PM_{10} in London During 2003

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Abstract

During 2003 London experienced a series of widespread PM_{10} pollution episodes. Elevated particulate matter concentrations were measured at all background sites during February, March, April and August, with lesser incidents being experienced during September and November. Source apportionment analysis of PM_{10} and $PM_{2.5}$ reveals that the first 5 episodes were predominately caused by secondary PM_{10} from distant sources, with the summer episodes also being linked to photochemistry. The influx of secondary PM_{10} during 2003 can be compared to the secondary episode experienced in London during spring 1996. During 2003 the secondary PM_{10} was sufficient to cause the daily mean concentration of PM_{10} to exceed 50 µgm^{-3} on 20 days without additional PM_{10} from primary sources. During 1996, 34 such days were experienced. The November 2003 episode was associated with Guy Fawkes Night fireworks. Roadside sites measured additional PM_{10} from local traffic, which increased the roadside concentrations during PM_{10} incidents and caused additional incidents not measured at background sites.

The incidents during 2003 reversed the established trend of declining PM_{10} concentrations in London. Breaches of the 2005 EU Limit Value for PM_{10} were largely confined to roadside sites in Central London and several roadside sites in Outer London. The difference between roadside and background PM_{10} concentrations, with respect to the EU Limit Value, suggests that control of road traffic sources may be sufficient to manage any recurrence of these episodes. A required reduction of primary PM_{10} emissions of 30% has been calculated for the typical Inner London roadside site Kensington & Chelsea 2. The practicality of implementing such road traffic measures is, however, an open question.

Introduction

Air quality limit values for PM_{10} were set at the European wide level by the first Daughter Directive (99/30/EC) under the Air Quality Framework Directive (96/62/EC). The Daughter Directive stipulates that by the start of 2005 the daily mean PM_{10} concentration should not exceed 50 µgm^{-3} on more than 35 occasions per year and the annual mean should not exceed 40 µgm^{-3}. Additionally by 2010, the daily mean PM_{10} concentration should not exceed 50 µgm^{-3} on more than 7 occasions per year, and the annual mean should be less than 20 µgm^{-3}. The first Daughter Directive stipulates that PM_{10} should be measured gravimetrically for assessment against the EU Limit Value.

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The 2005 EU Limit Values for PM_{10} have been incorporated into UK law in the Air Quality Regulations 2000. In London, the Greater London Assembly (GLA) has responsibilities for the management of air pollution in the capital in conjunction with the London local authorities. The Limit Values for PM_{10} have been incorporated into the Mayor's Air Quality Strategy (GLA 2002).

This paper reports preliminary analysis of the PM_{10} measured in London during 2003; apportioning PM_{10} between different source categories to explain the cause of each episode, and these measurements were placed in the context of both the EU Limit Values and measurements since 1994.

Method

Measurements

Air quality in London is monitored by the London Air Quality Network (LAQN) and the UK Automatic Urban and Rural Network (AURN). During 2003 there were 99 monitoring sites in the LAQN area (including AURN sites); 71 sites measuring PM_{10} with the vast majority (59) using the Tapered Element Oscillating Micro Balance (TEOM^{TM}) method. Further information about these monitoring sites can be obtained from www.erg.kcl.ac.uk and from www.airquality.co.uk.

This study used automatic measurements of PM_{10} and $PM_{2.5}$ made using the TEOM method. Measurements of NO_X used in this study were made using the chemiluminescent method with automatic equipment subject to fortnightly calibration traceable to National Metrological Standards. Automatic NO_X and PM_{10} instruments were subject to twice yearly independent audit by the National Physical Laboratory or AEAt plc.

