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Analysis of the relationship between urban background air pollution concentrations and the personal exposure of office workers in Dublin, Ireland, using baseline separation techniques

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ABSTRACT

Real–time concentrations of PM_{10} were monitored over a 24 hour period for a number of different subjects as part of an investigation to examine the influence of daily activities and locations on the personal exposure of city centre office workers to air pollution. The resulting data comprised time series plots consisting of a series of peaks and troughs as a result of exposure to the differing sources of particulate matter subjects were encountering as well as the underlying background concentration. In order to separate the background concentration component from the data a number of baseflow separation techniques were employed, commonly used in stream–flow hydrology. Filter separation and frequency analysis techniques were examined comparing their predictions of background concentration with urban background concentration measurements for reference. The results of this investigation highlight a number of different approaches to separating background concentration from real–time personal exposure data. These methods will enable further investigation of purely activity and location based personal exposures as well as improvements in the numerical modelling of air pollution exposure in future. The results of this investigation also demonstrate a novel synergy in methods of analysis between the fields of air pollution and hydrology.

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1. Introduction

In recent years, research in the field of air pollution and human health has begun to focus its attention more on the investigation of personal exposure. Measurements of personal exposure to particulate air pollution have been shown to have more direct links with adverse impacts on human health compared to background concentrations (Seaton et al., 1995; Schwartz et al., 1996; Pope, 2000; Dockery, 2001). Therefore the previous traditional and current regulatory monitoring of background air pollution concentrations has seen a shift in terms of health assessment to personal exposure measurements.

The average daily personal exposure experienced by a typical urban office worker is a multifaceted conglomeration of the effects of the numerous sources of air pollution the typical individual experiences on a daily basis. In an attempt to better understand the daily personal exposure of office workers, an investigation is underway, the PALM project (Personal–exposure, Activity and Location Model), in Dublin Ireland whereby real–time personal exposure to particulate matter is being monitored for various subjects while also monitoring their activities and locations (McCreddin et al., 2009). These data then facilitate the derivation of different components of personal exposure according to the activity and/or location of the subject in question. The analysis of these components of personal exposure is expected to produce the capability for better predictions of personal exposure to air pollution in future and a method of modelling personal exposure based on activity and location.

Of the numerous components of exposure being investigated in the PALM project (such as transport emissions, indoor air emissions, environmental tobacco smoke, point sources, etc.) the background concentration at any given location is an ever present contribution to the overall personal exposure of an individual regardless of the activities they are performing. Therefore it was deemed necessary to investigate methods of extracting the background exposure component from the real–time personal exposure measurements. The extraction of this data would enable: the assessment of the contribution of background air pollution to overall personal exposure, comparisons of the contribution of background and non–background exposure components, and subsequently better prediction of personal exposure overall.

Background concentration has been defined as the concentration of air pollution in the atmosphere at any one location which is not directly affected by local emission sources (Tchepel et al., 2010). Background concentration is however not a fixed value and varies in that it may be influenced by regional air quality and indirectly by local sources. Emissions of pollutants from neighbouring cities may travel long distances to influence the background concentration of another city on a regional scale (Beelen et al., 2009). Background concentration may also vary from hour to hour where it is indirectly influenced by local emissions i.e. background concentration is likely to increase in response to peak traffic emissions or decrease at night in response to minimal traffic emissions (Moreno et al., 2009). Background concentration has also been shown to vary on a spatial as well as temporal scale. The background concentration of air quality is likely to be considerably different on a large spatial scale between urban, sub–urban and rural environments due to lower rates of local emission in less densely populated areas (Beelen et al., 2009). Furthermore the background concentration in the different microenvironments people regularly pass between (e.g. office, home, outdoor urban, outdoor sub–urban, etc) is also likely to vary. Previous investigations have regularly found concentrations of air pollution indoors which is lower than the outdoor background concentration (Colome et al., 1992).

Previous investigations have been carried out which investigated the relationships between personal exposure and background concentrations using various techniques (Ballesta et al., 2008). However, the problem presented in extracting the contribution of background concentration from a 24–hour time series of personal exposure data was noted to be similar in nature to that of baseflow separation in the field of stream–flow hydrology. Here the contribution of groundwater is required to be separated from a time series of overall stream discharge to assess the contribution of surface run–off to a storm flow (Ekhardt, 2008). In the field of hydrology the flow of water in a stream is often assumed to comprise a component of flow associated with surface run–off and a component of flow associated with baseflow (flow from groundwater) (Aksoy et al., 2009). Surface run–off can be described as ”quick–response flow” which results in rapidly occurring spikes in the time series flow record while the baseflow produces a more steady response due to the slow nature of flow through aquifers and is thus ”slow–response flow”. Like background concentration, baseflow varies both temporally and spatially and is indirectly influenced by “local emissions” of precipitation. Baseflow is likely to increase in response to a local rainfall event or decrease in response to dry periods.

