# POSITIVE MATRIX FACTORIZATION (PMF) 5.0

EPA United States Environmental Protection Agency

# AGENDA

- Source apportionment analysis
- Positive matrix factorization (PMF) model
- Common tracers in the atmosphere
- Examples
- Final tips & takeaways

# What is source apportionment in atmospheric sciences?

With source apportionment analysis we will know:

- Where does this pollution come from?
- How much of it comes from traffic, industry, agriculture, natural sources, etc.?

**Source apportionment is critically important in atmospheric sciences because it helps *identify* and *quantify* the contributions of different emission (pollution) sources to air quality.**

# Why is important the source apportionment in atmospheric sciences?

### 1. Effective Air Quality Management

Understanding the sources of pollutants (e.g., vehicles, industry, agriculture, wildfires) allows policymakers to target the most significant contributors with regulations or interventions.

### 2. Public Health Protection

Different pollution sources can have varying health impacts. For example, fine particles from diesel exhaust may be more harmful than those from natural dust. Apportionment helps prioritize actions to reduce the most toxic sources.

### 3. Model Validation and Improvement

Chemical transport and air quality models rely on ***assumptions about emissions***. Source apportionment studies provide ***real-world data*** to validate and refine these models.

# Why is important the source apportionment in atmospheric sciences?

**4. Climate Change Implications**

Some pollutants affect both air quality and climate (e.g., black carbon, ozone). Source apportionment informs strategies that co-benefit climate and air quality goals.

**5. Global Pollution**

Air pollution doesn't have borders. Apportionment can distinguish between local and long-range transported pollution, guiding diplomatic or regional cooperation.




# WHAT IS THE POSITIVE MATRIX FACTORIZATION (PMF) MODEL?

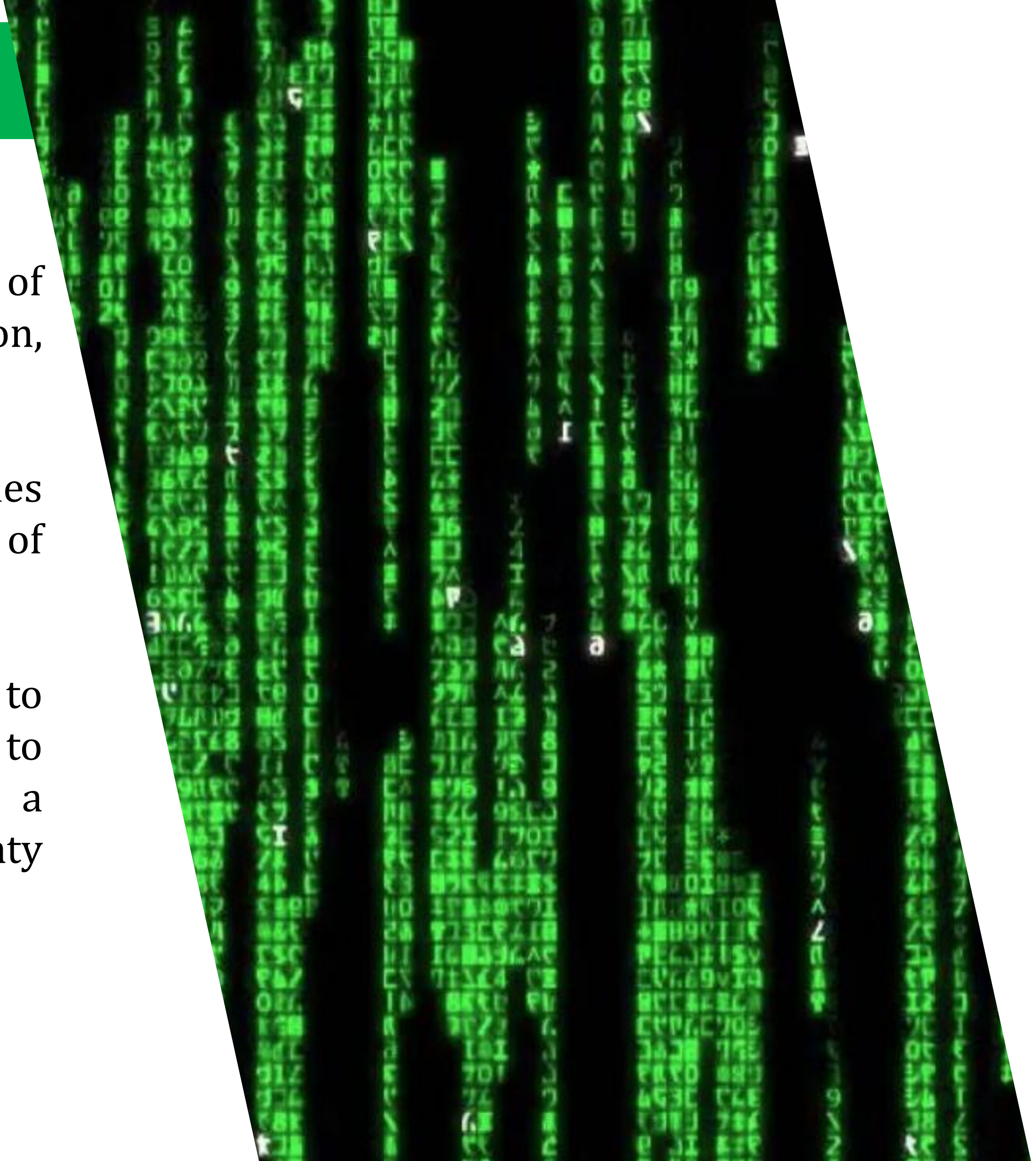
# WHAT IS THE POSITIVE MATRIX FACTORIZATION (PMF) MODEL?

The PMF Model can analyze a wide range of environmental sample data: sediments, wet deposition, surface water, and ambient air.

EPA's PMF Model reduces the large number of variables in complex analytical data sets to combinations of species called source types and source contributions.

The source types are identified by comparing them to measured profiles. Source contributions are used to determine how much each source contributed to a sample. In addition, PMF provides robust uncertainty estimates and diagnostics.

https://www.epa.gov/air-research/positive-matrix-factorization-model-environmental-data-analyses



# What is the Positive Matrix Factorization (PMF) Model?

•PMF is a **receptor model** that analyzes measured concentrations of pollutants (e.g., $PM_{2.5}$ chemical components) at a given location.
•It statistically decomposes this data into a set of **source profiles** and **contributions** over time—without requiring prior knowledge of the sources.

**How it works:**
•The observed concentration matrix **X** is approximated by multiplying two matrices:

$$\mathbf{X} = \mathbf{G} \cdot \mathbf{F} + \mathbf{E}$$

- **G** = Contributions of each source to each sample (time series)
- **F** = Chemical profiles of sources (what each source emits)
- **E** = Residual (unexplained part)

**Cons:**
•**Requires expertise to interpret results**
•Sometimes sensitive to missing or noisy data

# HOW DOES THE MODEL WORK?

**Input:**

PMF users provide files of sample species ***concentrations*** and ***uncertainties*** and the number of sources. The model calculates source profiles or fingerprints, source contributions, and source profile uncertainties. PMF Model results are constrained to provide positive source contributions, and the uncertainty weighted difference between the observed and predicted species concentration is minimized.

| | A | B | C | D | E | F | G | H | I | J | K | L | M | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | Aluminum | Ammoniun | Bromine | Calcium | Chlorine | Copper | EC | Iron | Lead | Manganes | Nickel | Nitrate | OC |
| 2 | DATE | µg/m3 | µg/m3 | µg/m3 | µg/m3 | µg/m3 | µg/m3 | µg/m3 | µg/m3 | µg/m3 | µg/m3 | µg/m3 | µg/m3 | µg/m3 |
| 3 | 2/9/2000 | 0.0201 | 3.6020 | 0.0107 | 0.0676 | 0.0647 | 0.0059 | 3.1230 | 0.1497 | 0.0157 | 0.0043 | 0.0577 | 5.3700 | 7.3930 |
| 4 | 2/15/2000 | 0.0057 | 1.3740 | 0.0006 | 0.0325 | 0.0016 | 0.0019 | 1.0710 | 0.0673 | 0.0055 | 0.0004 | 0.0285 | 0.8785 | 3.3310 |
| 5 | 2/27/2000 | 0.0029 | 2.1860 | 0.0028 | 0.0422 | 0.0288 | 0.0028 | 0.6732 | 0.0727 | 0.0073 | 0.0002 | 0.0215 | 3.8820 | 5.2030 |
| 6 | 3/4/2000 | 0.0011 | 0.4501 | 0.0014 | 0.0329 | 0.0024 | 0.0010 | 0.5503 | 0.0483 | 0.0061 | 0.0004 | 0.0188 | 0.4562 | 3.6160 |
| 7 | 3/10/2000 | 0.0075 | 0.3099 | 0.0006 | 0.0247 | 0.0039 | 0.0003 | 0.2869 | 0.0565 | 0.0032 | 0.0016 | 0.0083 | 0.6763 | 2.8140 |
| 8 | 3/22/2000 | 0.0006 | 1.1570 | 0.0033 | 0.0265 | 0.0015 | 0.0029 | 0.9487 | 0.0821 | 0.0044 | 0.0012 | 0.0107 | 1.0670 | 2.4150 |
| 9 | 4/6/2000 | 0.0256 | 1.3520 | 0.0025 | 0.0863 | 0.0026 | 0.0041 | 2.1990 | 0.1492 | 0.0089 | 0.0034 | 0.0254 | 1.4660 | 4.7350 |
| 10 | 4/9/2000 | 0.0165 | 0.2800 | 0.0011 | 0.0263 | 0.0016 | 0.0003 | 0.8535 | 0.0396 | 0.0017 | 0.0019 | 0.0257 | 0.2515 | 1.6760 |
| 11 | 4/12/2000 | 0.0108 | 1.1290 | 0.0026 | 0.0304 | 0.0080 | 0.0046 | 0.9983 | 0.0959 | 0.0042 | 0.0001 | 0.0344 | 1.1900 | 2.6360 |
| 12 | 4/15/2000 | 0.0065 | 1.5640 | 0.0037 | 0.1075 | 0.0296 | 0.0059 | 3.1430 | 0.1976 | 0.0110 | 0.0026 | 0.0437 | 4.3040 | 6.9460 |
| 13 | 4/18/2000 | 0.0072 | 0.1983 | 0.0028 | 0.0351 | 0.0073 | 0.0017 | 0.6603 | 0.0539 | 0.0004 | 0.0027 | 0.0082 | 0.6816 | 1.9990 |
| 14 | 4/21/2000 | 0.0092 | 0.1432 | 0.0022 | 0.0250 | 0.0042 | 0.0023 | 0.7096 | 0.0765 | 0.0003 | 0.0009 | 0.0126 | 0.6017 | 1.7230 |
| 15 | 4/24/2000 | 0.0289 | 0.4066 | 0.0000 | 0.0337 | 0.0007 | 0.0006 | 1.1100 | 0.0830 | 0.0067 | 0.0005 | 0.0256 | 0.2174 | 2.4420 |
| 16 | 4/27/2000 | 0.0033 | 1.5030 | 0.0031 | 0.0329 | 0.0010 | 0.0024 | 1.4970 | 0.0840 | 0.0082 | 0.0013 | 0.0247 | 3.3670 | 3.5360 |
| 17 | 4/30/2000 | 0.0120 | 0.5734 | 0.0021 | 0.0442 | 0.0097 | 0.0022 | 0.6726 | 0.0741 | 0.0025 | 0.0041 | 0.0153 | 0.5117 | 3.3610 |
| 18 | 5/3/2000 | 0.0098 | 1.3200 | 0.0014 | 0.0365 | 0.0039 | 0.0015 | 1.1210 | 0.0735 | 0.0077 | 0.0000 | 0.0056 | 1.3380 | 4.2670 |
| 19 | 5/12/2000 | 0.0209 | 0.1049 | 0.0013 | 0.0394 | 0.0003 | 0.0033 | 1.2070 | 0.1108 | 0.0046 | 0.0000 | 0.0114 | 0.6438 | 3.8460 |
| 20 | 5/15/2000 | 0.0096 | 1.1600 | 0.0010 | 0.0337 | 0.0023 | 0.0002 | 0.8730 | 0.0902 | 0.0064 | 0.0004 | 0.0167 | 0.3547 | 3.1960 |
| 21 | 5/18/2000 | 0.0348 | 2.9630 | 0.0037 | 0.1088 | 0.0083 | 0.0066 | 1.9910 | 0.1519 | 0.0054 | 0.0031 | 0.0166 | 3.3450 | 6.1610 |
| 22 | 5/21/2000 | 0.0008 | 1.9910 | 0.0014 | 0.0409 | 0.0011 | 0.0025 | 0.4828 | 0.0449 | 0.0038 | 0.0018 | 0.0099 | 2.0890 | 2.5760 |
| 23 | 5/24/2000 | 0.0057 | 1.8440 | 0.0010 | 0.0386 | 0.0013 | 0.0005 | 1.4190 | 0.0957 | 0.0045 | 0.0007 | 0.0553 | 1.3390 | 4.2690 |