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The EU limit value requires gravimetric measurement of $PM_{10.}$ However, the vast majority of PM_{10} measurements in (and around) London are made using automatic methods, mainly the TEOM (1400a and 1400ab). Allen *et al.* (1997), Smith *et al.* (1997), Green *et al.* (2001), Charron *et al.* (2004) and others have observed that the TEOM produces a lower measurement of PM_{10} than that derived gravimetrically due to greater sampling losses of semi-volatile particulate and particle bound water from the TEOM. A ‘correction’ factor of 1.3 is recommended in the UK for comparison of TEOM PM_{10} measurements with the EU Directive (DETR, 1999). This ‘correction’ factor was applied to all TEOM PM_{10} measurements in this study. In the absence of a recommended ‘correction’ factor for TEOM $PM_{2.5}$ measurements, the ‘correction’ factor of 1.3 was also been applied to these measurements. It is, however, recognised that the ‘correction’ factor will depend on particle composition (Charron *et al.* 2004) and this is therefore likely to lead to inaccuracies when applied to $PM_{2.5}$. In all cases TEOM instruments were operated using their default settings with the exception of Mass Concentration Averaging Time and Storage Interval, which were both set to 900 seconds.

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The analysis presented in this study is based on preliminary measurements of air pollution during 2003. More detailed analysis will be undertaken following the publication of a final measurement dataset later in 2004.

Modelling method

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The PM_{10} modelling methodology is detailed in Fuller *et al*. 2002. The model apportions PM_{10} by source through analysis of measurements of annual mean NO_X, PM_{10} and $PM_{2.5}$ across a network of monitoring sites. PM_{10} is identified as arising from three source components; primary (associated with NO_X), secondary (mainly the $PM_{2.5}$ not associated with NO_X) and natural (the PM_{10}-$PM_{2.5}$ component not associated with NO_X). Daily mean secondary and natural components were then derived from long term monitoring sites across London. Total daily mean PM_{10} concentrations at any location were then calculated by adding the secondary and natural PM_{10} to primary PM_{10} derived from NO_X at the location.

The application of the modelling method in this preliminary study had three departures from that described in Fuller *et al.* 2002.

Firstly, the daily mean secondary and natural components were derived from a single background site in Bexley. This preliminary analysis does not contain sufficient PM_{10} and $PM_{2.5}$ measurements to apportion PM_{10} on each day of the year. More detailed source apportionment will be undertaken following the availability of a ratified dataset.

Secondly, allowance was made for the measurement offset of +3 μgm^{-3} (raw TEOM) applied by the TEOM to all measured mass concentrations (Patashnick and Rupprecht 1991, Rupprecht and Patashnick Co. Inc. 1992, Rupprecht and Patashnick Co. Inc. 1996). Following the application of the 1.3 ‘correction’ factor (DETR 1999) this offset has a value of 3.9 μgm^{-3}. The model described in Fuller *et al.* 2002 apportioned this offset to secondary sources of PM_{10}. Here the offset was introduced as a separate PM_{10} source. Retention of the offset within the model ensured comparability between the source apportionment method and TEOM measurements, and also maintained the applicability of the 1.3 ‘correction’ factor to the source apportioned PM_{10}.

Thirdly, the factors for the calculation of primary PM_{10} and $PM_{2.5}$ from measured NO_X concentration were revised based on analysis of measurements during 2001. The following factors were used

$$\text{Primary } PM_{10}\ (\mu gm^{-3}) = 0.105\ (\mu gm^{-3}\ ppb^{-1}) * NO_X\ (ppb)$$

$$\text{Primary } PM_{2.5}\ (\mu gm^{-3}) = 0.828\ (\mu gm^{-3}\ ppb^{-1}) * NO_X\ (ppb)$$

Results

Measurements

Figure 1 shows the daily mean PM_{10} concentration measured at Kensington & Chelsea 1; a typical Inner London background site, and the mean PM_{10} concentration on each day during the preceding five years. Figure 1 shows 7 distinct episodes during 2003 when the daily mean PM_{10} concentration exceeded 50 μgm^{-3}. These episodes are labelled A to G. Episodes A to D were obvious elevations above the 5 year mean.

