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Systematic evaluation of ozone control policies using an Ozone Source Apportionment method

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HIGHLIGHTS

- ► Four monthly CAMx simulation of O_3 for the PRD (Jan, Apr, Jul and Oct) were analyzed.
- ► OSAT used to analyze the source/impact relationships amongst cities by source type/region.
- ► Mutual impact of O_3 episodes amongst cities in PRD varies greatly by season.
- ► GZ sources are impacting itself and other cities greatly, particularly its mobile sources.
- ► HK sources have smaller local impact, but impact downwind cities substantially.

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ABSTRACT

Ground-level ozone is a secondary pollutant that causes serious health and environmental damage. One of the main challenges in controlling ground-level ozone is to identify the categories of ozone precursor species that contribute the most to ozone levels, and the regions from which they are emitted. In this study, we apply a photochemical model source apportionment tool to identify the contributions of various precursors to seasonal ozone levels in Hong Kong (HK) and the Pearl River Delta (PRD) region, according to their source regions and categories. We establish a full precursor contribution matrix for the ozone concentrations in all cities within the HK/PRD region. This matrix can be used to rank the relative importance of precursors by source region/category for each city. It can also be used to show how the precursor emissions from any city/category affect ozone levels in neighboring cities. The results show substantial seasonal variation in the source contributions from the HK/PRD region. During ozone episodes, precursors from the region accounted for 68–80% of ozone concentrations in July and 35–55% in October, but only 19–32% in January and April. For all of the cities in the PRD, the top three precursor categories contributing to ozone episodes were mobile, point and area sources. Biogenic and point sources were more important in July than in October. In contrast, the ranking of contributing source regions showed considerable variation across cities and seasons, implying substantial variations in the ways in which precursors from one city affect ozone levels in neighboring cities. Our results show that source contribution and impact analysis can be very useful for evaluating the ozone control strategies of local governments. For the PRD region, a local reduction in mobile, area and point sources, together with regional collaborations on pollution control, are of particular importance in effectively reducing episodic ozone concentrations.

1. Introduction

China's rapid economic development has been accompanied by a serious deterioration in air quality. The Hong Kong and the Pearl River Delta (HK/PRD) region, situated in the complex terrain of Southern China's coastal area, is a developed zone that suffers from a serious air quality problem (Wang et al., 2003a,b; Chan and Yao,

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2008). Ozone is one of the major air pollution problems in the region. Ozone is a constituent of photochemical smog produced by many highly energetic reactions, ranging from combustion to photocopying. A high concentration of ozone causes serious health and environmental damage (Mauzerall et al., 2005; Bell and Dominici, 2008). For example, a high level of ozone can reduce lung capacity, cause acute respiratory problems and aggravate asthma. Ozone is a secondary pollutant generated by a series of chemical reactions that occur when its two main precursors, nitrogen oxides (NO_x) and volatile organic carbon compounds (VOC) such as xylene, react in the atmosphere in the presence of sunlight. In the PRD region, the emission sources of the precursors are complex: about 53% of NO_x emissions are released from power plants and industrial boilers and about 36% from road vehicles. The remaining is released from situations such as shipping, residential and airport sources (Zheng et al., 2009). While about 40% of VOC emissions are released from non-road vehicles, 25% are released from VOC-related production such as paints, coatings and domestic products, with another 25% stemming from biogenic sources, and the remaining are from industrial sources (Zheng et al., 2009). Therefore, effective emission control depends on the source categories and is limited by the state-of-art control measures of ozone precursors in different source sectors. Furthermore, because the relationship between ozone concentration and ozone precursors is nonlinear, determining the control priorities for the contributing sources should not be based solely on the emission inventory.

In addition, the lifetimes of ozone and its precursors are different. The formation and depletion of ozone may take a few hours. The generated ozone can be transported over tens to hundreds of kilometers, depending on meteorological conditions. Therefore, ozone pollution typically exhibits regional and even super-regional characteristics (Wang et al., 1998; So and Wang, 2003; Daum et al., 2004; Zhang et al., 2008a; Zheng et al., 2009, 2010; Li, 2011; Li et al., 2012). This implies that to control ozone in a particular location, in addition to identifying the contribution of local sources, the ozone formed locally and transported upwind must also be identified. Identifying how much ground level ozone originates from different sources is fundamental for designing effective ozone control strategies. For example, brute force method, decoupled direct method (DDM) and high-order DDM have been incorporated into 3D chemical transport model for examining the source apportionment of ozone (Cohan et al., 2005). From the perspective of VOC and NO_x, respectively, Ying and Krishnan (2010) and Zhang and Ying (2011) apportioned the contribution by source categories/regions to ozone concentrations in Texas using tracer-based source apportionment technology incorporated in Community Multiscale Air Quality (CMAQ) model. Although such investigations have been carried out for various regions in North America (Yarwood et al., 1996; Cohan et al., 2005; Passerini et al., 2011; Ying and Krishnan, 2010; Zhang and Ying, 2011), few studies have been conducted in Asia (Wang et al., 2005). A comprehensive study of the effect of ozone precursors on geographical and sector perspectives will provide a better understanding of the chemical and physical processes of ozone formation and depletion.

