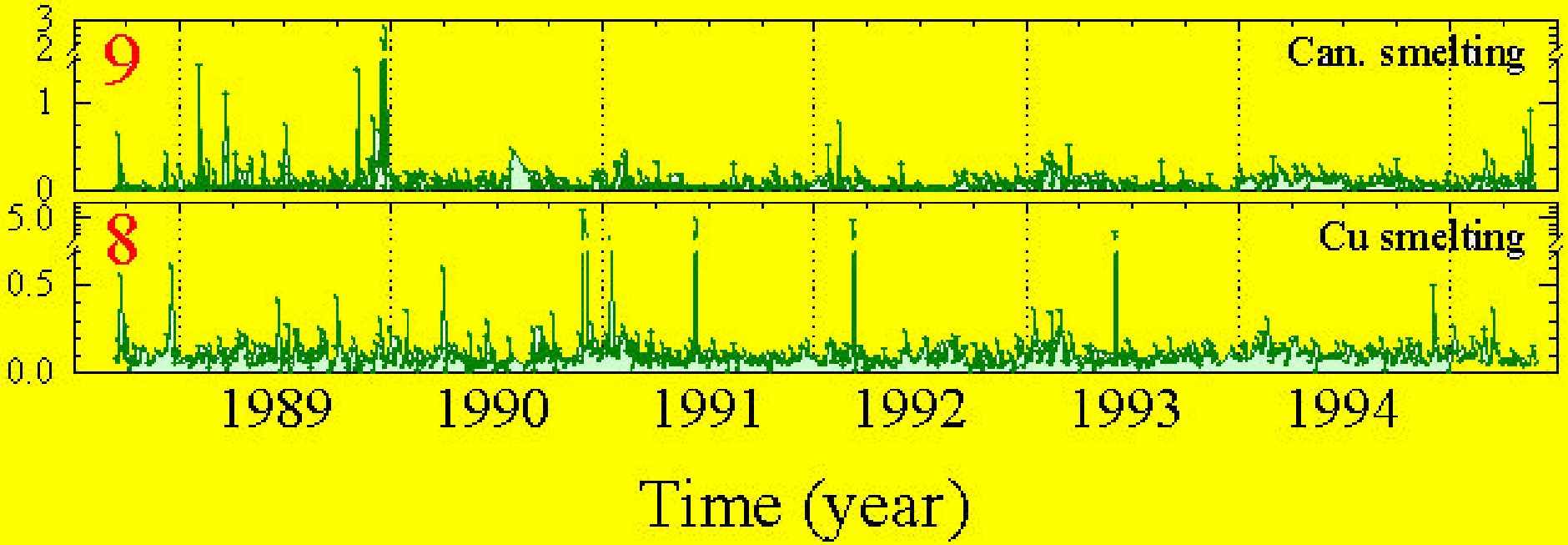

4
MW S-Coal
30
20
10
0
3
East Coast Oil
5
0
2
MW W-Coal
5
0
1989
1990
1991
1992
1993
1994
Time (year)

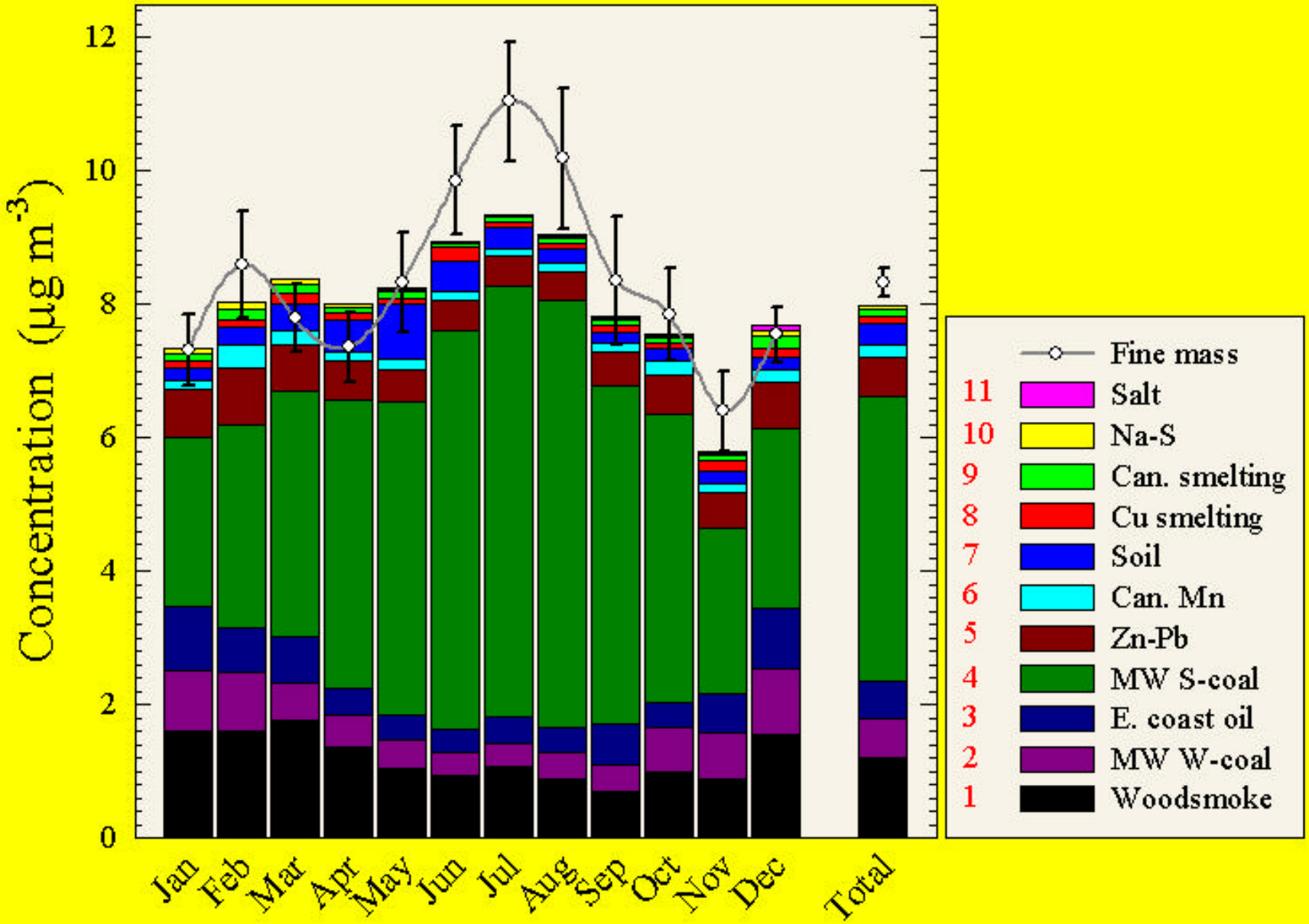

Winter
Summer
Total Coal
Coal Contribution (ng m-3)
100000
10000
1000
100
10
1988
1989
1990
1991
1992
1993
1994
1995
Date