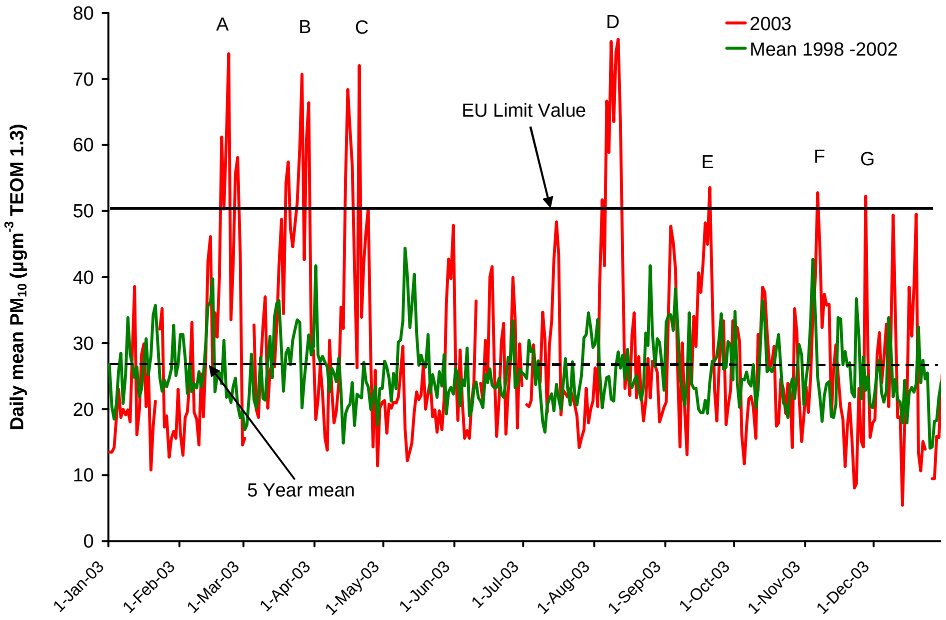

Figure 1 Daily mean PM_{10} measured by TEOM (*1.3) at Kensington & Chelsea 1. Measurements during 2003 and the mean concentration during 1998 – 2002 are shown.

Figure 2 shows the number of daily mean PM_{10} measurements above 50 μgm^{-3}, as a running annual count, at three different types of location. The long-term measurements at Inner London background sites exhibit a downward trend from around 50 days above 50 μgm^{-3} in 1995 to around 10 days in 2002. The similar downward trend of all site types reflects a reduction in secondary and primary PM_{10} emissions, whilst the convergence in the number of daily means above 50 μgm^{-3} reflects the reduction in traffic emissions of primary PM_{10}.

During 1995 typical Inner London background sites exceeded the 2005 EU Limit Value, which implied a widespread breach of the Limit Value throughout London. The situation deteriorated during Spring 1996 due to the substantial secondary episode at this time (APEG 1999, Stedman 1997). As a consequence, 76 daily means above 50 μgm^{-3} were measured in Inner London during the year ending April 1996; more than double the 2005 Limit Value of 35 days. A repetition of such an episode would clearly provide challenges for air quality management. The additional days above 50 μgm^{-3} caused by the Spring 1996 episode left the running count in Spring 1997. Other events affecting the number of daily means above 50 μgm^{-3} included a primary episode during Autumn 1997 and the unsettled weather in late 2000. Inner London background sites have consistently achieved the 2005 EU Limit Value since 1998. The number of daily means above 50 μgm^{-3} measured at Outer London sites was only marginally below those measured in Inner London. A larger difference can be seen between the background and kerb/roadside sites in Inner London than between outer and Inner London background sites.

