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The air quality and health impacts of domestic trans-boundary pollution in various regions of China

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ABSTRACT

Air pollution is one of the most pressing environmental problems in China. Literature has reported that outdoor air pollution leads to adverse health problems every year in China. Recent measurement studies found the important regional nature of particulates in China. Trans-boundary air pollution within China has yet to be fully understood. This study aimed to comprehensively understand the processes of domestic trans-boundary air pollution in China and to apportion the impacts of emissions in different regions on air quality and public health. We applied a state-of-the-art air quality model to simulate air quality in China and then adapted a form of integrated concentration–response function for China to estimate the resultant amount of premature mortality due to exposures to $PM_{2.5}$. Our findings show that domestic trans-boundary impacts (TBI), on average, account for 27% of the total $PM_{2.5}$ in China. We estimated that outdoor air pollution caused ~870,000 (95% CI: 130,000–1500,000) premature mortalities in China in 2010, of which on average 18% are attributed to TBI. Among all the regions, North China is the largest contributor to TBI due to 41% of the health impacts of its emissions occurring in other regions. Taiwan (TW) is the smallest contributor to TBI occurring in China, contributing 2% of the national TBI, while TBI causes 22% of the premature mortalities due to outdoor air pollution in TW. Our findings pinpoint the significant impacts of TBI on public health in China, indicating the need for cross-region cooperation to mitigate the air quality impacts and the nation's resultant health problems.

1. Introduction

Extensive literature has reported the severity of the air pollution problem in China, including the sharp decrease in visibility (Chang et al., 2009) and the increase in the number of haze episodes occurring in various metropolises (Chan and Yao, 2008). Epidemiological studies have reported that life expectancy becomes shorter in regions in China (Chen et al., 2013; Guo et al., 2013) with high particulate matter (PM) concentrations. Premature mortality due to outdoor air pollution has already been ranked as the top cause of death in China (Yang et al., 2013). Recent research has estimated that outdoor air pollution causes more deaths in China every year than in any other countries worldwide (Lelieveld et al., 2015). This evidence indicates that air pollution in China is indeed a pressing problem that needs to be solved.

Trans-boundary air pollution is one of the important environmental problems at a range of spatial scales including the global, regional and local scales. Literature has identified the trans-boundary pollutants between countries. Lin et al. (2014) applied a modeling approach to investigate the impact of transported pollutants from China across the Pacific Ocean to the west coast of the United States (US). The study found an association between pollutant concentration levels along the west coast of the US and emissions of export production in China, highlighting the remarkable contribution of trans-boundary air pollution. Lee et al. (2013) analyzed the synoptic pattern in an air pollution episode and investigated trans-boundary transport of coarse particulate matter from China to Seoul, South Korea. On the other hand, some studies focused on the regional scale. For example, Lam et al. (2005) simulated ozone formation in a summer episode in Hong Kong by using a backward trajectory method. The authors reported that the northerly wind transports pollutants from mainland China to Hong Kong, contributing 60–90% of the total ozone in Hong Kong. The above studies consistently indicated the importance of trans-boundary air pollution. Huang et al. (2014) employed an offline analytical approach and statistical techniques to apportion the sources of aerosol in China. This study highlighted the significant trans-boundary nature of particulates in China. Hitherto, none of the studies have comprehensively investigated the processes of trans-boundary air pollution and quantified the resultant air quality and health impacts. The trans-boundary air pollution has

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thus become a major challenge for air quality management and it has also resulted in a global air pollution problem (Wang et al., 2014; Wuebbles et al., 2007).

In addition, to effectively assess the health impacts of air pollution in China, an applicable concentration-response function (CRF) for China, which has a relatively high $PM_{2.5}$ concentration, is necessary. The CRFs commonly used in other studies (Ostro, 2004; USEPA, 2011) were typically developed based on global data or the data collected in developed countries, where the environment is relatively clean compared to that in developing countries. Literature has found that the human response to air pollution may vary under various levels of background fine particulate matter ($PM_{2.5}$) (Burnett et al., 2014). This highlights that the CRFs derived in developed countries may not be applicable to developing countries such as China. Burnett et al. established a form of integrated CRF for relatively polluted environments. The coefficients derived in their work were however based on global data such that their CRF may not be directly applicable to China. A China-specific CRF is therefore essential to achieve a precise health impact assessment in China. Up to now, such a CRF has not been available yet.

