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# New Directions: The future of European urban air quality monitoring

## 1. Introduction

Air quality, especially in urban areas, deteriorated with the industrial revolution and the following centuries. It is only during the last 60 years, following e.g. the infamous London smog episode (1952), that the health impacts of air pollution have been recognised and acted upon. In the developed world, abatement strategies and closure of major industries have led to significant air quality improvements (Harrison, 2004; Lamarque et al., 2010; Monks et al., 2009; Smith et al., 2011; Tørseth et al., 2012). However, current air pollution levels in Europe and North America have still important short-term (Samoli et al., 2008) and long-term health effects (Beelen et al., 2013; Pope et al., 2009; Raaschou-Nielsen et al., 2013) including increases in mortality and corresponding decreases in life expectancy, as well as effects on respiratory and cardiovascular morbidity (WHO REVIHAAP project, 2013). The evaluation of current research within the Clean Air for Europe (CAFE) process has clearly shown that investments in further air quality improvements will have a beneficial return financially, in terms of population health, environmental improvements and in quality of life (Bell et al., 2011; EEA, 2007; Pascal et al., 2013). This is similarly seen in the USA (Esworthy, 2013) and supported e.g. by the results of Parrish et al. (2009) in mega-cities across the world.

The measurement of air quality changed dramatically during the last century reflecting the concurrent knowledge about the adverse effects of air pollution, as well as through technological developments. The earliest measurement methods were often labour intensive, needed long analysis times and had a low time resolution. Routine measurements of air quality can be traced back to the Montsouris Observatory in Paris, where ozone was measured between 1876 and 1910 (Volz and Kley, 1988). Since then, scientists have pursued the concept of making measurements of air pollutants at fixed monitoring sites using well established, calibrated and comparable methods. Developments in air quality monitoring techniques during the second half of the 20th century enabled higher data quality to be obtained, with lower detection limits, using automated, continuous methods. One of the first real-time measurement techniques was initially developed by Fowler as early as 1949 (Fowler, 1949) for the measurement of e.g. hydrocarbons (Jacobs et al., 1959).

Developments in online air quality monitoring enabled the development of public warning systems and immediate notifications if alert thresholds were exceeded. Short-term measures could then be taken to reduce emissions during pollution episodes. Measures included traffic reductions and closure of industrial facilities during e.g. winter smog episodes in Germany in the early 80's (Bruckmann et al., 1986). Such reactive measures are now commonplace in new legislation (EC Directive, 2008; CFR 40, 2011; JAPC, 2011), along with public information to help vulnerable people to cope with pollution episodes (Kelly et al., 2012).

## 2. Air quality monitoring today and recent progress

In the EU, the current air quality monitoring strategy is mainly driven by the need to achieve and to comply with limit values. Consequently, monitoring sites are predominantly installed where exceedances of limits are likely to occur. However, within Europe, a new additional requirement to reduce average pollution exposure of the urban population marks an important change in policy direction. In brief, the concept is based on the measurement of $PM_{2.5}$ (mass concentration of airborne particles $< 2.5$ µm in diameter) at urban background stations. The average $PM_{2.5}$ concentration of selected urban background sites in a given country over a period of 3 years forms the so-called Average Exposure Indicator (AEI, Brown and Woods, 2012). This AEI should not exceed a limit value of 20 µg $m^{-3}$ by 2015, and should be reduced by a percentage (depending on the initial $PM_{2.5}$ concentration) by 2020. This emphasis on large-scale pollution reduction should bring health benefits to a much larger number of people than reductions focussed solely on "hot spots". However, when a limited number of fixed-site monitors are available, this approach only works well for pollutants with a low spatial variation like $PM_{2.5}$. For air quality metrics with higher spatial variability a suitable monitoring approach must be pursued. Recent progress in two aspects of monitoring technologies now makes this possible:

- Developments in air quality monitoring techniques, such as
  - small, low-cost, outdoor-installable or portable devices/sensors with low power consumption,
  - automated multicomponent analysers,
  - analysers for new particle metrics (e.g. black carbon, particle number or surface area).
- Developments in data retrieval and analysis, e.g.
  - for the determination of the spatial variability of air pollutants on urban scales based on data from multiple low-cost sensors and geographic information systems (GIS),
  - integrated data systems allowing real-time interactions between pollution monitoring, public information and pollution reduction measures.