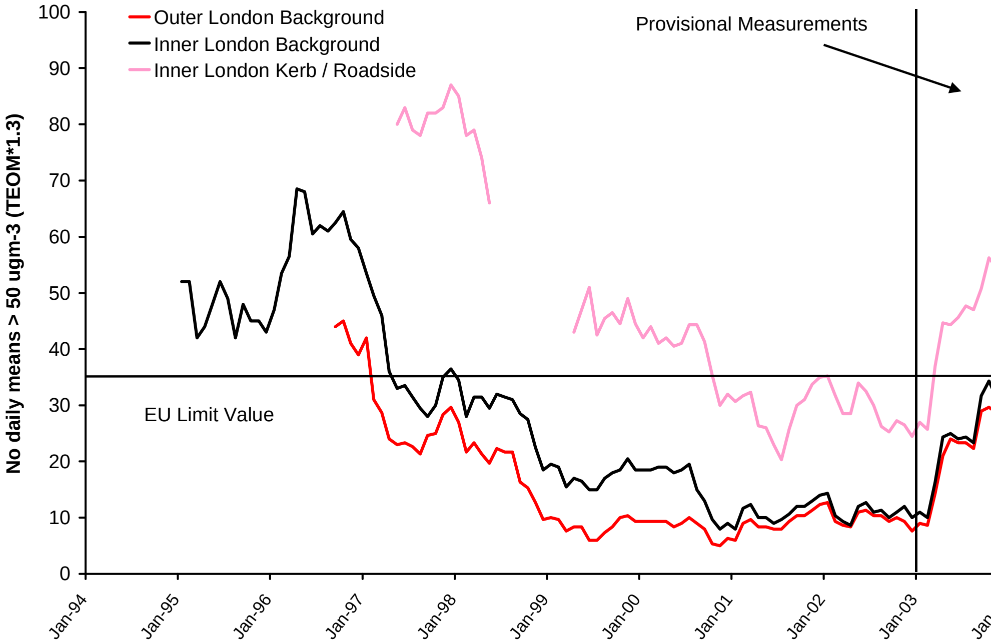

Figure 2 Number of days when daily mean PM_{10} exceeded 50 µgm^{-3} (TEOM*1.3) shown as a running annual count measured at three types of location in London.

The number of daily means above 50 µgm^{-3} at the kerb/roadside in Inner London follows a similar trend to background, albeit with additional days due to local traffic emissions. Inner London roadside sites have generally achieved the 2005 EU Limit Value since 2000. Measurements at Marylebone Road are not shown in Figure 2but have been in the range 70–160 days per year and show variations in part due to local events such as building works.

The provisional measurements shown in Figure 2 suggest that the previously improving trend in PM_{10} concentration was reversed in 2003; with 2003 PM_{10} levels being comparable to those during 1998. Provisional measurements shown in Figure 2 reflect the impact of the PM_{10} episodes in 2003. Compared to 2002, background sites measured around 20 additional daily means above 50 µgm^{-3} during 2003, with kerb/roadside sites in Inner London measuring around 30 such additional days. The results presented in Figure 2 are means calculated from a sample of sites within each site type and therefore mask individual site variations. The majority of Inner London background TEOM sites did not exceed the Limit Value; the exception being Tower Hamlets 1 where building works may have caused additional local PM_{10}. Regrettably, insufficient TEOM measurements of Central London background conditions were therefore available to determine if the EU Limit Value was exceeded in this area. An estimate of the PM_{10} in Central London has been made using the available measurements from the Bloomsbury background site and measurements from Kensington & Chelsea 1 in Inner London. It is estimated that Central London background locations measured at least 33 daily means above 50 µgm^{-3}. There is hence a possibility that background locations in Central London exceeded the Limit Value. By the end of 2003, road and kerbside TEOM sites in Inner London had exceeded the 2005 EU Limit Value by a large margin. However the attainment of the Limit Value at background locations suggests that reduction of local primary PM_{10} at roadside and kerbside locations in Inner London may lead to the attainment of the Limit Value at these locations. The required reduction in local primary PM_{10} can be calculated following source apportionment of the measured PM_{10}.

Source Apportionment

Figure 3 compares the measured PM_{10} and the total PM_{10} derived from the source apportionment model. Overall the modelled daily mean concentrations compare well with a co-relation coefficient (r^2) of 0.92. The modelled annual mean (27.8 µgm^{-3}) compares well with the measured annual mean (28.5 µgm^{-3}).