Some similarities therefore exist in the relationships between surface run–off/baseflow and personal/background exposure concentrations. Personal exposure is susceptible to the effects of various air pollution sources and as a result, presents a series of rapid response spikes in its time series history, personal exposure could be described as ”quick–response exposure”. Background concentration however is slow to respond to instantaneous increases in local air pollution concentration and instead provides a steady response to the overall air quality of the locality which could be described as “slow–response exposure”. Clearly fundamental differences exist in the underlying mechanics of the two relationships, however the two are certainly analogous to a certain degree. Therefore it was assumed that an adaptation of baseflow separation techniques to air pollution time series data could provide useful predictions of background air pollution. Numerous such methodologies exist in the field of hydrology and these have been investigated for their performance in the prediction of baseflow by numerous investigators (Bougthon, 1988; Chapman and Maxwell, 1996; Brodie and Hostetler, 2005; Ekhardt, 2005; Ekhardt, 2008; Aksoy et al., 2009). This paper presents an investigation of these methodologies to enable this extraction to be carried out using adaptations of baseflow separation techniques commonly used in the study of stream–flow hydrology.

2. Methodology

2.1. Personal exposure monitoring

Real time personal exposure sampling of PM_{10} was carried out using a Metone, Aerocet 531 aerosol profiler (MetOne Inc, 2003). The Aerocet 531 is a real–time photometric sampler, an automatic instrument that estimates PM in a range of 1, 2, 5, 7 and 10 µm in aerodynamic diameters. The instrument uses a right angle scattering method at 0.780 µm. The source light travels at a right angle to the collection system and detector, and the instrument uses the information from the scattered particles to calculate a mass per unit volume. A mean particle diameter is calculated for each of the five different sizes (Kumar et al., 2007). This mean particle diameter is used to calculate a volume (cubic meters), which is then multiplied by the number of particles and then a generic density (µg/m^3). The resulting mass is divided by the volume of air sampled for a mass per unit volume measurement (µg/m^3). The sampler was used to record concentrations of PM_{10} at 2 minute intervals over a 24 hour period. The Aerocet–531 was chosen because it is a portable handheld device, weighing approximately 0.88 kg, which made it extremely convenient for use in a personal exposure study of this nature where numerous volunteers were required to carry the device on their person for 24 hours. Ten samples were recorded between February and July 2009 by 6 separate volunteers. Each of the volunteers lived in the greater Dublin area and worked in an office environment in the city centre. Figure 1, shows a typical 24–hour time series profile recorded during this investigation.

During sampling, the location of each subject was also monitored using a GPS (Garmin GPSMAP® 60CSx) tracking device which each volunteer kept on their person at all times. Figure 2 shows a plan view of the 24 hour location pattern of one of the volunteers during their sampling. The sampling volunteers were instructed to keep the sampling kit (GPS & Aerocet 531) on their person at all times during the 24–hour sampling period. A small satchel was employed during sampling to house the sampling equipment together and prevent interference from the subjects. Volunteers were also instructed to complete a simple time series diary of their activities during the day (e.g. 8 am – 9 am, commuting by car; 9 am – 10 am in office; etc).

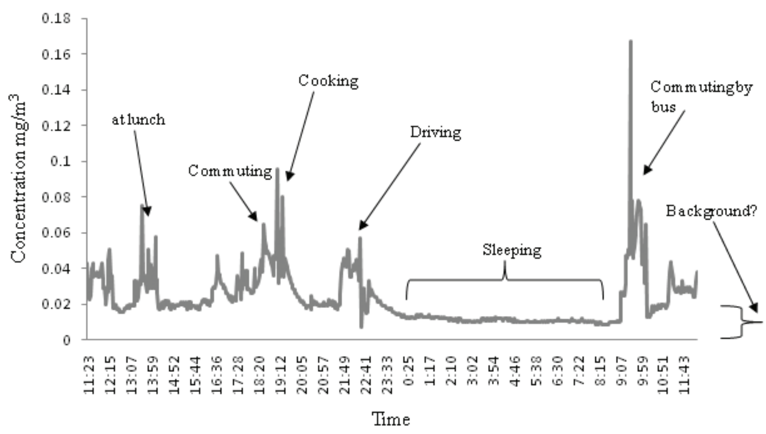

Figure 1. *Typical 24 hour time series profile of personal exposure to PM_{10}.*