Making it personal – will small / portable sensors transform air pollution management and research?

The first meeting of the Clean Air Research Futures Group

Introduction – Who are the Clean Air Research Futures Group?

Air pollution is an old but constantly evolving research topic. The Clean Air Research Futures Group (CARFuG) is part of the UK Research and Innovation and Met Office Strategic Priorities Fund Clean Air Programme. It is convened by the UK Clean Air Champions to help to shape the future research agenda; to highlight new issues, evidence gaps and research needs.

The group brings together a broad range of participants, including people from industry, government, and NGO communities as well as researchers in fields such as health, transport, and urban planning to discuss a defined topic. Members are invited by the Clean Air Champions and vary according to the topic. Membership comprises people who will be tackling these issues in their future careers. For this reason, we are focusing on the inclusion of people in early and mid-career.

This discussion paper follows the first CARFuG meeting which took place on 6th October 2021.

Small and portable air pollution sensors

If only we could see the air pollution around us, we could identify the culprits and avoid exposure. From an early age we are taught not to drink dirty water and to make healthy food choices, but we have less opportunity to see and avoid harmful air.

Many start-up businesses, and some established equipment suppliers, are now selling small sensors that we can use to measure the air pollution around us. Search for “air pollution sensor” on the internet and you will be met with a bewildering array of devices. These are more affordable, costing hundreds of pounds rather than the tens of thousands required for the instruments used in regulatory and research networks. They are also often battery or solar powered making them portable and deployable in large numbers across an area.

Small and portable sensors could open exciting new opportunities for community engagement and personal action as well as opportunities to collect data from locations where high-quality reference instruments cannot be used.

But do they work? How can we use them to tell us more about the air pollution that we breathe? Do they open new opportunities to address knowledge gaps to help us manage air pollution?

As framed neatly in the meeting, the challenge is to place the right sensor in the right place, at the right time and to provide the right data to the right person in a way that is then understood and can be actionable.

Priority research needs and opportunities

Several priority needs arose in the discussion. These are listed below and briefly discussed in the rest of this document:

- New ways of validating or calibrating sensors are required, perhaps using network analysis. Current best practice based on colocation data is too resource-intensive for large deployments, they do not track changes in performance over time and when sensors move to different exposure environments.

- New approaches are needed to integrate small sensor and personal exposure measurements to provide an overall perspective on air pollution across an area or population. New methods are required to use these data in epidemiological research and health impact analysis.

- Interdisciplinary projects are needed to investigate the role of personal air pollution information to support behaviour change. These should also include long-term follow-up to investigate if behaviour change is maintained.

- Data governance and privacy issues need to be considered in small sensors and personal exposure measurement, especially for cloud-based post-processing and geo-located data.

- Guidance is needed for community groups, local authorities, regulators and researchers on the use and application of small sensors. This should include performance standards at point of sale, methods to get the best quality data and routes for measurements to be used in the wider air quality management process.

- Health yardsticks are required to help users to understand the concentrations and exposures that they measure and to help researchers to engage with communities. The current UK daily air quality index is not sufficient for this.

- Studies or / and reviews are needed to investigate if small sensors and personal measurement are an effective way, or the best way, to create change in air pollution concentrations and exposure.

- Finally, we must be careful to ensure that feedback and greater personal information on air pollution does not lead to a narrative where the onus of change is left to individuals rather than government and other stakeholders. If communities can gain a voice through citizen science it is important that researchers and regulators work with the seldom heard, poorer communities to ensure that they are not overlooked and left behind.

Uncertainty – how good is good enough?

I am sure that every air pollution and environmental exposure research group will have experimented with small sensors in the last five or six years. Many local authorities and campaign groups have used them too. While expectations are high at the start of these projects, getting good quality and useful data is challenging and I am sure that many sensors are sitting un-used and unloved in cupboards.

In a comment paper in Nature in 2016, Lewis and Edwards wrote of the need to test small sensors to avoid regulators being flooded with incorrect or erroneous data.

