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Long-term trends of ambient particulate matter emission source contributions and the accountability of control strategies in Hong Kong over 1998–2008

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HIGHLIGHTS

► Positive Matrix Factorization is applied to identify PM_{10} sources in Hong Kong.
► Local and non-local PM_{10} sources are classified based on spatiotemporal variations.
► Local control measures on vehicle exhaust are effective with more than 50% reduction.
► Local reduction is totally offset by increased contributions from non-local sources.
► A coordinated, regional-scale air quality management plan is urgently needed.

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ABSTRACT

Despite extensive emission control measures targeting motor vehicles and to a lesser extent other sources, annual-average PM_{10} mass concentrations in Hong Kong have remained relatively constant for the past several years and for some air quality metrics, such as the frequency of poor visibility days, conditions have degraded. The underlying drivers for these long-term trends were examined by performing source apportionment on eleven years (1998–2008) of data for seven monitoring sites in the Hong Kong PM_{10} chemical speciation network. Nine factors were resolved using Positive Matrix Factorization. These factors were assigned to emission source categories that were classified as local (operationally defined as within the Hong Kong Special Administrative Region) or non-local based on temporal and spatial patterns in the source contribution estimates. This data-driven analysis provides strong evidence that local controls on motor vehicle emissions have been effective in reducing motor vehicle-related ambient PM_{10} burdens with annual-average contributions at neighborhood- and larger-scale monitoring stations decreasing by $\sim 6\ \mu g\ m^{-3}$ over the eleven year period. However, this improvement has been offset by an increase in annual-average contributions from non-local contributions, especially secondary sulfate and nitrate, of $\sim 8\ \mu g\ m^{-3}$ over the same time period. As a result, non-local source contributions to urban-scale PM_{10} have increased from 58% in 1998 to 70% in 2008. Most of the motor vehicle-related decrease and non-local source driven increase occurred over the period 1998–2004 with more modest changes thereafter. Non-local contributions increased most dramatically for secondary sulfate and secondary nitrate factors and thus combustion-related control strategies, including but not limited to power plants, are needed for sources located in the Pearl River Delta and more distant regions to improve air quality conditions in Hong Kong. PMF-resolved source contribution estimates were also used to examine differential contributions of emission source categories during high PM episodes compared to study-average behavior. While contributions from all source categories increased to some extent on high PM days, the increases were disproportionately high for the non-local sources. Thus, controls on emission sources located outside the Hong Kong Special Administrative Region will be needed to effectively decrease the frequency and severity of high PM episodes.

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1. Introduction

During the past twenty years, the environmental authorities in Hong Kong have undertaken a series of air pollution control measures including but not limited to requirements for low-sulfur diesel fuel, lead-free gasoline, three-way catalytic converters, conversion of diesel taxis and minibuses to liquefied petroleum gas, and capping the VOC content of some solvents and consumer products. Despite these measures, the long-term trends for various ambient air quality metrics show either no improvement or a worsening of conditions. For example, the open circles in Fig. 1 show the annual-average PM_{10} mass concentration composited over six monitoring stations that collectively represent urban-scale conditions (these sites are described later in this paper). Hourly data from the PM_{10} monitoring network were used to construct the annual averages. Annual-average PM_{10} mass was relatively constant over the period from 1998 to 2008 with a 9% increase in mass for the five years starting in 2004 compared to the five year period starting in 1998. The solid circles in Fig. 1 show the percentage of hours with poor visibility (visibility less than 8 km with relative humidity less than or equal to 80%) measured at the Hong Kong Observatory (HKO, 2012). The frequency of poor visibility days increased throughout the 1990s with more dramatic increases during first half of the 2000s. A local maximum was observed in 2004 (18% of hours) with the frequency of poor visibility hours decreasing through 2008 and then increasing again through 2011. The frequency of hours with poor visibility increased by 47% for the five years starting in 2004 compared to the five year period starting in 1998. The substantially greater worsening of visibility compared to the more modest increase in PM_{10} mass has been driven by changes in chemical composition of the PM_{10} aerosol. Fig. 1 also shows that over the period from 1998 to about 2004, for the same six sites used to construct the PM_{10} TEOM mass trend, the annual average total carbon dramatically decreased while annual average sulfate significantly increased. Thus, while there was little change in PM_{10} mass during this period, the composition shifted towards an aerosol with higher mass extinction efficiency that leads to a reduction in visibility (Andreae et al., 2008).