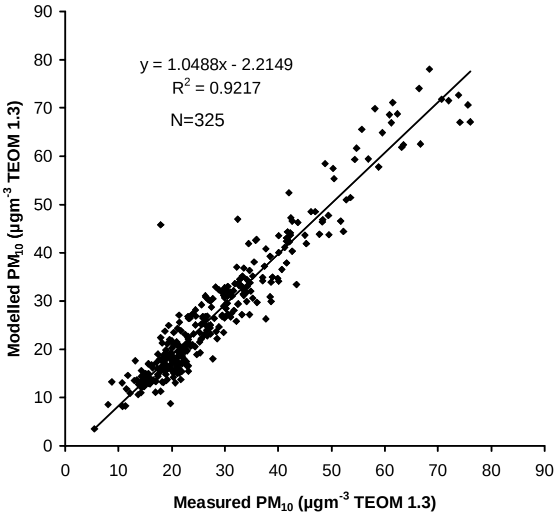

Figure 3 Regression analysis of daily mean measured PM_{10} and total PM_{10} derived from the source apportionment model for the Kensington & Chelsea 1 monitoring site.

Figure 4 shows the source apportionment of PM_{10} measured at Kensington & Chelsea 1; a typical Inner London background site. Daily means above 50 µgm^{-3} were due to distinct episodes; labelled A to F. The PM_{10} concentration during episode G and the modelled daily mean did not exceed 50 µgm^{-3} at this time. During episodes A to E, PM_{10} was dominated by secondary particulate brought into London from continental sources. The imported secondary PM_{10} is present in the $PM_{2.5}$ as expected and is also present in the coarse (PM_{10} - $PM_{2.5}$) fraction which is indicated by elevated concentrations of the secondary and natural coarse particulate during the episodes A to E. The daily mean secondary and natural coarse particulate concentration reached an annual maximum of 32 µgm^{-3} on the 15th April 2004 at the start of episode C which may be indicative of a Saharan dust episode similar to the episode that affected southern England during March 2000 (Ryall *et al.* 2002). Episodes B to E were associated with photo-chemical activity as indicated by elevated concentrations of ground level ozone. Episode D was dominated by secondary PM_{10} and coincided with record-breaking temperatures and the highest ground-level O_3 concentrations measured in London since 1990. Episode F was caused by Guy Fawkes Night bonfires and fireworks. The source apportionment method is not accurate at this time due to large local sources of particulate that are not also sources of NO_X.

