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# Fast increasing of surface ozone concentrations in Pearl River Delta characterized by a regional air quality monitoring network during 2006–2011

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ABSTRACT

Based on the observation by a Regional Air Quality Monitoring Network including 16 monitoring stations, temporal and spatial variations of ozone ($O_3$), $NO_2$ and total oxidant (O*x*) were analyzed by both linear regression and cluster analysis. A fast increase of regional $O_3$ concentrations of 0.86 ppbV/yr was found for the annual averaged values from 2006 to 2011 in Guangdong, China. Such fast $O_3$ increase is accompanied by a correspondingly fast NO*x* reduction as indicated by a fast $NO_2$ reduction rate of 0.61 ppbV/yr. Based on a cluster analysis, the monitoring stations were classified into two major categories – rural stations (non-urban) and suburban/urban stations. The $O_3$ concentrations at rural stations were relatively conserved while those at suburban/urban stations showed a fast increase rate of 2.0 ppbV/yr accompanied by a $NO_2$ reduction rate of 1.2 ppbV/yr. Moreover, a rapid increase of the averaged $O_3$ concentrations in springtime (13%/yr referred to 2006 level) was observed, which may result from the increase of solar duration, reduction of precipitation in Guangdong and transport from Eastern Central China. Application of smog production algorithm showed that the photochemical $O_3$ production is mainly volatile organic compounds (VOC)-controlled. However, the photochemical $O_3$ production is sensitive to both NO*x* and VOC for $O_3$ pollution episode. Accordingly, it is expected that a combined NO*x* and VOC reduction will be helpful for the reduction of the $O_3$ pollution episodes in Pearl River Delta while stringent VOC emission control is in general required for the regional $O_3$ pollution control.

## Introduction

After four decades of rapid economic development, recently China passed Japan as the second largest economy worldwide. In parallel to the fast economic growth, the air quality showed a serious deterioration at a national scale. In three eastern megacity areas, such as the Beijing-Tianjin area, the Pearl River Delta (PRD) and the Yangtze River Delta, pollution episodes with ozone ($O_3$) concentrations larger than 93 ppbV (200 μg/m$^3$) corresponding to the Chinese national air quality standard were frequently reported in recent years (Lu et al., 2010a, 2010b; Shao et al., 2006; Wang et al., 2003, 2010; Zhang et al., 2008b). As is well known, $O_3$ is toxic toward human-beings (Bell et al., 2004), agriculture (Wang et al., 2005) and ecosystem (Ashmore, 2005). In China, an epidemiologic study showed that an increase of 10 μg/m$^3$ (ca. 5 ppbV) of the averaged $O_3$ concentrations over the previous 2 days would cause 0.81% increase in total mortality over PRD from 2006 to 2008 (Tao et al., 2012). As diagnosed by both regional and global models, high $O_3$ concentrations in China not only showed detrimental effects in China and neighboring countries (Heald et al., 2003), but also show

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significant impacts on global radiation budget and thus contributed to the issue of global climate change (Hudman et al., 2004). Overall, it is important to review the available $O_3$ records in China with the ancillary environmental and emission changes in major Chinese city clusters like PRD to evaluate the near surface changes of the ambient $O_3$ concentrations and therefore contribute to the planning of the regional or national $O_3$ mitigation options.

For the time being, knowledge of the long-term $O_3$ trends in China is still limited due to the lack of long-term measurements compared to that of Europe and United States (Parrish et al., 2012 and reference therein). The $O_3$ concentration observed in Lin'an station, a regional background site in eastern China, showed an increase of the variation amplitude of the observed $O_3$ concentrations with a slight decreasing trend (–0.37 ± 0.23 ppbV/yr) of the monthly mean values during the period of 1991–2006 (Xu et al., 2008). The $O_3$ concentration at a coastal site (Hok Tsui) in Hong Kong increased by 0.58 ppbV/yr during 1994–2007, which was attributed to increased emissions of $NO_2$ (and possibly volatile organic compounds (VOC) as well) in the upwind coastal regions of mainland China (Wang et al., 2009). Tang et al. (2009) diagnosed an $O_3$ increasing trend of (1.1 ± 0.5) ppbV/yr during 2001–2006 in Beijing due to the reduction of NO*x* emissions and elevated VOC emissions. Ding et al. (2008) abstracted a positive $O_3$ trend of 2%/yr during 1995–2005 in Beijing toward the enhanced anthropogenic NO*x* emissions in Beijing and surrounding areas. In contrast, an $O_3$ trend of 0.96 ppbV/yr diagnosed for Taipei during 1994–2005 was caused by a decrease of the titration effect due to the reduced NO concentration so that the total oxidant (O*x* = $O_3$ + $NO_2$) was conserved (Chou et al., 2006).

