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Projecting ozone-related mortality in East China

Lina Madaniyazi [a], Tatsuya Nagashima [b], Yuming Guo [c], Xiaochuan Pan [d], Shilu Tong [a,*]

[a] School of Public Health and Social Work, Kelvin Grove, QLD 4059, Australia
[b] Center for Regional Environmental Research (Regional Atmospheric Modelling Section), National Institute for Environmental Studies, 16-2 Onogawa, Tsukuba, Ibaraki 305-8506, Japan
[c] School of Public Health, University of Queensland, Herston, QLD 4006, Australia
[d] School of Public Health, Peking University, Beijing, China

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ABSTRACT

Background: The concentrations of ozone (O_3) in China are increasing, especially in East China, but its future trends and potential health impacts remain to be explored.
Objectives: The objective was to assess future trends in O_3 concentrations and related premature death in East China between 2005 and 2030.
Methods: First, a global chemical transport model (MIROC-ESM-CHEM) and regional chemical transport modelling system (including the Weather Research and Forecasting model and the Community Multiscale Air Quality model) were combined to estimate daily O_3 concentrations in 2005 and 2030 in East China under the "current legislation" (CLE) and "maximum technically feasible reduction" (MFR) scenarios which were applied globally. O_3 concentrations were then linked with population projections, mortality projections, and O_3-mortality associations to estimate changes in O_3-related mortality in East China.
Results: The annual mean O_3 concentration was projected to increase in East China between 2005 and 2030 under the CLE scenario, while decrease under the MFR scenario. Under the CLE scenario, O_3-attributable health burden could increase by at least 40,000 premature deaths in East China, without considering the population growth. Under the MFR scenario, the health burden could decrease by up to 260,000 premature deaths as a result of the reduction in O_3 concentration with a static population. However, when the population growth was considered, O_3-attributable health burden could increase by up to 46,000 premature deaths in East China under the MFR scenario.
Conclusions: The results suggest that the health burden attributable to O_3 may increase in East China in 2030.

1. Introduction

Exposure to ground-level ozone (O_3) has been consistently linked to adverse health outcomes (Bell et al., 2004; Shang et al., 2013; Jerrett et al., 2009). For example, a recent meta-analysis in China has reported that the daily total mortality rises by 0.48% (95% Confidence Intervals (95% CI): 0.38, 0.58), for a 10 μg/m^3 increase in ambient O_3 concentration (Shang et al., 2013).

Ground-level O_3 is formed in the atmosphere by the reaction of volatile organic compounds (VOCs) and nitrogen oxides (NO_x) in the presence of sunlight. VOCs have many anthropogenic (e.g., motor vehicles, chemical plants, refineries, and factories) and biogenic sources (e.g., oak, citrus, and pine) (Bernard et al., 2001). Likewise, NO_x has various sources including motor vehicles, power plants, other sources of combustion (e.g., residential and commercial furnaces), and natural sources including lightning and biologic processes in soil (Bernard et al., 2001). The concentration of O_3 depends on not only the emissions but also climatic conditions. For example, increased temperature can increase concentrations of O_3 by accelerating the rates of photochemical reaction and higher biogenic VOCs emissions (Penrod et al., 2014).

In the last decade, future trends in O_3 concentration and related health impacts have been projected on different spatial scales, with most projections undertaken in developed countries (Madaniyazi et al., 2015a; Knowlton et al., 2004; Post et al., 2012). Based on the global projection studies, developing regions with large emissions and dense populations may suffer more from increasing O_3 levels in the future (Madaniyazi et al., 2015a). However, only a few projection studies have been conducted in these areas (Dholakia et al., 2013; Wang & Mauzerall, 2006; Kan et al., 2004; Li et al., 2004), including China - the most rapidly developing country in the world (Wang & Mauzerall, 2006; Kan et al., 2004; Li et al., 2004) and none have focused on O_3 pollution.

In China, O_3 has become one of the major air pollutants, particularly in East China. Based on the air quality report from the Ministry of Environmental Protection for 74 cities during the first half of 2013, the daily maximum 8-hour average concentrations of O_3 (DMA8) in Beijing-Tianjin-Hebei, the Yangtze River Delta (YRD), and the Pearl River

* Corresponding author at: School of Public Health and Social Work, Institute of Health Biomedical Innovation, Queensland University of Technology, Kelvin Grove, QLD 4059, Australia.
E-mail address: s.tong@qut.edu.au (S. Tong).

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Delta (PRD) all exceeded the National Ambient Air Quality Standards (NAQQS) (GB3095-2012) Grade II of DMA8 (160 μg/m^3) by more than 10% (China National Environmental Monitoring Centre, 2014). In addition, an increasing trend in O_3 concentration has been observed in China. For example, from 2006 to 2013, the annual average concentrations of O_3 increased by 13% in the PRD, while SO_2, NO_2, and PM_{10} decreased by 62%, 13% and 15%, respectively, during the same period (Pearl River Delta Air Quality Management and Monitoring Special Panel, 2013).

A comprehensive air pollution prevention and control plan was issued in September 2013 to control the air pollution in three key regions in East China (Beijing-Tianjin-Hebei, YRD, and PRD regions) and 10 cities clusters across China (The General Office of the State Council of China, 2013). All three key regions are located in East China — the most developed and densely populated area in China. Due to the large energy consumption and dense population, air pollution in East China has become a significant public concern (Liu et al., 2013a; Chan & Yao, 2008). In addition, it has been reported that Asian emissions, especially from China, contribute to high O_3 episodes over the western United States (U.S.) (Lin et al., 2012), suggesting that air pollution from O_3 in China has become a global issue. Thus, projecting future trends in O_3 concentration and related health impacts in East China will not only help the Chinese government to plan emission control legislation, but also benefit global efforts to control air pollution.