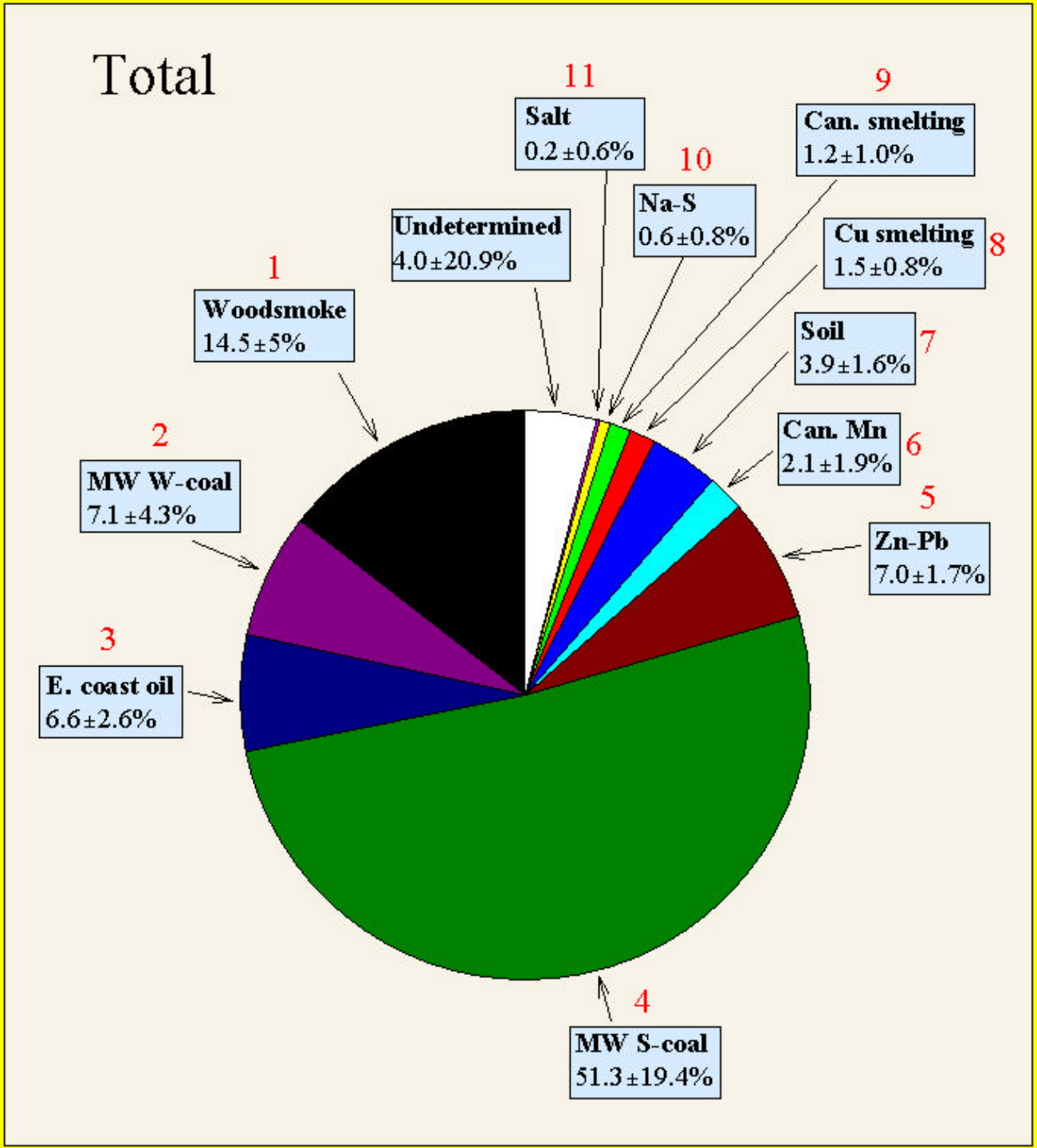

6
Can. Mn
10^5
10^3
Al
As
BC
Br
Ca
Cl
Cr
Cu
Fe
H
K
Mg
Mn
Mo
Na
Ni
P
Pb
Rb
S
Se
Si
Sr
Ti
V
Zn
Zr

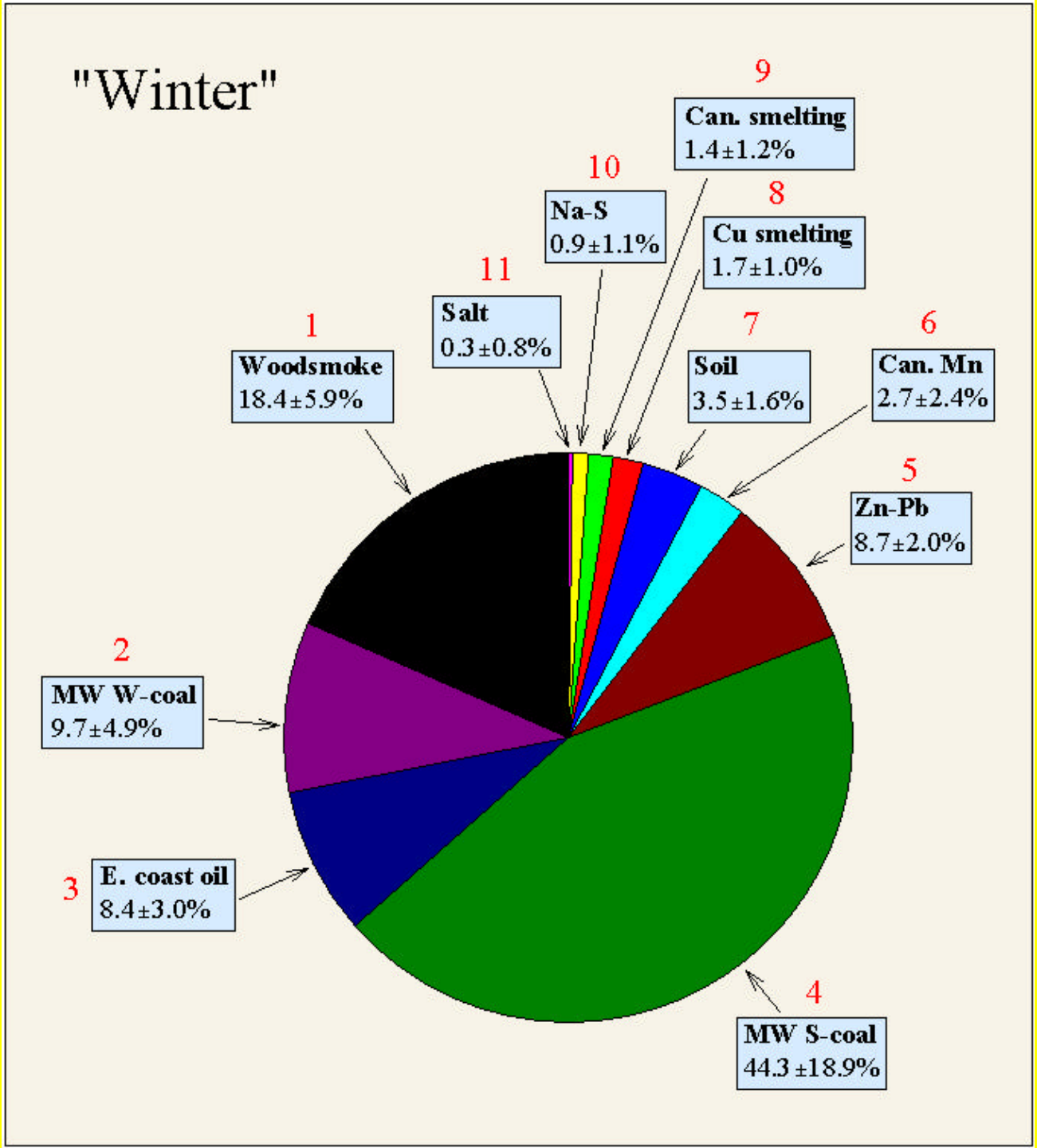

6
Can. Mn
5
1
0
1989
1990
1991
1992
1993
1994
Time (year)

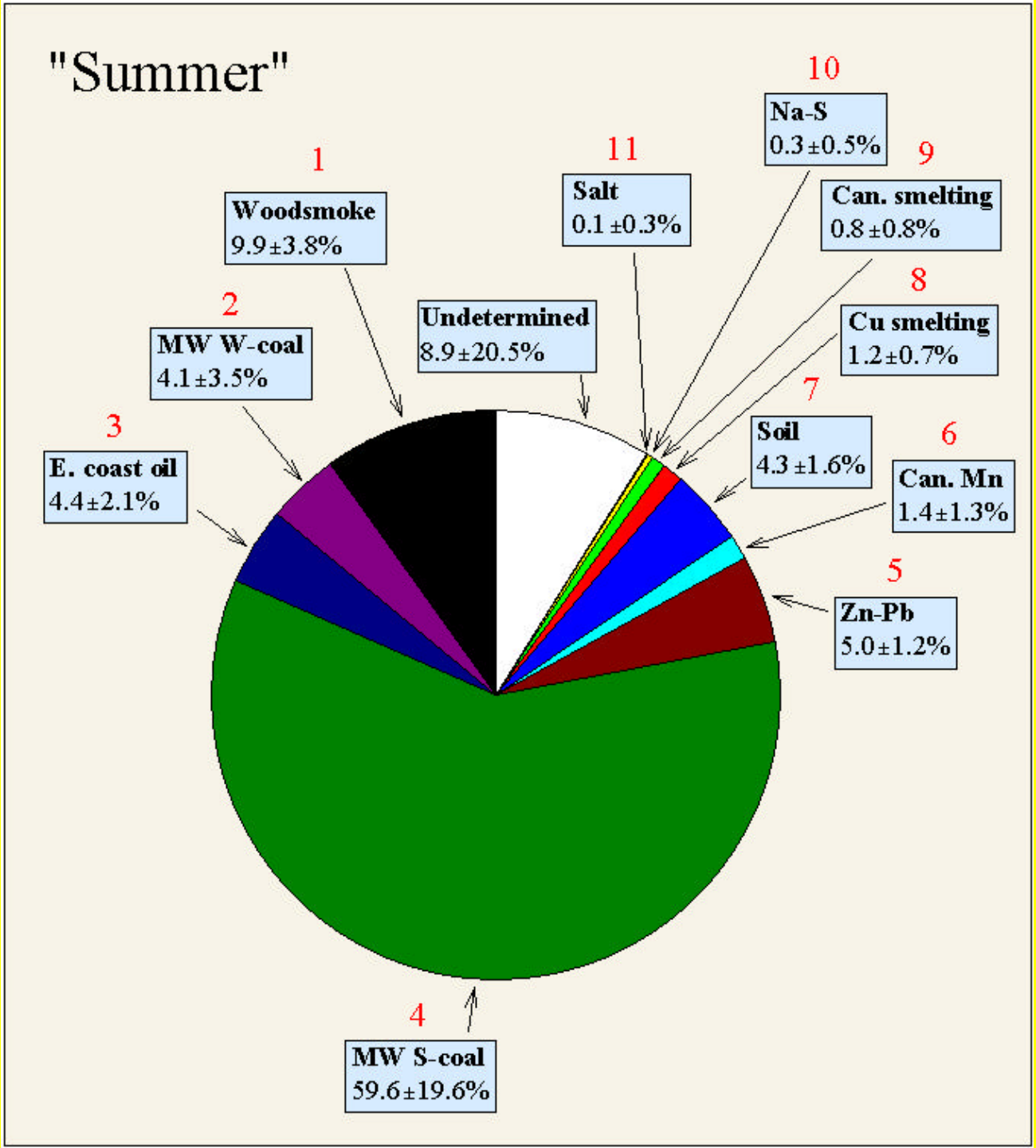

9
Can. smelting
10^5
10^3
8
Cu smelting
10^5
10^3
Al
As
BC
Br
Ca
Cl
Cr
Cu
Fe
H
K
Mg
Mn
Mo
Na
Ni
P
Pb
Rb
S
Se
Si
Sr
Ti
V
Zn
Zr


9
Can. smelting
3
2
1
0
8
Cu smelting
5.0
0.5
0.0
1989
1990
1991
1992
1993
1994
Time (year)


Concentration (µg m-3)
0
2
4
6
8
10
12
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Total
Fine mass
11 Salt
10 Na-S
9 Can. smelting
8 Cu smelting
7 Soil
6 Can. Mn
5 Zn-Pb
4 MW S-coal
3 E. coast oil
2 MW W-coal
1 Woodsmoke


Total
11
Salt
0.2±0.6%
9
Can. smelting
1.2±1.0%
10
Na-S
0.6±0.8%
Undetermined
4.0±20.9%
Cu smelting
1.5±0.8%
8
1
Woodsmoke
14.5±5%
Soil
3.9±1.6%
7
2
Can. Mn
2.1±1.9%
6
MW W-coal
7.1±4.3%
5
Zn-Pb
7.0±1.7%
3
E. coast oil
6.6±2.6%
4
MW S-coal
51.3±19.4%


"Winter"
9
Can. smelting
1.4±1.2%
10
Na-S
0.9±1.1%
8
Cu smelting
1.7±1.0%
11
Salt
0.3±0.8%
1
Woodsmoke
18.4±5.9%
7
Soil
3.5±1.6%
6
Can. Mn
2.7±2.4%
5
Zn-Pb
8.7±2.0%
2
MW W-coal
9.7±4.9%
3
E. coast oil
8.4±3.0%
4
MW S-coal
44.3 ±18.9%


"Summer"
1
Woodsmoke
9.9±3.8%
2
MW W-coal
4.1±3.5%
3
E. coast oil
4.4±2.1%
4
MW S-coal
59.6±19.6%
Undetermined
8.9±20.5%
11
Salt
0.1±0.3%
10
Na-S
0.3±0.5%
9
Can. smelting
0.8±0.8%
8
Cu smelting
1.2±0.7%
7
Soil
4.3±1.6%
6
Can. Mn
1.4±1.3%
5
Zn-Pb
5.0±1.2%

Potential Source Contribution Function

The potential source contribution function can be described as follows: if a trajectory endpoint lies at a cell of address (i, j), the trajectory is assumed to collect material emitted in the cell. Once aerosol is incorporated into the air parcel, it can be transported along the trajectory to the receptor site. The objective is to develop a probability field suggesting likely source locations of the material that results in high measured values at the receptor site.

Potential Source Contribution Function

The number of endpoints falling into a single grid cell is $n_{i,j}$. Some of these trajectory endpoints are associated with sampling intervals when the greater contribution of a particular source is equal to that of the 60th percentile value in the distribution of that species. The number of endpoints is $m_{i,j}$.

Potential Source Contribution Function

The potential source contribution function (PSCF) is then defined as

$$PSCF_{ij} = \frac{m_{ij}}{n_{ij}}$$

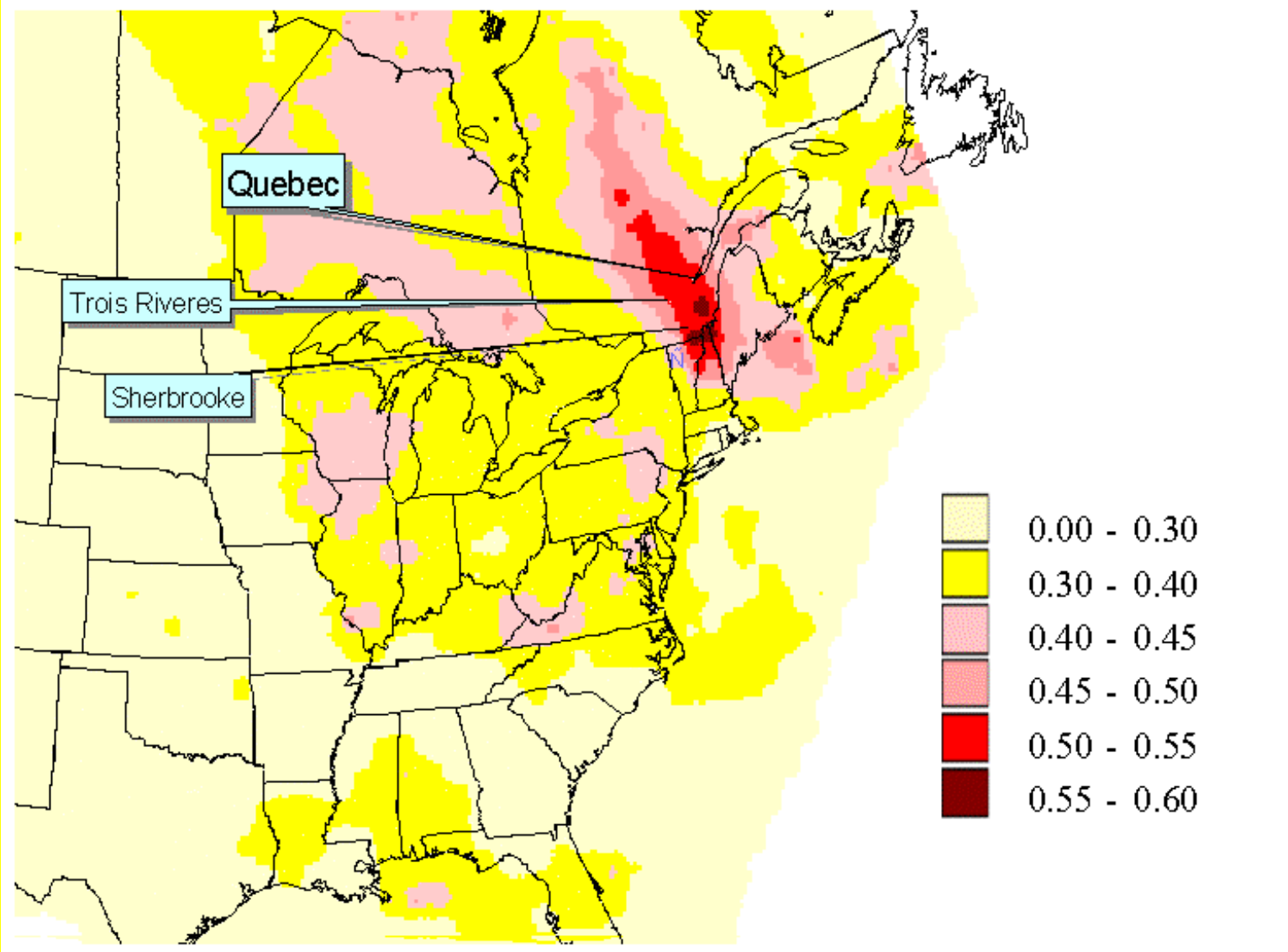
Potential Source Contribution Function

The potential source contribution function can be interpreted as a conditional probability describing the spatial distribution of probable geographical source locations inferred by using trajectories arriving at the sampling site. Cells related to the high values of potential source contribution function are the potential source areas.

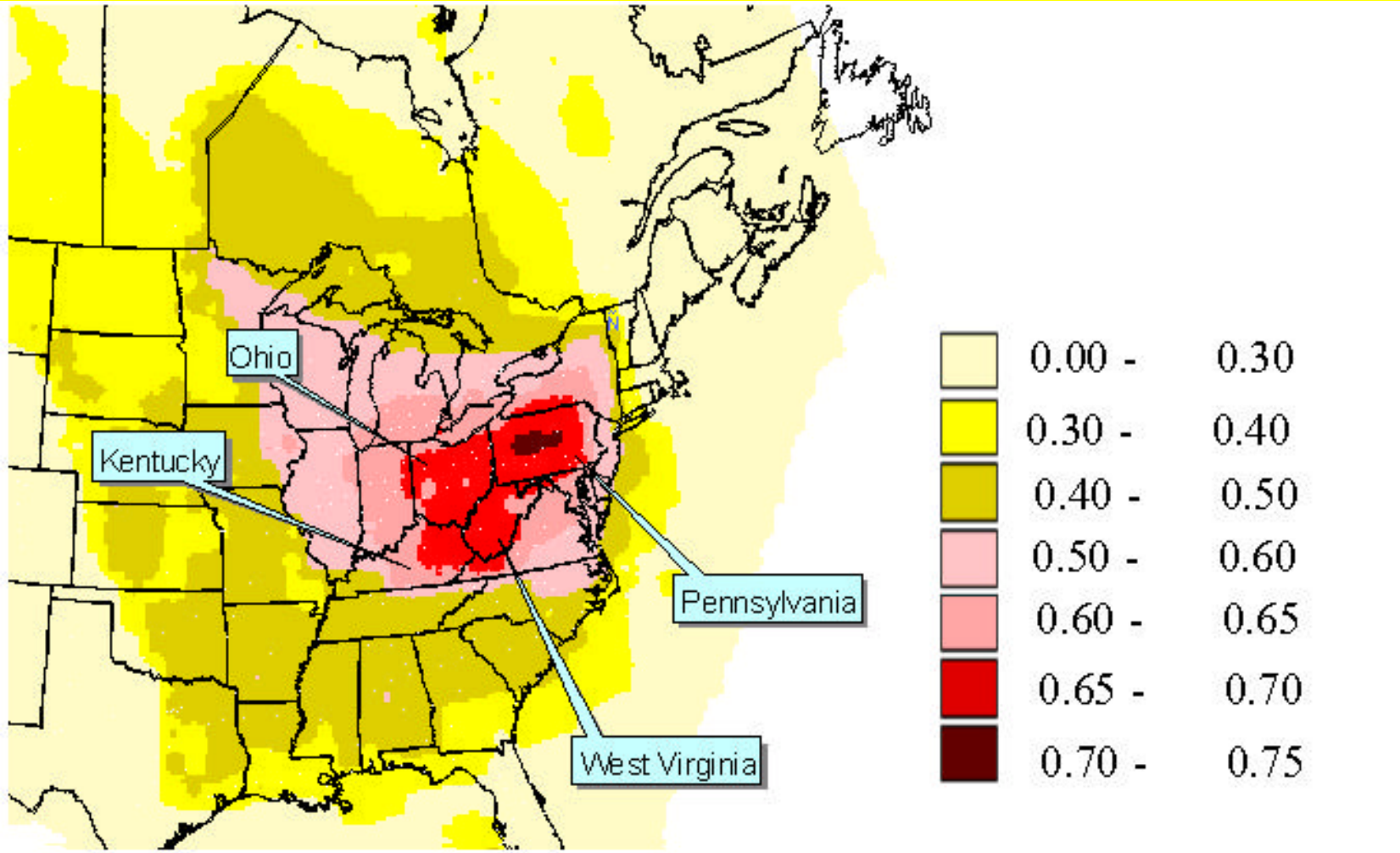
Potential Source Contribution Function

The trajectory data consist of 12 trajectories for the 10 random air parcels calculations for each day of the 853 days of sampling. There are 37 endpoints in each trajectory. Therefore, the total number of the endpoints was $12 \times 10 \times 853 \times 37$ or about 3.8×10^6. The grid covers most of North America with 2,966 cells of 1 degree by 1 degree latitude and longitude so that in average there are $3.8 \times 10^6/2966$ or about 1280 endpoints per cell.

