Low cost source apportionment

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Problems with air pollution control

- Limited measurements
- Limited information on the sources of pollution
- A combination of cheap material and easy but established methodologies can help
- We are trying to extend the applications of low-cost sensors in source apportionment studies

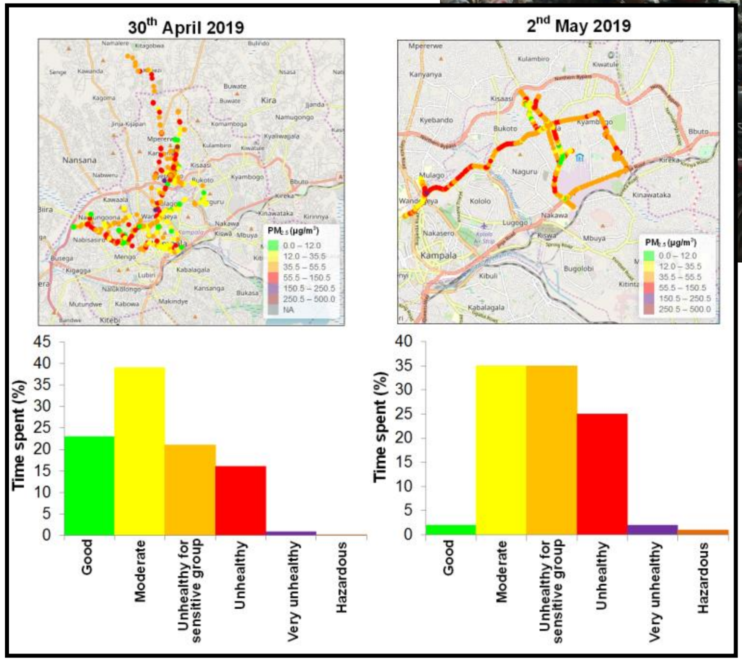
Problem 1 - There is a paucity of good quality air pollution data

Solution: Low cost monitors

Not without problems – need for calibration and QA/QC. But pretty good especially for PM mass concentration measurements.

Measurements at much lower costs allows for greater network densities.

Smaller size/weight also allows for a greater diversity of measurements.



Crilley et al. (2018) Atmos. Meas. Techniques. '*Evaluation of a low-cost optical particle counter for ambient air monitoring*'
Crilley et al. (2020) Atmos. Meas. Techniques. '*Effect of aerosol composition on the performance of low-cost optical particle counter correction factors*'
Singh et al (2021) Environmental Research Comms *'Air quality assessment in three East African cities using calibrated low-cost sensors with a focus on road-based hotspots'*

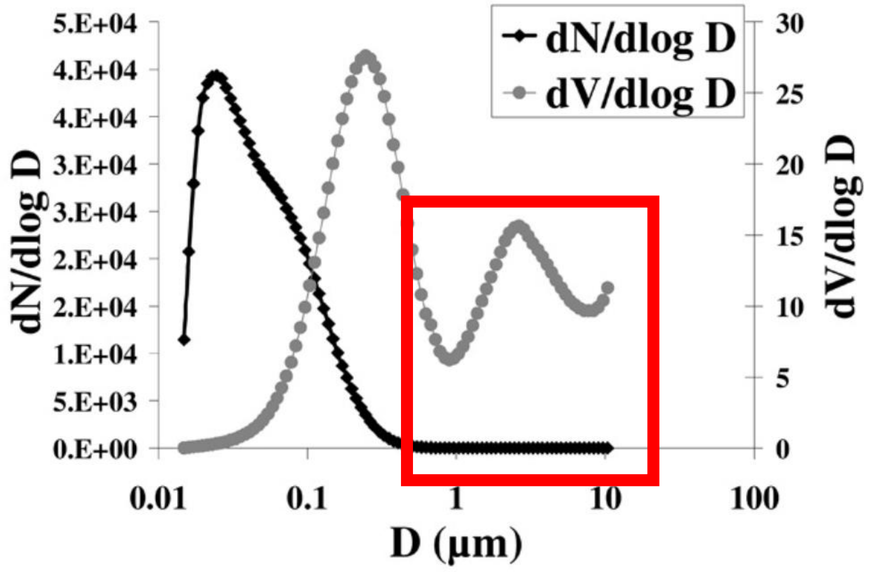
Problem 2 - There is a lack of source apportionment

Successful air quality management and control not only requires measurement of air pollution levels, but it also requires information on the sources and their relative importance.

Without this critical, targeted information on pollution sources, it is difficult to reduce air pollution.

Historically source apportionment has been done using expensive regulatory grade equipment.

Can it be done with low cost optical particle sensors?



Harrison et al. (2011) Environ. Sci. Technol.