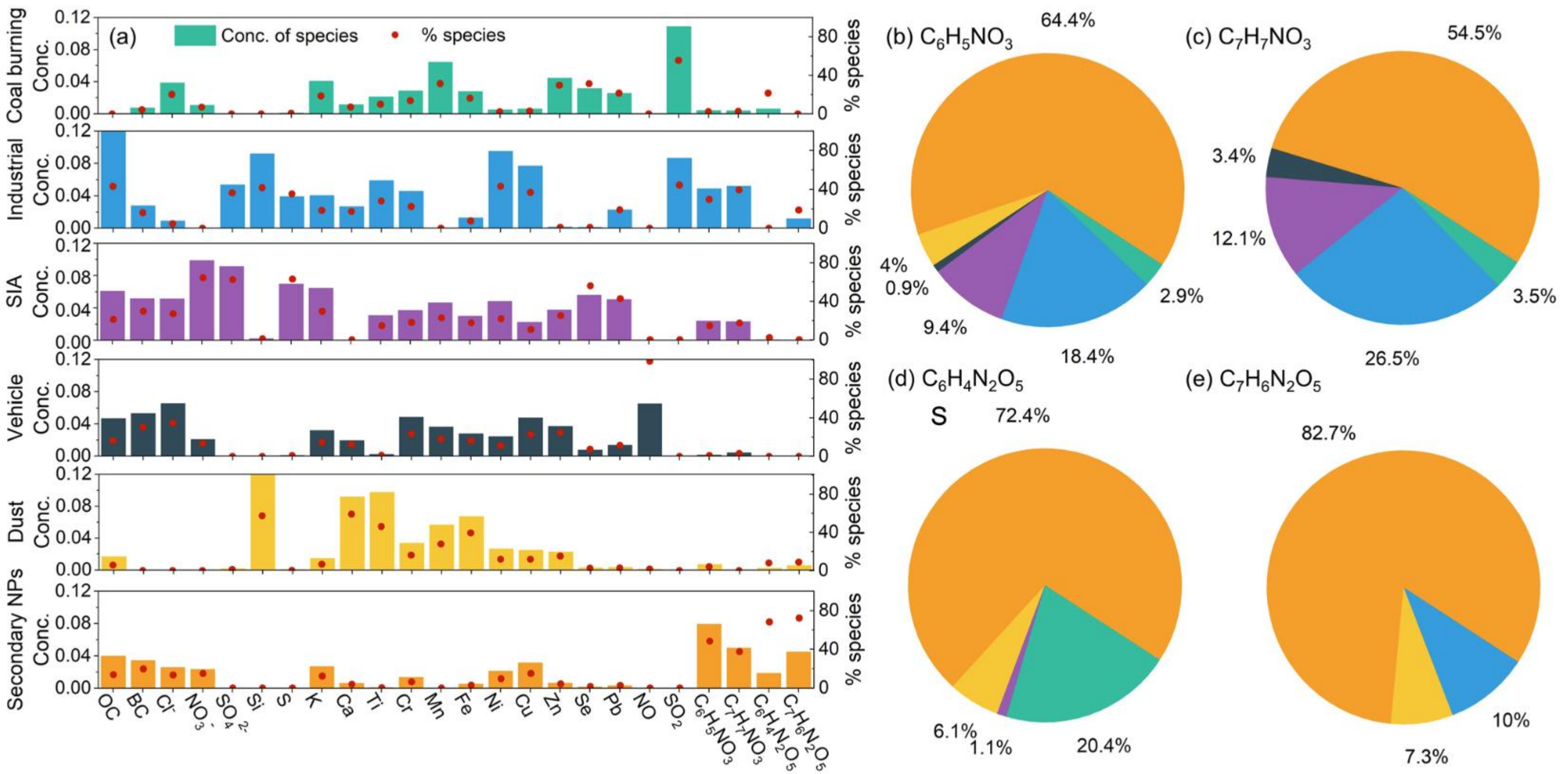
| | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| 1 | unc | Aluminum | Ammoniur | Arsenic | Barium | Bromine | Calcium | Chlorine |
| 2 | 2 | 0.00419 | 0.0125 | 0.00098 | 0.0068 | 0.0016 | 0.0038 | 0.002635 |
| 3 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| 4 | | | | | | | | |

# HOW DOES THE MODEL WORK?

**Output:**
PMF Model software uses graphical user interfaces that ease data input, visualization of model diagnostics, and exporting of results.

The model is free of charge and does not require a license or other software to use.

Algorithms used in the PMF Model have been peer reviewed by leading air and water quality management scientists.




https://www.epa.gov/air-research/positive-matrix-factorization-model-environmental-data-analyses

*Men Xia et al., 2023, Journal of Geophysical Research: Atmospheres 128(22) DOI: 10.1029/2023JD039551*

# What are the tracers?

**In environmental science, tracers or markers are substances or indicators used to track the movement, origin, or fate in natural systems such as water, in atmosphere, or in a biological organism.**

## Typical characteristic of a tracer:

- The tracer, must be emitted exclusively or predominantly by specific sources, giving those sources a relatively unique chemical signature.
- The tracer compound should be chemically stable in the atmosphere, reacting slowly enough to remain unchanged from the point of emission to the receptor site.
- Ideally, a tracer should not be formed through atmospheric reactions, nor should it volatilize during transport, in order to ensure that mass balance is maintained.

# Key tracers in atmospheric sciences

## Natural Sources

**Desert dust**

**Sea salts**

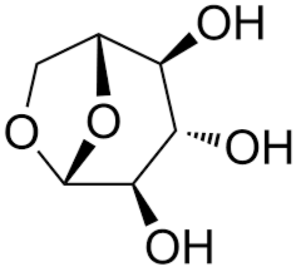
**Biomass burning**

**Al, Si, nss-Ca $^{2+}$**

$$\text{nss-Ca}^{2+} = \text{Total Ca}^{2+} - \left(\frac{\text{Ca}^{2+}}{\text{Na}^{+}}\right)_{\text{sea water}} \times \text{Na}^{+}_{\text{sample}}$$

**CL, ss-$Na^{+}$**

**Levoglucosan, nss-$K^{+}$**




*nss: non-sea salt*

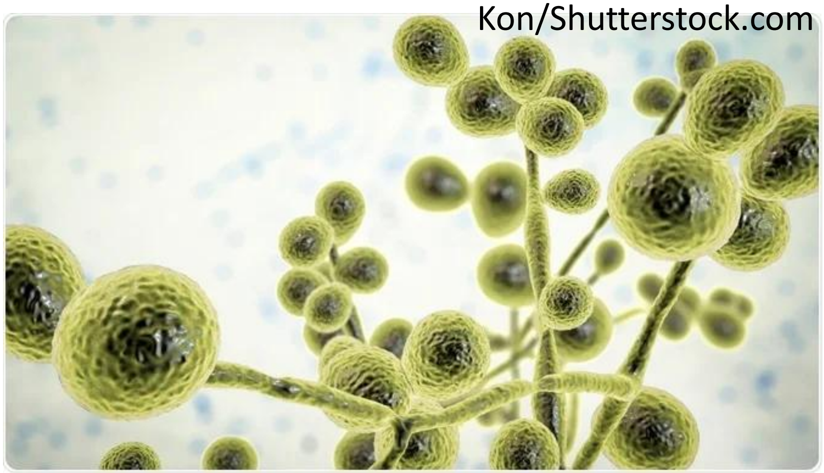
**[nss−$Ca^{2+}$]= [$Ca^{2+}$ ] – 0.0383 × [$Na^{+}$]**

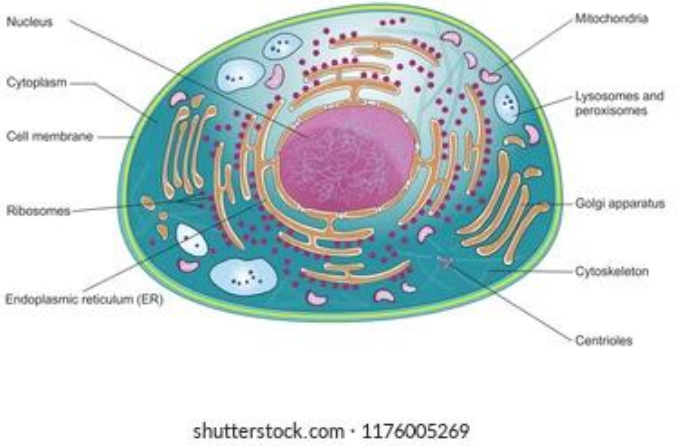
**[nss−$K^{+}$]= [$K^{+}$ ] – 0.0371 × [$Na^{+}$]**

# Key tracers in atmospheric sciences

## Natural Sources

Image Credit: Kateryna Kon/Shutterstock.com



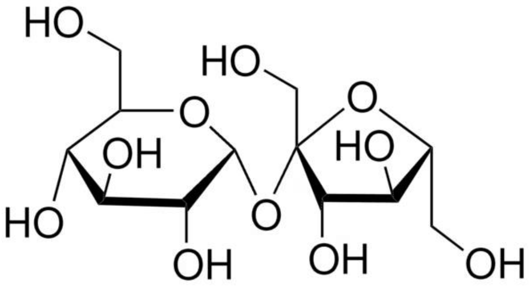



**Pollen**

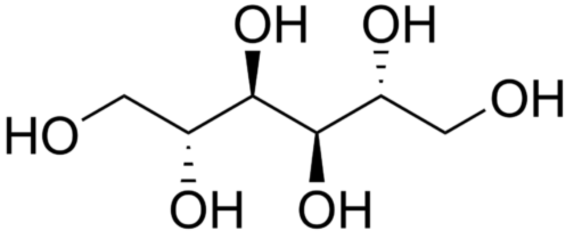
**Fungi**

**Mammals cells**

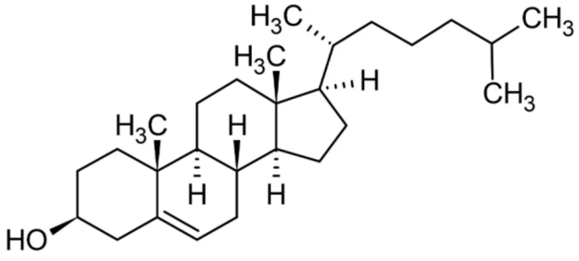
## Sucrose



## Mannitol



## Cholesterol



# Key tracers in atmospheric sciences

## Anthropogenic Sources


**Ship emissions**

**V and Ni**
**Emissions from marine fuel combustion**

**Industry and other anthropogenic emission**

**nss-$SO_4^{2-}$, $NO_3^-$, Pb, Cd, Cr**
**Cu, Fe → brake/tires**

**Industrial Sources**

**nss-$SO_4^{2-}$, Pb, Cd, Cr, Zn**

$$[nss{-}SO_2{}^{-4}] = [SO_2{}^{-4}]_{total} - 0.2517 \times [Na^+]$$

# Other Key tracers in atmospheric sciences

| Organics markers ↔ Origins | |
|---|---|
| MSA | Marine SOA |
| Levoglucosan | Primary biomass burning |
| 1-Nitropyrene (1-NP) | Diesel emission |
| 6H-Dibenzo[b,d]pyran-6-one | SOA PAH |
| Benzo[a]fluorenone | SOA/POA PAH |
| Benzo[b]fluorenone | SOA/POA PAH |
| 9-Nitroanthracene | SOA/POA PAH |
| 2-Nitrofluoranthene | SOA PAH |
| DHOPA | SOA Toluene |
| 4-Methyl-5-nitrocatechol | SOA Phenolic compounds |
| 3-Methyl-5-nitrocatechol | SOA Phenolic compounds |
| 2-Methylerythritol | SOA Isoprene |
| $\alpha$-Methylglyceric acid | SOA Isoprene |

**Credit to Prof. Hopke**

# PMF applications in atmospheric sciences

## EXAMPLES

# EXAMPLE-1

# Identifying the sources of atmospheric organic Phosphorus

npj | climate and atmospheric science

Explore content ⌄ About the journal ⌄ Publish with us ⌄

nature › npj climate and atmospheric science › articles › article

Article | Open access | Published: 03 December 2021

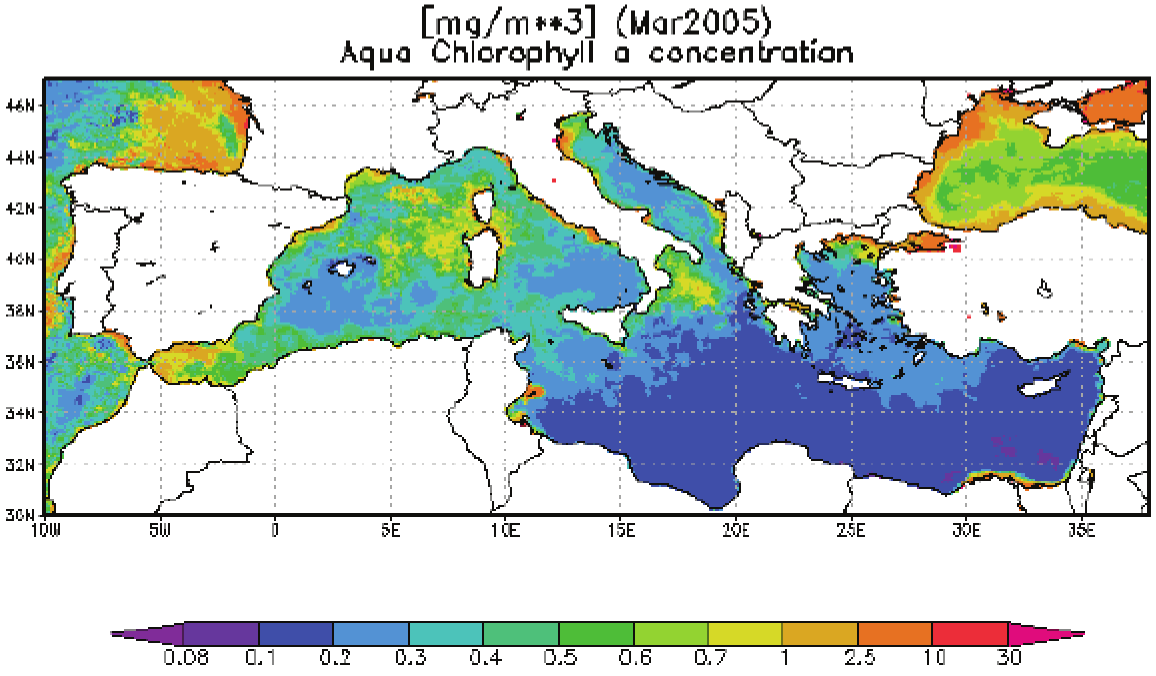
## Bioaerosols and dust are the dominant sources of organic P in atmospheric particles

Kalliopi Violaki, Athanasios Nenes, Maria Tsagkaraki, Marco Paglione, Stéphanie Jacquet, Richard Sempéré & Christos Panagiotopoulos

# • Background of the paper….

## Why is important the study of P for Mediterranean sea

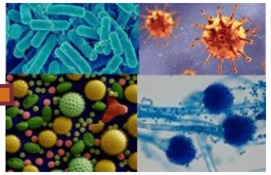
- It is known that East MS in P limited, while the atmosphere considered as an important nutrient path for the pelagic marine organisms, especially during stratification period (usually from May-September).
- Decode the chemical structure of the P fraction could reveal valuable information regarding their bioavailability in the marine environment.
- Understanding better the atmospheric chemistry of  P compounds and beyond the biochemical cycle of P.