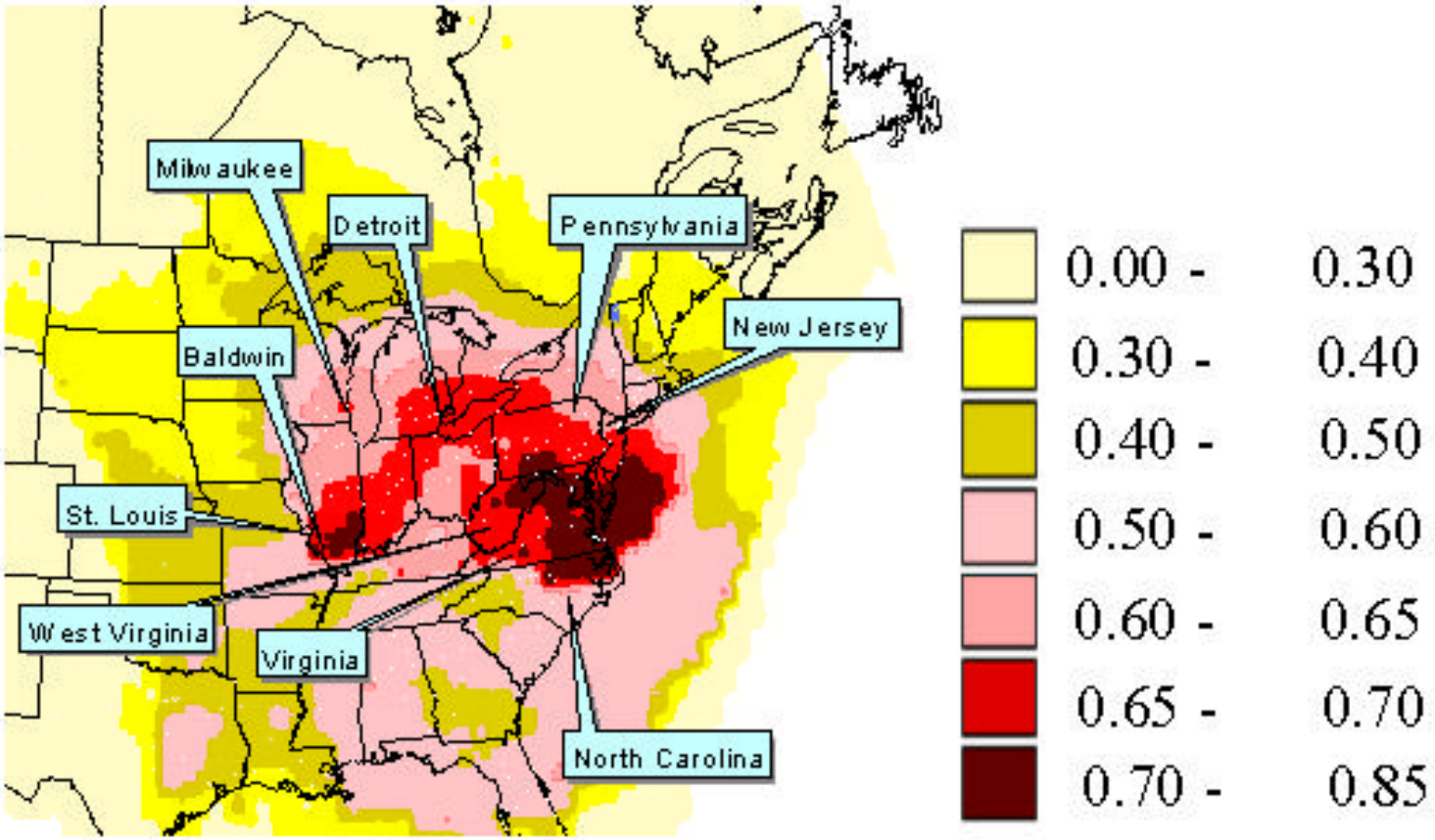
Woodsmoke


Quebec
Trois Riveres
Sherbrooke
0.00 - 0.30
0.30 - 0.40
0.40 - 0.45
0.45 - 0.50
0.50 - 0.55
0.55 - 0.60

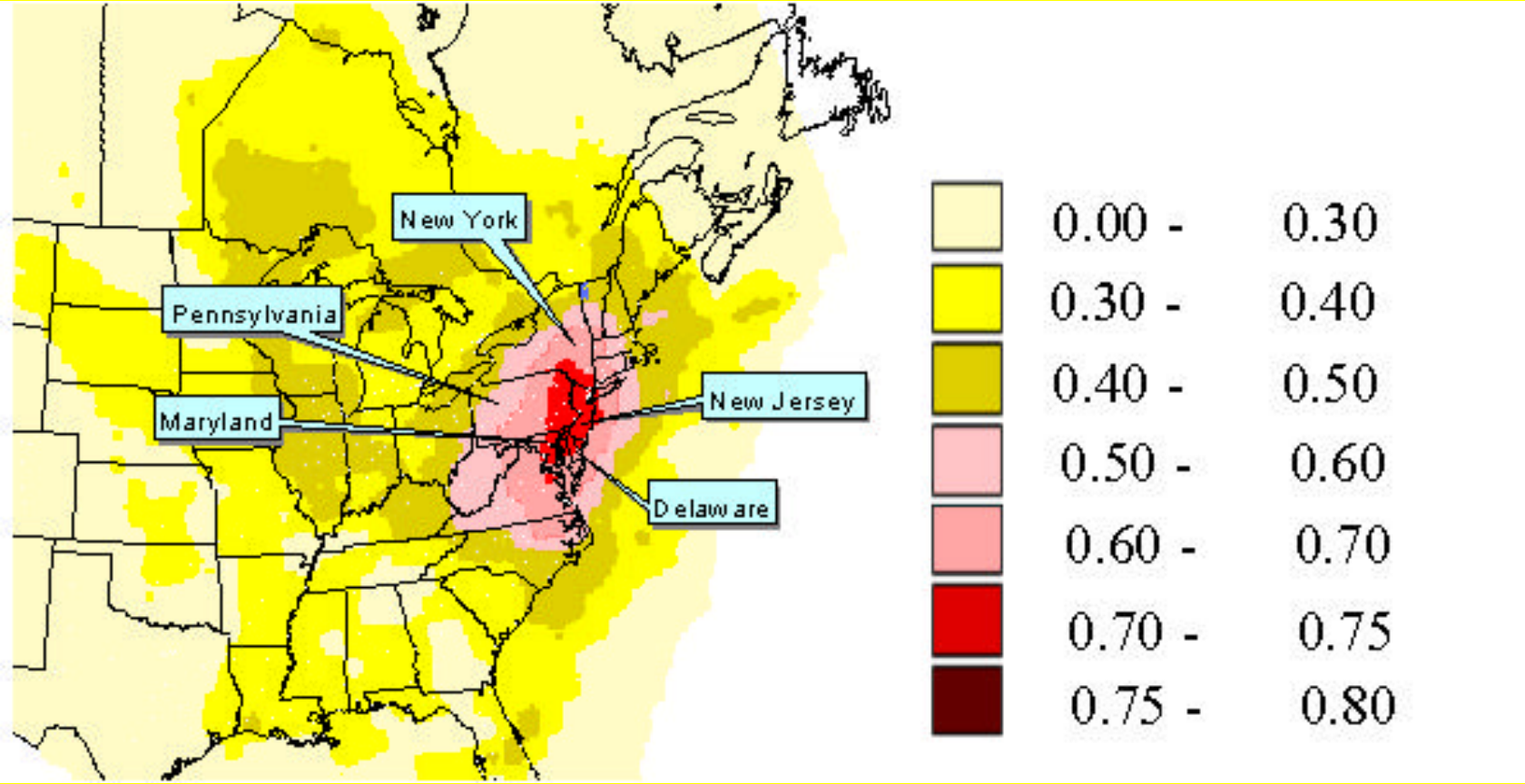
Winter Midwestern Coal



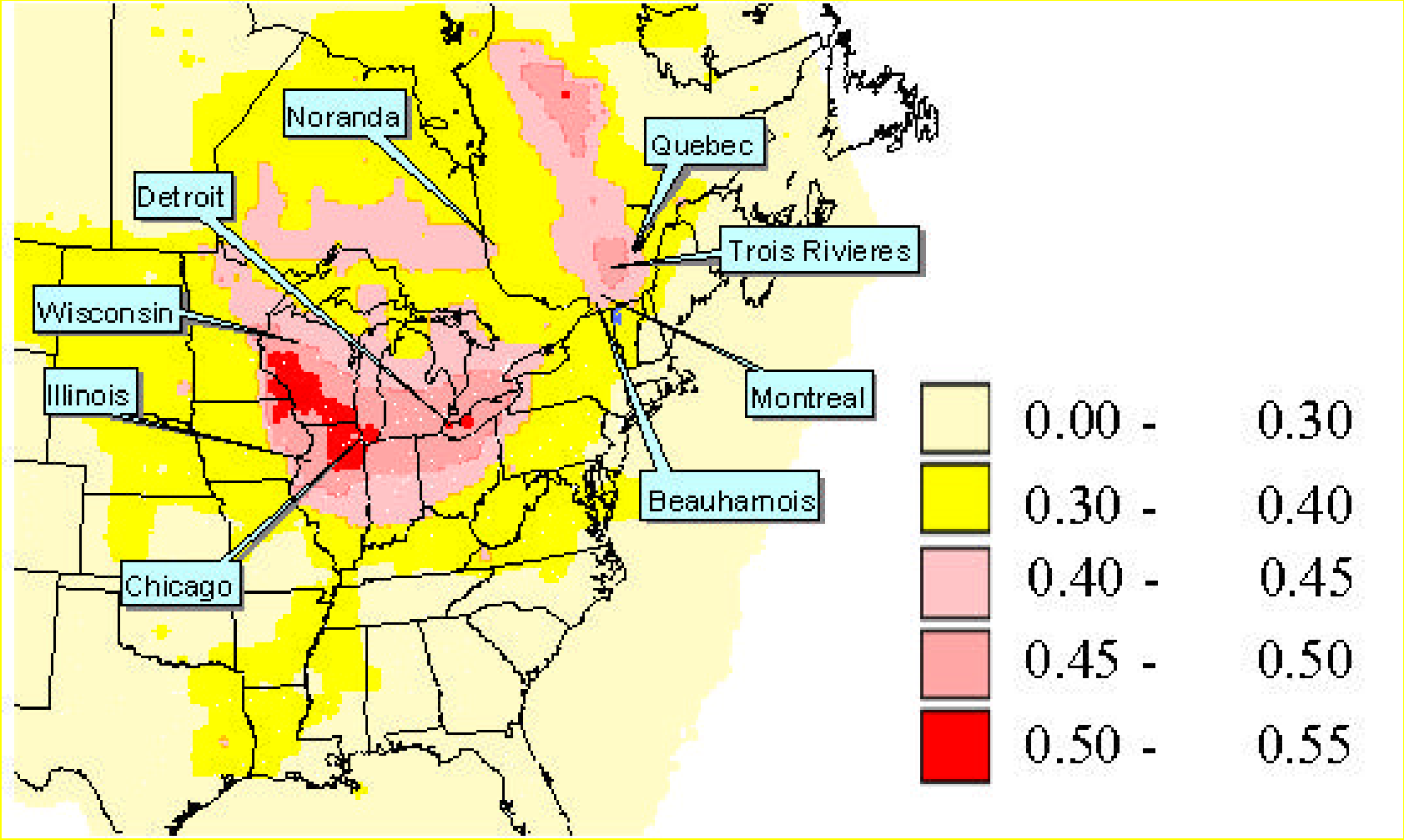
Summer Midwestern Coal



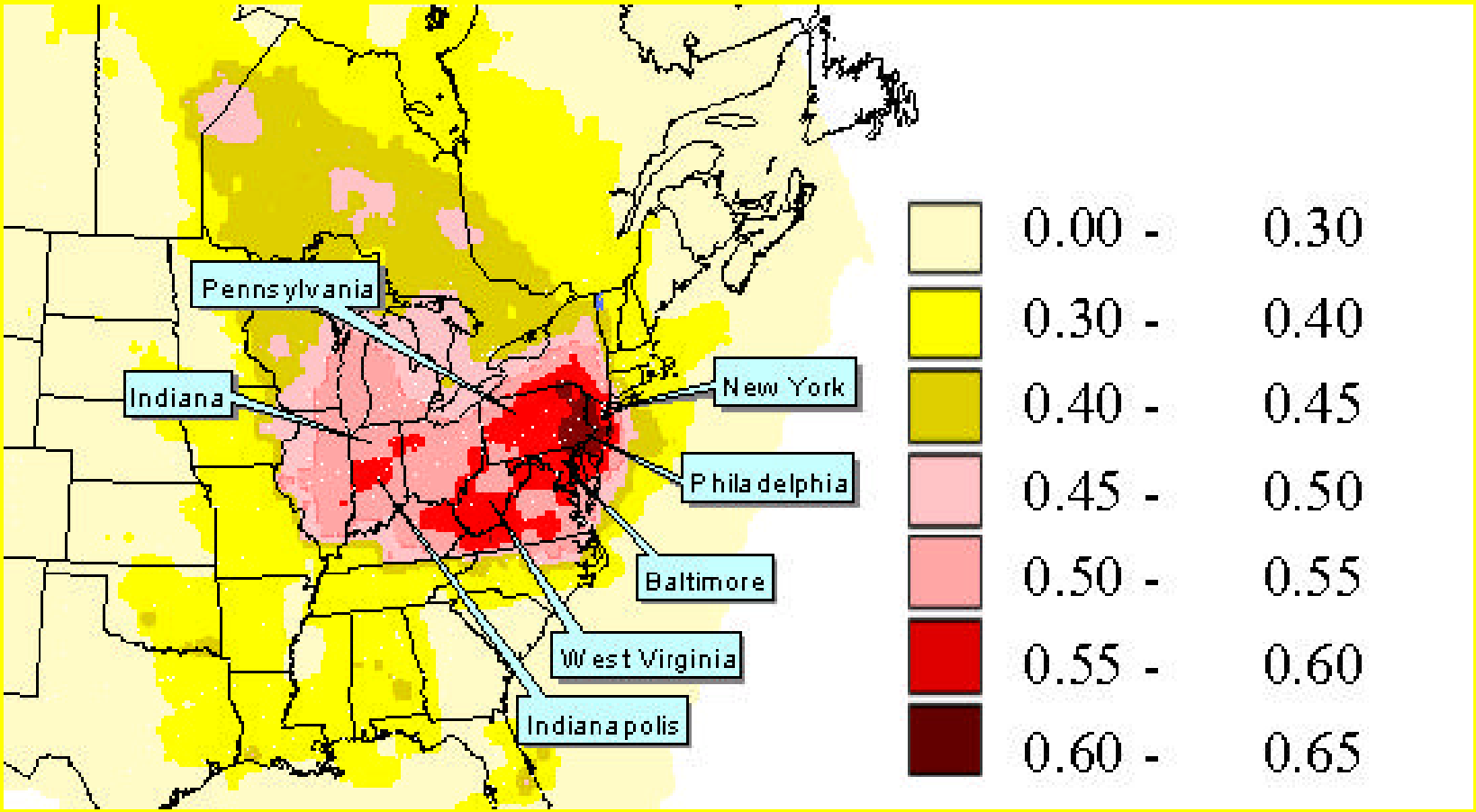
East Coast Oil



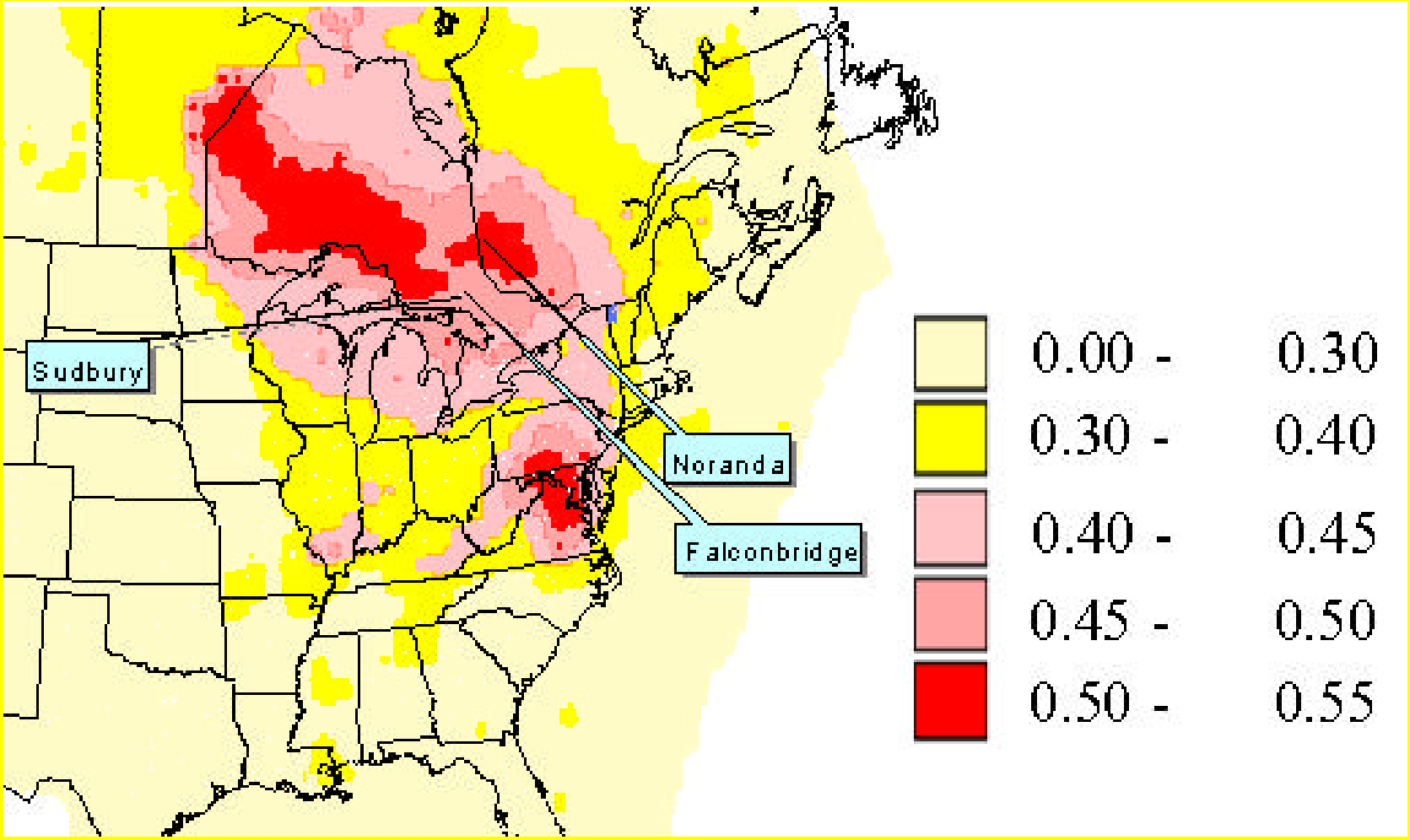
Canadian Manganese



Copper Smelter



Canadian Ni Smelters



NEW DIRECTIONS

- The least-squares factor analysis approach permits more complex models to be developed.
- Such models permit greater resolution of sources and provide indication of source location relative to receptor site.
- Can be modified to include reactivity.