Bousiotis et al. (2021) Assessing the sources of particles at an urban background site using both regulatory instruments and low-cost sensors–a comparative study. *Atmospheric Measurement Techniques*, *14*(6), pp.4139-4155. https://doi.org/10.5194/amt-14-4139-2021

Bousiotis et al. (2022). A study on the performance of low-cost sensors for source apportionment at an urban background site. Atmospheric Measurement Techniques Discussions, pp.1-40. https://doi.org/10.5194/amt-2022-84

Methodology

Optical particle Sizer (Alphasense OPC-N3)

- Size range 0.38 – 40 um
- Cost ca. £250

Statistical methods are used to separate the particle profiles.

- k-means clustering is a source identification method
- Positive Matrix Factorization (PMF) is a multivariate data analysis method

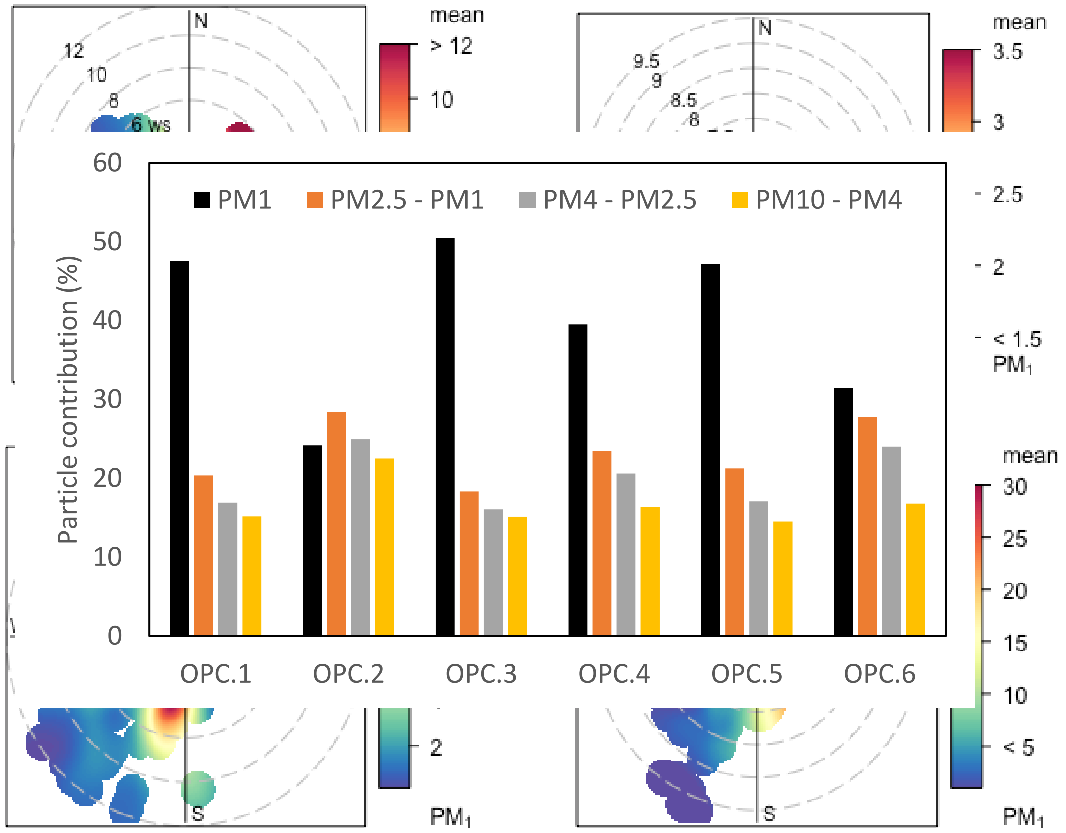
With additional information (meteorological conditions, temporal variations etc.) they are assigned to sources.

Source Apportionment Case Studies

- Birmingham urban background at the Birmingham Air Quality Supersite (BAQS)
- HS2 construction site
- Quarry
- Roadside
- Indoors air quality
- Identification of pollen and fungi at the Birmingham Institute of Forest Research (BIFoR)

Results of the k-means at BAQS

- Sources associated with Birmingham's city centre, the residential area near the University, the train station etc. were successfully separated.
- This gives us detailed information of the sources and their effect on the air quality at the site.