Several studies related to the impact analysis of single or multiple sources of ozone precursors have been performed for specific areas in the HK/PRD region, using various air quality models (Zhang et al., 1999; Hao et al., 2007; Wang et al., 2001; T. Wang et al., 2003a,b; Zhang et al., 2008b; Li et al., 2012). For example, Wang et al. (2005) estimated the impact from major sources (transportation, industry and power generation) of Guangdong province on ozone levels during March 2001 through model sensitivity studies. Nevertheless, most of these studies have only focused on the source contributions for specific locations or specific categories or specific periods through model sensitivity studies. There has also been a lack of comprehensive air quality management strategies for handling multi-source air pollution problems using a holistic approach (Loh and Ng, 2005). Li et al. (2012) examined the local, regional and super-regional contributions to surface ozone levels in the PRD. They found that although the super-regional source is normally the highest contributor to ozone pollution during non-episode days, elevated local and regional contributions from the HK/PRD are the major cause of high ozone episode days in the region. Therefore, we need to establish detailed precursor contribution relationships, partitioned by different emission source sectors and geographic areas (i.e. administrative district and city) within the HK/PRD region, to obtain a better understanding of the relationship between ozone levels and emission sources over Southern China. Such understanding is needed as the foundation for developing effective ozone control strategies to reduce the high ozone levels over this region, with its complex terrain and meteorology. We also have a separated study about PM simulations and the PM apportionment, which will be published in the same Pearl River Delta Special Issue (Wu et al., 2012).

In this study, we apply mass-balance source apportionment analysis to obtain the contributions to ground-level ozone from different source regions and source categories within the HK/PRD region. Section 2 describes the model system, model configurations and the Ozone Source Apportionment Technology (OSAT) methodology. Section 3 presents the evaluation of both meteorological and air quality models. Section 4 analyzes the contribution of different source categories and source regions to the ground-level ozone of all of the cities within the PRD region using the OSAT method. The source impact of ozone precursors from one city on ozone levels in neighboring cities is also analyzed using the OSAT method. Finally, Section 5 summarizes the results.

2. Data, model and methodology

2.1. Model system

Our air quality modeling system uses the Sparse Matrix Operating Kernel Emissions model (SMOKE version 2.4) for emission processing, the Fifth-Generation NCAR/Penn State Mesoscale Model Version 3.7 (MM5) (Grell et al., 1994) for meteorology, and the Comprehensive Air quality Model with extensions (CAMx) 5.10 for chemical transport modeling. Our modeling system has three nested meshes with grid resolutions of 27 km, 9 km and 3 km. The nesting grids are denoted as D1, D2 and D3 (Fig. 1). We use the

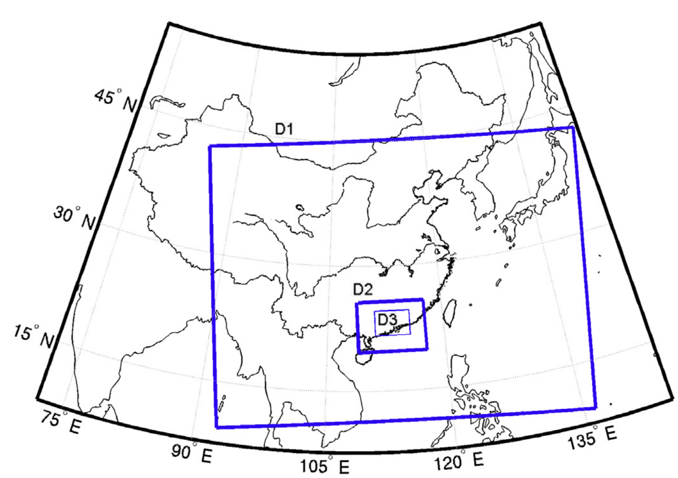

Fig. 1. The 27-km, 9-km and 3-km domains for CTM nested domains denoted as D1, D2 and D3, respectively.