First developments with regard to the latter bullet points are currently ongoing, see e.g. Resch et al. (2011).

## 3. Recommendations for the future

Looking forward, the recent developments in monitoring techniques, data retrieval and analysis offer the possibility for

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regulatory monitoring to move beyond the approach based on fixed monitoring sites (Kuhlbusch et al., 2013). There are two main components to this:

### 3.1. Integration of air quality data from diverse sources

Future air quality monitoring should combine all available “monitoring” activities and maximise the advantages of each to improve population exposure assessment. The main activities are:

- Fixed sites: Deliver high quality and time resolved data, but at the cost of less detailed spatial information.
- Mobile and flexible installations: Allow the collection of highly spatially and temporally resolved data using small, low consumption monitoring devices.
- Modelling: Enables the calculation of the spatial and temporal variation of air pollutants in urban areas at all locations, but often with relatively high uncertainty.
- Combination of local and regional air quality information: Facilitates the assessment of regional scale and transboundary contributions to exposure levels.
- Remote sensing, including satellites: Observation of air pollutants over a wide area, but lacking height resolution that would allow for direct use in exposure/health related air quality monitoring.

In the short to medium term, the current focus of air quality monitoring in Europe needs to continue on the basis of fixed monitoring sites. However, in the long term, the increased use of urban-scale modelling linked to fewer fixed monitoring sites and a network of mobile, flexible monitors supplemented by remote monitoring, should be explored. Validated model results may well provide a more reliable long-term population AEI than fixed monitoring sites alone. This approach would allow the higher data quality obtained from measurements to be linked to the better spatial information obtained from modelling. Greater use of modelling would also allow comprehensive scenario testing to develop better abatement strategies, improvements in public information and the visualisation of air pollution exposure. However, it must be remembered that models can only tell us about so-called known unknowns. A key role of fixed measurement networks in future should therefore be to provide high quality data to underpin sensor and model based assessments. This calls for a more comprehensive integrated measurement infrastructure using multiple monitoring methods.

It is clear that substantial gains may be realised through the future systematic development and integration of these measurement and assessment techniques into a single homogeneous information network, minimising the risks of pitfalls, and maximising the benefits of each information source, to produce a high quality spatially- and temporally-resolved data set in near real time.

### 3.2. Integration of air quality monitoring and research through an overarching strategy

The challenges of managing urban air pollution have evolved substantially since the 1950s and will continue to evolve in the future due to changes in the causal factors and as a consequence of new scientific insights. However, delays of many years can occur before the outputs from new research are taken up and subsequently used by policy makers. To counter this lag, research and monitoring should be strongly integrated through a strategy so that the large investments are explicitly geared to addressing research questions effectively, alongside the assessment of limit value compliance and the population exposure. One way this could be accomplished is to create dedicated areas for research and monitoring of air quality (ARMAQs), in carefully selected urban agglomerations, to facilitate research into such things as:

- new monitoring devices for fixed or mobile measurement locations, for both new and existing metrics,
- new data collection, analysis and visualisation tools,
- improved exposure assessments for population-based health effect studies,
- the development and testing of alternative air quality indicators for urban air quality and health.

This can be seen as an extension of the so-called super-site concept.

Despite air quality monitoring being designed to protect human health, analysis of health impact does not form an integral part of current air quality assessments. Future monitoring strategies should therefore include the collection and assimilation of health effects data, along with air quality data, which should also include new pollutants and alternative metrics. This would allow direct and rapid assessment of the success of air pollution abatement measures, and would greatly improve the detection of relationships and trends in air pollution health impacts. An extension to other environmental stressors can be envisaged which would further enhance our knowledge on environmental and health issues. ARMAQs with integrated health monitoring and epidemiologic research could be used to develop and evaluate pilot-test strategies for health effects-oriented air quality monitoring.

The current review of the European air quality policy (launched in 2011), upcoming research under Horizon 2020 as well as the next revision of the European air quality directive foreseen for 2018 will be an excellent framework to further develop European air quality legislation and regulation, taking climate change issues into account, and so to improve the environment, human health, and the quality of life in Europe, along the lines we have described.

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