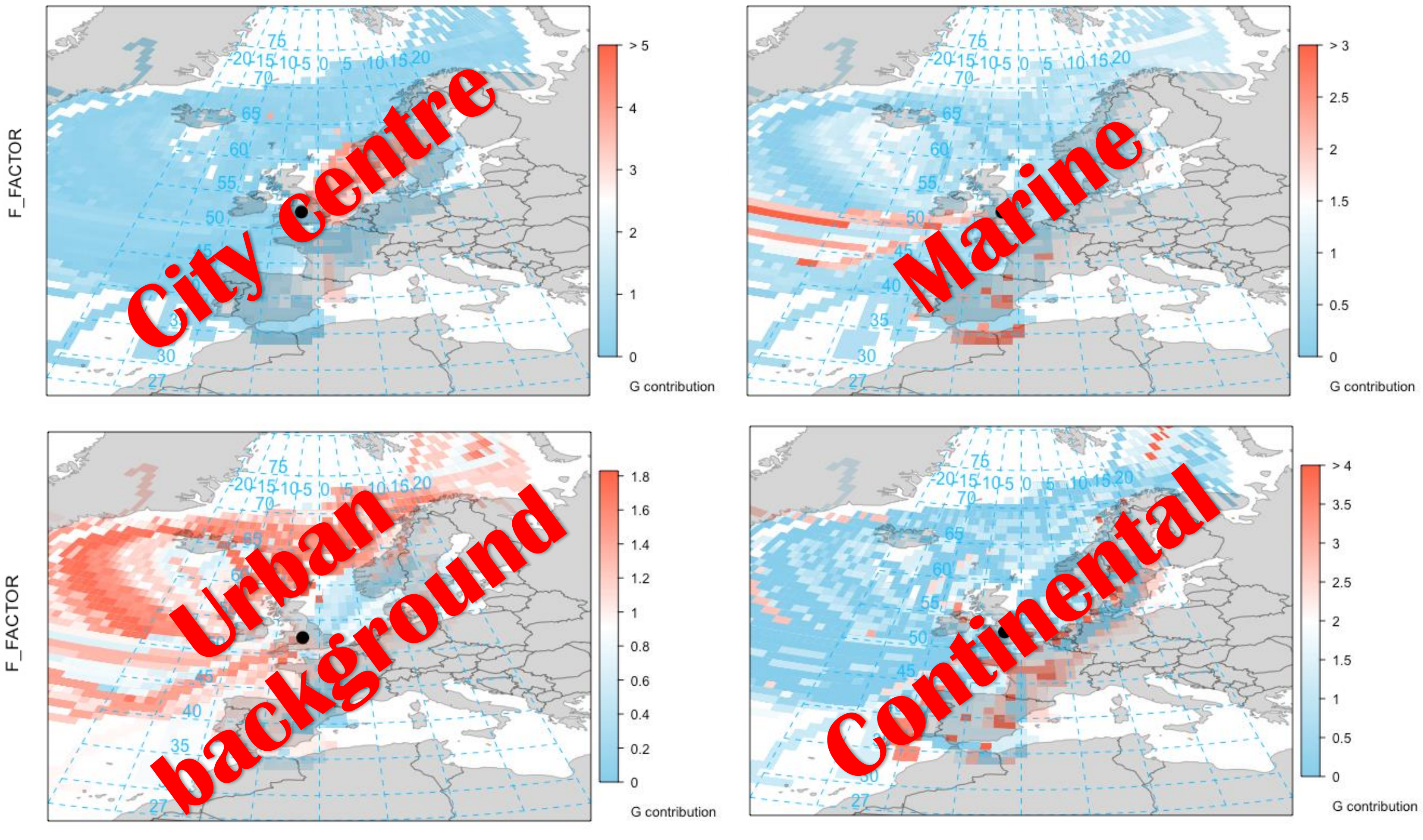


Polar plots of PM_1 concentrations of the clusters from the k-means analysis.

Bousiotis, D. et al., 2021. Assessing the sources of particles at an urban background site using both regulatory instruments and low-cost sensors – a comparative study. Atm. Meas. Tech., 14(6), 4139–4155. https://doi.org/10.5194/amt-14-4139-2021

Results from the Two-step PMF analysis

- We tested the PMF on low-cost sensor data, as well as a combination of low-cost and regulatory grade measurements