# The global P sources according to modeling assessment

**Scenario B**

**26%**



**17%**

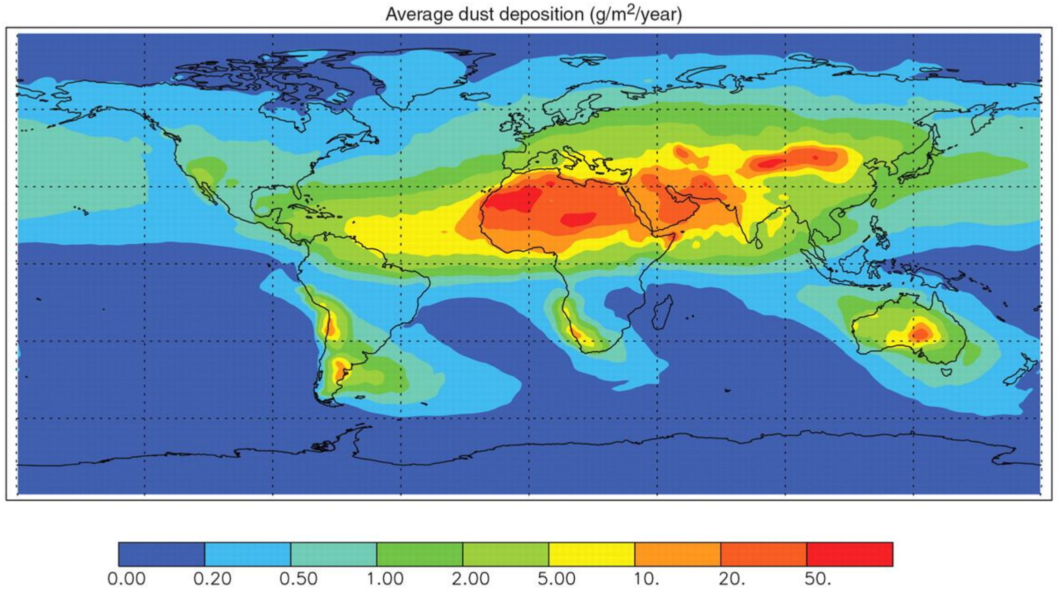
**52%**

**4.6%**

**0.2%**

**Total global P: 3.5 Tg P $y^{-1}$**

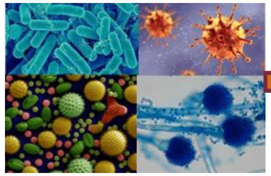
*Wang et al., 2015*




- Mediterranean seams to follow the scenario A due to proximity to Sahara desert.
- Scenario B could be a future scenario or a more regional scenario in areas with high frequency of BB events.
- Is missing the source distribution in org-P and inorg-P, which could explain different processes in P cycle.

**Scenario A**

**84%**



**12%**

**2%**

**2%**

**0.4%**

**0.4%**

**Total global P: 1.37 Tg P $y^{-1}$**

*Mahowald et al., 2008, Myriokefalitakis et al., 2016*

# EXAMPLE-1

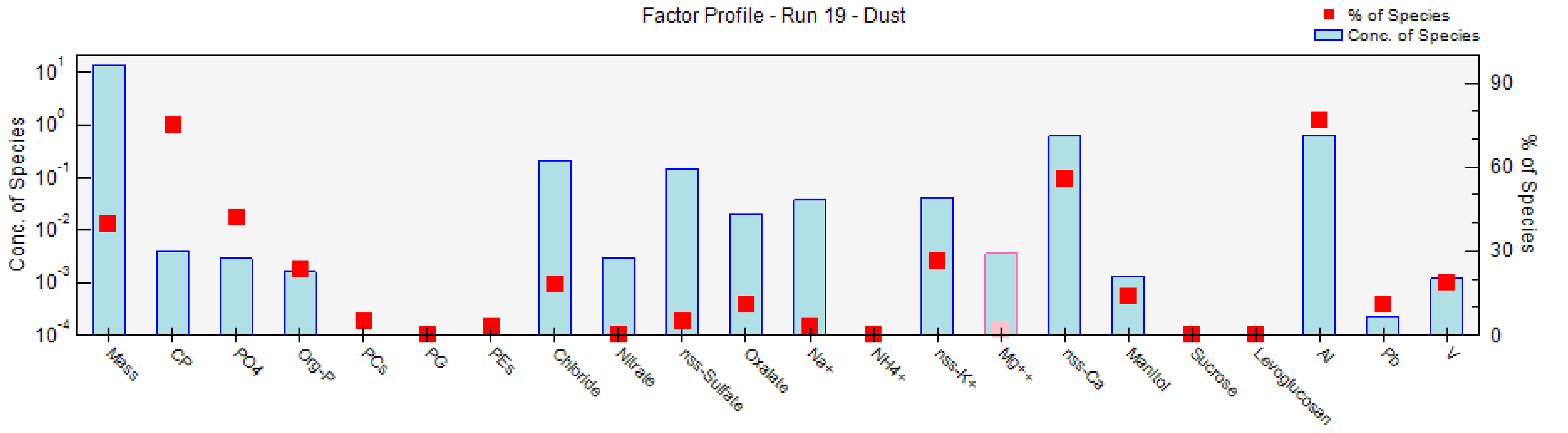
# Identifying the sources of atmospheric organic Phosphorus

**Supplementary Table 8:** Characteristic tracers for the identification of the PMF factors.

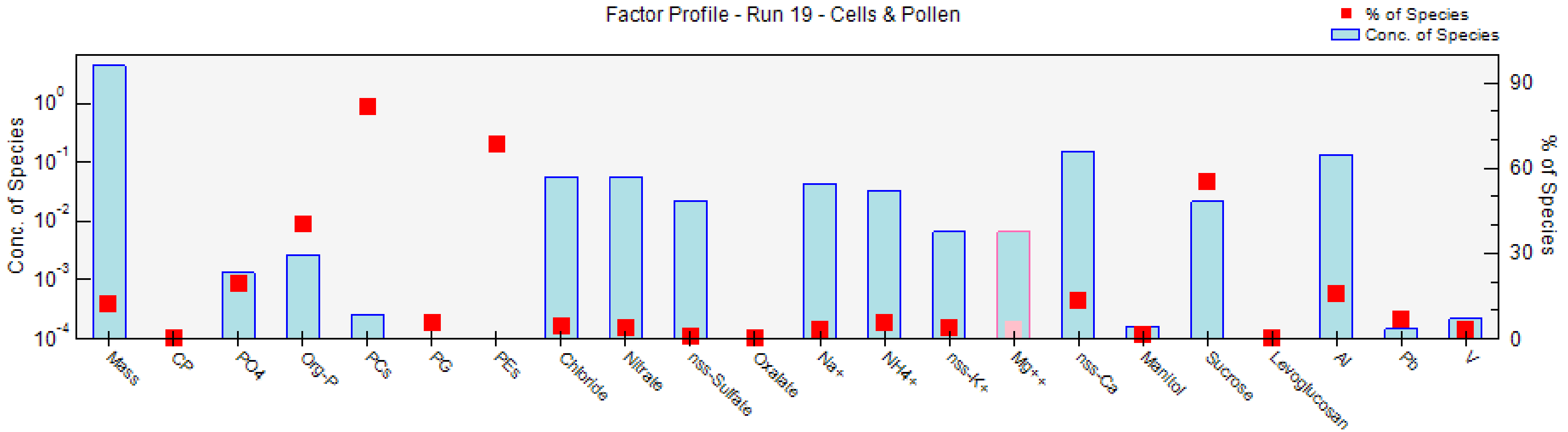
| Identified factors | Specific tracers | References |
|---|---|---|
| Cells & Pollen | PCs, PEs, sucrose | Womiloju et al. 2003[2], Fu et al., 2012[3] |
| Fungi | Mannitol | Fu et al., 2012[3] |
| Sahara dust | Aluminium, nss-$Ca^{2+}$ | Belis et al., 2019[4] |
| Anthropogenic | Nitrate, Pb, V | Belis et al., 2019[4] |
| Secondary sulfate | Nss-$SO_4^{2-}$, $NH_4^+$ | Manousakas et al., 2017[5] |
| Biomass burning | nss-$K^+$, Levoglucosan | Belis et al., 2019[4] |
| Sea-salts | $Cl^-$, $Mg^{2+}$ | Belis et al., 2019[4] Manousakas et al., 2017[5] |