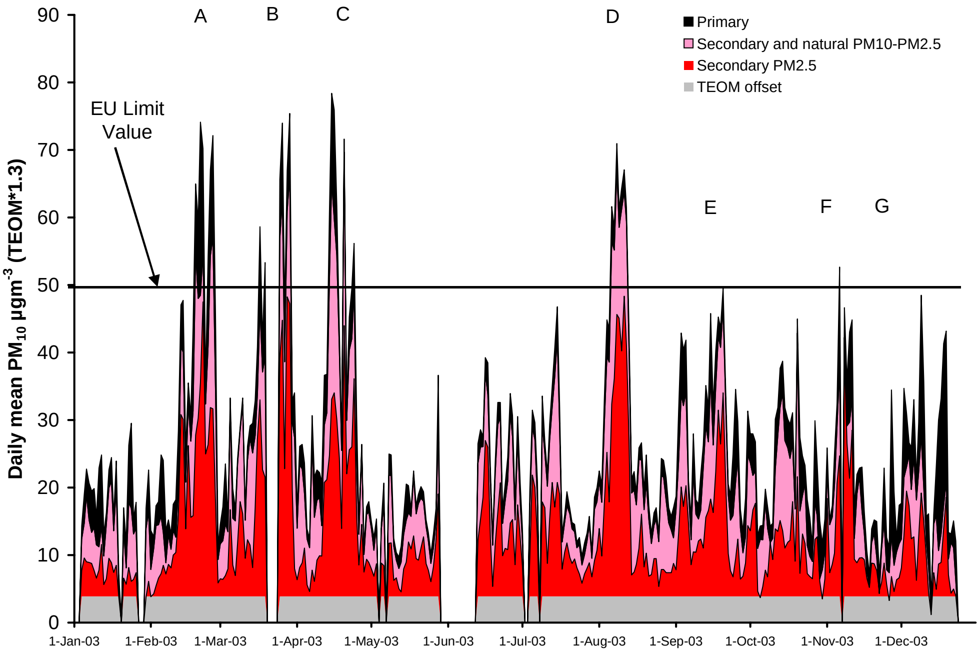

Figure 4 Source apportioned daily mean PM_{10} at the Inner London background site Kensington & Chelsea 1 with episodes labelled

Figure 5 shows the source apportionment of PM_{10} measured at Kensington & Chelsea 2; a typical Inner London roadside site. Due to its proximity to a major road the site experienced more primary PM_{10} particulate than the background site. This additional primary PM_{10} increased the impact of episodes A to E, with additional daily means above 50 µgm^{-3}

(TEOM*1.3). The additional primary PM_{10} also led to 4 further episodes not measured at the background site; these are labelled 1 to 4 in Figure 3. Episodes 1 to 3 were caused by a mixture of local primary and secondary particulate. Episode 4 was dominated by local primary sources and is a classic winter-time pollution episode occurring in poor dispersion conditions.

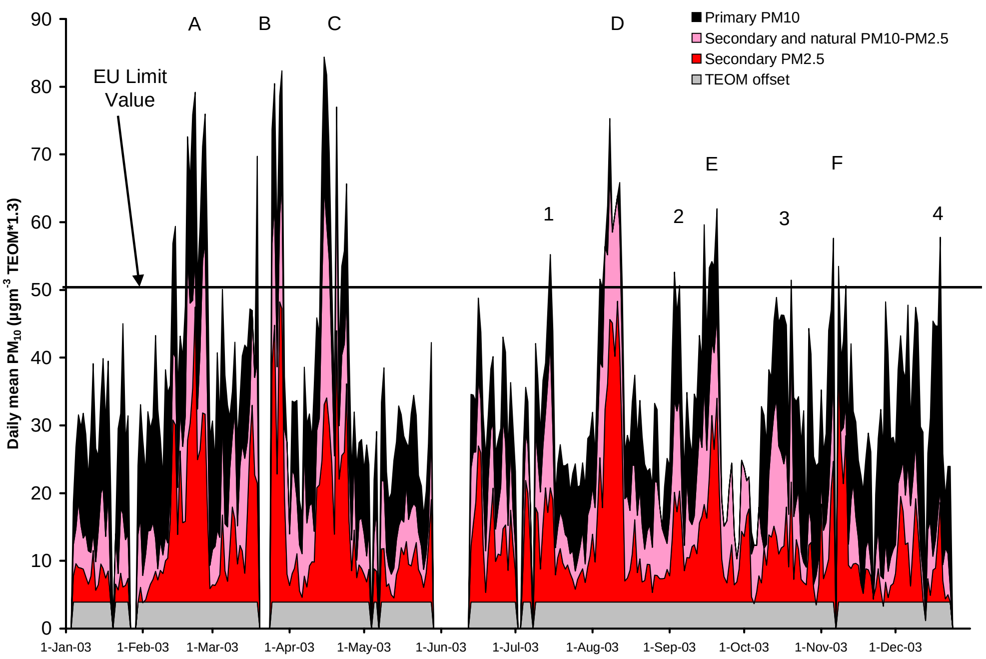

Figure 5 Source apportioned daily mean PM_{10} at the Inner London roadside site Kensington & Chelsea 2 with episodes labelled.