2. Materials and methods

2.1. Study area

According to the general classification of different regions of the National Bureau of Statistics of the People's Republic of China, East China includes Beijing-Tianjin-Hebei (Beijing, Tianjin, and Hebei Province), YRD (Jiangsu, Zhejiang, and Shanghai), PRD (Guangdong), Liaoning, Shandong, Fujian, and Hainan. The three key regions, including Beijing-Tianjin-Hebei, YRD, and PRD, cover only 6% of the country's land area, but account for nearly 27% of the country's population, 43% of the nation's GDP, and 20% and 28% of the country's SO_2 and NO_x emissions (http://www.greenpeace.org/eastasia/publications/reports/climate, 2014).

2.2. Data analysis

First, O_3 concentrations were projected in East China in 2005 and 2030. They were then linked with population, mortality, and O_3-mortality association to estimate changes in O_3-related premature mortality between 2005 and 2030. In this study, "premature mortality" refers to the absolute numbers of premature mortality. As different assumptions were adopted on future emissions, population, and total mortality, the ranges of final outcomes were estimated for O_3-related premature total, cardiovascular, and respiratory mortality in East China, including results for each province and municipality. The similar methods were applied in another of our projection study on fine particles in East China (Madaniyazi et al., 2015b).

2.2.1. O_3 concentration modelling system

First, the global distribution of O_3 with the horizontal resolution of about 300 km × 300 km was simulated using the global chemical transport model (MIROC-ESM-CHEM (Watanabe et al., 2011)). The 6-hourly output of meteorological variables and daily output of chemical variables from MIROC-ESM-CHEM were then introduced as boundary conditions into the regional chemical transport modelling system to simulate O_3 concentrations at a horizontal resolution of 80 km × 80 km. The regional chemical transport modelling system included regional weather and air quality models: the Weather Research and Forecasting (WRF) model (Shamarock et al., 2008) and the Community Multiscale Air Quality (CMAQ) model (Byun & Schere, 2006). The DMA8 for 2005 and 2030 were calculated.

The O_3 concentration was projected for the future (year 2030) under the following two global scale scenarios developed by the International Institute of Applied Systems Analysis (IIASA) (Cofala et al., 2006):

(a) Using the "current legislation" scenario (CLE) — the economic growth and expected impacts of present emission control legislation in each province and municipality were taken into account, based on the Tenth Plan (2001–2005) of the Five Year Plans of China (FYP).

(b) Using the "maximum technically feasible reduction" scenario (MFR) — according to the Tenth Plan of FYP, the best available emission control technologies were assumed to be fully implemented, without considering the cost.

By using emission levels, and social, and economic developments in 2005, O_3 concentration in 2005 was simulated under a present day scenario (year 2005).

As described above, the boundary conditions for the regional model were taken from the global scale simulations by MIROC-ESM-CHEM (Akimoto et al., 2015) assuming changes in the emissions of O_3 precursors including methane (CH_4) according to the scenarios. In the regional simulation by CMAQ, CH_4 concentration was fixed at 1850 ppbv for all the scenarios, which might over or under estimate O_3 concentration. However, the differences in CH_4 concentration among the scenarios estimated in the MIROC-ESM-CHEM simulation (Akimoto et al., 2015) were not so large (less than 10%). In addition, Akimoto et al. (Akimoto et al., 2015) found out that 4% reduction of CH_4 concentration between the scenarios barely led to any changes in the numbers of high O_3 days (DMA8 < 75 ppbv). Therefore, we consider that the bias of O_3 projection owing to the application of fixed CH_4 concentration in the regional simulation is not so significant.

2.2.2. O_3-related mortality between 2005 and 2030

The following risk assessment framework was used to assess daily premature mortality attributable to O_3 in 2005 and 2030, respectively: (Knowlton et al., 2004)

$$\text{Daily premature mortality attributable to } O_3(t) = \text{daily } O_3 \text{ concentration } (t) \times \text{CRF} \times \text{baseline mortality rate } (t) \times \text{population}(t)$$

where CRF is the concentration-response function (O_3-mortality association) quantifying the magnitude of the proportional change in daily mortality in response to a given changes in daily O_3 concentration (C), t is the year of simulation (i.e., year 2005 or 2030). The daily O_3-related premature mortality (cases) in 2005 and 2030 was estimated to calculate the annual O_3-related premature mortality in 2005 and 2030, respectively. Then, the difference of annual O_3-attributable premature mortality was calculated between 2005 and 2030.

Although there is evidence regarding the long-term effect of O_3 on mortality (Jerrett et al., 2009; West et al., 2006), it was not considered in this study due to the scarcity of studies on such an issue in China. As the potential threshold for O_3 concentration below which no adverse health impacts would happen has been suggested (Kim et al., 2004), two assumptions were considered regarding the threshold for O_3-mortality associations. First, it was assumed that there was no threshold. Second, the WHO Air Quality Guidelines (AQG) for O_3 (DMA8: 100 μg/m^3) was assumed to be the threshold.

2.2.3. Mortality rate projection

Firstly, the regional total, cardiovascular, and respiratory mortality rate were assumed to remain static from 2005 and 2030; therefore, the mortality for the year 2005 was used as the first assumption. The regional mortality data in each province and municipality for the year 2005 were collected from statistical yearbooks for 2005.

Secondly, the projected regional total mortality data for 2030 from IIASA was used as the second assumption, which was described in detail