Uncertainty is one of the few things that we can sure of. Uncertainty in measurement is often the main topic of discussions around the use of small and portable sensors and occupied a lot of the CARFuG discussion. Normally measurement uncertainty is framed in terms of accuracy and precision but in the case of small and portable sensors we also have to consider specificity; does the instrument measure the target pollutant and what can interfere with this? While it is possible to locate sensors next to reference instruments and create conversion factors to correct for bias and offsets, sensors can perform differently when moved to another location or in different meteorological conditions. This is especially problematic for portable and personal measurements and for measurements in indoor environments. Discussion in CARFuG highlighted problems with measurement of gaseous pollutants but it was the consensus that particle measurements had less uncertainty. However, we should not expect small sensors to perform as well as reference instruments.

It was common practice amongst the group to collocate small and portable sensors alongside reference instrument before deployment. However, this is very resource intensive and provides challenges for deploying large numbers of sensors. Also, we need to be able to track sensor performance over time.

Is it better to think in terms of the required uncertainty for the application? For instance, is it sufficient to measure relative concentrations over time or between places rather than absolute values? Also, even uncertain measurements can be useful where we have no other data; in developing countries, for instance, but also here in the UK many exposure micro-environments are not covered by other types of measurement or models. However, methods are needed to integrate and combine small sampler or portable measurements with other measurements and models.

Air quality maps from models and interpolations reference measurements can help us understand sources and exposure. They can also help us target areas where more measurements, such as those from small sensors may reduce overall model uncertainty. These may be places far away from other measurements or in zones where steep spatial gradients are predicted. Also, models can only tell us about the known unknowns[1]. One powerful example was provided by a local authority who had equipped members of their environmental team with small PM sensors. Carrying these sensors revealed particle pollution hotspots from restaurant cooking; especially from those using charcoal

[1] Credit to the late Donald Rumsfeld https://www.scientificamerican.com/article/rumsfelds-wisdom/

grills. These were not listed in emissions inventories and therefore not known to city-wide air pollution models.

Measurements are not the only way to gain information on personal exposure. Both London and Paris have highly spatial resolved, near real-time, pollution models. These can be linked to routing applications to enable people to choose low-pollution ways to travel or linked to phone location information to help people understand their exposure through the day. This approach could offer a lower cost alternative to personalised or localised pollution measurement and many opportunities for researchers to link exposure, location and activity for many more people than they could using personal sensors.

From new measurements to useful information

Small sensors can help us understand pollutant concentrations in a wider range of settings than we can measure at present. By attaching sensors to people, we can track not only concentrations in different environments but also a person's exposure as they travel through them i.e. the time integral of concentration.

Many of us wear fitness watches and most of us carry smart phones. Connecting these devices to small sensors offers new ways to display air pollution information and integrate it into our lives. This can be though fitness apps and activity trackers or mapping and navigation tools.

There are many yardsticks to help people understand outdoor air pollution in their cities. International bodies such as the EU and World Health Organisation set guidelines and limits. There are also limits in UK law. The UK has a Daily Air Quality Index that describes air pollution as low, moderate, high or very high and links this to health advice. Members of CARFuG said that they had struggled to give people health feedback on the personal and micro-environment measurements that they make. There is an urgent need for guidelines and yardsticks to allow people to understand concentrations in micro-environments and their own exposure, to turn measurements into actionable information.

Similar challenges exist in using small sensor data in health research. Today most epidemiological research assumes that individuals are exposed to the air outside their home addresses. New approaches are needed to make use of more detailed concentrations and exposure information from small and portable sensors in both outdoor and indoor environments. Better measurements may also help clinicians and patients manage their exposure and to understand personal asthma triggers.

Behavioural change and democratisation

Much of the CARFuG discussion focused on the opportunities to feedback to people about the air pollution around them; to engage and empower individuals and communities in protective actions and the underlying solutions. This was discussed in terms of both democratisation; allowing people to measure the air pollution that they breathe, in the locations that concern them rather than relying on data from official monitoring sites that are located according to regulatory needs. One local authority mentioned a large increase in queries from the public who were taking their own measurements, showing that this was already underway.

Despite this there are few examples where community measurements or citizen science projects have been taken on board by regulators and translated into action. Only two examples were given in the meeting; one being a local authority led project that worked with residents around a road closure and another where local residents undertook their own programme. Both examples used NO_2 diffusion tubes. Traction with the policy-making progress was only achieved because the community was helped to follow official guidance. In these cases, the technical guidance for local authority air quality management was used (LAQM TG16) but this does not cover small and portable sensors. It was clear from the meeting that there is an urgent need for guidance and expert support so that community measurements can be made in a way that can have direct impact on air quality management.

