Technical advice note on lower cost air pollution sensors

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Introduction

Low cost air pollution sensor networks are an appealing new technology for use in both research and operational applications. They offer the potential to greatly increase the spatial resolution of observations, provide localised validation of models and more precise estimates of human exposure, particularly in locations that do not have traditional monitors. Arrays of air pollution sensors are now being used in indoors [1,2,3,4,] and out[5,6,7,8] and there are an increasing diversity of applications being proposed in the atmospheric sciences[9]. Low cost sensors utilise a very wide range of different underpinning technologies and the fundamental analytical principles can differ significantly from methods used in current regulatory measurements and in global networks of observations such as WMO-Global Atmosphere Watch. This advice note is aimed at users considering adopting sensor approaches for pollution measurement; it identifies some of the basic technologies, some key operational factors and possible deployment scenarios.

Basic principles

The low cost sensor descriptor spans a very wide range of different devices from those with unit costs of only a few dollars through to complex miniaturised micro-electro-mechanical instruments costing several thousand. Most of the major urban and regional air pollutants can now be detected using sensor-based methods including O_3, CO, NO, NO_2, SO_2, total VOCs and particulate matter (PM). Many commercialised instruments package together multiple different sensors within a single device to support multi-parameter measurements.

Gas phase air pollutants are typically detected using sensors based on either metal oxide (MO) sensing or electrochemical (EC) sensing. MO sensors work on the principle of a surface oxidation of reducing gaseous pollutants that then generate a change in the electrical conductivity of the semiconductor material. A measurement of the change in surface conductance, and hence resistance, is proportional to the atmospheric concentration. In EC sensors gaseous pollutants and oxygen react in a pair of amperometric fuel cells, the current generated again being proportional to the concentration of the pollutant. For particulate matter a variety of methods are available, with the most common being optical detection of particle number based on light scattering principles.

- ***Recommendation 1: It is essential that users identify the underpinning sensor technologies being used since this impacts on data quality and fit to application.***

Key considerations

Methods for air pollution measurements in GAW, and in most regulatory environments, use analytical methods that have a high degree of molecular specificity, for example through the use of spectroscopic and mass spectrometric identification of the pollutant being measured. Whilst sensors can be optimised to maximise their responses to certain chemicals, the analytical techniques are generally less specific. Consideration must be given to potential interferences, or false signals, generated by other components present in air. There is a considerable and growing literature on this subject, beyond the scope of this advice note, but some examples are discussed here.

Some sensors show a degree of sensitivity and response to other reactive air pollutants and also to stable but abundant gases such as water vapour, methane or carbon dioxide; these interference signals must be corrected for before a chemically-specific measurement value can be reported. Many commercial devices attempt corrections of this kind automatically, but this should be independently evaluated wherever possible against known reference measurements. Optical detection of particle number uses some basic principles that are common to some more expensive reference instruments. Humidity is known to affect the response of sensor optical particle counters, and the value returned is not easily translated into a mass concentration of particles, which is the metric of air quality standards.

Current reference methods for air pollution are typically based on instruments that operate under tightly defined environmental conditions. Internal components of many instruments are temperature controlled for stability and the instruments themselves housed in climate-controlled cabinets or laboratories. Sensor packages are typically mounted outside (for example on lamp-posts), have limited or no thermal regulation and the sensing element is exposed to a very wide range of environmental conditions and are often battery powered. This inevitably impacts on the measurement and again corrections must be made for the influence of these broader environments effects.

- ***Recommendation 2: Sensor measurements can be impacted by a wide range of different chemical and physical interferences. Any corrections that are made to account for these need to be validated against reference measurements.***