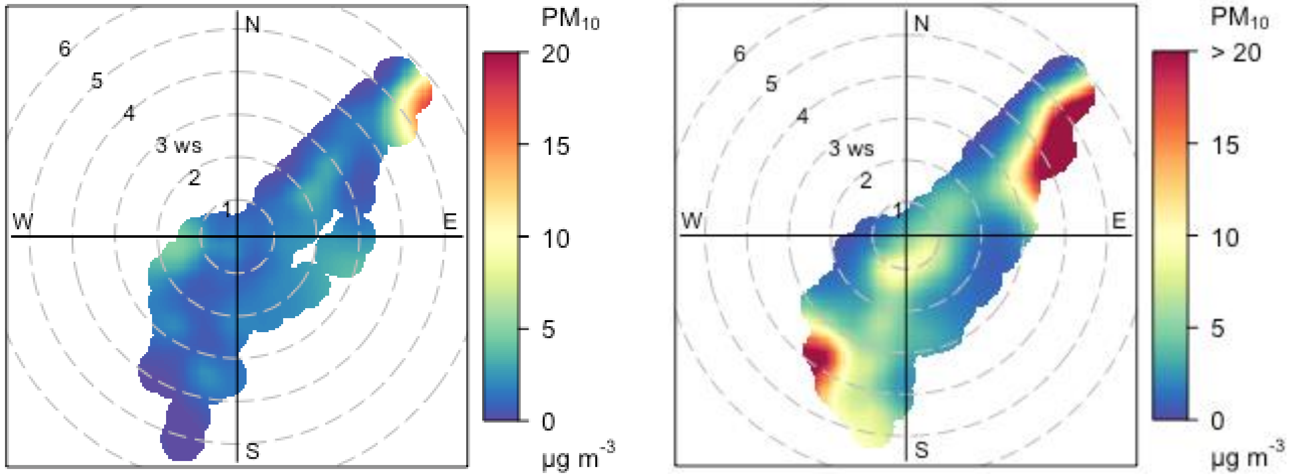


Back trajectory analysis of the factors from the LC second step analysis

Bousiotis, D. et al., 2022. A study on the performance of low-cost sensors for source apportionment at an urban background site. Atmos. Meas. Tech., 15, 4047–4061, https://doi.org/10.5194/amt-15-4047-2022

Curzon Street HS2 Construction Site

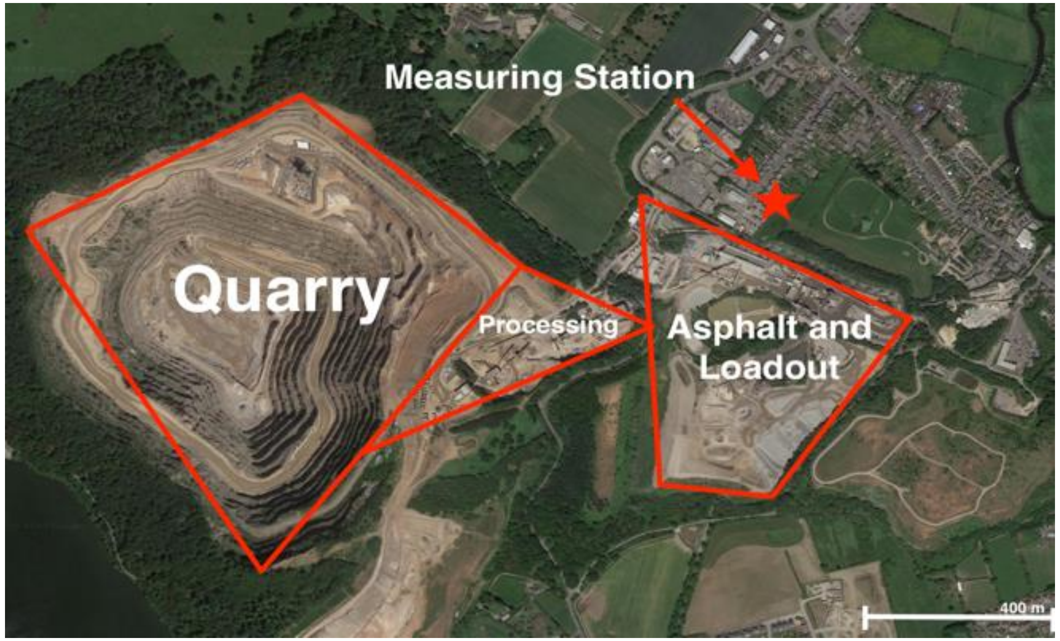
Estimated PM_{10} concentrations for (a) non-working and (b) working hours for factor F4 at Curzon Street



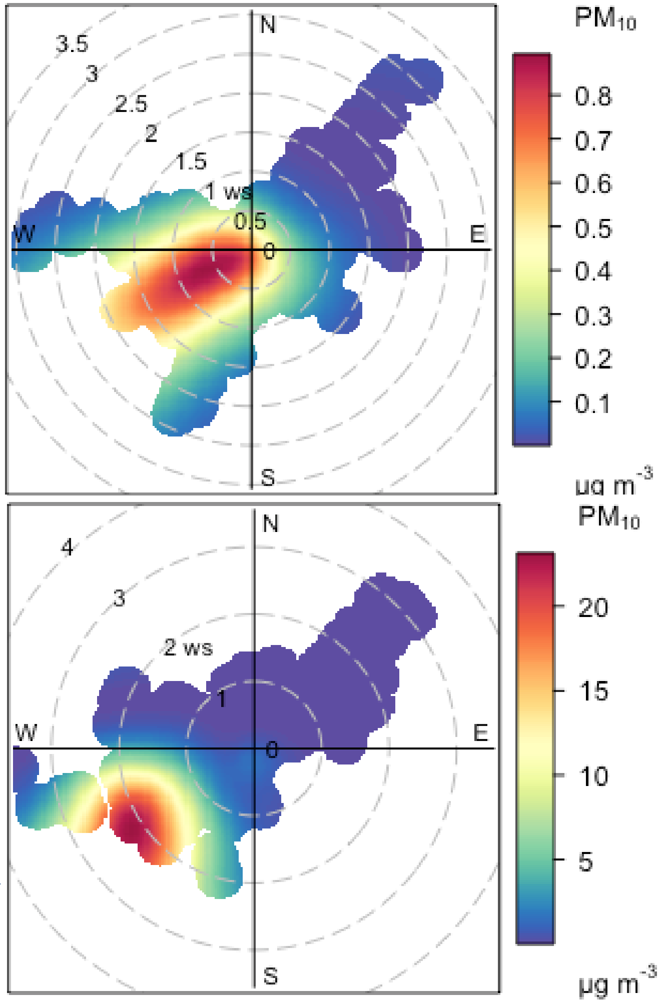
Factor	Association
F1	Urban background 1
F2	Construction site 1
F3	Urban background 2
F4	Construction site 2
F5	Regional background (marine)