## Factors in PMF= Source profile

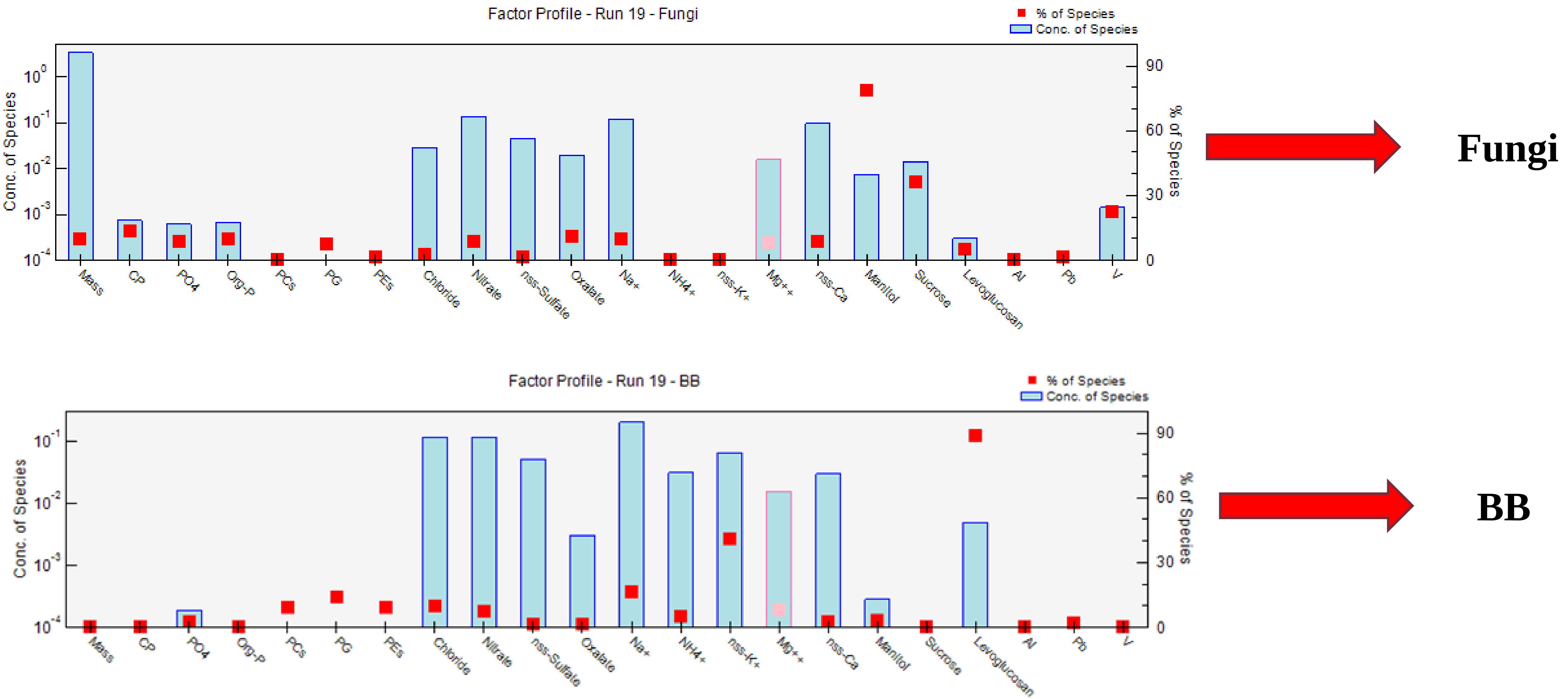
# Sources suggested by PMF 5.0



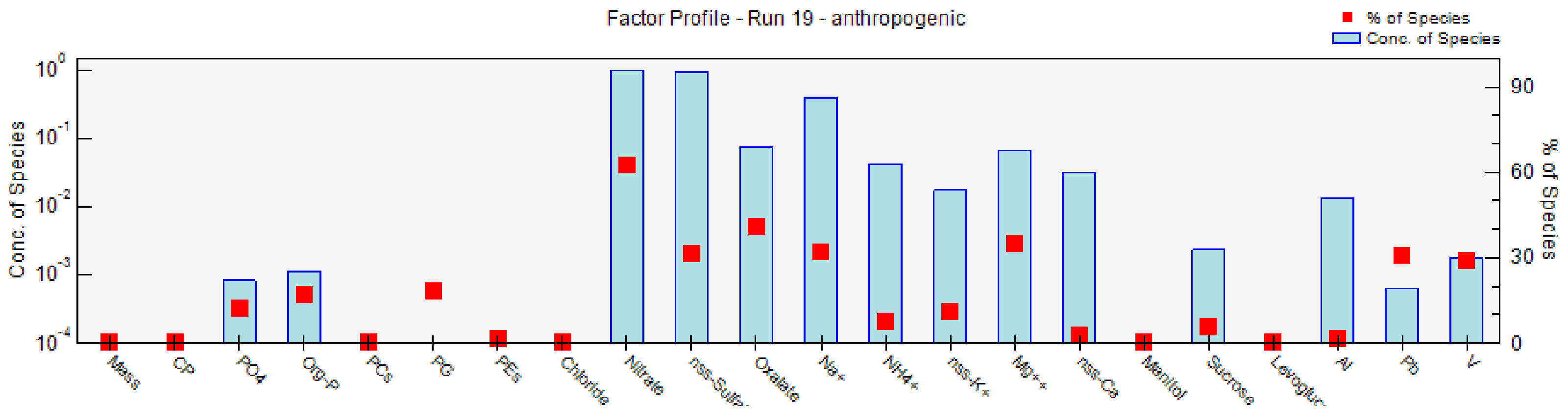

Dust



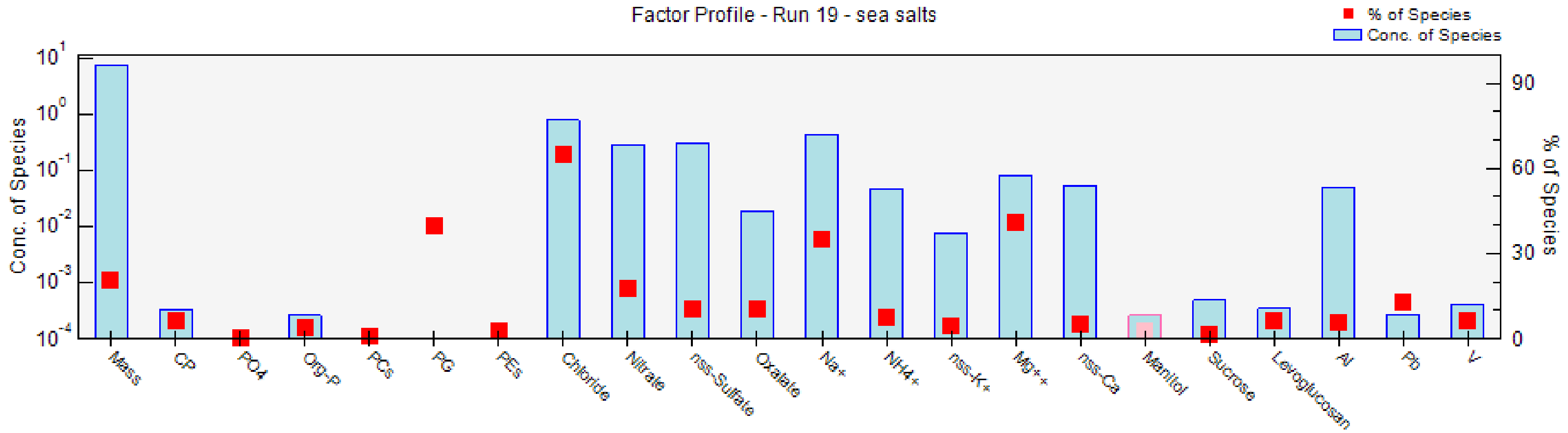

Cells &Pollen



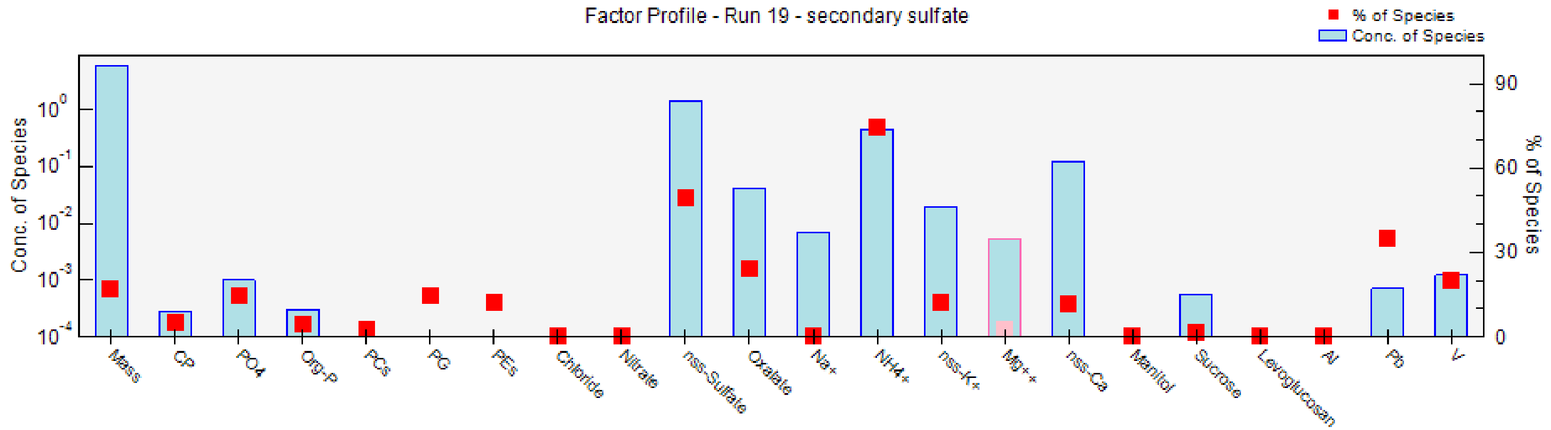
Factor Profile - Run 19 - Fungi
% of Species
Conc. of Species
Conc. of Species
% of Species
Mass
CP
PO4
Org-P
PCs
PG
PEs
Chloride
Nitrate
nss-Sulfate
Oxalate
Na+
NH4+
nss-K+
Mg++
nss-Ca
Manitol
Sucrose
Levoglucosan
Al
Pb
V
Fungi
Factor Profile - Run 19 - BB
% of Species
Conc. of Species
Conc. of Species
% of Species
BB




Anthropogenic

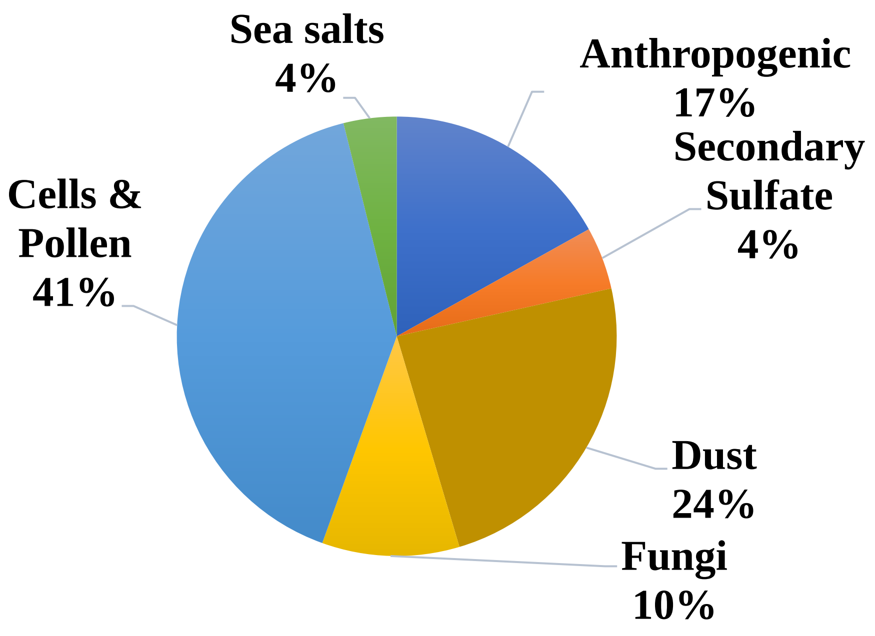


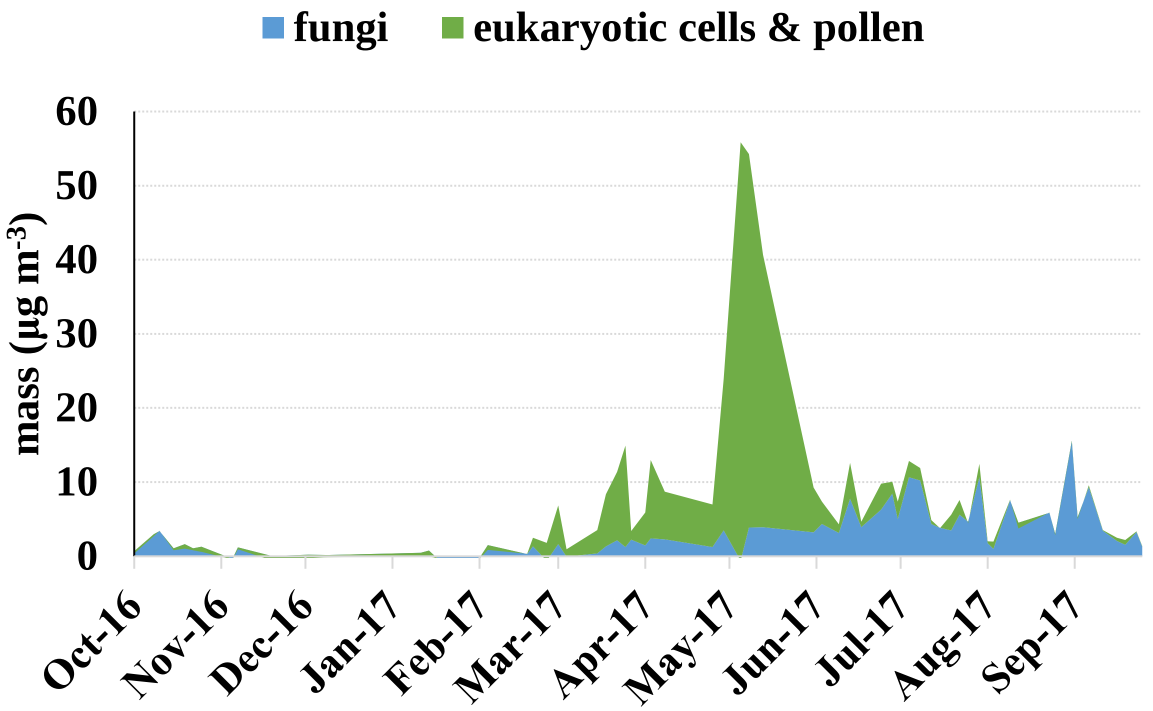

Sea salts




Secondary sulfate

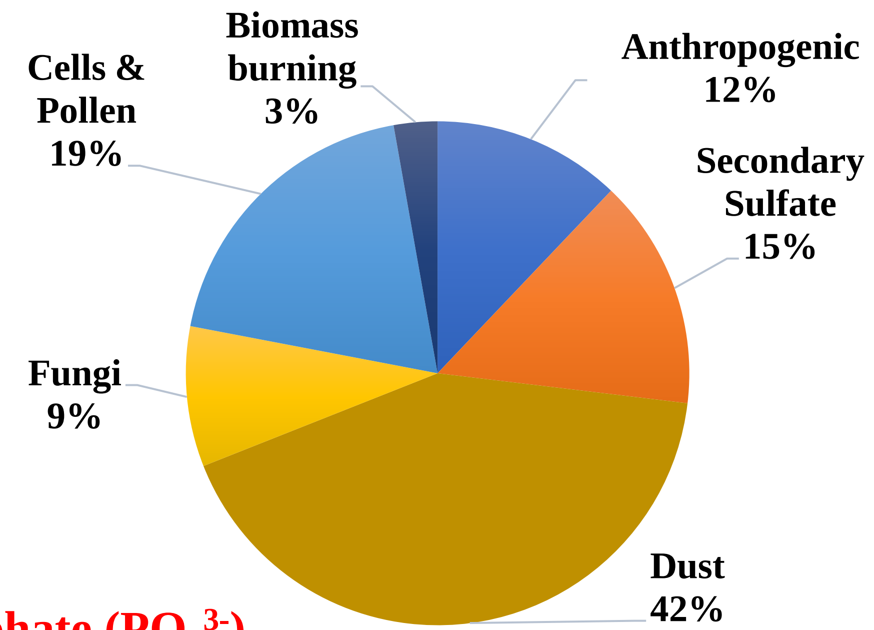
# Sources of organic P



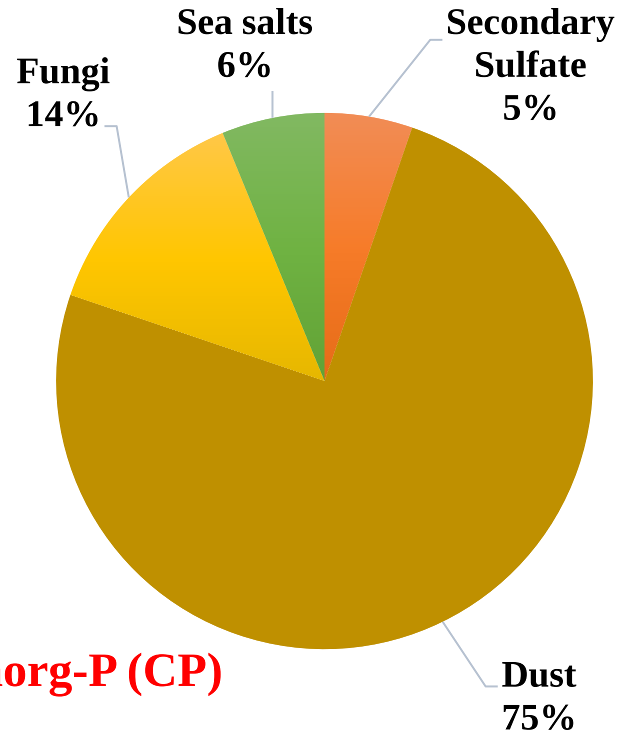




- Bioaerosols contribute with 51% to total org-P sources.
- They present seasonality, dominating during spring and summer (stratification period).
- Dust contribute with 24% to total org-P sources.
- The anthropogenic emissions are also important contributor to organic P fraction with ~17% and secondary produced due to acid solubilization is 4%. Global models suggest that 10% of atmospheric org-P is emitted from human activities (Kanakidou et al., 2012).

# Sources of inorganic P



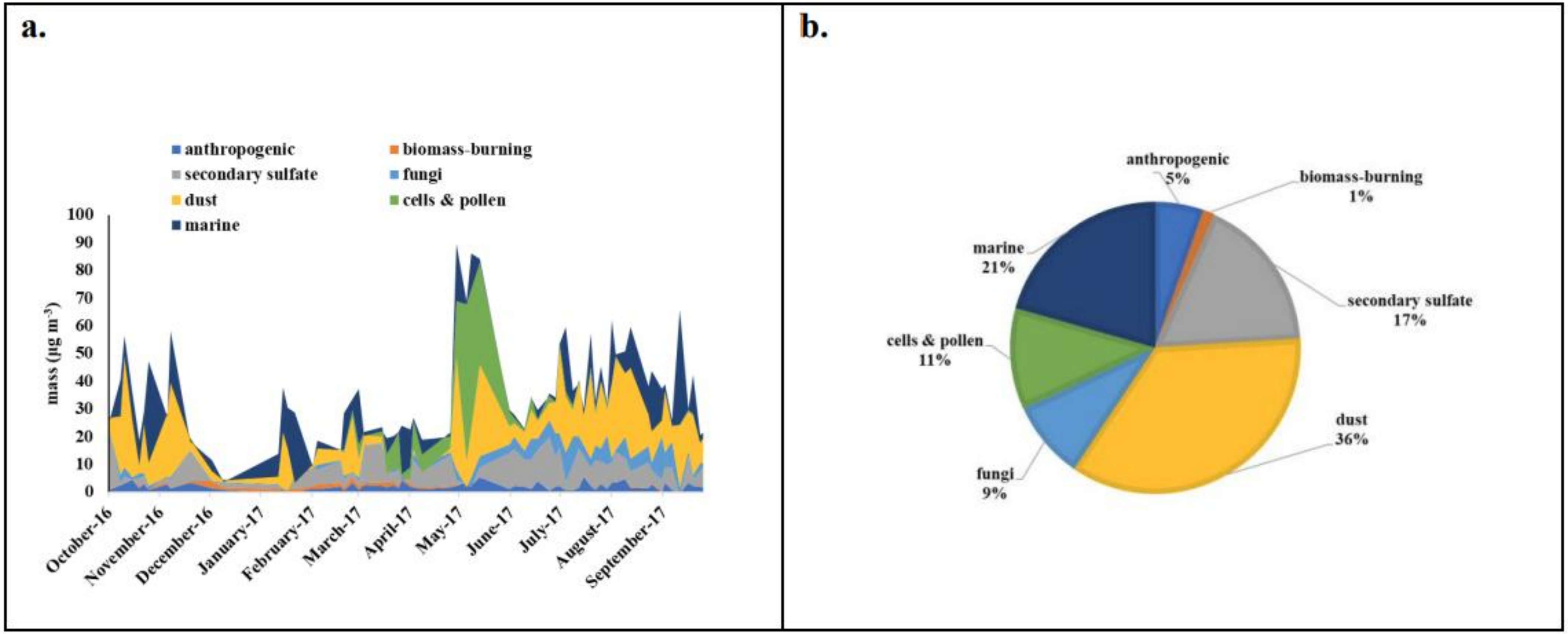

Phosphate ($PO_4^{3-}$)




Condensed inorg-P (CP)