Calibration

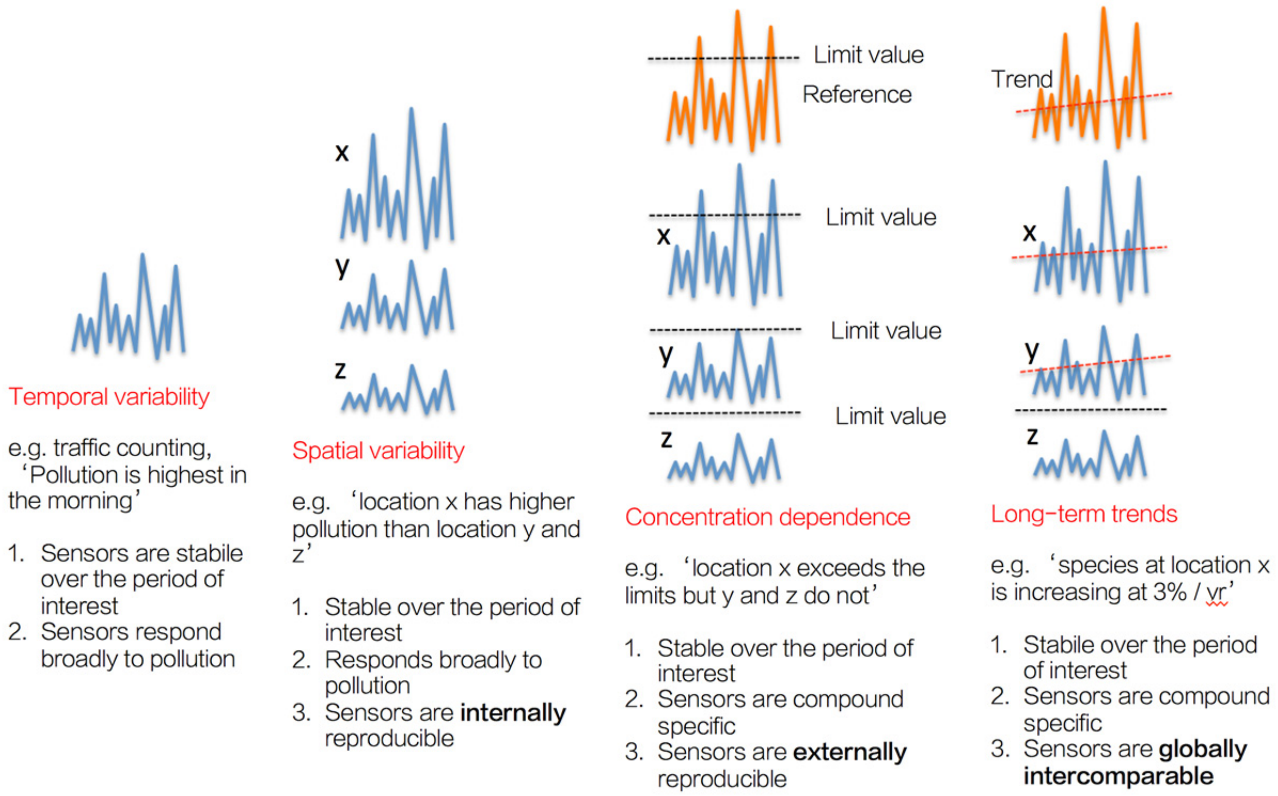
Existing methods for air pollution measurement are supported by a traceable set of reference materials, and calibration (and zero-ing) is typically a daily or weekly occurrence. Calibration and associated QA/QC is typically one of the mostly costly aspects of operational air pollution networks. Sensor networks rely primarily on a one-time factory calibration and one-time zero setpoint. They are not easily field calibrated due to a variety of reasons, for example many sensors do not respond in a representative way to synthetic gas standards in nitrogen. Calibrating very large numbers of sensors across a city may be physically impractical. The real-world long-term stability of air pollution sensors is not yet proven and there is little peer-reviewed literature that would support that a single calibration factor would be applicable over periods of months to years. Literature sources also caution that extrapolating laboratory calibration results to the real-world may not be appropriate and that field calibration is essential to account for local environmental conditions. The relative changes in response in a population of identical sensors over time has also not yet been reported in literature and this impacts on longer-term estimates of uncertainty.

- **Recommendation 3: Air pollution sensors must be treated like any other analytical instrument. They will likely require regular field calibration and will show long-term changes and drift in sensitivity and response.**

Applications

There are a very broad range of different applications where air pollution sensors could be used, ranging from direct replacements for regulatory methods through to purely indicative measurements of pollution in general terms[10]. It is important that the analytical requirements of each application are matched against the proven capabilities of any given sensor device. Since the variety of sensors on the commercial market is wide there is no straightforward answer to the question “what can sensors be used for”? This must be established by the user on a case-by-case basis.

A generalised set of possible example applications are shown in the figure below alongside a measurement ‘question’ and then a set of sensor technical requirements. The scenarios increase in challenge from left to right. The applications identified here include the use of sensors to determine temporal variability, spatial variability, concentration dependence and long-terms trends. Many other applications can be conceived of, but in all cases the appropriateness of sensors for the task must be established.



- **Recommendation 4: The current body of research literature would support the use of low cost air pollution sensors for certain applications but not others. The advice is summarised below.**

  i) Peer-reviewed literature would indicate that many current sensor technologies provide a useful qualitative measurement of the temporal variability of general air pollution levels at a given location over periods of days to months.

  ii) There is some evidence to support the use of sensors to assess spatial variability in air pollution, that is, the *relative* differences in overall air pollution between two different geographic locations.

  iii) There is rather limited evidence for sensors being an appropriate method to assess the concentration dependence of a specific chemical, for example for determining compliance with legal or regulatory standards.

  iv) There is no evidence for sensor approaches being currently suitable for discerning long-term trends in atmospheric composition.

The advice provided here summarises the technical view of the Reactive Gases Science Advisory Group (RG-SAG) of WMO-GAW following its 5th meeting in Stanley, Australia on 10th November 2016. The advice is based on the available peer-reviewed evidence at that time. It is acknowledged that this is a fast moving field of technology and this advice will likely require frequent revision in light of new literature.

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