Air quality management initiatives on a local or even city-wide scale can only have impact on the primary PM_{10}. Given this it is possible to calculate the reduction in primary PM_{10} concentration necessary to achieve the 2005 Limit Value at the Kensington & Chelsea 2 site. Figure 6 shows the relationship between the annual mean primary PM_{10} at Kensington & Chelsea 2 and the annual number of days with mean PM_{10} > 50 μgm^{-3} based on the source apportionment of measurements during 2003. Changes in annual mean primary PM_{10} were assumed to apply equally to all primary PM_{10} at the site throughout the year. This analysis showed that the annual mean concentration of primary PM_{10} would have to be reduced by 30% to achieve the 2005 EU Limit Value for 2003 measurements at this location.

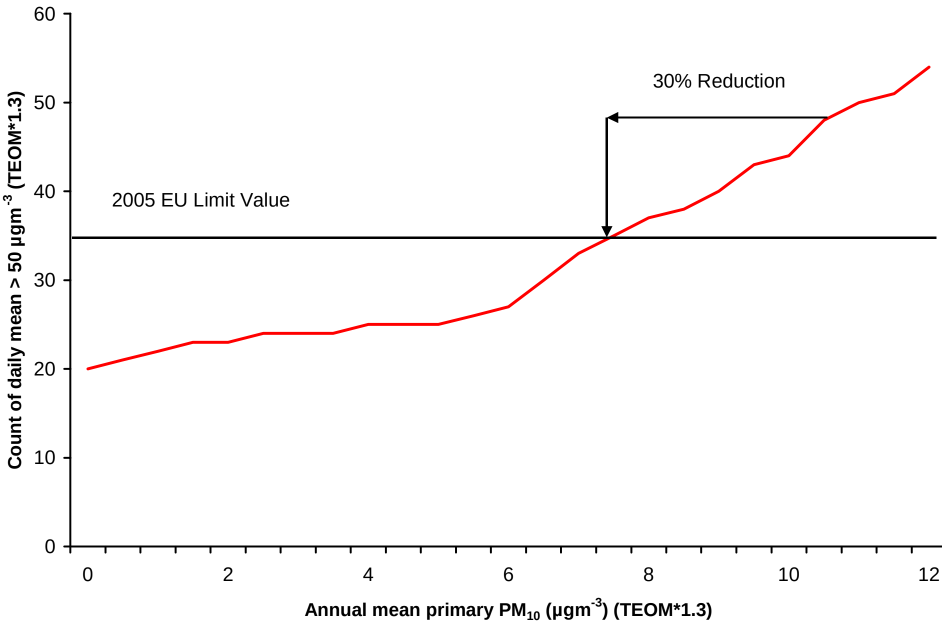

Figure 6 Relationship between annual mean concentration of primary PM_{10} at Kensington & Chelsea 2 and the annual number of days with mean PM_{10} > 50 µgm^{-3}

Source apportionment of PM_{10} has determined that the main episodes, during February, March, April and August were caused by increased PM_{10} from secondary and natural sources. The secondary and natural PM_{10} episodes are similar to those experienced during 1996. A comparison between the severity of the secondary PM_{10} episodes during 2003 and those in 1996 is not straightforward and would need to account for the reduction in emissions of secondary PM_{10} precursors. However, source apportionment allowed a simple comparison of the number of daily means above 50 µgm^{-3} due solely to secondary and natural particulate, and showed that 34 such daily means were measured during 1996 compared to around 20 during 2003.

Conclusions

During 2003 London experienced a series of PM_{10} episodes. Provisional measurements show that the 2005 EU Limit Value was exceeded at roadside and kerbside sites in Inner London and at several such sites in Outer London. Source apportionment allowed the causes of the PM_{10} episodes to be determined, and showed that the 2003 episodes were largely caused by regional sources; secondary and natural PM_{10}. Nevertheless attainment of the 2005 EU Limit Value, during the circumstances experienced during 2003, can be achieved at roadside sites in Inner London by a reduction in the concentration (and therefore emissions) of local primary PM_{10}. It is estimated that a local primary PM_{10} reduction of 30% would be required to attain the 2005 EU Limit Value at the typical Inner London roadside site Kensington & Chelsea 2.

Acknowledgements

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