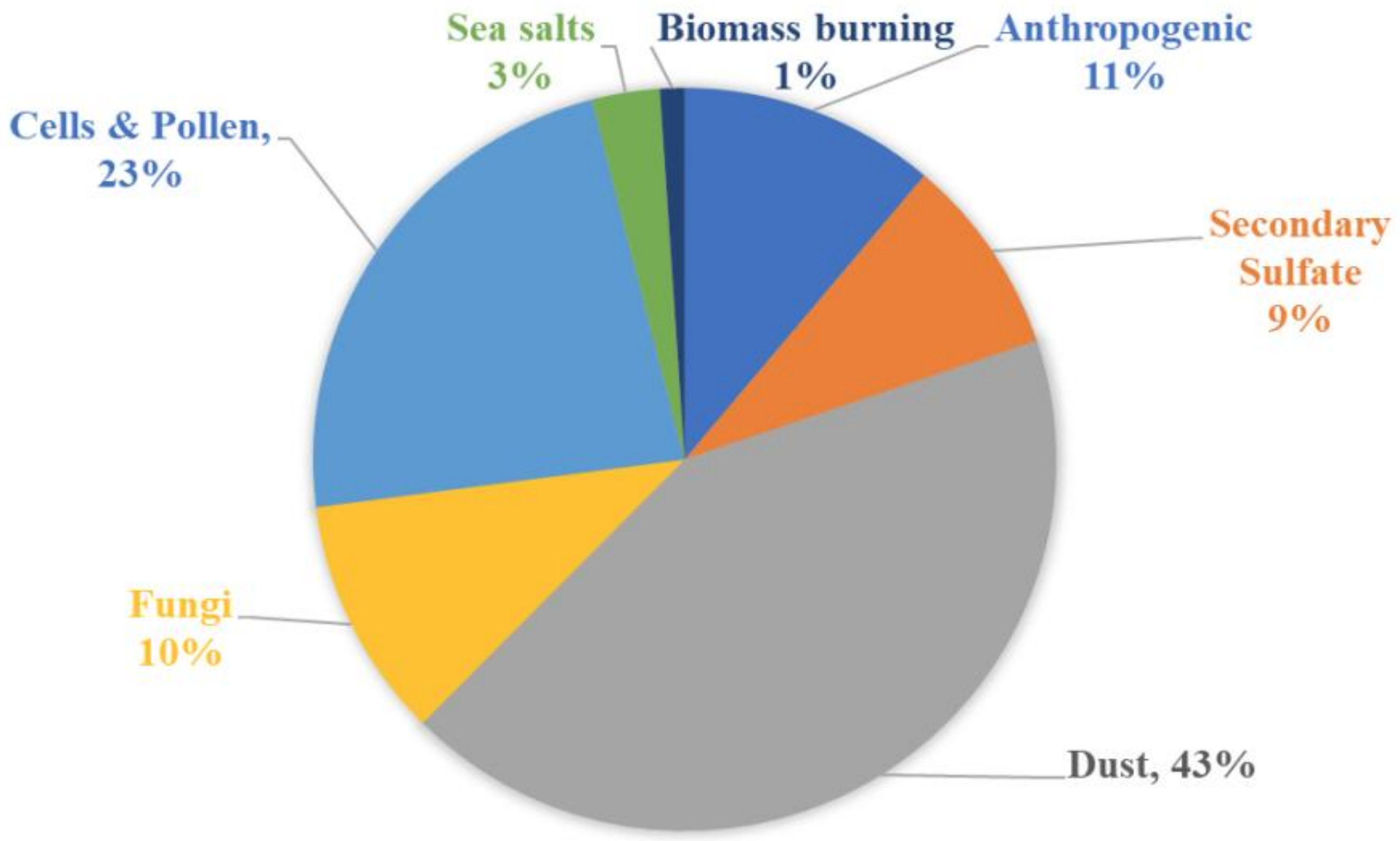
- Dust is the dominant source of both phosphate & CP.
- They present seasonality, dominating during spring and autumn.
- Anthropogenic emission produced more soluble P contributing primary with 12% and secondary with 15%. This estimation is similar with the proposed global percentage of 14.3% by Mahowald et al. (2008).

# EXAMPLE-1




**Supplementary Figure 6: Relative contributions to the particulate mass of the seven sources identified by PMF: contributions are shown with their variability in time (a) and expressed as average of the whole measurement period (b).**

# EXAMPLE-1



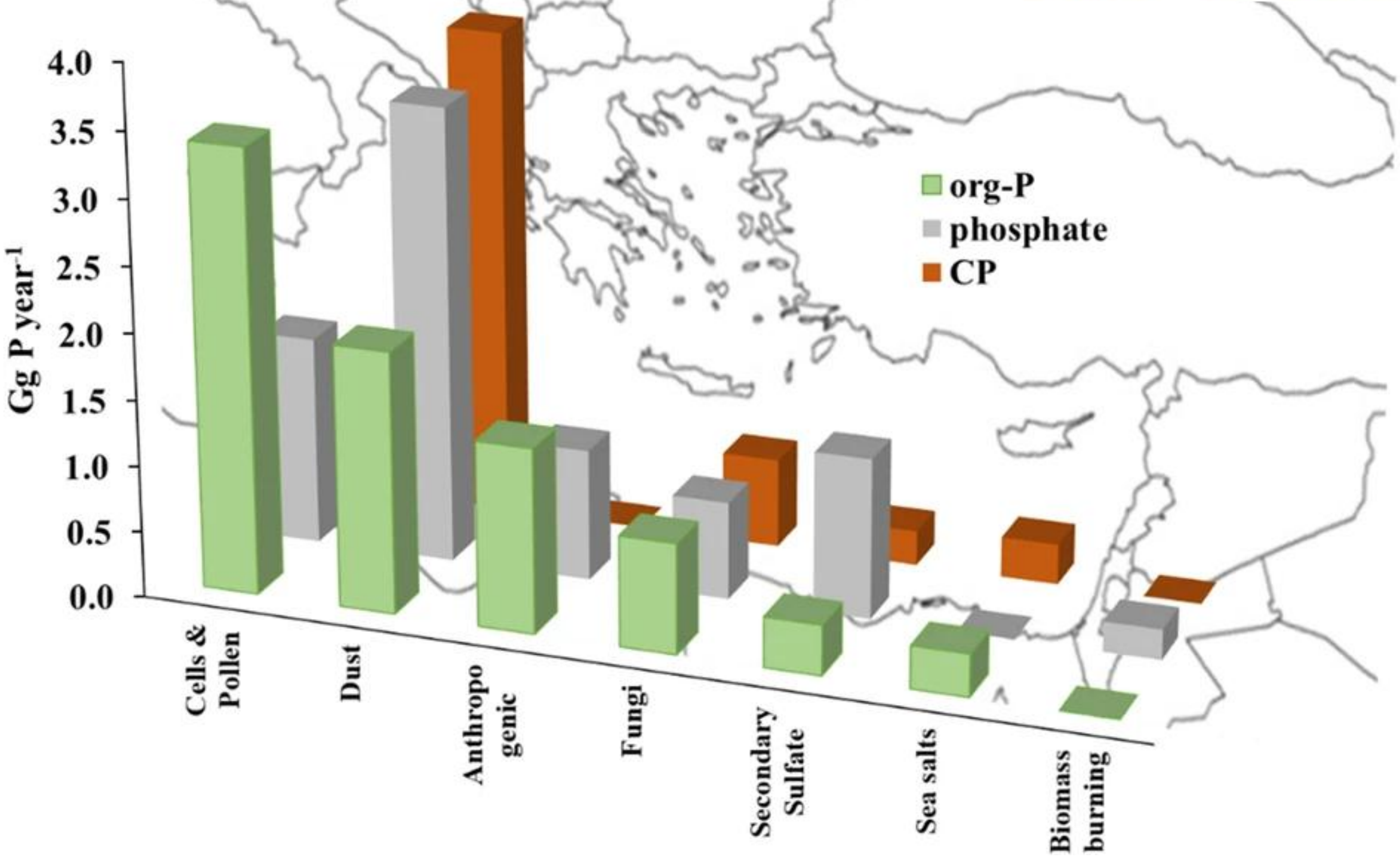

**Supplementary Figure 8: Contribution percentage of the different atmospheric sources to total P (TP) over the Eastern Mediterranean area during a one-year period (2016-2017) for total suspended particles. TP was calculated to be 21.5 Gg P year$^{-1}$**

.

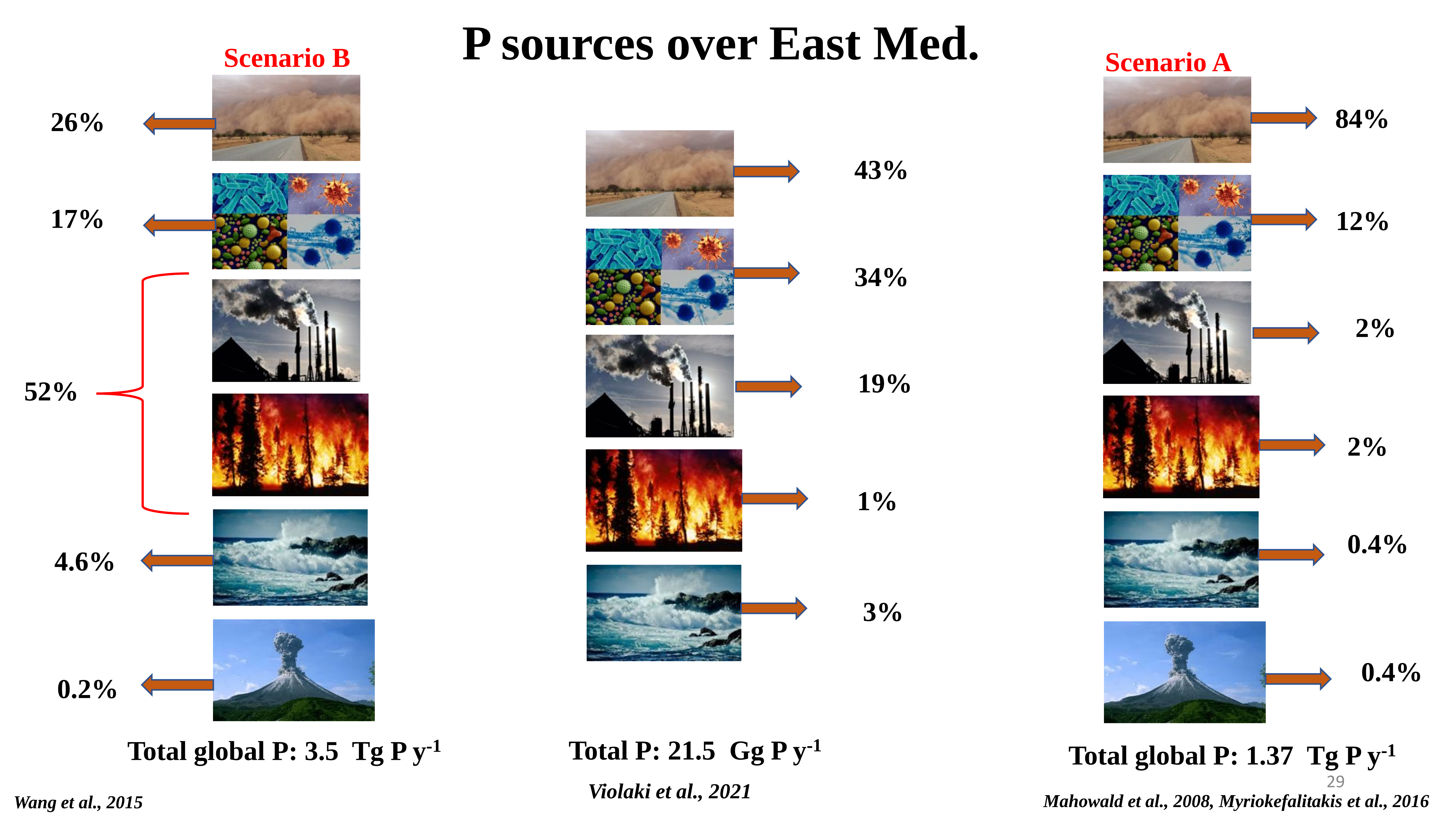
Article | Open access | Published: 03 December 2021

# Bioaerosols and dust are the dominant sources of organic P in atmospheric particles

Kalliopi Violaki, Athanasios Nenes, Maria Tsagkaraki, Marco Paglione, Stéphanie Jacquet, Rich
Sempéré & Christos Panagiotopoulos




**Estimation of the annual deposition fluxes (in Gg P year$^{-1}$) of phosphorus species and their distribution to different sources over the eastern Mediterranean during one-year period (2016–2017) for total suspended particles. Total P was calculated to be 21.5 Gg P year$^{-1}$.**


P sources over East Med.
Scenario B
26%
17%
52%
4.6%
0.2%
Total global P: 3.5 Tg P y-1
Wang et al., 2015
43%
34%
19%
1%
3%
Total P: 21.5 Gg P y-1
Violaki et al., 2021
Scenario A
84%
12%
2%
2%
0.4%
0.4%
Total global P: 1.37 Tg P y-1
Mahowald et al., 2008, Myriokefalitakis et al., 2016
29

# EXAMPLE-2

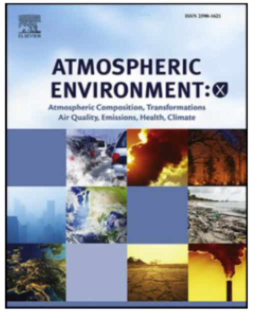
ATMOSPHERIC ENVIRONMENT: X 14 (2022) 100165

Contents lists available at ScienceDirect

Atmospheric Environment: X

journal homepage: www.journals.elsevier.com/atmospheric-environment-x

ELSEVIER




# Source identification of the elemental fraction of particulate matter using size segregated, highly time-resolved data and an optimized source apportionment approach

M. Manousakas [a,*], M. Furger [a], K.R. Daellenbach [a], F. Canonaco [b], G. Chen [a], A. Tobler [a,b], P. Rai [a], L. Qi [a], A.H. Tremper [c], D. Green [c,d], C. Hueglin [e], J.G. Slowik [a], I. El Haddad [a], A.S. H. Prevot [a,**]

[a] *Paul Scherrer Institute, Laboratory of Atmospheric Chemistry, 5232, Villigen, PSI, Switzerland*
[b] *Datalystica Ltd., Park InnovAARE, 5234, Villigen, Switzerland*
[c] *MRC Centre for Environment and Health, Environmental Research Group, Imperial College London, UK*
[d] *NIHR HPRU in Environmental Exposures and Health, Imperial College London, UK*
[e] *Laboratory for Air Pollution and Environmental Technology, Swiss Federal Laboratories for Materials Science and Technology (Empa), Überlandstrasse 129, 8600, Dübendorf, Switzerland*

# EXAMPLE-2

## Background of the study

This study aimed to:

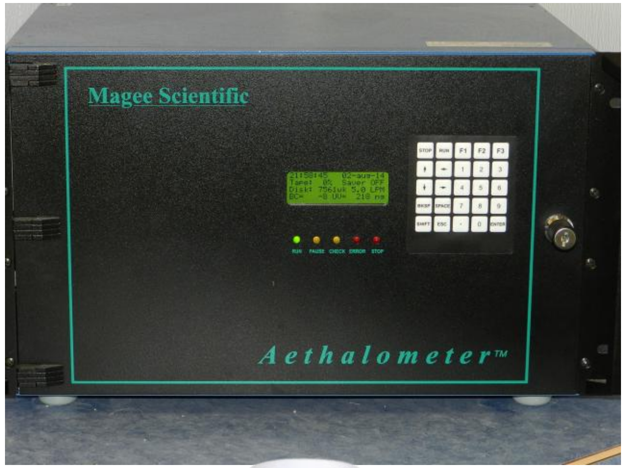
- Identify the sources of PM elements in Zürich, Switzerland, using size-segregated elemental composition data.
- PMF analysis was performed using a combined dataset of $PM_{2.5}$ and PMcoarse ($PM_{10-2.5}$).
- The ***high-time resolution*** of the elemental data coupled with the size-segregated information led to improved Source Apportionment results in this urban environment.