Advanced Models

- The concentration of particles from a source depends on the transport to the receptor site including wind speed, direction, mixing height, and atmospheric chemistry.
- Strength of the emissions may depend on weekday/weekend, time of year, etc.

Advanced Models

- How to incorporate additional information like wind speed, direction, etc. into the analysis. This is what we are terming an advanced factor analysis model.

Advanced Models

- To present the expanded factor analysis approach, the model is described from the viewpoint of one source, denoted by p.
- In reality, there are several sources and the observed concentrations are sums of contributions due to all sources, p=1,..., P.

Advanced Models

- In the customary bilinear analysis, the contribution r_{ijp} of source p on day i to concentration of chemical species j is represented by the product $g_{ip}f_{jp}$, where g_{ip} corresponds to the strength of source p on day i, and f_{jp} corresponds to the concentration of compound j in the emission signature of source p.

Advanced Models

- In the expanded PMF analysis, the bilinear equation is augmented by another more complicated set of equations that contain modeling information.

Advanced Models

- The contribution r_{ijp} of source p is represented by the following expression:

$$r_{ijp} = m_{ip} f_{jp} = \mathbf{D}(d_i, p)\mathbf{V}(v_i, p) f_{jp}$$

- The known values ä$_i$ and v_i indicate wind direction and wind speed on day i. The symbols **D** and **V** represent matrices, consisting of unknown values to be estimated during the fitting process. Their columns numbered p correspond to source number p.

Advanced Models

- The index value $\ddot{a}_i$ for day *i* is typically obtained by dividing the average wind direction of day *i* (in degrees) by ten and rounding to nearest integer.
- The values v_i are obtained from a chosen classification of wind speeds.

Advanced Models

- In component form, the equations of the model are

$$x_{ij} = \sum_{p=1}^{P} g_{ip} f_{jp} + e_{ij}$$

$$x_{ij} = \sum_{p=1}^{P} m_{ip} f_{jp} + e'_{ij}$$

$$= \sum_{p=1}^{P} \mathbf{D}(d_i, p)\mathbf{V}(v_i, p) f_{jp} + e'_{ij}$$

Advanced Models

- The notation m_{ip} does not indicate a factor element to be determined, such as g_{ip}, but the expression defined by the physical model in question.
- In different physical models, m_{ip} will correspond to different expressions. Because the variability of m_{ip} is restricted by the model, the second set of equations will produce a significantly poorer fit to the data than the first set of equations.

Advanced Models

- Thus, the error estimates connected with the second set of equations must be (much) larger than the error estimates connected with the first set of equations.
- The task of solving this expanded PMF model means that values of the unknown factor matrices G, F, D, and V are to be determined so that the model fits the data as well as possible.

Advanced Models

- In other words, the sum-of-squares value, Q, defined by

$$Q = \sum_{i=1}^{I}\sum_{j=1}^{J}(e_{ij}/s_{ij})^2 + \sum_{i=1}^{I}\sum_{j=1}^{J}(e'_{ij}/s'_{ij})^2$$

is minimized with respect to the matrices G, F, D, and V, while the residuals e_{ij} and e'_{ij} are determined by the model equations.

Advanced Models

- Since there are other sources of variation such as weekend/weekday source activity patterns or seasonal differences in emission rates or in atmospheric chemistry, additional factors are included in the model.

Advanced Models

- Wind direction, wind speed, time of year, and weekend/weekday were used. In this case, 24 one-hour average values are available for wind speed and direction.
- Time of year will be aggregated into six two-month periods or *seasons*, indicated for each day *i* by the index variables $ó_i$.

Advanced Models

- The non-linear dependencies are now defined by:

$$m_{ip} = \mathbf{W}(w_i, p)\mathbf{S}(s_i, p)\sum_{h=1}^{24}\mathbf{D}(d_{ih}, p)\mathbf{V}(v_{ih}, p)$$

- where **D**(ä$_{ih}$, *p*) is an element with the index for the wind direction during hour *h* of day *i* for the *p*th source, **V**(í$_{ih}$, *p*) is the element with the index for the wind speed during hour *h* of day *i* for the *p*th source, **W**(ù$_i$, *p*) is the element with the index corresponding to day *i* for the weekday/weekend factor for the *p*th source, and **S**(ó$_i$, *p*) is the element with the index corresponding to the time-of-year classification of day *i* for the *p*th source.

Advanced Models

- The expanded model consists of the basic bilinear equations plus the set of physical model equations:

$$x_{ij} = \sum_{p=1}^{P} g_{ip} f_{jp} + e_{ij}$$

$$x_{ij} = \sum_{p=1}^{P} m_{ip} f_{jp} + e'_{ij}$$

$$= \sum_{p=1}^{P} \mathbf{W}(w_i, p)\mathbf{S}(s_i, p) \sum_{h=1}^{24} \mathbf{D}(d_{ih}, p)\mathbf{V}(v_{ih}, p)\ f_{jp}$$

$$+\ e'_{ij}$$

Palookaville

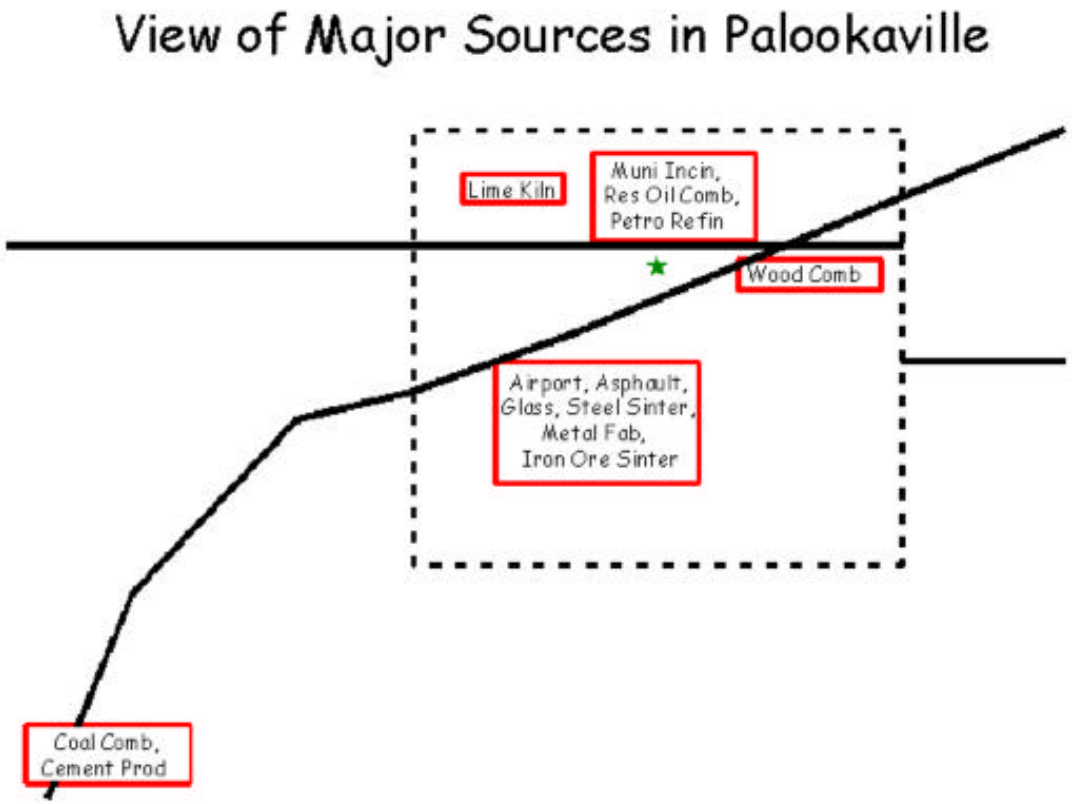
- Simulated data were produced by EPA for a February 2000 workshop.
- 16 Sources distributed around a single receptor site.
- Data prepared through the use of the ISC-ST model.

Palookaville

- Fifteen of the 16 sources are found
- Good reproduction of the source profiles is obtained
- Details are in

  Utilizing Wind Direction and Wind Speed as Independent Variables in Multilinear Receptor Modeling Studies, P. Paatero and P.K. Hopke, *Chemom. Intell. Lab. Syst.* 60: 25-41 (2002).

Palookaville



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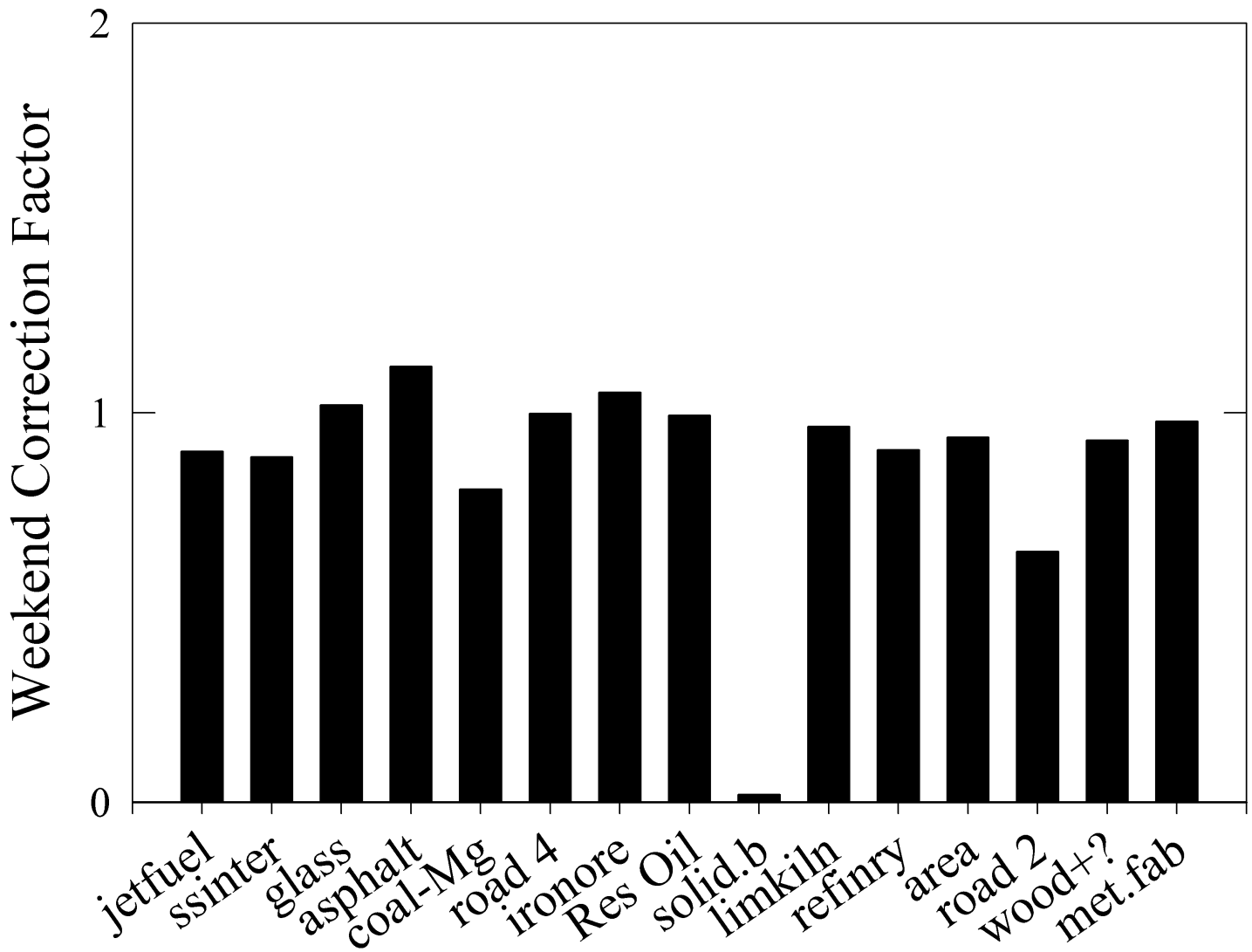

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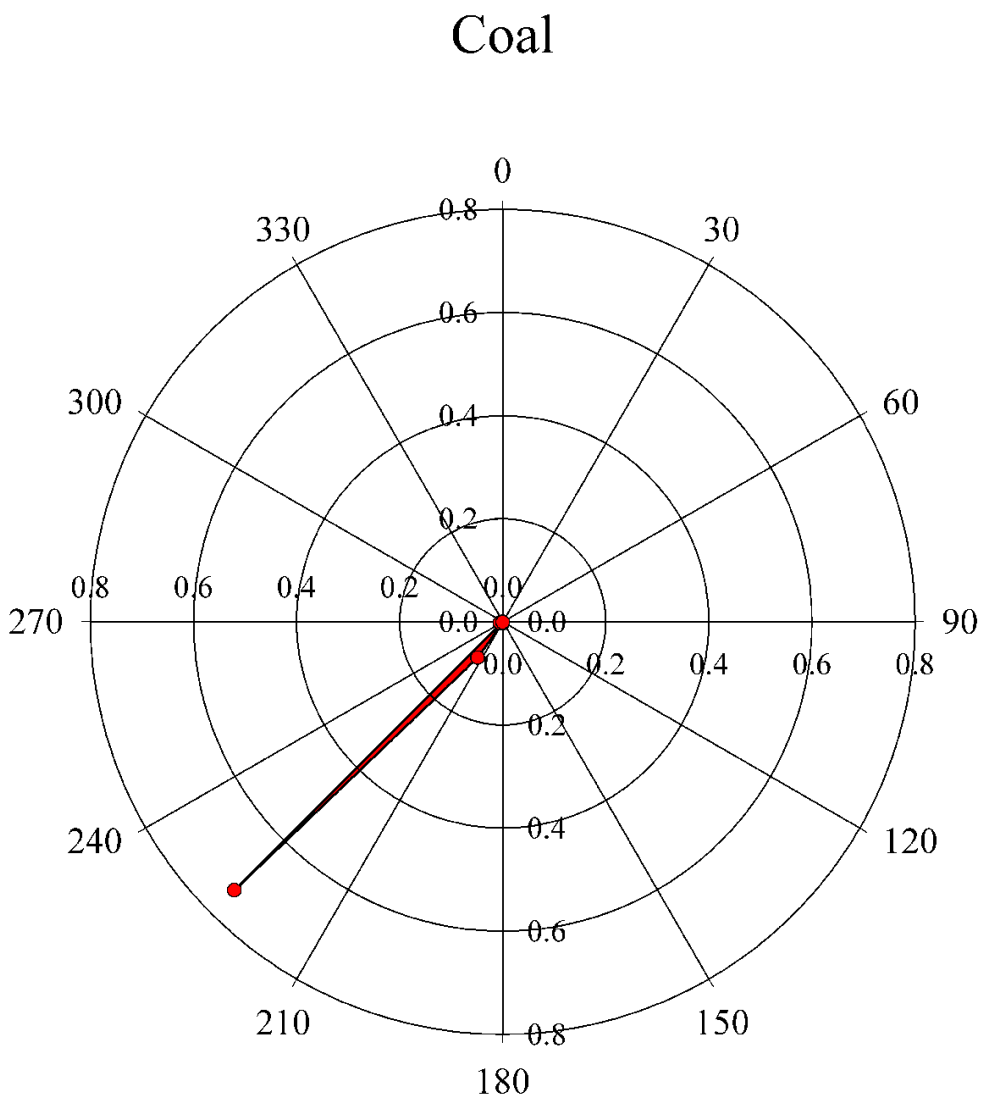