The two most pervasive air pollution issues in Hong Kong are street-level (especially near roadway) air quality and regional-scale air quality that affects not only Hong Kong but also the entire Pearl River Delta (PRD). The emission inventory reveals gasoline and diesel vehicles to be the main sources of street-level pollution (Zheng et al., 2009a). Regional-scale air pollution, however, is caused by the cumulative impacts from numerous emission source categories such as motor vehicles, marine vessel emissions, industry and power plants located in Hong Kong, the greater PRD region, and beyond. As shown in Fig. 2, the PRD region of Guangdong Province, which historically was Hong Kong's hinterland, has become highly urbanized and indeed has developed as the largest workshop in the world. Over the past fifteen years, pollutant emissions within the PRD region have increased dramatically as a result of booming industrial activities and relatively modest pollution control regulations. Therefore, the pollutants transported from the greater PRD region to Hong Kong are expected to have correspondingly increased.

Effective air quality management necessarily requires setting priorities and therefore it is important to identify the emission source categories leading to deterioration of air quality in Hong Kong and quantify the long-term trends in the contributions from such sources. To the extent there are large contributions from within the Hong Kong Special Administrative Region (HKSAR) the local government can implement additional controls on. However, if the dominant contributions are from the greater PRD area and more distant regions, a regional planning process that involves cooperation between Hong Kong, Guangdong Province and perhaps other provinces in Mainland China will be necessary to efficiently manage air quality in Hong Kong.

This study was commissioned to extend our previous work to apportion ambient PM_{10} levels in Hong Kong (Yuan et al., 2006; Huang et al., 2009) with emphasis on further identifying and quantifying the drivers for the long terms trends in Hong Kong air quality such as those features demonstrated in Fig. 1. Insights were sought into whether air quality benefits from prior control measures could be elucidated from routine monitoring data. This information could be used to frame and prioritize future control policies. Following the methodology of the previous studies, receptor modeling was performed on the PM_{10} speciation data.

2. Data collection and analysis

For more than twenty years, the Hong Kong Environmental Protection Department (HKEPD) has operated a PM_{10} chemical speciation network (network) that has included several

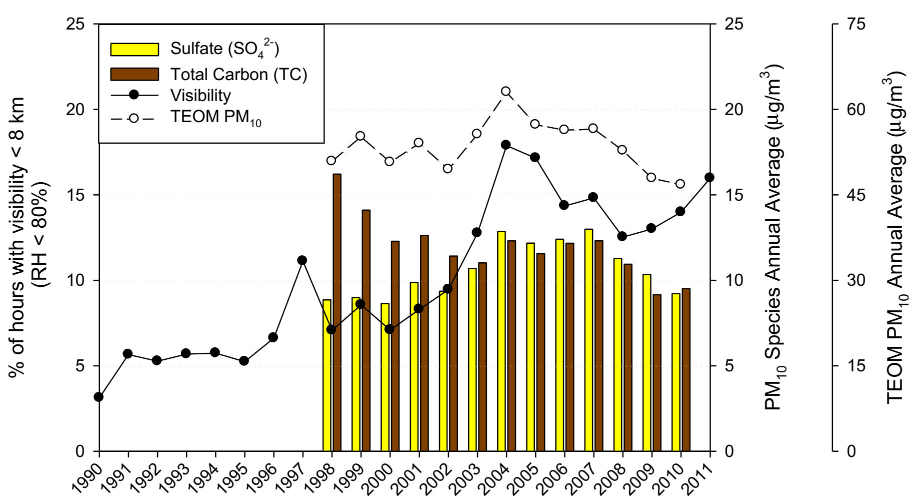

Fig. 1. Historical trends for visibility impairment and PM_{10} mass, sulfate and total carbon. Data sources and calculation methodology are described in the text.