To reveal air pollution levels and long-term variation trends of various pollutants in PRD, a comprehensive Regional Air Quality Monitoring Network was established in PRD by Guangdong Provincial Environmental Monitoring Centre and Environmental Protection Department of the Hong Kong Special Administrative Region under the framework of the Hi-Tech Development Program (863) of China (Zheng et al., 2010). The network consists of 16 automatic air quality monitoring stations (**Fig. 1**) which are well distributed in different geochemical regimes to characterize the ambient conditions of rural, suburban and urban regions. In the present study, we attempt to abstract the $O_3$ and O*x* changes during 2006–2011 as characterized by this network with cluster and regression analysis. We explored the possible driving forces on the possible links to the changes of precursor emissions.

## 1 Data and methods

### 1.1 Data sources

$O_3$, NO and NO*x* concentrations over PRD from 1 January 2006 to 31 December 2011 were measured by 16 monitoring stations in the Regional Air Quality Monitoring Network of PRD (**Table 1**). $O_3$ and $NO_2$ in Liyuan were measured by OPSIS AR500 Analyzer with differential optical absorption spectroscopy from Sweden. $O_3$ in other 15 stations was measured by Thermo Scientific 49C $O_3$ analyzer with UV photometric technology from USA. $NO_2$ in other stations was measured by Thermo Scientific 42C NO-$NO_2$-NO*x* Analyzer with chemiluminescence technology from USA.

For comparison, we also collected $O_3$ data from other open sources (**Table 2**). Hourly NO, $NO_2$ and $O_3$ concentrations during 2000–2011 in Tap Mun, Tsuen Wan and Tung Chung and the annual average $O_3$ con-

**Table 1** Regional air quality monitoring stations in Pearl River Delta (PRD)

| Station (City) | Date | Longitude (°) | Latitude (°) | Elevation (m) |
|---|---|---|---|---|
| Chengzhong (Zhaoqing) | 2006–2011 | 112.47 | 23.05 | 21 |
| Xiapu (Huizhou) | 2006–2011 | 114.41 | 23.08 | 49 |
| Tap Mun (Hong Kong) | 2000–2011 | 114.36 | 22.47 | 26 |
| Jinguowan (Huizhou) | 2006–2011 | 114.38 | 22.94 | 77 |
| Tung Chung (Hong Kong) | 2000–2011 | 113.94 | 22.29 | 34.5 |
| Tianhu (Guangzhou) | 2006–2011 | 113.62 | 23.65 | 251 |
| Jinjuzui (Foshan) | 2006–2011 | 113.27 | 22.82 | 27 |
| Wanqingsha (Guangzhou) | 2006–2011 | 113.55 | 22.71 | 13 |
| Donghu (Jiangmen) | 2006–2011 | 113.08 | 22.59 | 17.5 |
| Tsuen Wan (Hong Kong) | 1999–2011 | 114.11 | 22.37 | 21 |
| Tangjia (Zhuhai) | 2006–2011 | 113.59 | 22.35 | 24 |
| Zimaling Park (Zhongshan) | 2006–2011 | 113.40 | 22.51 | 45 |
| Huijingcheng (Foshan) | 2006–2011 | 113.10 | 23.00 | 24 |
| Haogang (Dongguan) | 2006–2011 | 113.74 | 23.03 | 18 |
| Luhu Park (Guangzhou) | 2006–2011 | 113.28 | 23.15 | 30 |
| Liyuan (Shenzhen) | 2006–2011 | 114.10 | 22.55 | 38 |