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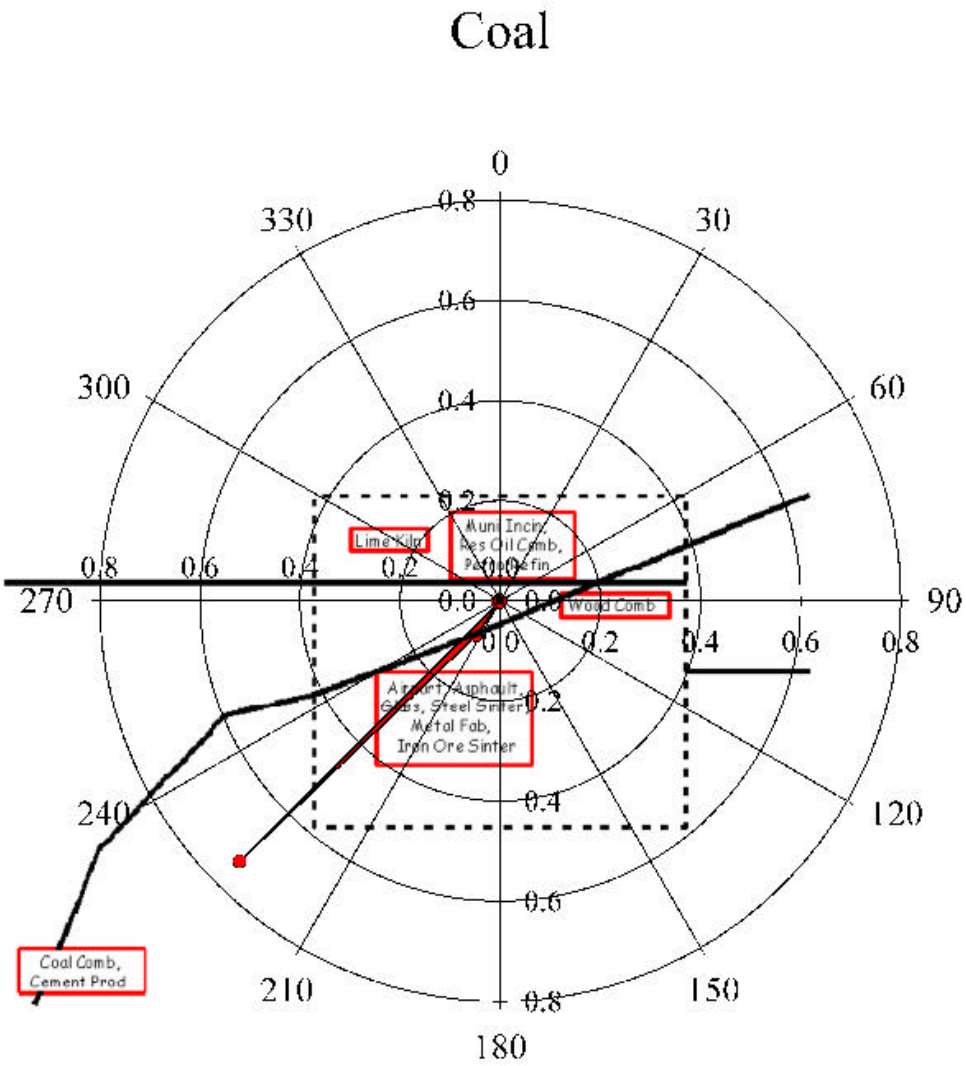

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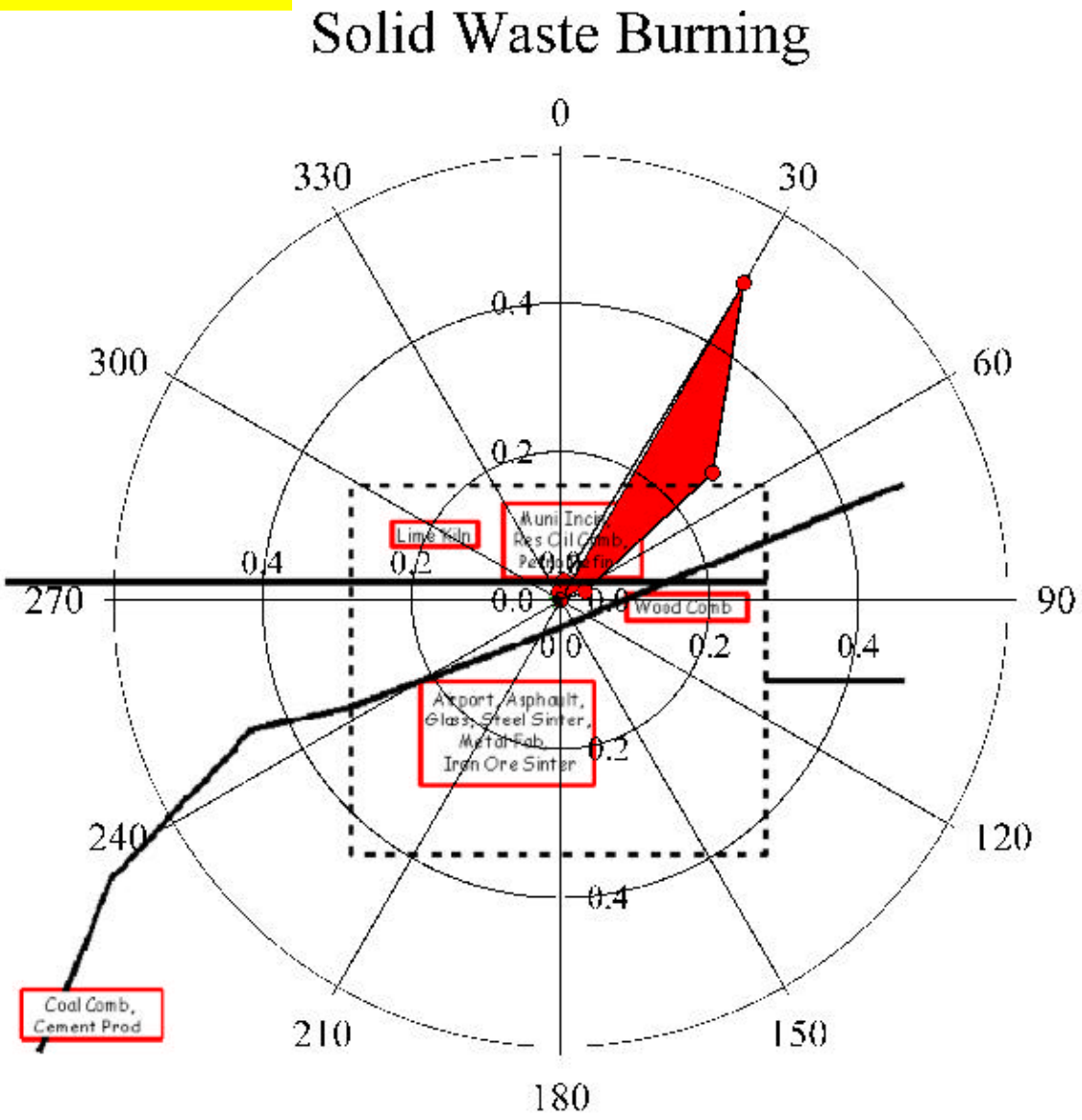

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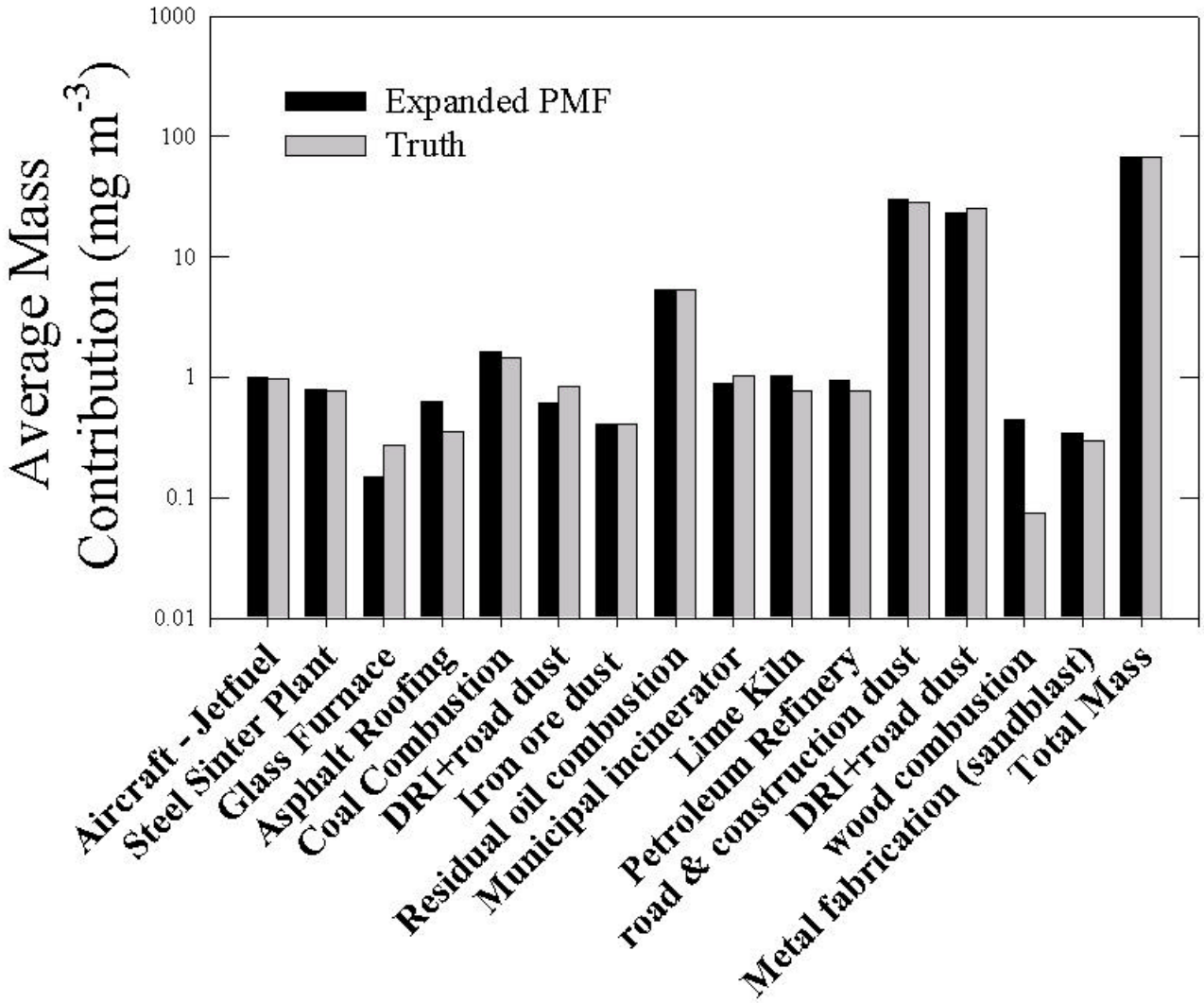


Phoenix, AR

The location of sampling site is Phoenix, AZ (3847 West Earl Drive, Latitude: N33E48'46", Longitude: W112E14'17", Elevation: 1007 ft). Two different samplers were operated at this site: a dual fine particle sequential sampler (DFPSS) (URG Corporation, Cary, NC) and a dichotomous sampler (Andersen Instruments, Inc., Smyrna, GA). The DFPSS collected only fine particle samples while the dichotomous sampler provided samples of fine and coarse particles.

Phoenix, AR

Daily, integrated 24-hour samples were collected on 37 millimeter (mm) diameter Teflon and quartz filter media for fine particle mass and species measurements using a dual fine particle sequential sampler (DFPSS). The samples were collected during the time period from March 1995 through June 1998. A total of 981 samples were finally obtained.

Phoenix, AR

Energy dispersive X-ray spectrometers were used to produce the chemical elemental concentration data. The quartz filters collected with the DFPSS were analyzed by Sunset Laboratory using the TOT technique. This technique measured both organic carbon (OC) and elemental carbon (EC). Each sample was characterized by the measured concentrations of the following 46 chemical elements: Na, Mg, Al, Si, P, S, Cl, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Br, Rb, Sr, Y, Zr, Mo, Rh, Pd, Ag, Cd, Sn, Sb,Te, I, Cs, Ba, La, W, Au, Hg, Pb, OC, and EC.

Conventional PMF Results

We extracted 8 factors including two biomass burning factors, motor vehicles, diesel vehicles, sea salt, copper smelters, soil, and a secondary aerosol tentatively identified as coal-fired power plants. These results were published in Ramadan *et al.*, *J. Air Waste Manage. Assoc.* 50:1308-1320 (2000).

Expanded PMF Model

In this case, we have attempted to solve the problem with only the model equations and not simultaneously with the normal CMB model equations.

Expanded PMF Model

The model is then

$$x_{ij} = \sum_{p=1}^{P} m_{ip} f_{jp} + e'_{ij}$$

Expanded PMF Model

Wind direction, wind speed, time of year, time-of-day, inlet change, and weekend/weekday were used. In this case, 24 one-hour average values are available for wind speed and direction.

Time of year will be aggregated into six two-month periods or *seasons*, indicated for each day *i* by the index variables F_i. (The Greek letter F is used for two purposes: F_{ij} indicates the error estimates of data values, while F_i indicates the season number for day *i*.).

For the values i=1 to i=60, F_i=1, meaning that January and February belong to the first season. For the values i=61 to i=121, F_i=2, and so on.

Expanded PMF Model

The non-linear dependencies are now defined by:

$$\mathrm{m}_{\mathrm{ip}} = \mathrm{I}(i_{\mathrm{i}},\mathrm{p})\mathbf{W}(w_{\mathrm{i}},\mathrm{p})\mathbf{S}(s_{\mathrm{i}},\mathrm{p})$$

$$\sum_{\mathrm{h}=1}^{24}\mathbf{D}(d_{\mathrm{ih}},\mathrm{p})\mathbf{V}(u_{\mathrm{ih}},\mathrm{p})\mathrm{T}(t_{\mathrm{ih}},\mathrm{p})$$

