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A case study in preferential sampling: Long term monitoring of air pollution in the UK

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ABSTRACT

The effects of air pollution are a major concern both in terms of the environment and human health. The majority of information relating to concentrations of air pollution comes from monitoring networks, data from which are used to inform regulatory criteria and in assessing health effects. In the latter case, measurements from the network are interpreted as being representative of levels to which populations are exposed. However there is the possibility of selection bias if monitoring sites are located in only the most polluted areas, a concept referred to as preferential sampling. Here we examine long-term changes in levels of air pollution from a monitoring network in the UK which was operational from the 1960s until 2006. During this unique period in history, concentrations fell dramatically from levels which would be unrecognisable in the UK today, reflecting changes in the large scale use of fossil fuels. As levels fell the network itself was subject to considerable change. We use spatio-temporal models, set within a Bayesian framework using INLA for inference, to model declining concentrations in relation to changes in the network. The results support the hypothesis of preferential sampling that has largely been ignored in environmental risk analysis.

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1. Introduction

Attempts to measure levels of air pollution in a regular and systematic way followed a series of major pollution episodes in the first half of the twentieth century. During an episode of fog in London in 1952 levels of Black Smoke (BS) exceeded 4, 500 μg m^{-3}, substantially higher than recent EU regulations which state a limit of 68 μg m^{-3} for a yearly average (or 213 for a daily peak). This episode was associated with 4000 excess deaths (Ministry of Health, 1954) and lead to the Clean Air Act of 1956 and the establishment of the world's first co-ordinated national air pollution monitoring network being established in the UK; the 'National Survey' (Clifton, 1964).

Monitoring networks such as this provide the vast majority of information that has been used to assess the levels of pollution with regards to regulatory criteria and may be used in further study, for example when studying the effects of air pollution on health. In both cases, measurements from the network are interpreted as being representative of the actual levels of pollution across the country and thus to which the population is exposed. This may not be the case if the locations at which measurements are made are related to the expected concentrations at those locations. Commonly locations may be retained, or introduced, where measurements might be expected to be high. This may be by design in order to check adherence to standards but will cause difficulties in obtaining representative measurements for use in epidemiological research or for informing policy.

The acute effects of air pollution have been extensively studied and increasingly focus has turned to longer term or chronic effects. In acute studies, daily counts of health outcomes are commonly related to short-term changes in daily levels of pollution, over short periods of time, typically a few years. During such periods the underlying monitoring networks might be expected to be relatively stable. In contrast, over extended periods of time, perhaps spanning several decades, networks may change considerably. The exact nature of the changes may introduce uncertainty into whether measurements can be assumed to be representative of actual exposures or whether they will be intrinsically biased. It is therefore very important to be aware of changes in the network over time and to be able to assess what effects these may have on the measurements that are recorded.

BS has been routinely measured in the UK since the early 1960s as part of the UK Smoke and Sulphur Dioxide network and its predecessor the National Survey. In later years, the network was used to monitor compliance with the relevant EC Directives on sulphur dioxide and suspended particulate matter. The monitoring network, which measures both SO_2 and BS, was established in the early 1960s, and by 1971 included over 1200 sites. As levels of BS and SO_2 pollution have declined, the network has been progressively rationalised and reduced in size and by 2006 when the network ceased to be operational it was comprised of 65 sites (BS continues to be monitored, but on a much smaller scale DEFRA, 2012).

As the network was reduced in size, there is the possibility of selection bias if there is a tendency for monitoring sites to be kept in the more polluted areas. This may occur for example, if the locations of sites remaining in the network were chosen to assess whether guidelines and policies were being adhered to. This will lead to *preferential sampling*, which occurs when the process that determines the locations of the monitoring sites and the process being modelled (concentrations) are in some ways dependent (Diggle et al., 2010). In the context of air pollution and health in epidemiological analyses, Guttorp and Sampson (2010) state that air pollution monitoring sites may be intentionally located for a number of reasons, including to measure: (i) background levels outside of urban areas; (ii) levels in residential areas; and (iii) levels near pollutant sources. Standard geostatistical methods which assume sampling is non-preferential are often employed despite the presence of a preferential sampling scheme. Ignoring preferential sampling may lead to incorrect inferences and biased estimates of pollution concentrations.

Historically, the examination of the potential effects of preferential sampling in the monitoring of environmental factors has been limited. Recently there have been a small number of papers which have attempted to address this issue including Diggle et al. (2010), Pati et al. (2011) and Gelfand et al. (2012). In the first of these, the effects of preferential sampling are characterised within a model-based geostatistical framework with a latent Gaussian field. Site locations are assumed to follow an inhomogeneous Poisson spatial process with intensity function proportional to the underlying field. The response is also assumed to be dependent on values of the field which induces