Fig. 1. The sampling point and central train station (right) in Zürich, Switzerland (left).

# Instruments

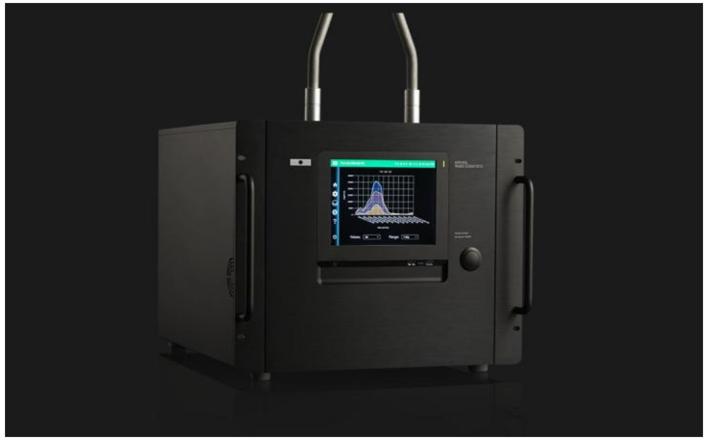
- Q-ACSM → $Cl^-$, $NH_4^+$, $NO_3^-$, $SO_4^{2-}$, Organic Aerosols (OA)
- AE33 aethalometer → Black Carbon
- Total carbon analyzer (TCA08) → Total Carbon
- Xact 625i ambient metals monitor

$PM_{2.5}$ and $PM_{10}$ concentrations of 37 elements (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, Nb, Cd, In, Sn, Sb, I, Ba, Hg, Tl, Pb, Bi)





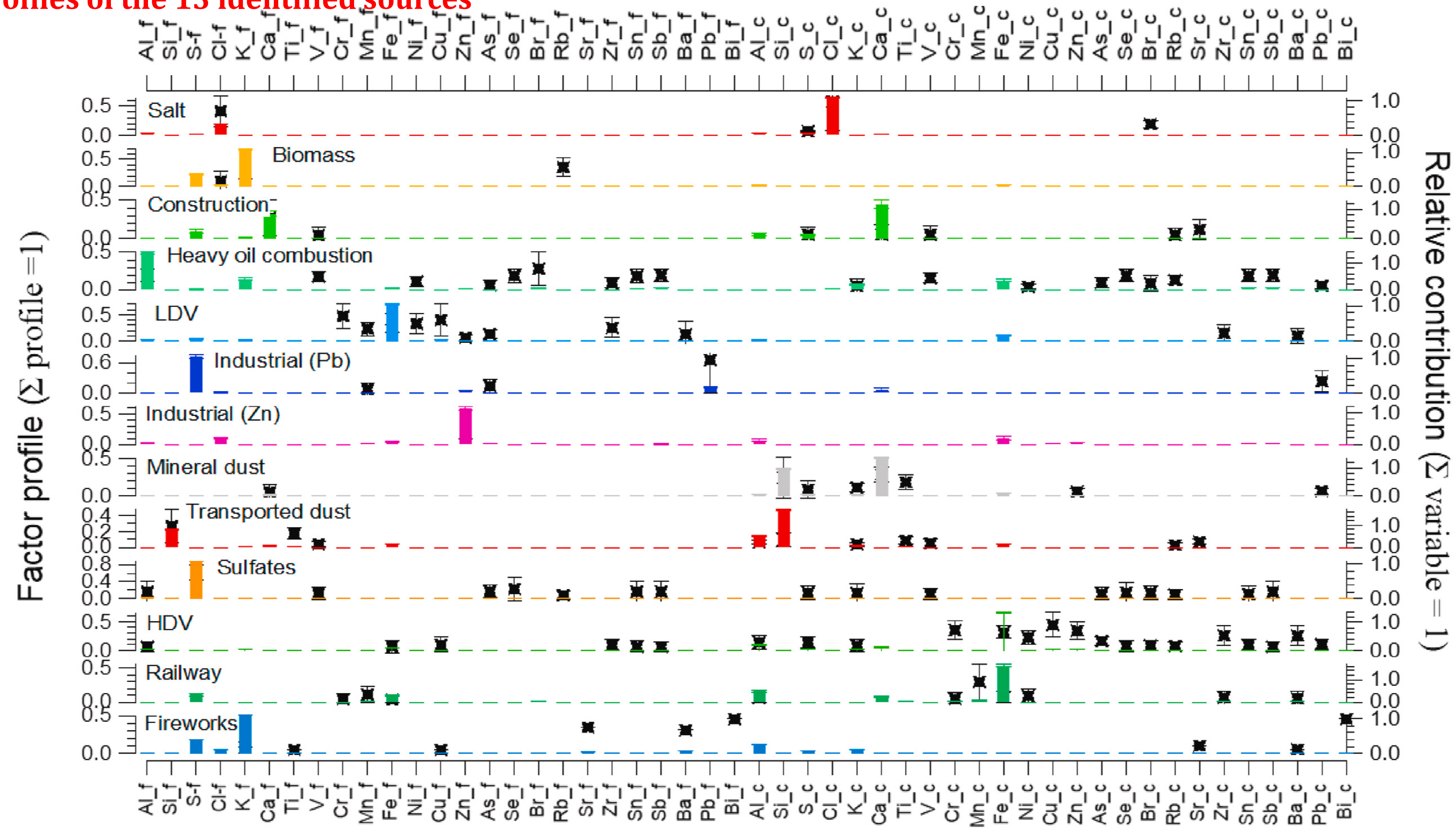
Q-ACSM



Total carbon analyzer

Xact 625i ambient metals monitor

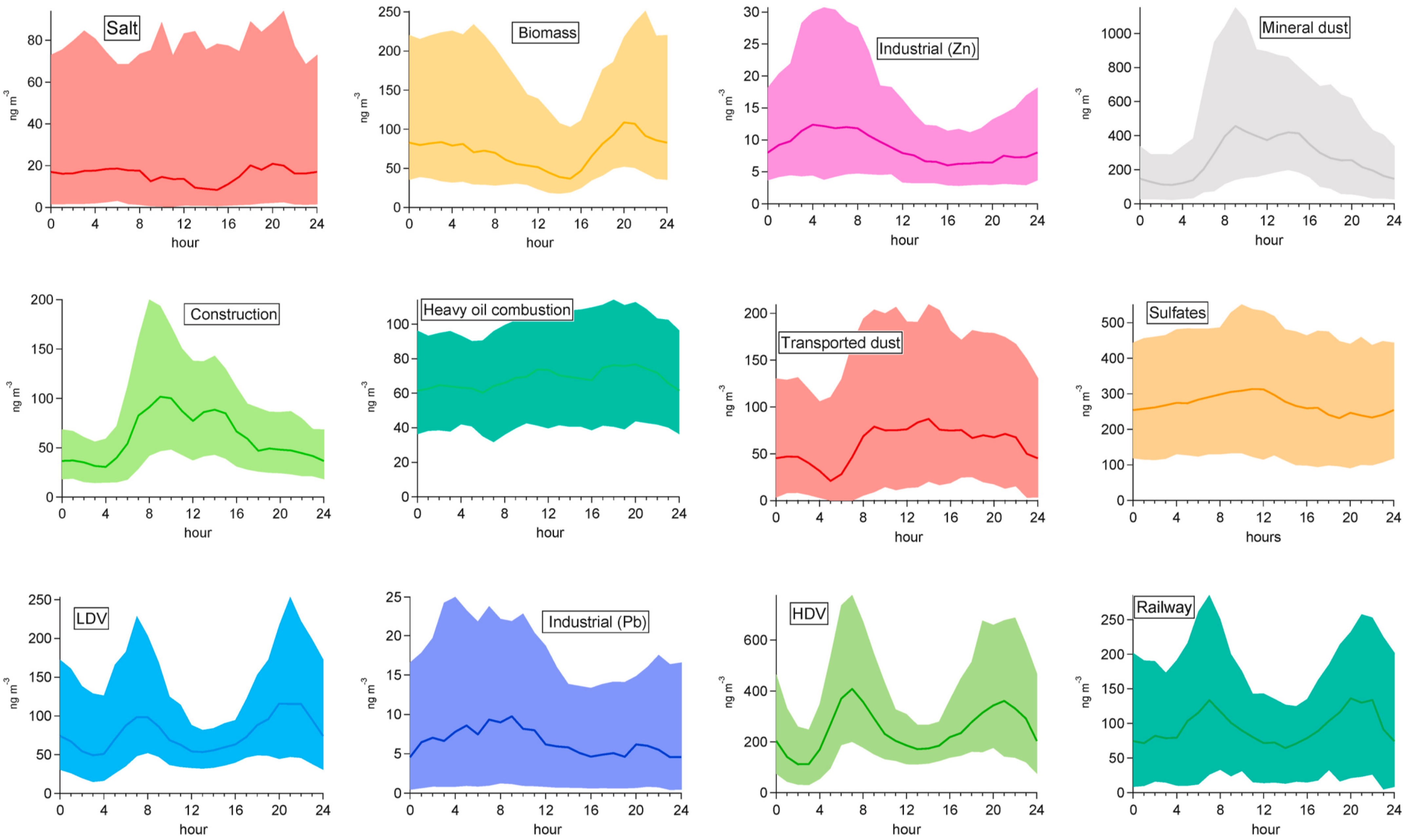
# Source profiles of the 13 identified sources

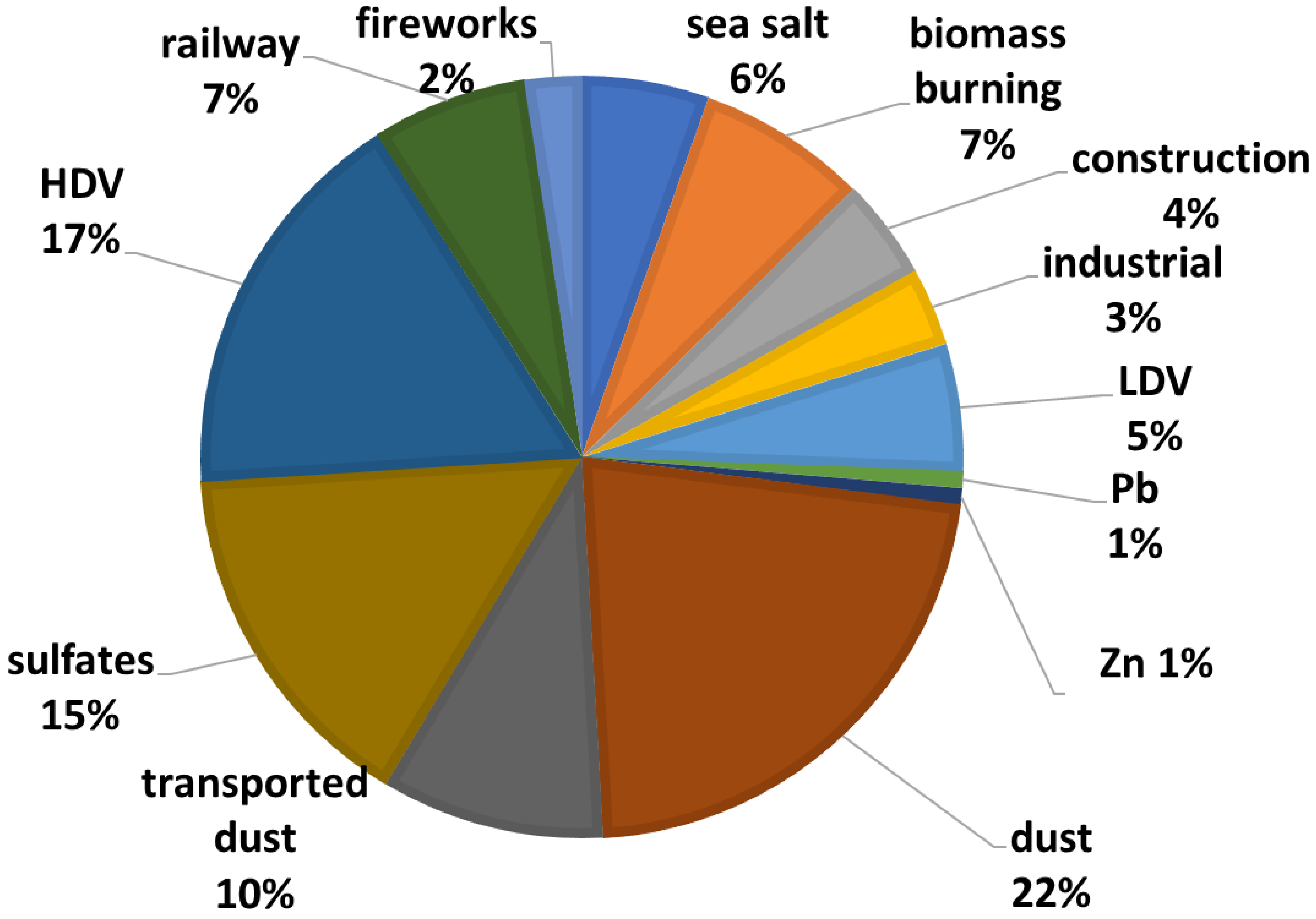



**LDV: Light-Duty Vehicles**
**HDV:Heavy-Duty Vehicles**

**_c :coarse fraction**
**f the fine fraction**

# Median diurnal variation of the source contributions in ng m$^{-3}$





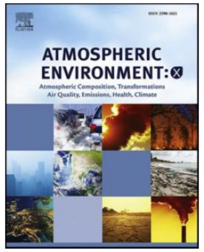

Manousakas et al., 2022

ELSEVIER

Contents lists available at ScienceDirect

Atmospheric Environment: X

journal homepage: www.journals.elsevier.com/atmospheric-environment-x



EXAMPLE-3

Atmos. Chem. Phys., 24, 1193–1212, 2024
https://doi.org/10.5194/acp-24-1193-2024


Atmospheric Chemistry and Physics
Open Access

# Source apportionment of $PM_{2.5}$ in Montréal, Canada, and health risk assessment for potentially toxic elements

Nansi Fakhri[1,2,4], Robin Stevens[2,3], Arnold Downey[2], Konstantina Oikonomou[4], Jean Sciare[4], Charbel Afif[1,4], and Patrick L. Hayes[2]