In addition to allowing people to understand the air pollution sources around them, the CARFuG discussion also highlighted the use of small or personal sensors to support behavioural change. This might be small sensors outside school gates to help parents understand, and change, school-run impacts, or personal measurement to help people understand where they are most exposed to air pollution and to think of ways that they could change this. The examples discussed used feedback from personal measurements in awareness raising and engagement projects with school children with; including a project where 30% of school children changed their commute to school. Although these measurements offer many opportunities for engagement, the benefit of such engagement would be greatly increased by health advice to help people understand if their exposure is harmful and positive actions that they could take.

It was clear from the discussion that future projects will require measurement experts to work with social scientists, and most especially behaviour change researchers, if the large efforts being expended in small and portable sensors are to realise their potential. Projects that aim to change behaviour should also include long-term follow-up to see if changes are sustained.

Avoiding perils and pitfalls

Many people measure the temperature in their garden where a precision of one or two degrees is fine, but an inaccurate air pollution sensor could falsely reassure or alarm and may lead to harm.

Currently, sensors are sold without any requirements on performance. By contrast, medical equipment has to meet legal requirements on safety and quality. Poor quality air pollution measurements may lead to people distrusting or disengaging from the information that they receive. It was felt that performance standards and supporting information were needed for small sensors. This could be based on the Environment Agency's MCERTS scheme or using criteria defined at a European-wide level by CEN. However, the complexity and cost of testing maybe seen as a barrier to market-entry by many device manufactures.

Many small sensors are connected to a manufacture's web-services for post processing and display on an internet dashboard. This raises important data protection issues especially for geo-located and time stamped personal measurements.

Despite the enthusiasm of many around the opportunities for democratisation and behaviour change, it is not clear if small sensor or personal exposure measurements are the best way to empower communities and affect change. There is a need for research on different types of awareness raising interventions to learn about their relative effectiveness. Small sensor and personal exposure projects

could be simply a diversion of resources away from taking action to control pollution at sources. We must be careful to ensure that feedback and greater personal information on air pollution does not lead to a narrative where the onus of change is left to individuals rather than government and other stakeholders. People differ in their opportunity to take action to change the air that they breathe. People that live in some of our most polluted communities often have fewest home, work, and transport choices. Pollution sensors cost money. If communities can gain a voice through citizen science it is important that the seldom heard communities, who often experience the greatest air pollution burden, are not overlooked and left behind.

Gary Fuller and the Clean Air Champions team, November 2021.

Attendees:

Dr Gary Fuller, Imperial College London (Chair)
Dr Jenny Baverstock, Clean Air Champion, University of Southampton
Dr Suzanne Bartington, Regional Clean Air Champion, Midlands to North of England
Dr Heather Price, Regional Clean Air Champion, Scotland
Prof Paul Lewis, Regional Clean Air Champion, Wales
Dr Neil Rowland, Regional Clean Air Champion, Northern Ireland
Dr Audrey de Nazelle, Imperial College London
Rob Day, AUK-BLF
Dr Rachel Aldred, University of Westminster
Ruth Calderwood, City of London
Sarah Legge, EPUK
James Stewart-Evans, PHE
Emma Hibbett, Imperial College London
Simon Ballard, Chichester City Council
Prof Rob Kinnersley, Environment Agency
Dr James Allan, University of Manchester
Dr Matt Loxham, University of Southampton
Dr Diana Varaden, Imperial College London
Thomas Johnson, Nottingham Trent University
Larissa Lockwood, Global Action Plan
Andrew Grieve, Imperial College London

Observer:

Kayla Schulte, University of Oxford

Presenters:

Dr Audrey de Nazelle, Imperial College London
Rob Day, AUK-BLF
Ruth Calderwood, City of London
Sarah Legge, EPUK
James Stewart-Evans, PHE
Prof Rob Kinnersley, Environment Agency
Dr James Allan, University of Manchester
Dr Matt Loxham, University of Southampton

Dr Diana Varaden, Imperial College London
Thomas Johnson, Nottingham Trent University
Larissa Lockwood, Global Action Plan
Andrew Grieve, Imperial College London