Bousiotis, D. et al., 2023. Towards comprehensive air quality management using low-cost sensors for pollution source apportionment, npj Climate and Atmospheric Science, NPJCLIMTSCI-01042 (in review)

The Mountsorrel Quarry



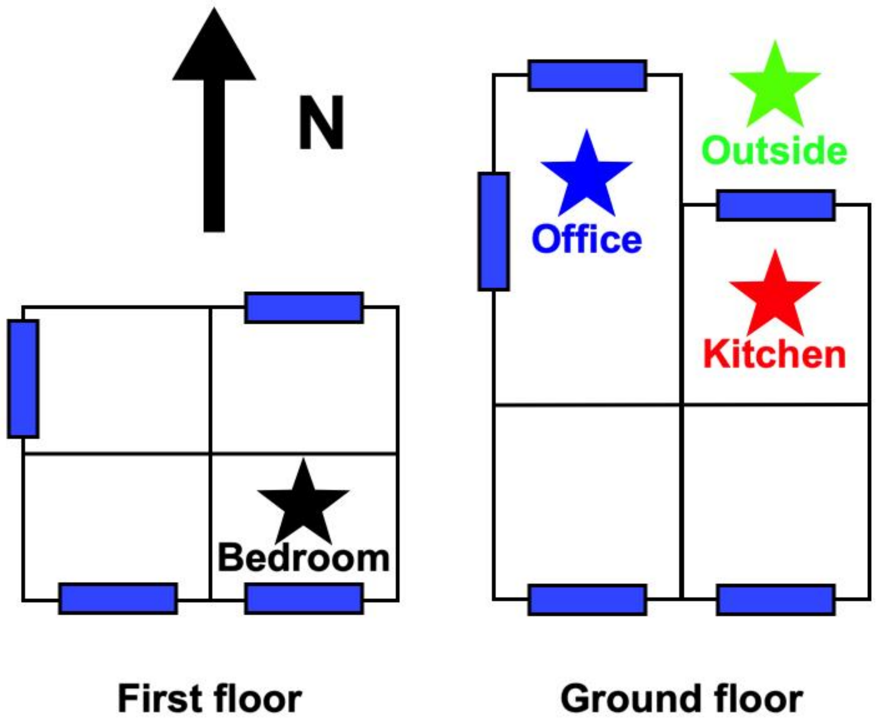
Factor	Association
F1	Urban background
F2	Quarry
F3	Regional background (marine)
F4	Undefined source (the nearby town?)



Polar plots of the estimated PM_{10} concentration for F2 (non-working (upper) and working hours (lower)