Expanded PMF Model

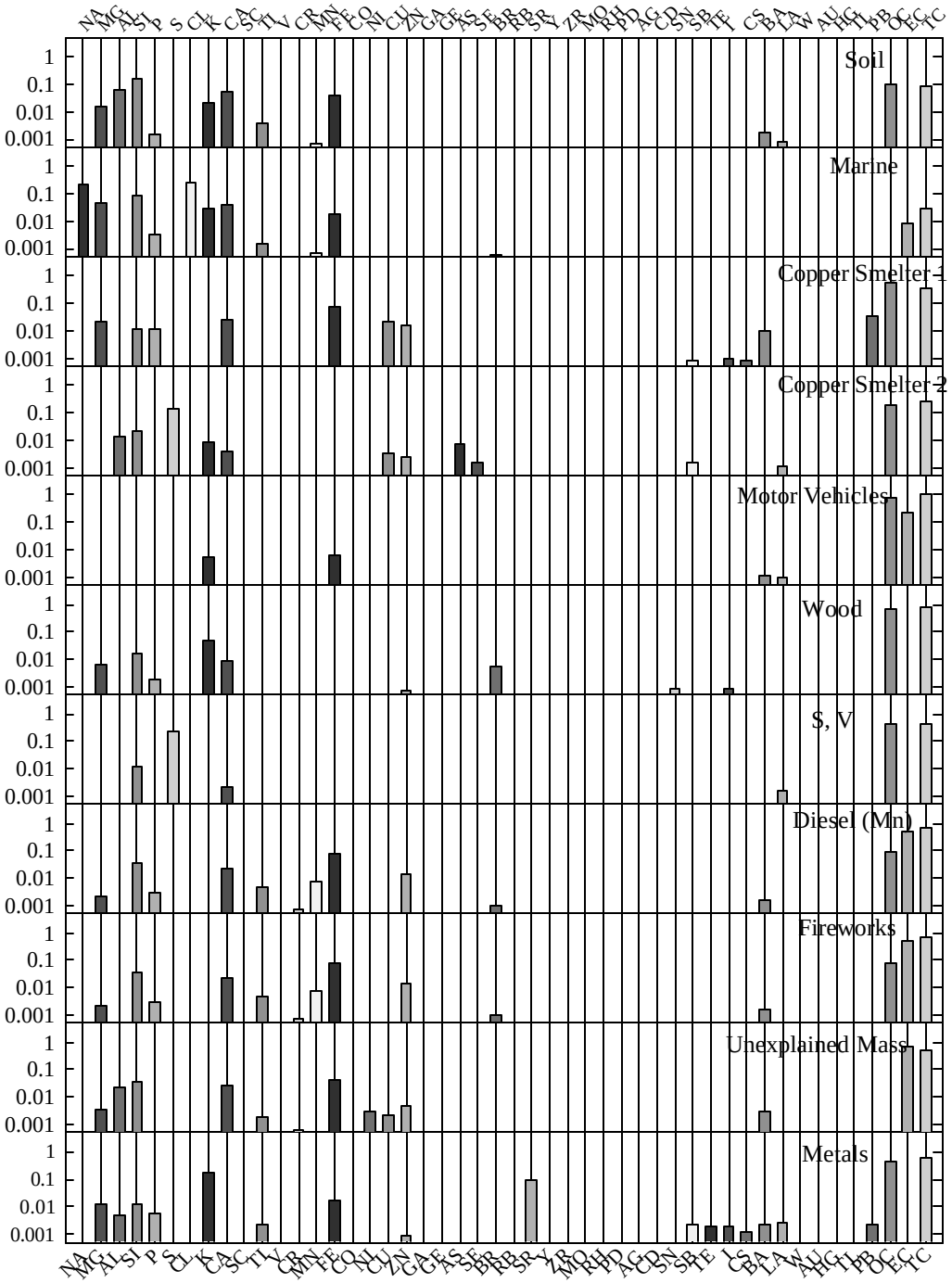
where **D**($*_{ih}$, *p*) is an element with the index for the wind direction during hour *h* of day *i* for the *p*th source, **V**($<_{ih}$, *p*) is the element with the index for the wind speed during hour *h* of day *i* for the *p*th source, **T(J**$_{ih}$,p) is the element with the index for time of day,

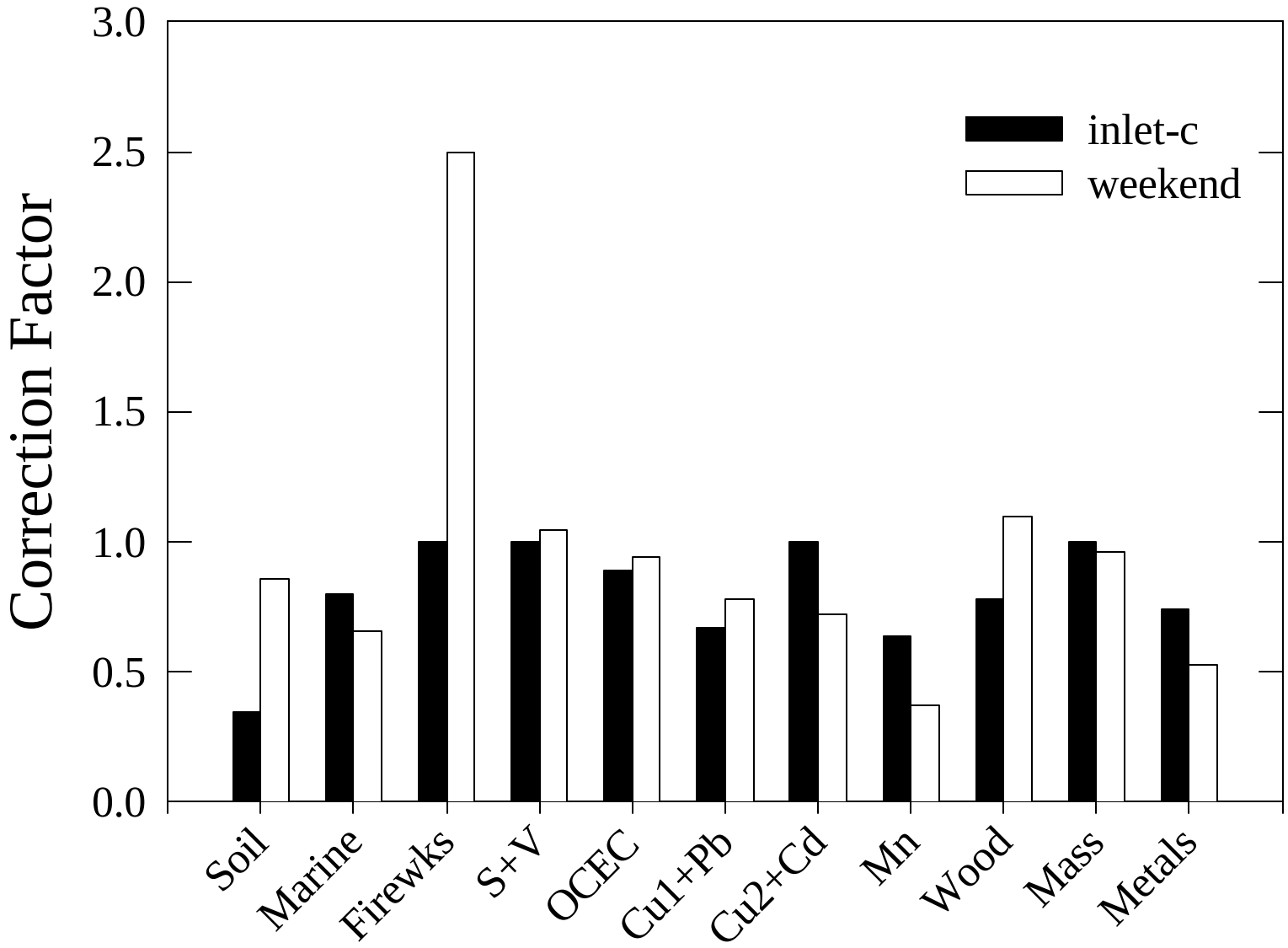
Expanded PMF Model

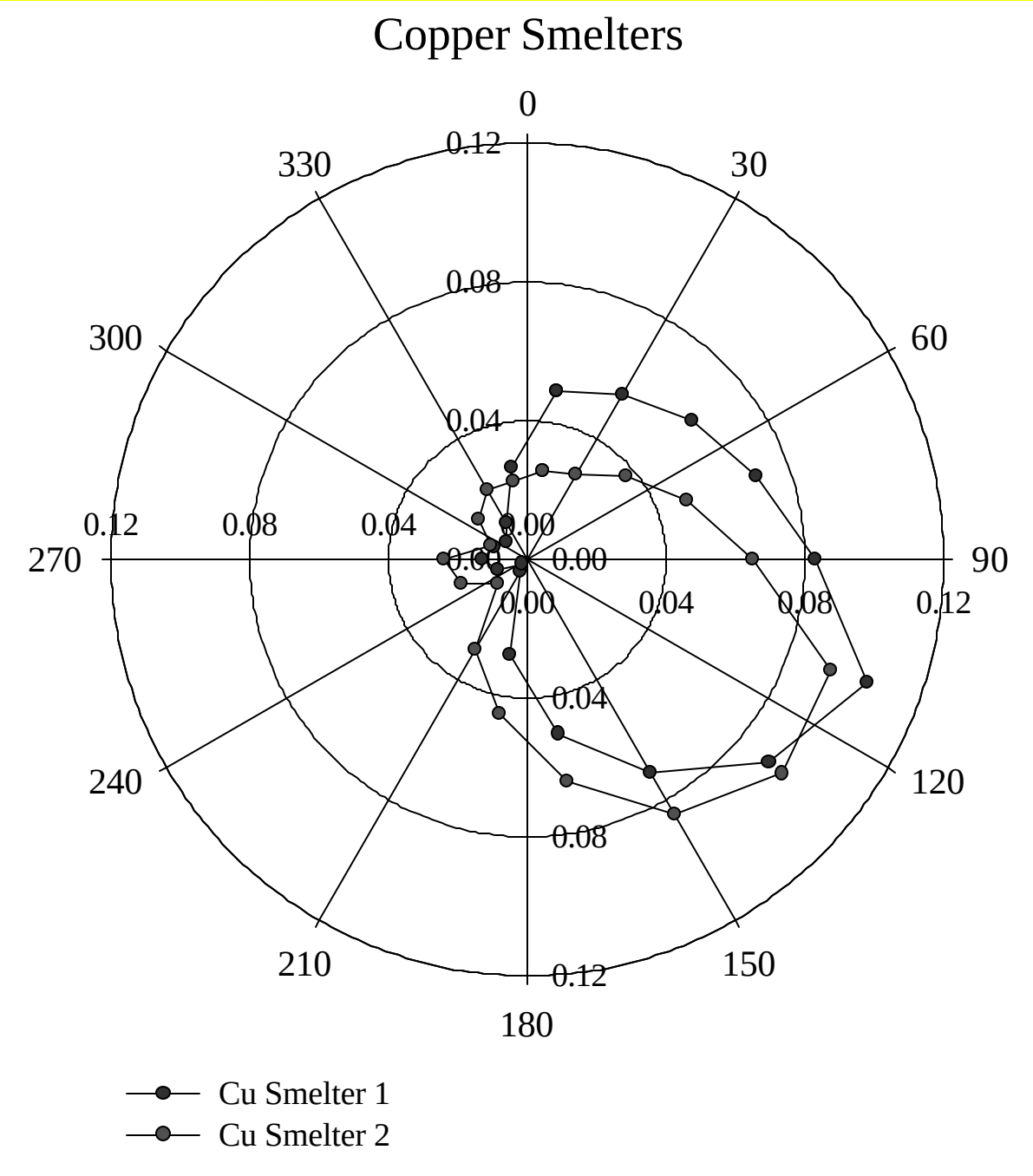
W(T_i, *p*) is the element with the index corresponding to day *i* for the weekday/weekend factor for the *p*th source, **I**(4_I,p) is the element with the index corresponding to before or after the change in the inlet, and **S**(F_i, *p*) is the element with the index corresponding to the time-of-year classification of day *i* for the *p*th source.

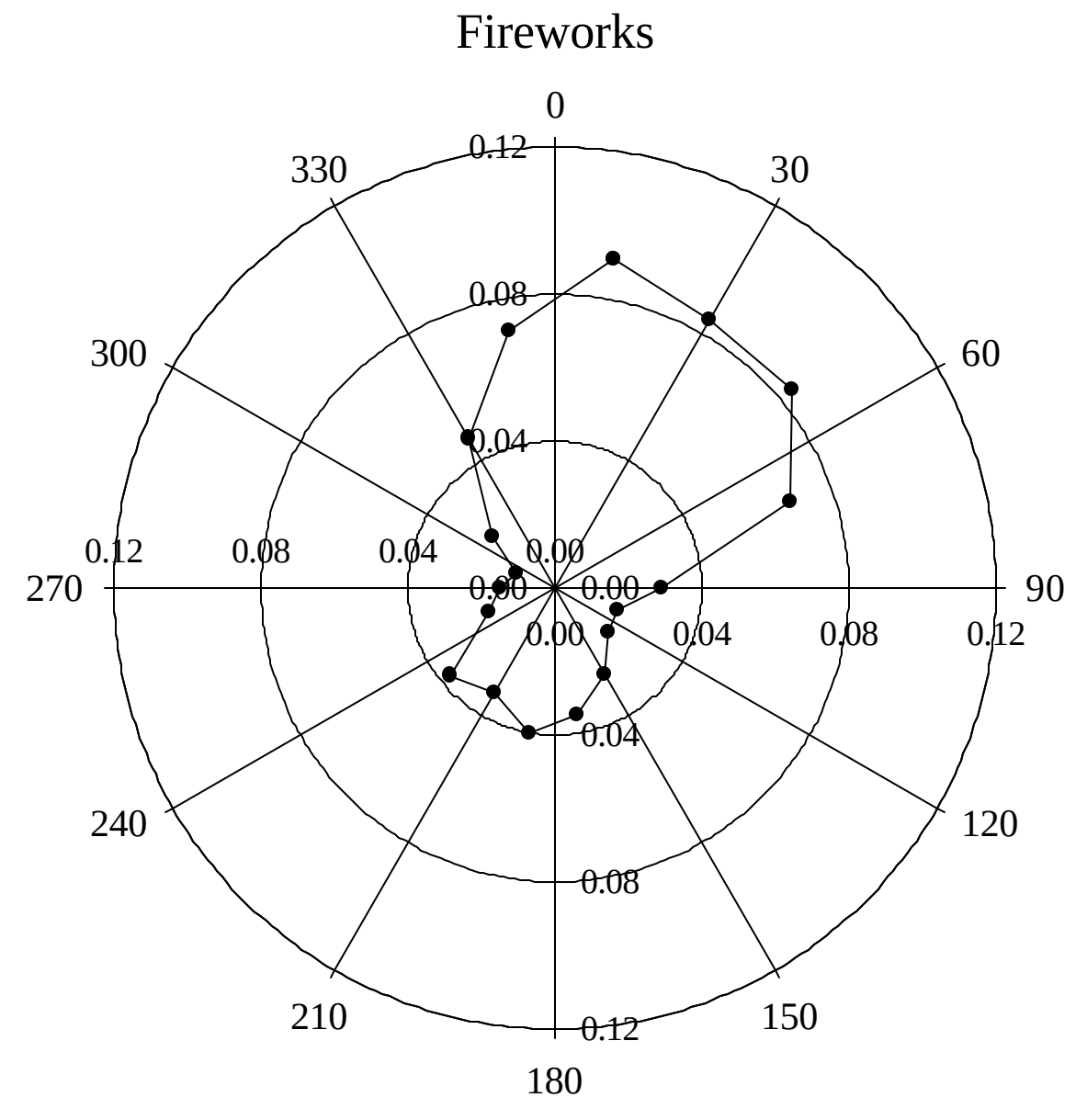
Expanded PMF Model

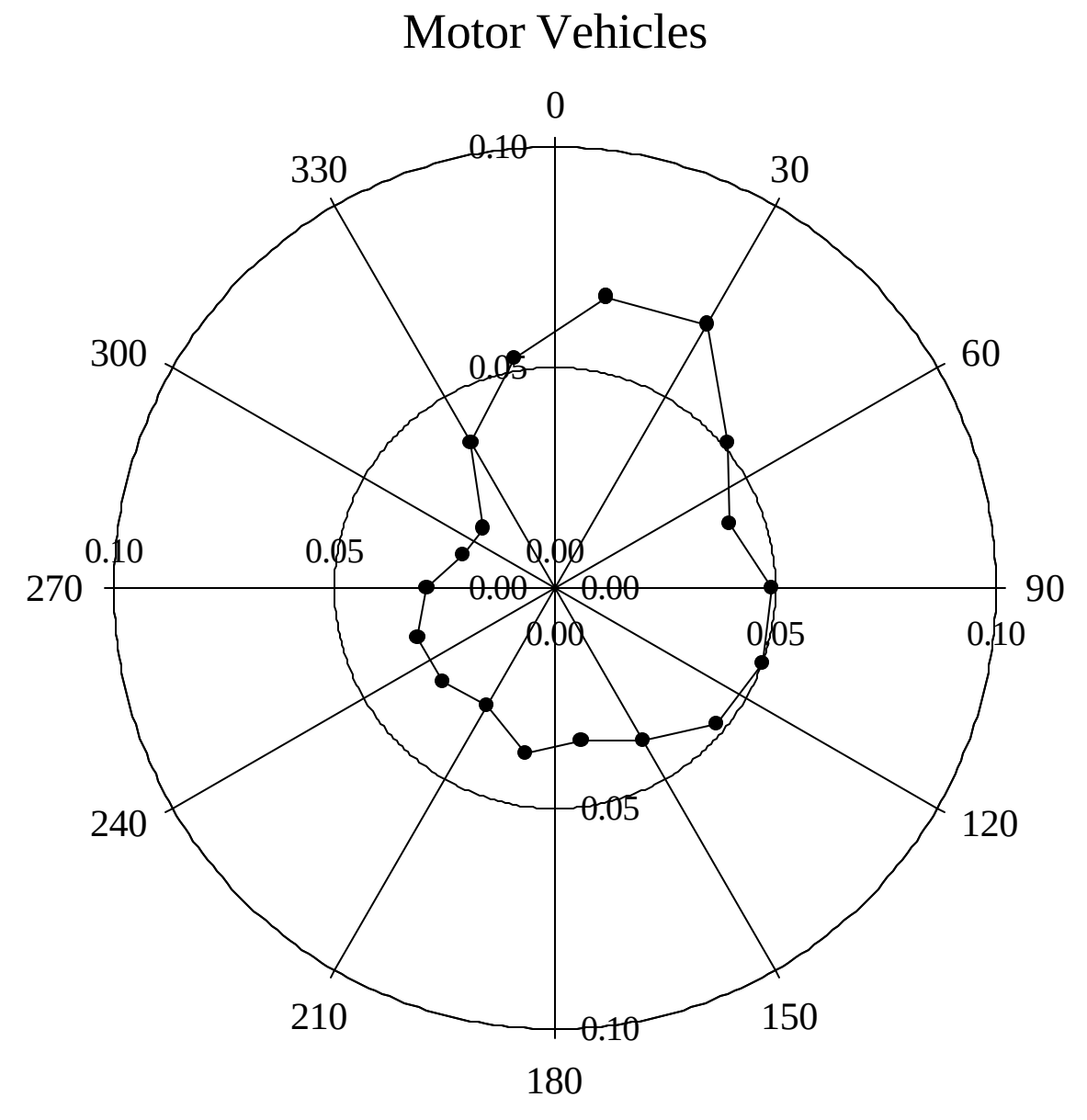
The expanded model permitted the extractions of eleven factors including sources identified as motor vehicles, diesel vehicles, wood smoke, soil, sulfur, 2 copper smelters, marine, metals, fireworks, and unmeasured mass