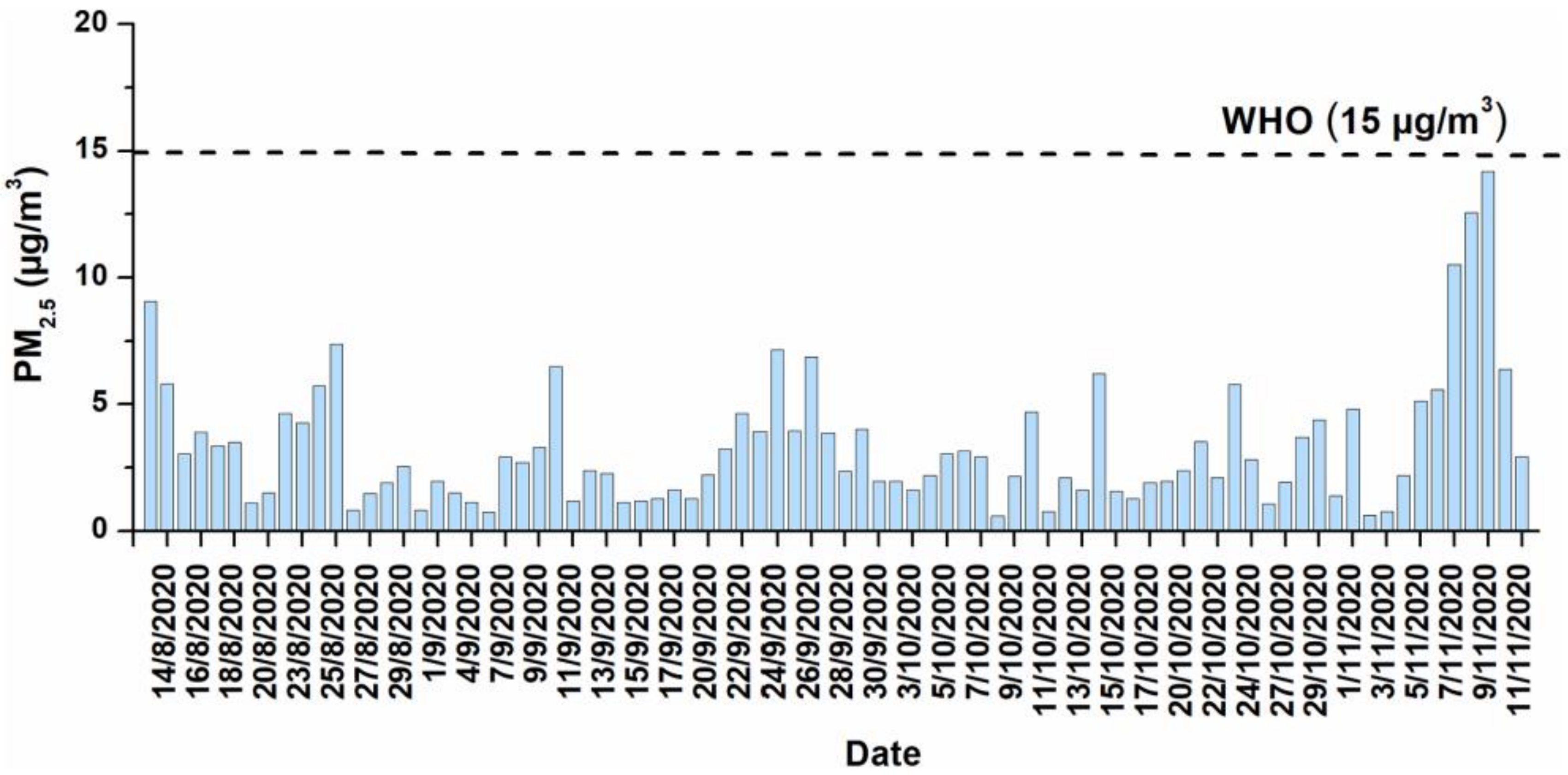


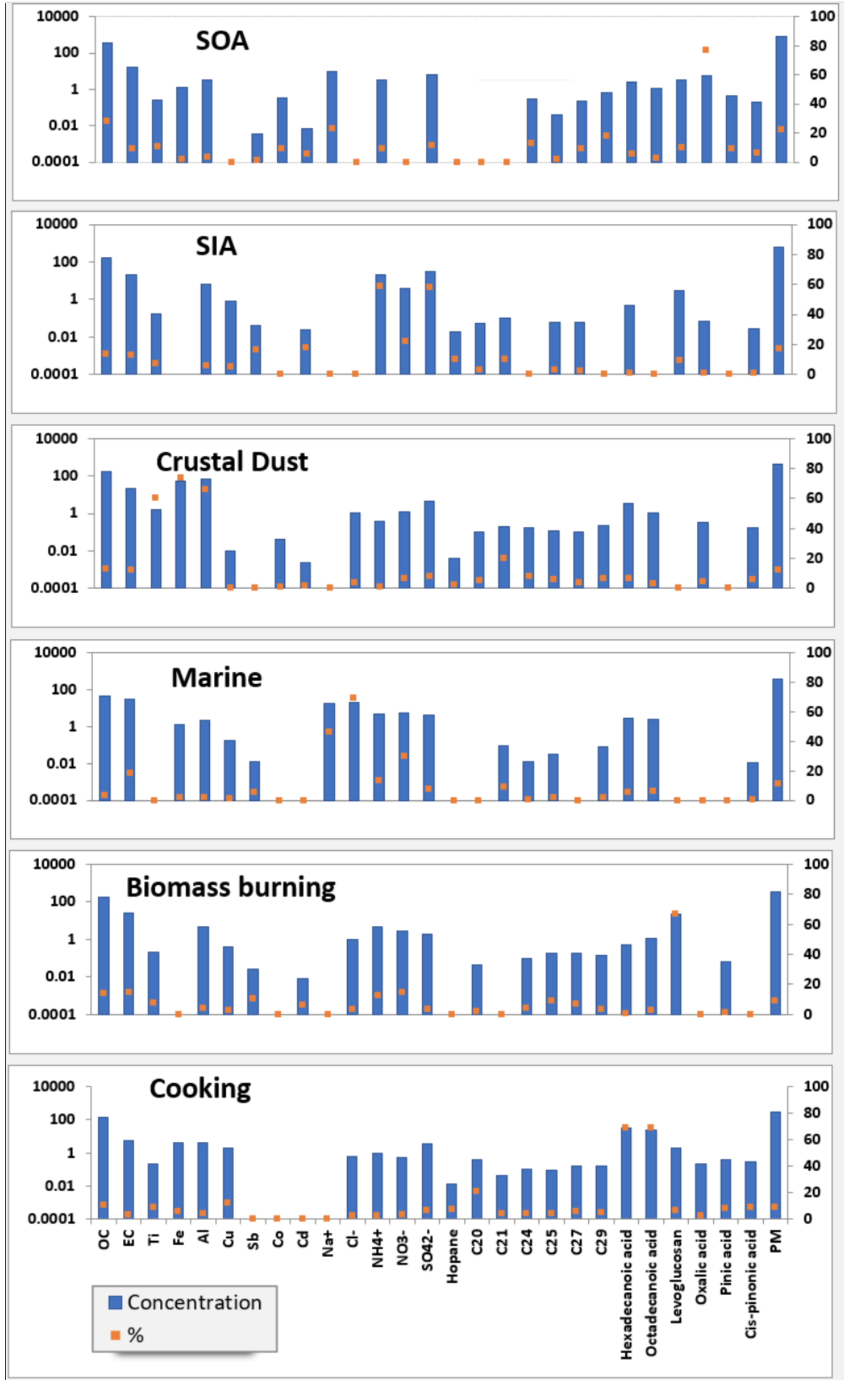

**Figure 1.** The temporal variation of $PM_{2.5}$ concentrations for the sampling period (13 August to 11 November 2020).

**Sampling was conducted at an urban site in Montréal from 13 August to 11 November 2020. The sampling site, labeled as MTL, was located on the rooftop of campus MIL (12 m above ground level) at the University of *Montréal* (45◦3102100 N, 73◦3701400 W) in the neighborhood of Outremont. The site is characterized by a *high density of residential and commercial premises*.**

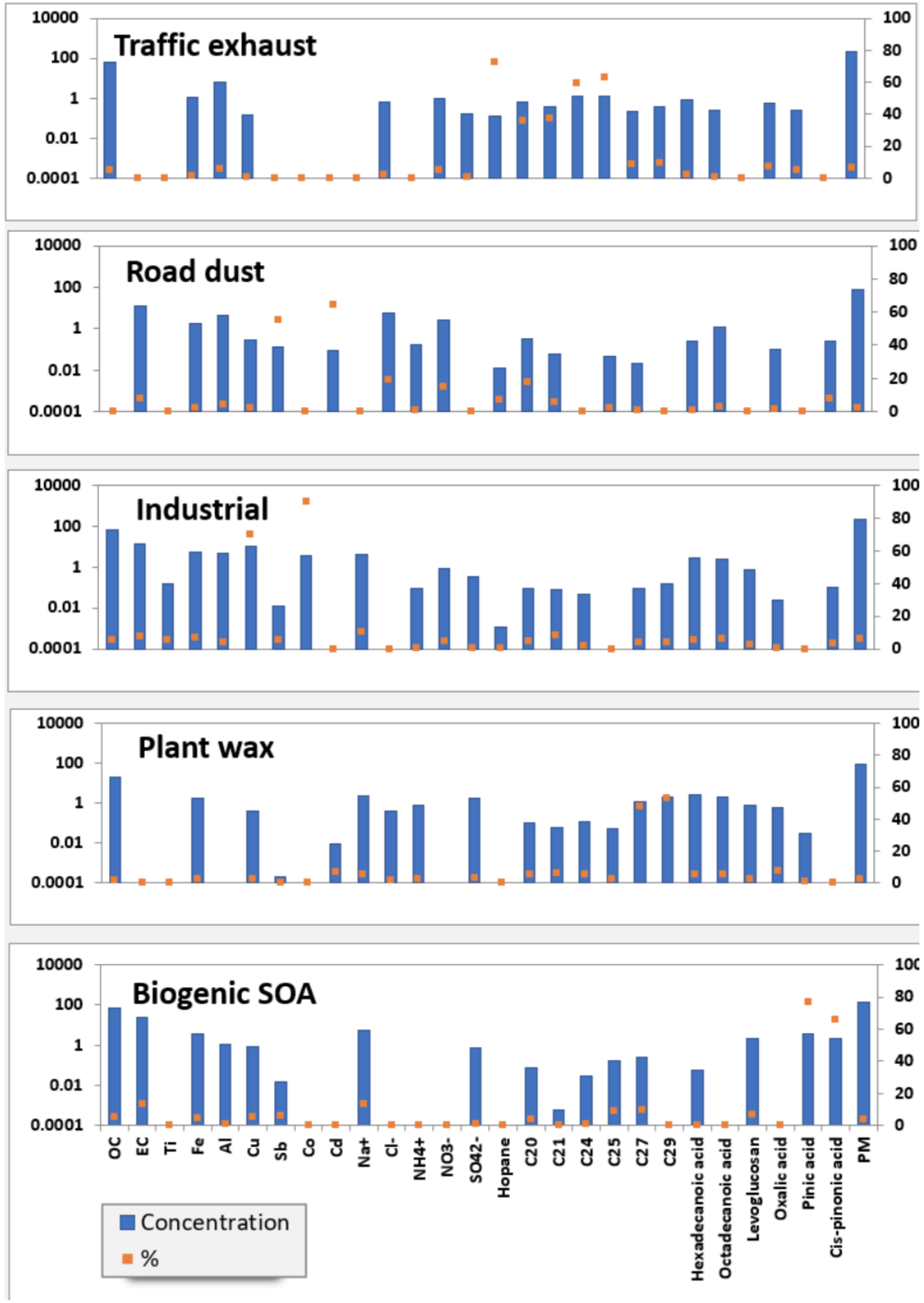
# Average concentrations ($ng\ m^{-3}$) of organic compounds in $PM_{2.5}$

| | Mean | SD | Range |
|---|---|---|---|
| 17α(H)-21β(H)-Hopane | 0.18 | 0.01 | 0.06–0.70 |
| *n*-Alkanes | | | |
| Tetradecane (C14) | 0.58 | 0.31 | 0.20–1.73 |
| Pentadecane (C15) | 0.48 | 0.66 | 0.28–4.27 |
| Hexadecane (C16) | 0.75 | 0.37 | 0.34–2.04 |
| Heptadecane (C17) | 0.71 | 0.67 | 0.22–5.20 |
| Octadecane (C18) | 0.99 | 1.69 | 0.18–8.29 |
| Nonadecane (C19) | 0.46 | 0.24 | 0.17–1.26 |
| Eicosane (C20) | 1.82 | 1.20 | 0.73–7.90 |
| Heneicosane (C21) | 0.99 | 0.35 | 0.37–2.14 |
| Docosane (C22) | 0.96 | 1.15 | 0.37–8.49 |
| Tricosane (C23) | 1.02 | 0.42 | 0.40–2.16 |
| Tetracosane (C24) | 2.24 | 1.61 | 0.82–11.16 |
| Pentacosane (C25) | 1.97 | 1.02 | 0.83–4.97 |
| Hexacosane (C26) | 1.51 | 0.84 | 0.48–3.96 |
| Heptacosane (C27) | 2.52 | 2.89 | 0.74–23.82 |
| Octacosane (C28) | 1.79 | 2.84 | 0.45–23.20 |
| Nonacosane (C29) | 3.84 | 3.78 | 0.73–3.37 |
| Triacontane (C30) | 1.12 | 1.41 | 0.12–7.07 |
| Hentriacontane (C31) | 1.56 | 0.96 | 0.34–6.72 |
| Sugars | | | |
| Levoglucosan | 33.72 | 6.45 | 6.45–126.40 |
| Mannosan | 1.03 | 0.94 | 0.15–4.59 |
| Mannitol | 2.14 | 3.22 | 0.23–18.91 |
| Arabitol | 3.14 | 4.29 | 0.29–39.00 |
| Glucose | 2.92 | 3.01 | 0.17–24.47 |
| Fatty acids | | | |
| Tetradecanoic acid | 4.17 | 1.40 | 1.66–7.97 |
| Hexadecanoic acid | 51.12 | 13.09 | 28.39–87-43 |
| Octadecanoic acid | 37.06 | 9.41 | 18.05–64.90 |
| Oleic acid | 4.43 | 1.65 | 2.51–13.05 |
| Dicarboxylic acids (DCAs) | | | |
| Oxalic acid (diC2) | 7.79 | 1.58 | 0.28–15.03 |
| Adipic acid(diC6) | 1.60 | 4.18 | 0.31–3.42 |
| Azelaic acid (diC9) | 5.93 | 2.18 | 1.12–15.01 |
| Biogenic SOA tracers | | | |
| Pinic acid | 4.73 | 1.78 | 0.21–8.93 |
| *cis*-Pinonic acid | 3.17 | 1.71 | 0.62–9.73 |