Indoor PMF study

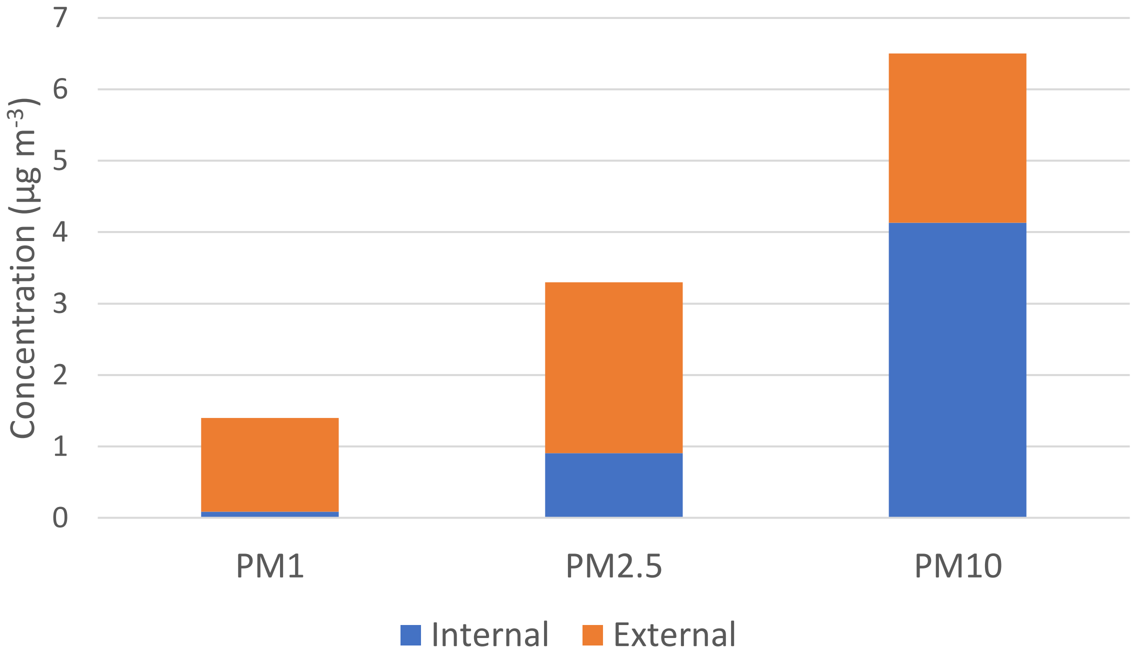
- A typical family house in a semi-rural area in Worcestershire
- 4 OPCs, 3 inside 1 outside.
- OPCs collocated with TSI 3330s



Bousiotis D. et al., 2023, Monitoring and apportioning sources of indoor air quality using low-cost particulate matter sensors, Environment International, ENVINT-D-23-00171 (in press).

Indoor PMF results

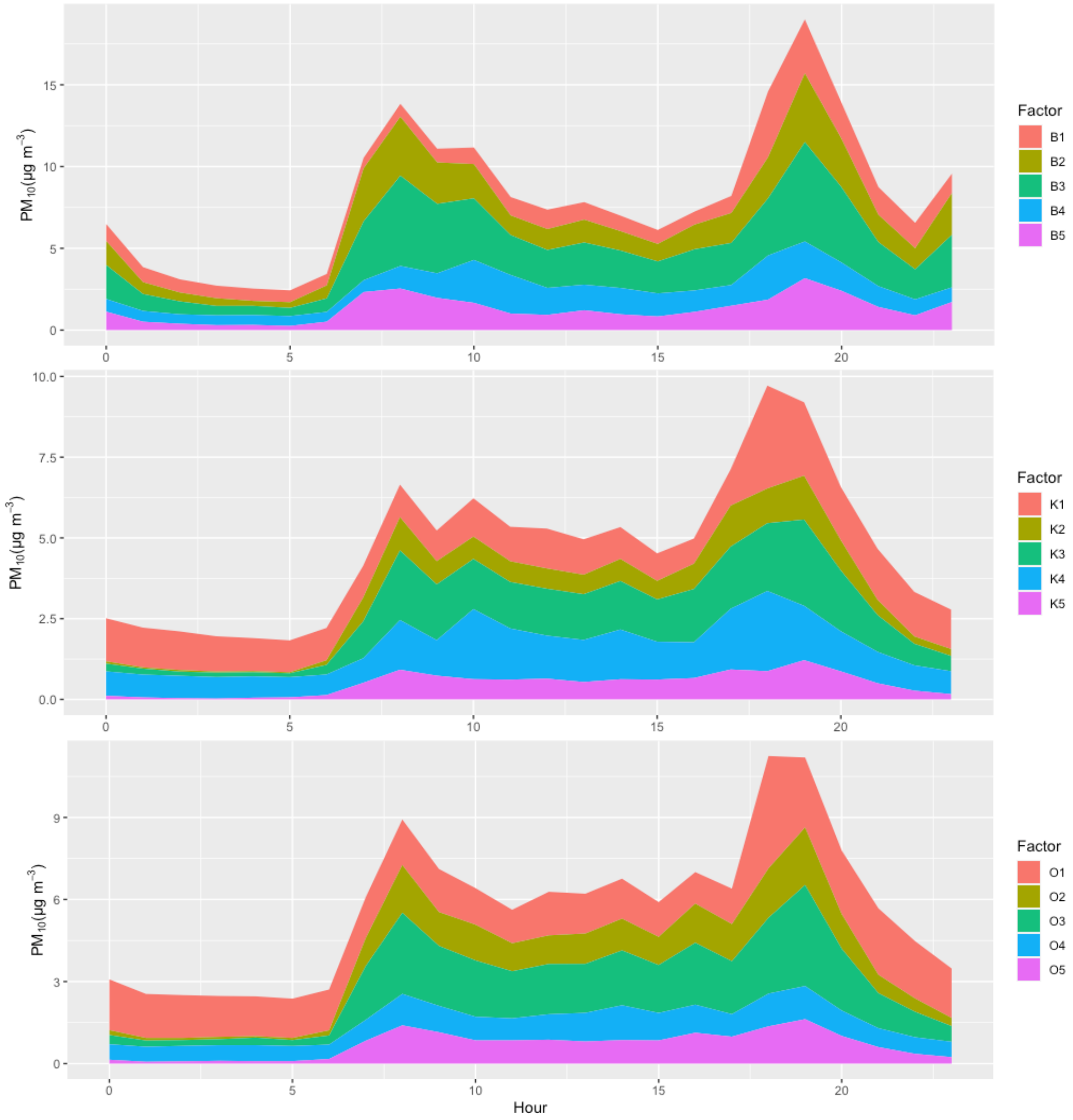
- We identified 5 different factors. 2 outdoor and 3 indoor.
- The influence of outdoor air was very size dependent.
- We assessed the daily exposure on an average working day separating the outdoor and indoor effect.