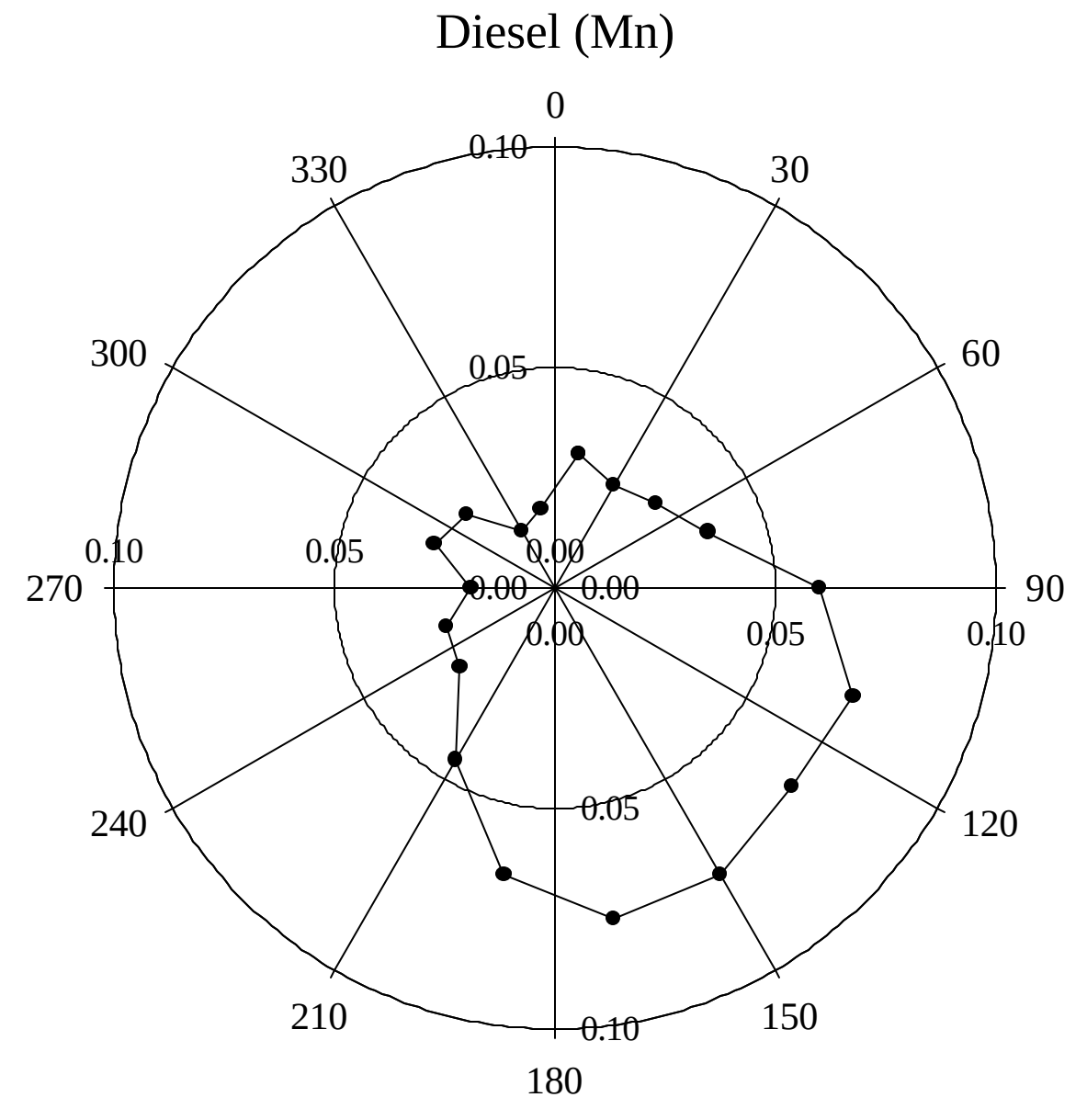

Soil
Marine
Copper Smelter 1
Copper Smelter 2
Motor Vehicles
Wood
S, V
Diesel (Mn)
Fireworks
Unexplained Mass
Metals
1
0.1
0.01
0.001

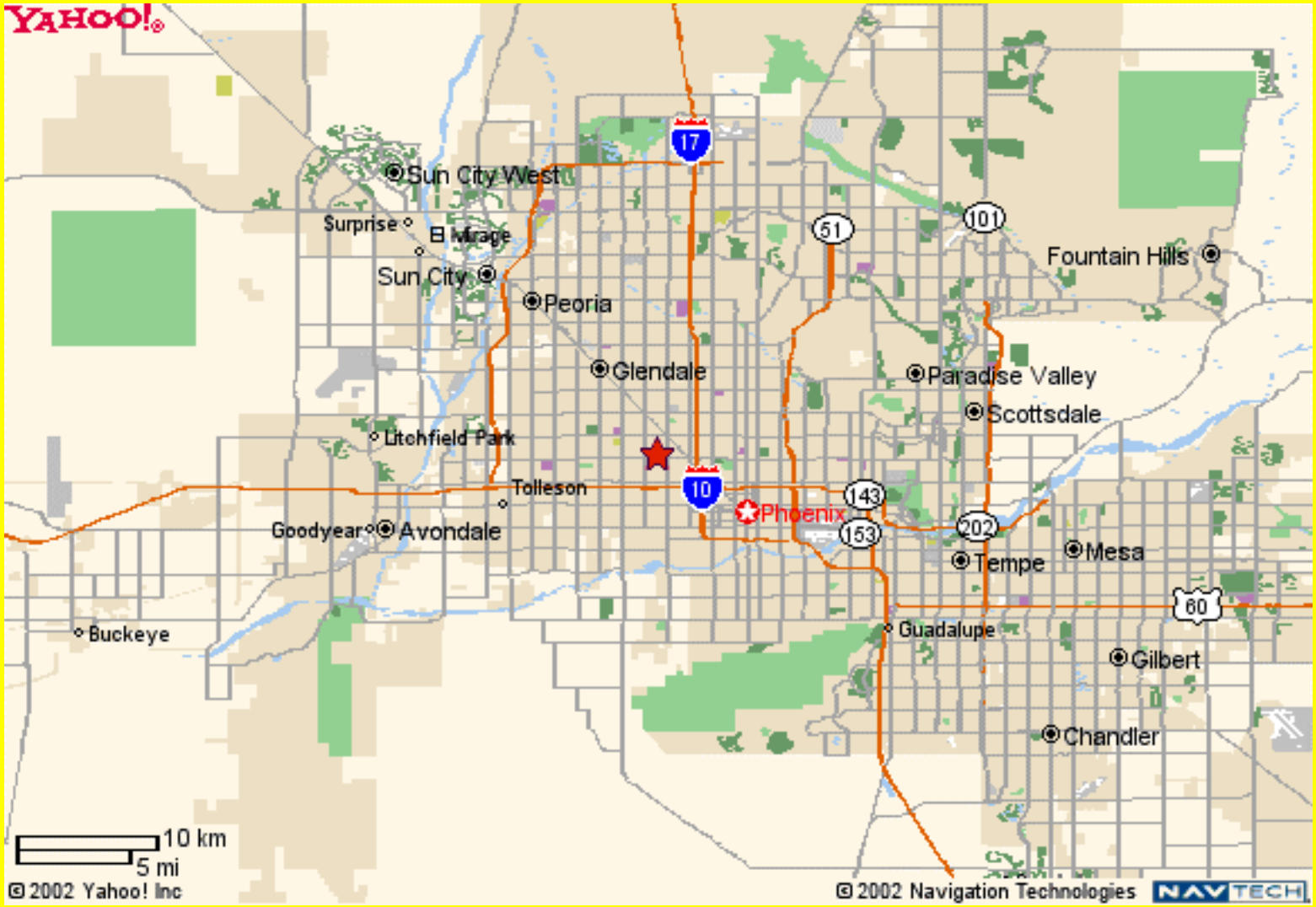

Correction Factor
3.0
2.5
2.0
1.5
1.0
0.5
0.0
inlet-c
weekend
Soil
Marine
Firewks
S+V
OCEC
Cu1+Pb
Cu2+Cd
Mn
Wood
Mass
Metals


Copper Smelters
0
30
60
90
120
150
180
210
240
270
300
330
0.12
0.08
0.04
0.00
Cu Smelter 1
Cu Smelter 2


Fireworks
0
30
60
90
120
150
180
210
240
270
300
330
0.12
0.08
0.04
0.00


Motor Vehicles
0
30
60
90
120
150
180
210
240
270
300
330
0.10
0.05
0.00
0.00
0.00
0.00
0.05
0.10
0.05
0.10
0.05
0.10


Diesel (Mn)
0
30
60
90
120
150
180
210
240
270
300
330
0.10
0.05
0.00
0.00
0.05
0.10
0.05
0.00
0.00
0.05
0.10


YAHOO!
Sun City West
Surprise
El Mirage
Sun City
Peoria
Glendale
Litchfield Park
Tolleson
Goodyear
Avondale
Buckeye
Phoenix
Paradise Valley
Scottsdale
Fountain Hills
Tempe
Mesa
Guadalupe
Gilbert
Chandler
17
10
51
101
143
153
202
60
10 km
5 mi
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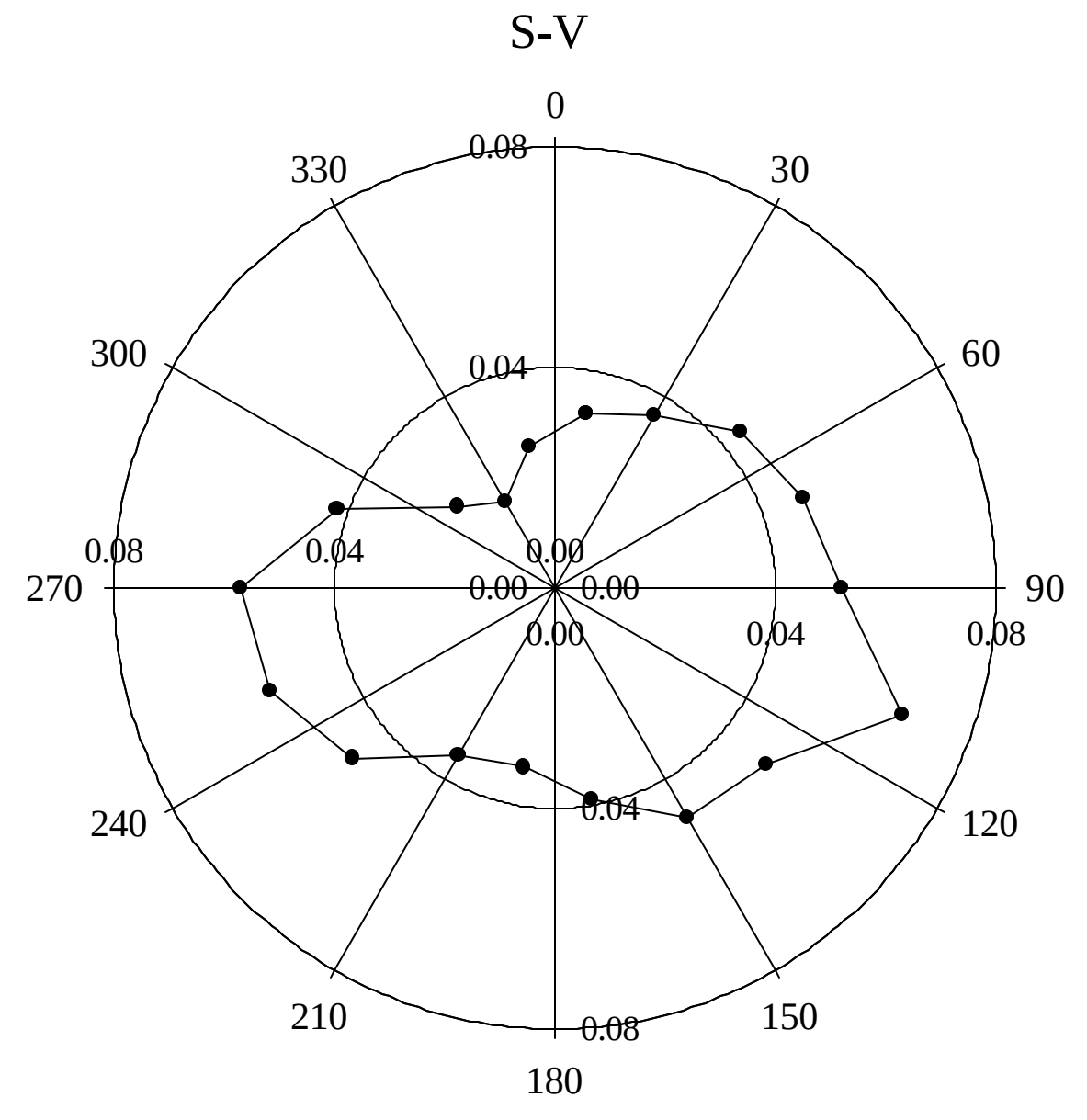
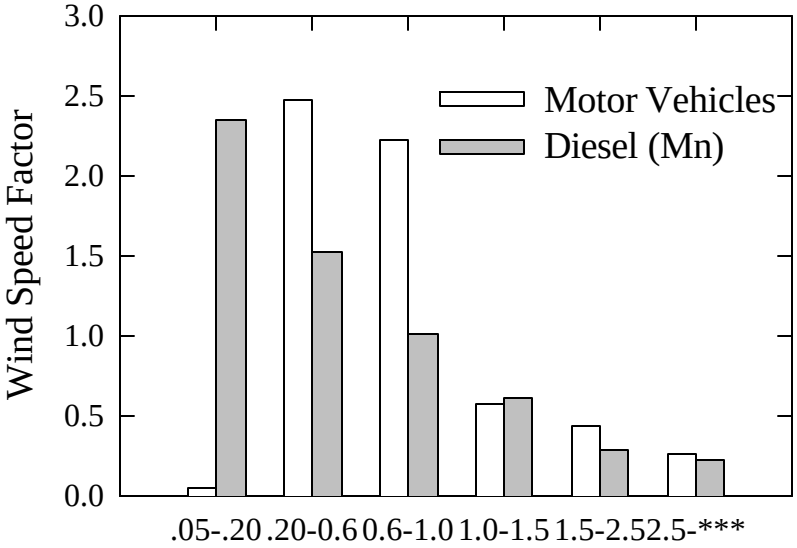
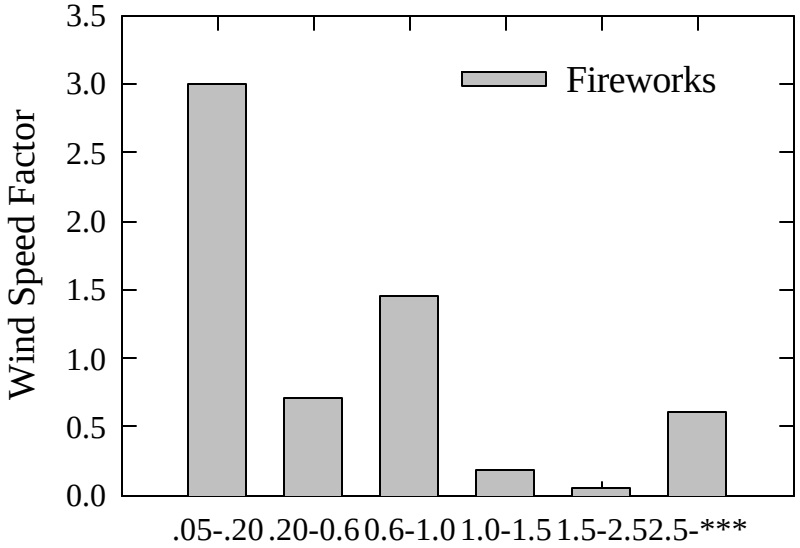
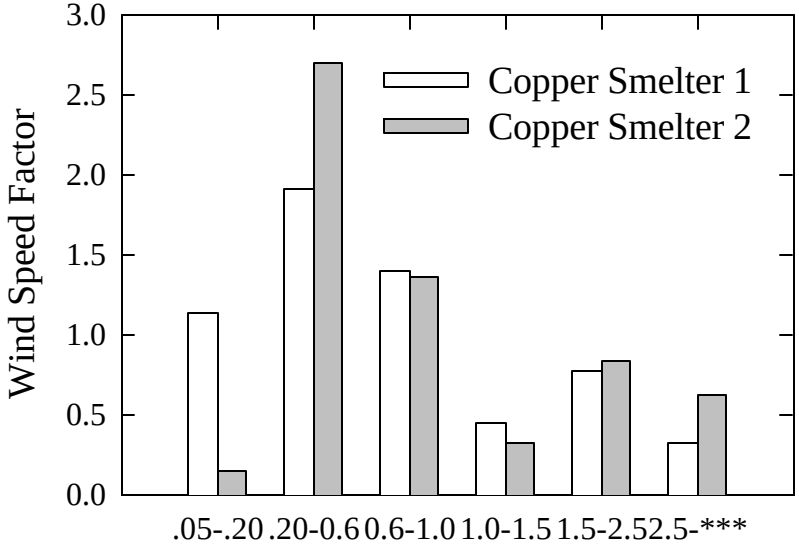
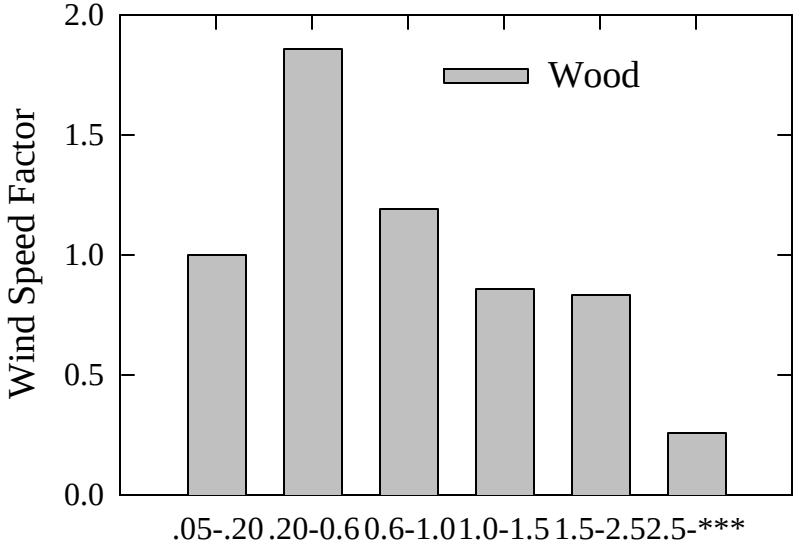
NAVTECH