This study comprehensively investigated the spatiotemporal and vertical patterns of domestic trans-boundary air pollution in seven regions of China based on the definition of the International Organization for Standardization (ISO) 3166–2 (International Organization for Standardization, 2007): East China (E); North China (N); Southcentral China (SC); Southwest China (SW); Northwest China (NW); Northeast China (NE); and Taiwan (TW) (Fig. 1). We estimated the portion of ground level $PM_{2.5}$ due to domestic trans-boundary air pollution, and then quantified the resultant premature mortalities by our China-specific CRFs dervied based on a range of epidemiological studies in China. This discussion mainly focused on the impacts in various regions, while the impacts in each province were provided in SI-8. We anticipate that this study will provide critical insight for atmospheric scientists and policy-makers to effectively mitigate trans-boundary air pollution, which has become an important global issue.

2. Material and methods

We employed a state-of-the-art atmospheric model system [Weather Research and Forecast (WRF)/Community Multi-scale Air Quality Modeling System (CMAQ)] with a compiled nationwide spatially, temporally and chemically resolved emission inventory in 2010 to simulate air quality in China (Janssens-Maenhout et al., 2011; Sindelarova et al., 2014; Wiedinmyer et al., 2014). To estimate the trans-boundary air pollution and its impact in each region, emissions of each region in model simulations were removed in turn as regional scenarios. We attributed the differences in $PM_{2.5}$ between each scenario and the baseline scenario, which included the emissions of all regions, to emissions of the respective region. We overlaid the distribution of trans-boundary $PM_{2.5}$ onto population data and then employed our China-specific CRFs, which was fitted based on the epidemiological samples in China, to

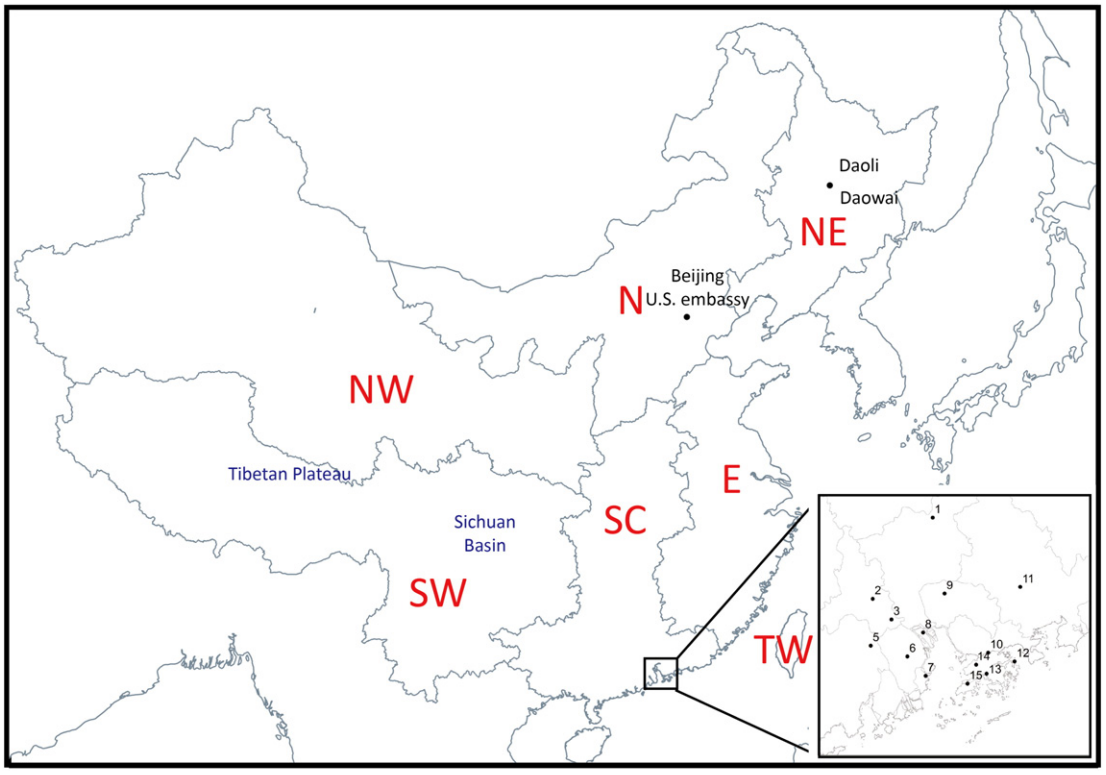

Fig. 1. Geographical location of regional divisions (red), geographical names (dark blue), and air quality monitoring stations (black) are depicted. The zoomed figure refers to the stations in the Guangdong Province.