Estimated PM exposure of an average work-at-home day

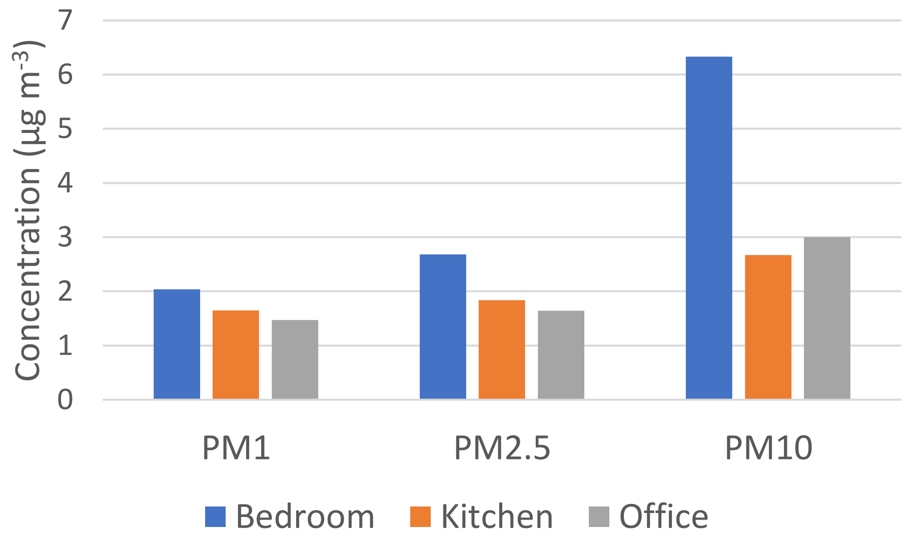
Indoor Source Apportionment

- Indoor environments have many sources:
  - Outdoor air infiltration
  - Cooking
  - Heating
  - Dust resuspension
  - Candles/incense
- Difficult to assign exactly what source is responsible for the different indoor factors



General results

- The nature of the room and activities done in it significantly affected the PM concentrations
- The highest average PM concentrations were found at the bedroom, but the sharpest peaks in the kitchen
- The PM concentrations were more than doubled when the family was present



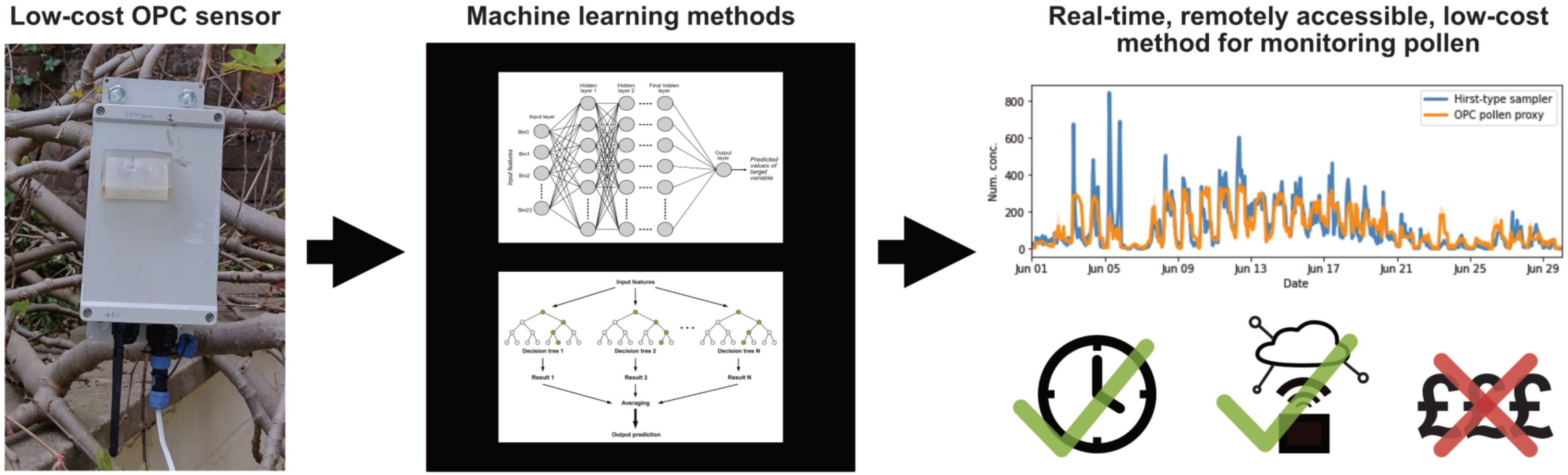
Average PM concentrations per room

Bioaerosols – pollen and fungal spores
A needle in a haystack problem – Machine learning rather than PMF