**Secondary inorganic aerosol (SIA) factor**




**Eleven factors**

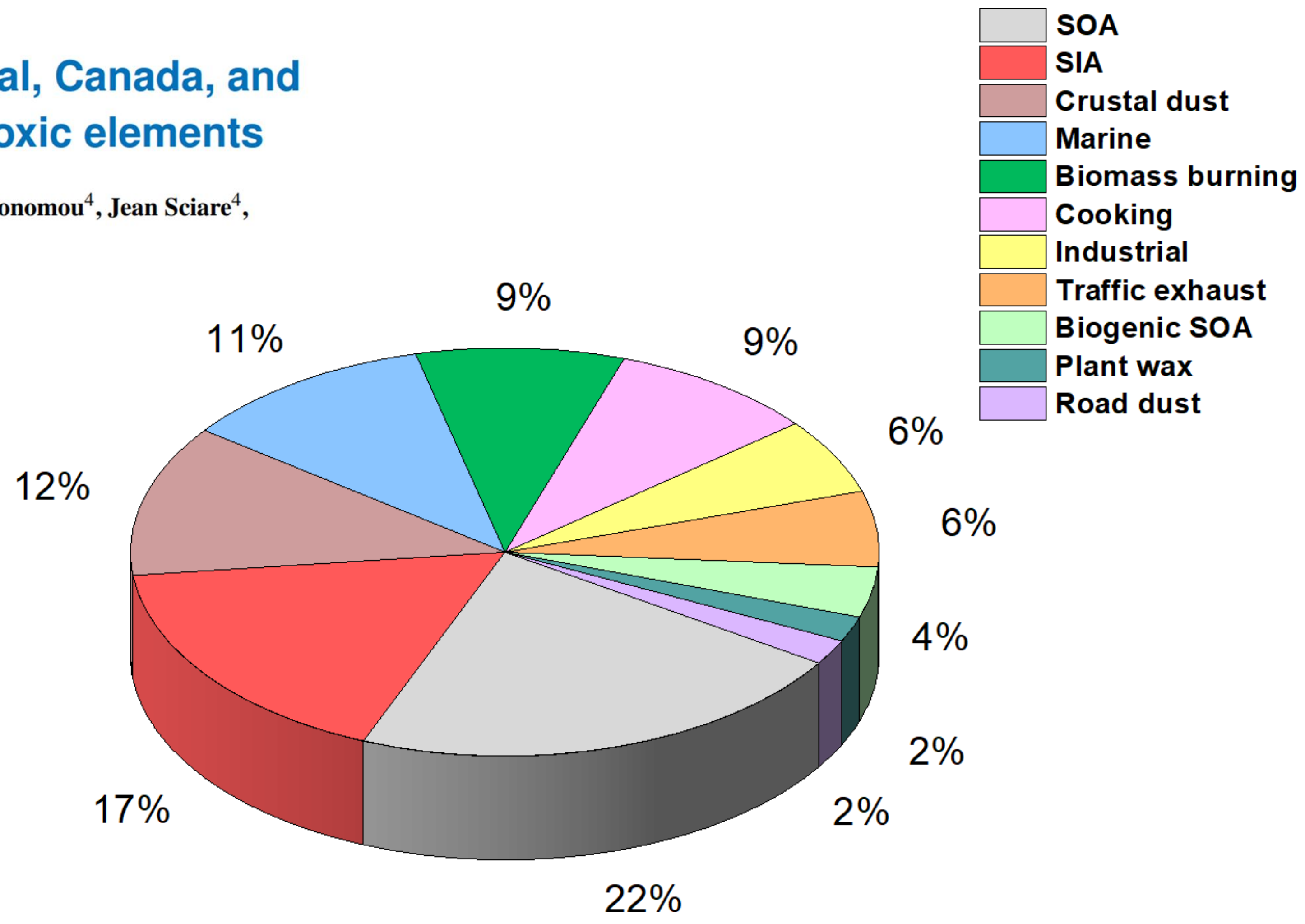


Atmos. Chem. Phys., 24, 1193–1212, 2024
https://doi.org/10.5194/acp-24-1193-2024

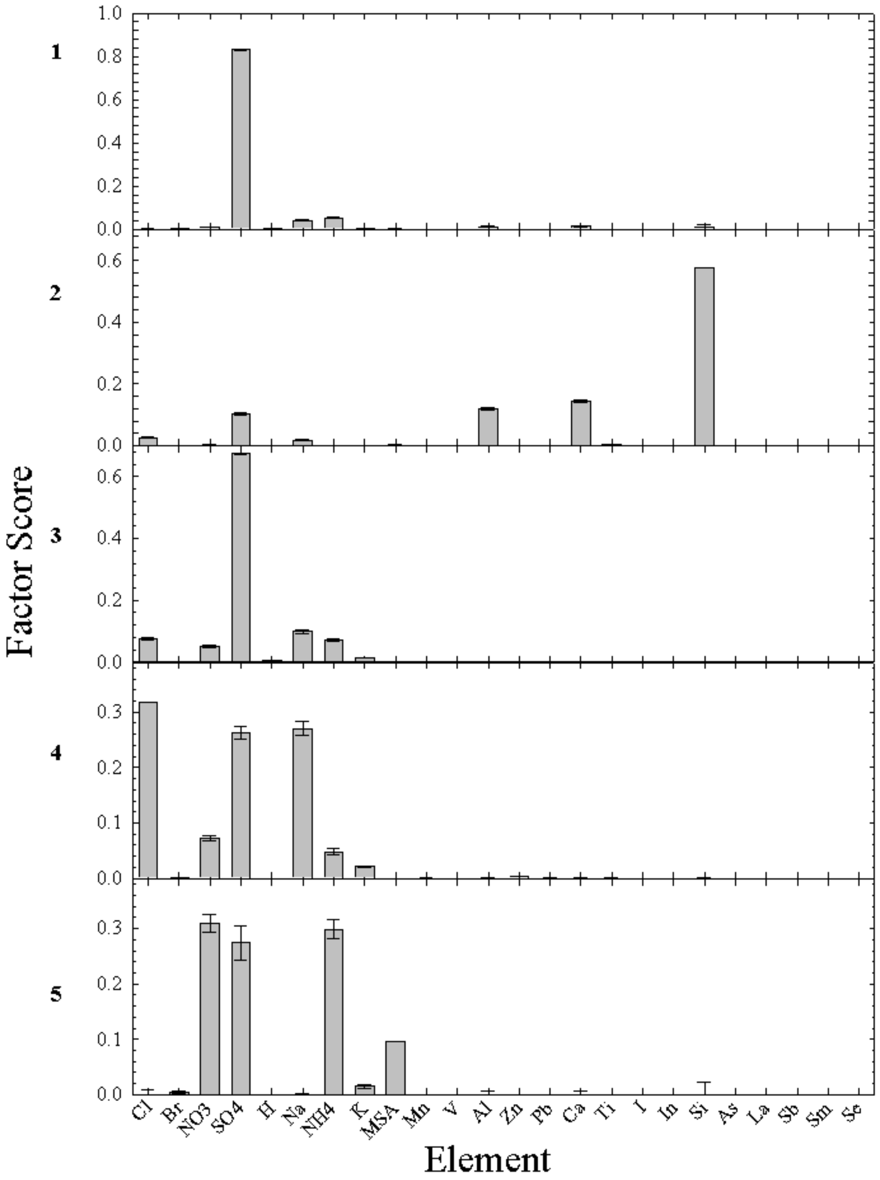

Atmospheric Chemistry and Physics
Open Access
EGU

# Source apportionment of $PM_{2.5}$ in Montréal, Canada, and health risk assessment for potentially toxic elements

Nansi Fakhri[1,2,4], Robin Stevens[2,3], Arnold Downey[2], Konstantina Oikonomou[4], Jean Sciare[4],
Charbel Afif[1,4], and Patrick L. Hayes[2]



# ARCTIC HAZE




Photochemistry at Polar Sunrise

Soil

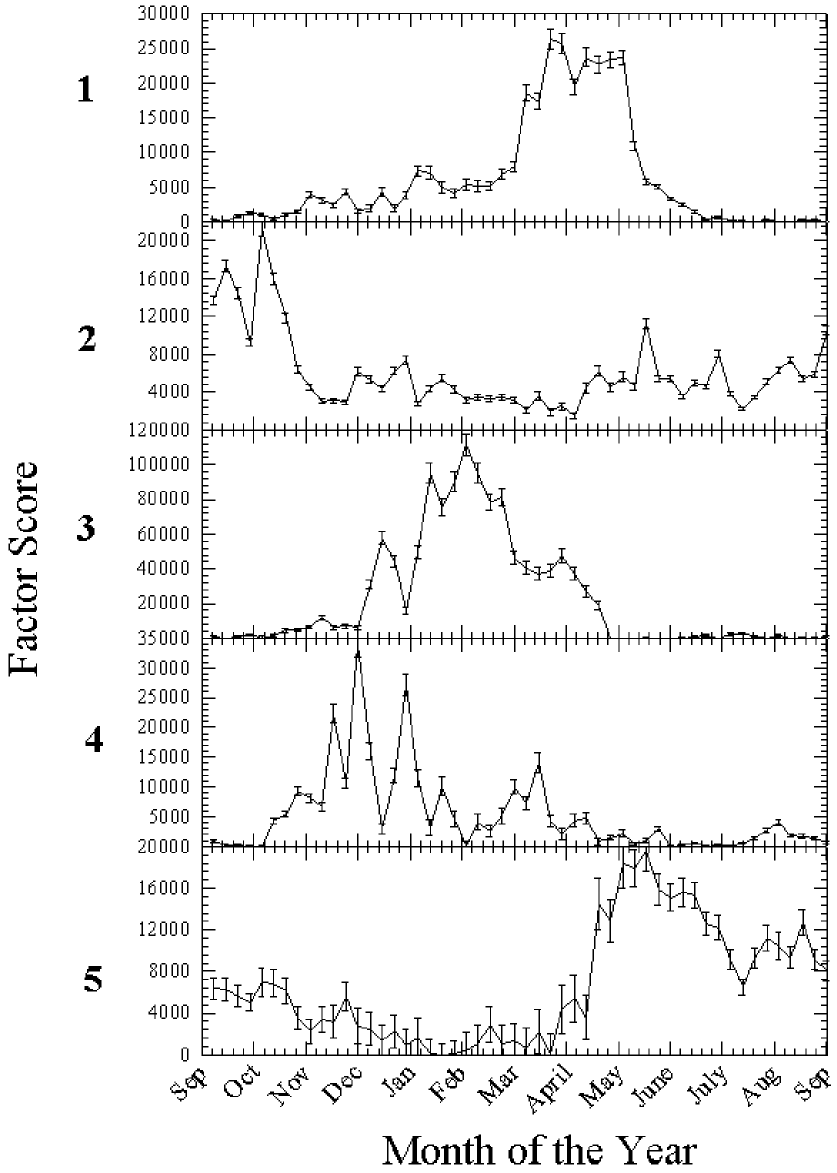
Transported Sulfate

Sea Salt

Biogenic sulfate

**Credit to Prof. Hopke**

# ARCTIC HAZE




Photochemistry at Polar Sunrise

Soil

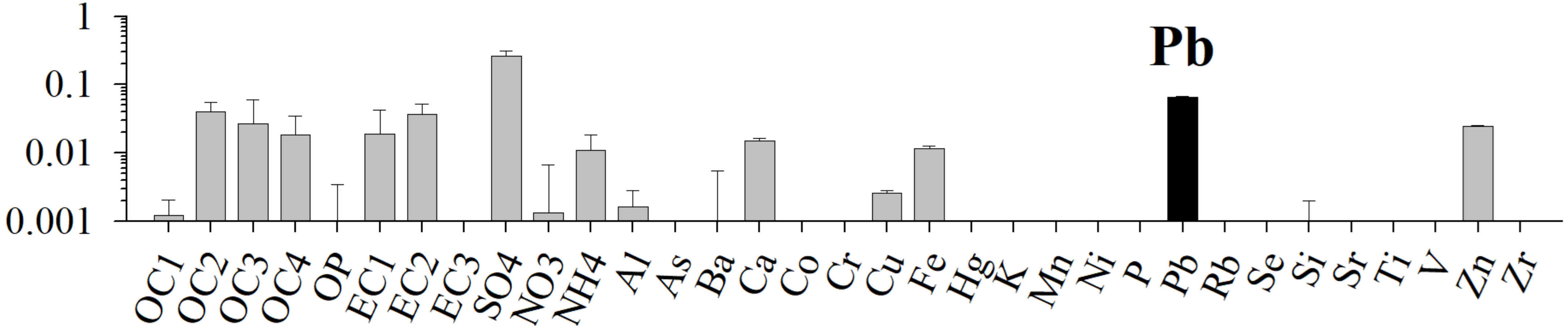
Transported Sulfate

Sea Salt

Biogenic sulfate

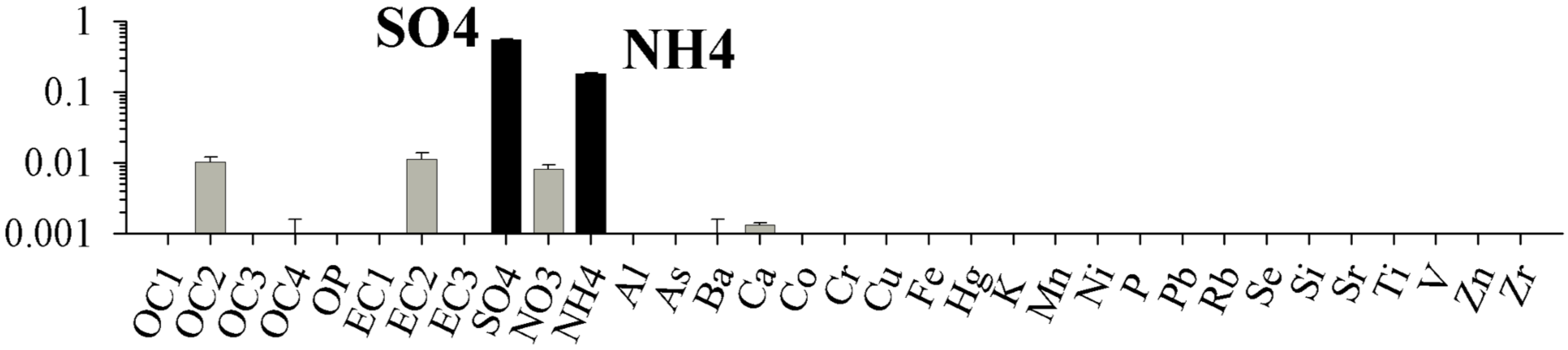
**Credit to Prof. Hopke**

# Lead Smelting




**Credit to Prof. Hopke**

# Secondary Sulfate




**Credit to Prof. Hopke**

# Thank You

Questions?

e-mail: kalliopi.violaki@epfl.ch