Twentieth century air pollution near London: a reconstruction from measurements of atmospheric electricity

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Summary

Past urban measurements of air pollution provide information with which to investigate human health effects from smoke exposure. Direct measurements of atmospheric smoke concentrations were made at Kew, near London, from the early twentieth century, using the density of an optical stain on a filter through which air was pumped. Atmospheric electrical measurements were also made at the same site, including the Vertical Potential Gradient, which is an effective proxy for smoke pollution levels. The electrical proxy method is used here to provide a consistent calibration for the early direct smoke measurements, extending the record to before the direct measurements began. Reconstruction of annual smoke concentrations from 1909 shows that the direct measurements in the early part of the 1920s were not reliable, and that the high concentrations of smoke in London occurring in the early 1950s, associated with substantial increases in mortality, were probably the largest annual values since 1909.

Introduction

Major changes in the composition and concentration of air pollutants in the UK occurred during the twentieth century. Observations show a notable transition from high to low levels of smoke concentrations, arising from regulatory changes after the Clean Air Act of 1956. Many measurements exist after the Clean Air Act, but there is less data available for smoke concentrations before it (Brimblecombe, 1987). Past smoke measurements are useful in studying effects of air pollution on human health, as they provide data for investigating long and short-term smoke exposure. For example, extreme smoke concentrations, such as those associated with the London smogs of 1952 and 1961, have been used to estimate excess mortality associated with the smog episodes. Reconstruction of smoke concentrations, which can extend the period of quantitative measurements, can increase the amount of data available for such studies.

A method using the measured electrical properties of atmospheric air has been developed for reconstructing past smoke pollution levels (Harrison and Aplin 2002, 2003). This technique has been used to infer smoke variations near London (Kew) in the 1860s (Harrison and Aplin 2002), and for metropolitan Paris in the 1890s (Harrison and Aplin, 2003), permitting the first quantitative comparison between nineteenth century pollution in Paris and London (Mössinger, 2004). The morning maximum surface smoke pollution concentration in 1893 Paris (70 ± 6µgm⁻³) was found to be substantially lower than the values for London in 1863 (170 ± 50 µgm⁻³).

Although initially crude, direct measurements of hourly smoke pollution were begun by the Meteorological Office at Kew Observatory, in Richmond near London in about 1912. Values obtained were tabulated and archived from 1921. These measurements continued until the closure of the observing site at the end of 1980. Smoke measurements at Kew used the Owens pollution recorder. This device pumped air at a constant rate through a filter paper, causing a dark stain to be recorded from deposition of the smoke particles. The blackness of the stain was compared with calibrated optical standards, established for known smoke concentrations. Comparison of the stain with the standards was subjective, and variations in the flow rate of air used changed the sensitivity during the early 1920s, producing some inconsistencies in the measurements obtained.

As well as smoke concentration, many other meteorological and geophysical measurements were made at Kew Observatory. The Kew measurements of the electrical properties of the atmosphere are of special interest for reconstructing the past aerosol and smoke properties of urban air, using the electrical proxy technique. Measurements of the Potential Gradient (effectively the magnitude of electric field on meteorologically undisturbed days) at Kew are used for this (Harrison and Aplin, 2002). The PG arises because of a vertical electric current flowing between the ionosphere and the surface, originating from thunderstorms and disturbed weather elsewhere on the planet. There is a close positive relation between the Potential Gradient (PG) and annual and monthly averages of smoke concentration. Uncalibrated measurements of the PG are known to have begun at Kew in the early 1840s (Harrison, 2003),

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but absolute monthly values from a very consistent set of instrumentation – the “Wilson apparatus” (Wilson 1906; Scrase 1934) – from 1909-1979, have recently been recovered and tabulated continuously for the first time (Harrison and Ingram, 2004).

In this study, the rediscovered values of PG are used to estimate annual averages of smoke concentration at Kew. This permits additional values of smoke concentration to be estimated, both before the direct measurements commenced and for the period when direct smoke measurements showed instrumental discontinuities.

**Materials and Methods**

The effect of particle concentration on the PG is well-understood theoretically (Harrison and Carslaw 2003), justifying the use of semi-empirical relationships between smoke concentration and PG where the two quantities are measured simultaneously. Smoke pollution reduces the electric conductivity of atmospheric air, and increases the PG. In air in which the PG variations are dominated by smoke fluctuations, the semi-empirical relationship between PG and smoke concentration permits changes in PG to be used as a proxy for smoke variations when the direct smoke determinations are not available or are unreliable.

Figure 1 shows the relationship between the PG measured using the Wilson apparatus at Kew, and the direct determinations of smoke concentration using the Owens device, for monthly averages in each case. The number of samples used in constructing the monthly average varies, but there are typically at least 10 days from each month, on which hourly measurements were obtained. (The values used are from before the Clean Air Act.)

Measurements before about 1930 were subject to some discontinuities because of changes in the flow rate of the sampled air and also difficulties with maintaining the standards. Some of the scatter in figure 1 is due to these early values. They are included, however, because it is not possible to separate the more and less reliable values *a priori*.

![Figure 1. Monthly averages of Potential Gradient (PG) obtained at Kew Observatory, plotted as a function of monthly averages of smoke mass concentration determined at the same site.](image)

**Results**

Using the semi-empirical linear relationship of figure 1, the annual values of PG at Kew have been used to estimate the smoke concentration. Figure 2 shows the values obtained, and the direct smoke measurements when available. (Monthly average measurements of smoke are also available from 1961 to the end of measurements at the site. These show a strong seasonal cycle, with a winter maximum and summer minimum.) For 1929-1949, the correlation between the direct and reconstructed smoke measurements is $r = 0.53$. There are, however, differences
between the reconstructed PG and the direct smoke measurements, particularly in the period before 1930 when inconsistencies in the use of the Owens instrument were reported. It is clear that there is less variability in the reconstructed smoke measurements, and that the large smoke concentrations measured before 1930 are inconsistent. Because of the substantial health effects of the 1952 smog, it is unlikely that the pre-1930 measurements, and, in particular, the very high values in the early 1920s, are correct. The reconstruction may therefore provide a better estimate of the early smoke concentrations.

Figure 2. Measured values of smoke concentration (annual averages 1921-1967 and monthly averages 1961-1981) obtained at Kew Observatory. A reconstruction of smoke concentration calculated from monthly averages of PG is also given, using the relationship between PG found in figure 1.

Conclusion
The electrical proxy method can be used to provide a consistent calibration for smoke measurements, when other techniques or adjacent measurement sites are not available for comparison. For Kew, a reconstruction of annual smoke concentrations back to 1909 shows that the annual maximum concentrations of the 1950s were probably not exceeded in the early part of the 1920s, as is suggested by the direct measurements.

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References