Peak pollen concentrations < 1,000 particles per m3

PM_{10} ~ $1x10^9$ particles per m^3

Assuming particles are 1 um in size and 20 ug/m3 of PM10
- Then ratio of Pollen/PM10 ~ $1/10^6$



Mills et al. 2023. Constructing a pollen proxy from low-cost Optical Particle Counter (OPC) data processed with Neural Networks and Random Forests. Science of The Total Environment, 871, p.161969.

Next steps for low cost source apportionment

- Source apportionment using low cost OPCs provides remarkably good results, compared to regulatory grade monitoring at a fraction of the cost.

- Works particularly well for sources of supermicron particles:
  - nuisance dust
  - Indoor air pollution sources
  - Bioaerosols (pollen, spores, etc)

- Potential for boundary line monitoring to be carried out more widely and for regulations to be smarter

- Networks of sensors opens the possibility of triangulating sources, to allow for local scale air quality management.

Conclusions

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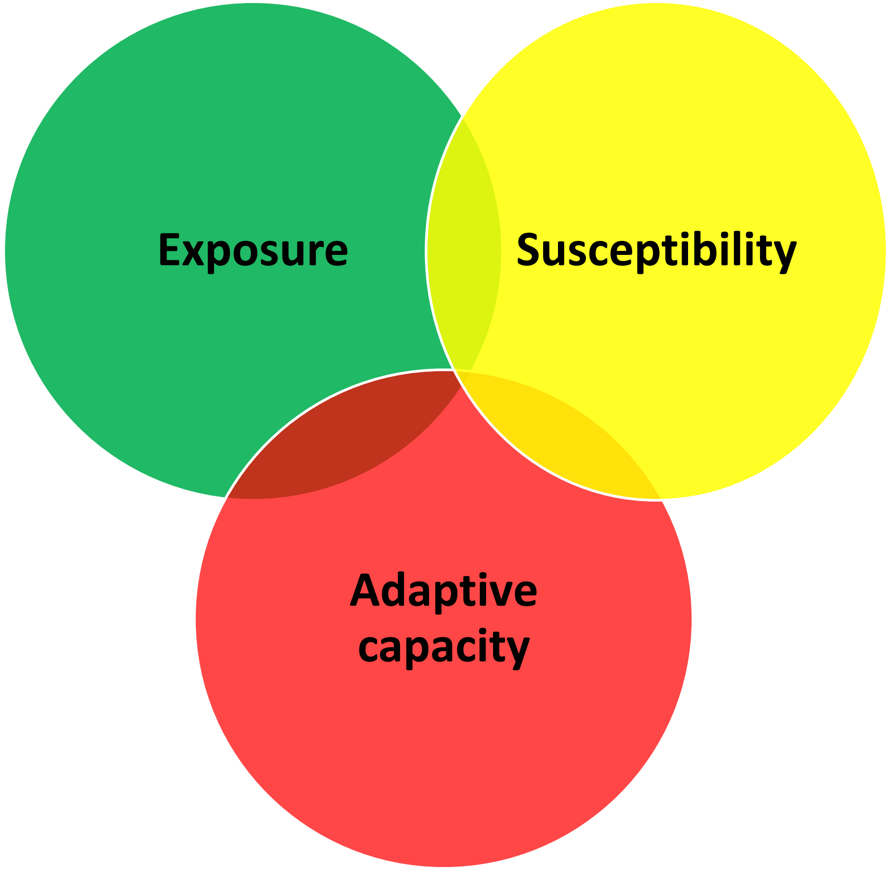
- Despite their shortcomings low-cost sensors are capable for pollution source apportionment in several scenarios.
- Source apportionment using various techniques
  - k-means clustering
  - PMF
  - machine learning techniques.
- This cheap alternative can help in the identification of pollution hot-spots and help to have better and more cost-effective ways to deal with them.
- We have tried the methodologies successfully in several different environments.
- In our latest application it successfully identified and apportioned indoor and outdoor sources in a family house.
  - Allows for a better understanding of vulnerability to air pollution by knowing where sources come from



Venn diagram of vulnerability

Thank you for listening!

Any questions - f.pope@bham.ac.uk

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