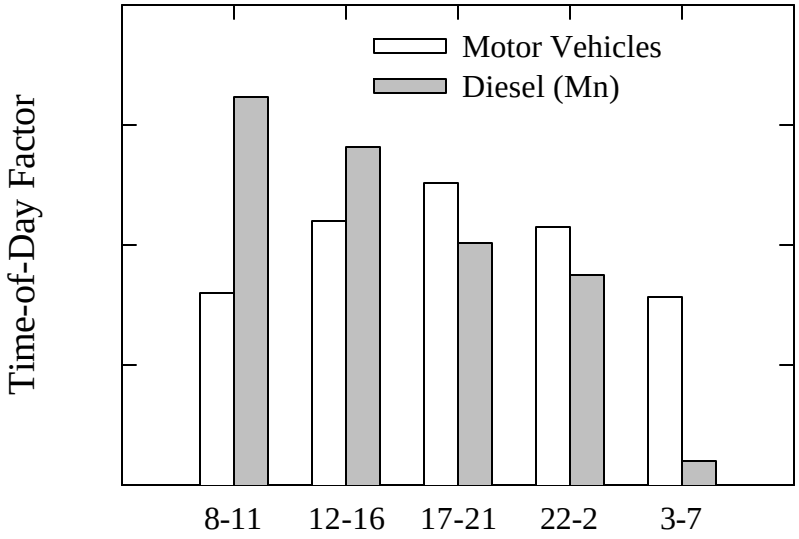

S-V
0
30
60
90
120
150
180
210
240
270
300
330
0.08
0.04
0.00
0.00
0.00
0.00
0.04
0.08
0.04
0.08

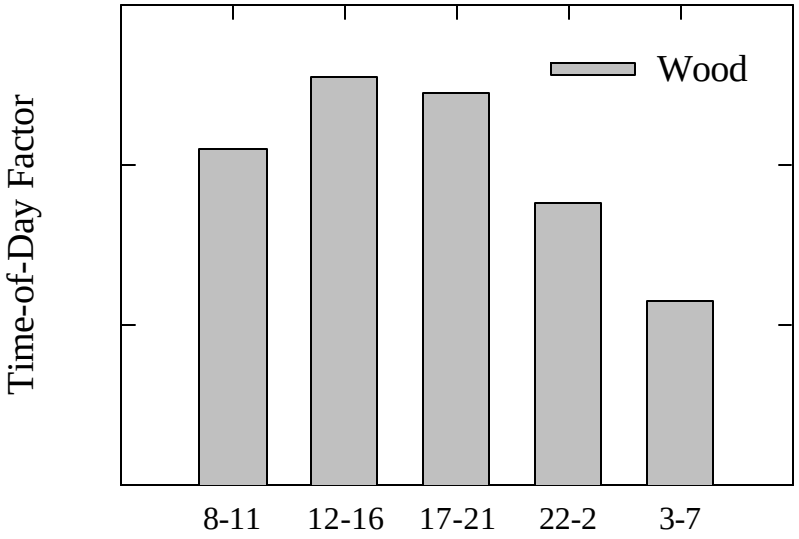

Wind Speed Factor
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Motor Vehicles
Diesel (Mn)
.05-.20
.20-0.6
0.6-1.0
1.0-1.5
1.5-2.5
2.5-***

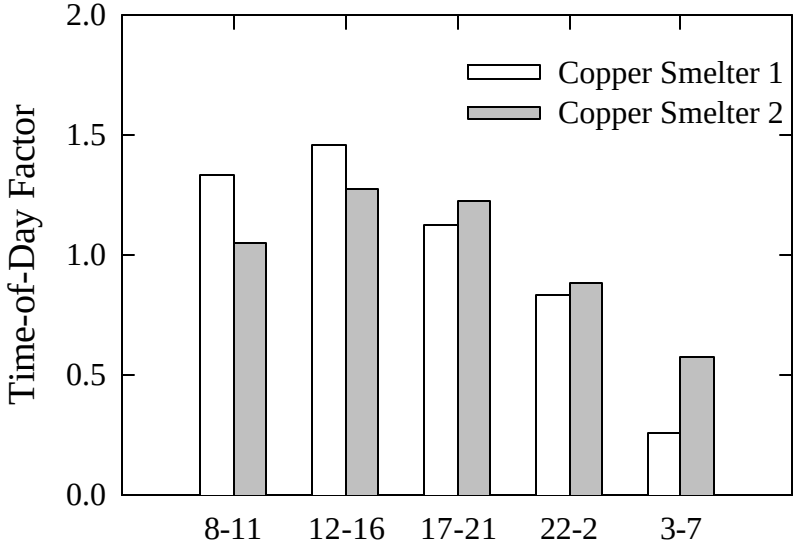

Wind Speed Factor
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Fireworks
.05-.20
.20-0.6
0.6-1.0
1.0-1.5
1.5-2.5
2.5-***

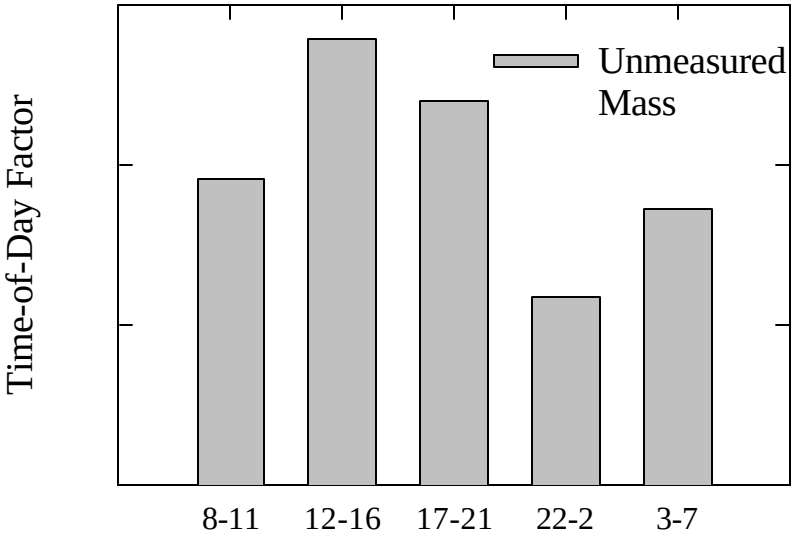

Wind Speed Factor
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Copper Smelter 1
Copper Smelter 2
.05-.20
.20-0.6
0.6-1.0
1.0-1.5
1.5-2.5
2.5-***

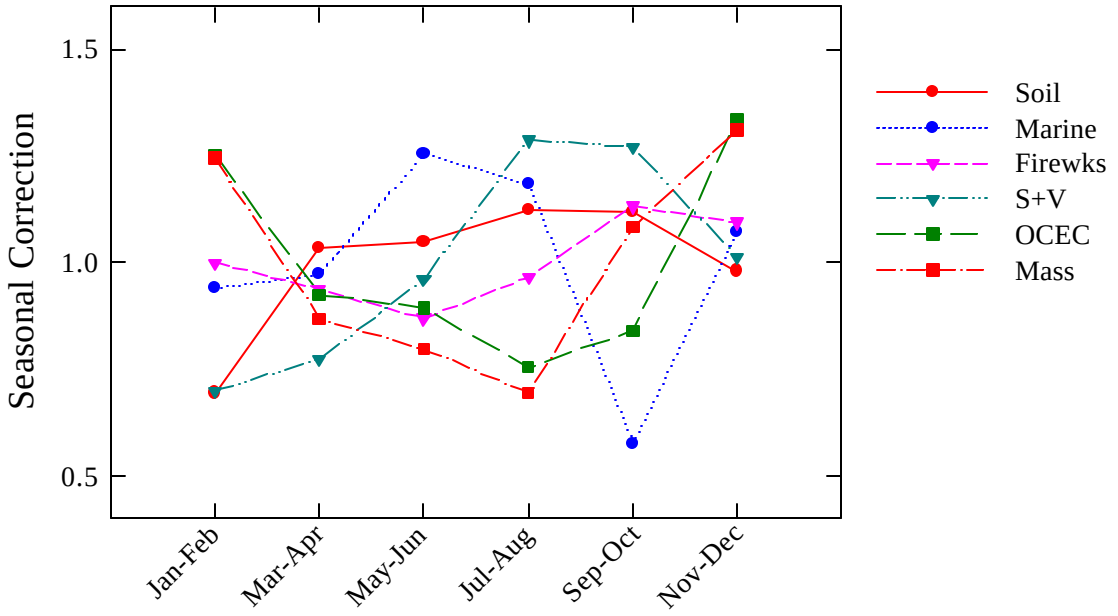

Wind Speed Factor
2.0
1.5
1.0
0.5
0.0
Wood
.05-.20
.20-0.6
0.6-1.0
1.0-1.5
1.5-2.5
2.5-***

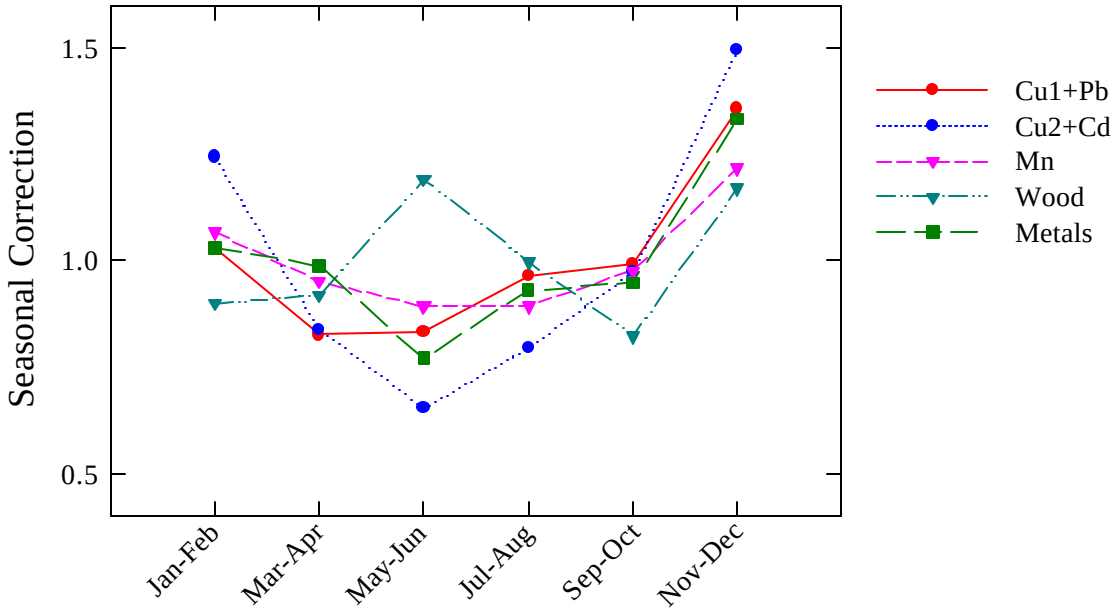

Motor Vehicles
Diesel (Mn)
Time-of-Day Factor
8-11
12-16
17-21
22-2
3-7


Wood
Time-of-Day Factor
8-11
12-16
17-21
22-2
3-7


2.0
1.5
1.0
0.5
0.0
Copper Smelter 1
Copper Smelter 2
Time-of-Day Factor
8-11
12-16
17-21
22-2
3-7


Unmeasured Mass
Time-of-Day Factor
8-11
12-16
17-21
22-2
3-7


Seasonal Correction
1.5
1.0
0.5
Jan-Feb
Mar-Apr
May-Jun
Jul-Aug
Sep-Oct
Nov-Dec
Soil
Marine
Firewks
S+V
OCEC
Mass


Seasonal Correction
1.5
1.0
0.5
Jan-Feb
Mar-Apr
May-Jun
Jul-Aug
Sep-Oct
Nov-Dec
Cu1+Pb
Cu2+Cd
Mn
Wood
Metals

QUESTIONS?

And thanks for the invitation to visit!