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A virtual geographic environment system for multiscale air quality analysis and decision making: A case study of SO_2 concentration simulation

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ABSTRACT

The spatial decision support system (SDSS) is widely used in environmental problem management. In this paper, focusing on the air quality problem in the Pearl River Delta, China, we present a virtual geographic environment (VGE) system to integrate multiscale meteorological and air quality models for policy making. It is a comprehensive modeling tool to aid decision makers and various stakeholders to participate in air quality management by providing geographic visualizations and friendly interfaces. With nested multiscale models, a synthetic understanding of cross-boundary air quality processes can be captured to understand both regional and local effects. With the help of Linux-Apache-MySQL-Perl (LAMP) architecture, users can manage and retrieve modeling data and model parameterizations to reach a consensus on the simulation results and share modeling knowledge. Aided by a high-resolved emission inventory, such a multiscale system enables practical applications for various scenarios. As a case study, the system was applied to simulate and analyze the SO_2 concentration process and local contribution in the Hong Kong Special Administrative Region (HKSAR) based on hourly simulation results with spatial resolutions of 0.5 and 3 km from multiscale models. The results from the multiscale modeling and the limited local contribution suggest that Hong Kong and the surrounding region should closely cooperate to develop a better environment.

1. Introduction

In recent years, air pollution has risen to harmful levels and has been a growing concern in the Hong Kong Special Administrative Region (HKSAR) (Chan & Yao, 2008; Yim, Fung, & Lau, 2010). Deteriorated air quality not only has adverse effects on economic development and low visibility (Wu et al. 2005) but also threatens public health (ChinaDialogue, 2008). Therefore, the Environment Protection Department of Hong Kong has been taking a series of measures to improve air quality at a high cost, spending more than HK$ 800 million in 2013–2014 (Environment Bureau, Transport & Housing Bureau, Food & Health Bureau, & Development Bureau, 2013).

Air pollution is a type of transboundary pollution (Lam, Wang, Wu, & Li, 2005). In this context, air quality problems in HKSAR are attributed not only to local sources, such as marine transportation but also to sources outside the territory, such as industry sources from the surrounding Pearl River Delta (PRD) region, particularly during winter because of the northeast winds (Fung & Wu, 2014; Guo et al. 2006; Jiang, Wang, Wang, Xie, & Zhao, 2008; Kwok, Fung, Lau, & Fu, 2010; Lee & Hills, 2003; Nie, Wang, Wang, Wei, & Liu, 2013). The nearby PRD Economic Zone, which has been the fastest growing economic area in China with high energy consumption, is responsible for degrading the air quality (Zhong et al. 2013). In addition, geographic and meteorological

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characteristics in HKSAR and the PRD region also contribute to the severe air quality conditions. As a result of the topography-induced flows and sea–land breeze, pollutants accumulate and react over several days (Fig. 1) (Ding, Wang, Zhao, Wang, & Li, 2004; Lo, Lau, Fung, & Chen, 2006; Wu et al. 2005).

In order to provide a scientific basis for understanding and managing such air quality problems with local and regional effects, many modeling studies have been conducted with extensive findings. For instance, Wang, Carmichael, Chen, Tang, and Wang (2005) analyzed the role played by emissions from transportation, industry, and power generation on the air quality in Guangdong Province, China, based on mesoscale modeling. Lam et al. (2005) studied an ozone episode during the warm season in Hong Kong and transboundary air pollution over the PRD region by using three simulation modules: an emission modeling system (EMS-95), a mesoscale model (MM5 V3.6), and the SARMAP air quality model. These models are capable of capturing the regional background field; however, the complex small-scale features and sharp gradients of the land surface in HKSAR and the PRD (Fig. 1) are smaller than the typical resolutions used in mesoscale models, such as MM5 and Community Multiscale Air Quality Modeling System (CMAQ) (Yim, Fung, Lau, & Kot, 2007). Therefore, to address the scale dependence of dynamic models (Zhang, Lin, Chen, Li, & Zeng, 2014), finer-scale models are preferred to simulate meteorological conditions and air quality (Liu, Chan, & Cheng, 2001; Wang et al. 2005). In this context, Yim et al. (2010) studied SO_2 apportionment to air quality in Hong Kong by using the CALPUFF model. Although all these studies have provided scientific evidence to understand the processes relevant to air quality, policy makers still face challenges in decision making given the following reasons:

1) HKSAR and the PRD region are governed as “One country, two systems” allowing for an autonomous HKSAR (including political system, economic affairs, etc.), which is different from PRD. Thus, simulations that focus only on the mesoscale or finer scale do not favor a comprehensive understanding of the multiscale air quality problem in both regions. There is a long history of disappointments in policy, management, and assessment arising from the failure to take scale and cross-scale dynamics in the systems into proper account (Argent, 2004; Cash et al. 2006; Su, Xiao, & Zhang, 2012; West & Hovelsrud, 2010). Therefore, in order to avoid intergovernmental conflict, multiscale and integrated simulations addressing both the mesoscale background emission field and the local features are significant to ensure a smooth collaboration between HKSAR and PRD regarding decision making.
2) There is no need to repeat the significance of cross-scale linkages, which have been extensively discussed by other researchers, for instance, Isakov et al. (2009). Instead, we focus on the proper consideration of such linkages in simulation systems. In the computation of differential equations, it is necessary to link multiscale models with a suitable scale ratio (between the grid resolutions of the main and nested models) to retain numerical stability, a suitable approximation, and the accuracy of the models (Baklanov & Nuterman, 2009), which should be considered when developing tools for understanding air quality processes.
3) Along with the management of air quality, collaboration across bureaus, departments, and the community is receiving attention and is one of three premises to implement the clean air plan proposed in 2013 (Environment Bureau et al. 2013). Systems would preferably store and manage both data and modeling settings to achieve this premise (Zhang, Chen, Li, Fang, & Lin, inpress; Conway, 2015). Such a design is necessary for different stakeholders to retrieve simulations and reach a consensus on the simulation results for assessing potential policy. In addition, a range of public participants with different backgrounds require user-friendly interfaces and visualization tools; otherwise, they would have difficulty interacting with the simulation system and negotiating with each other.

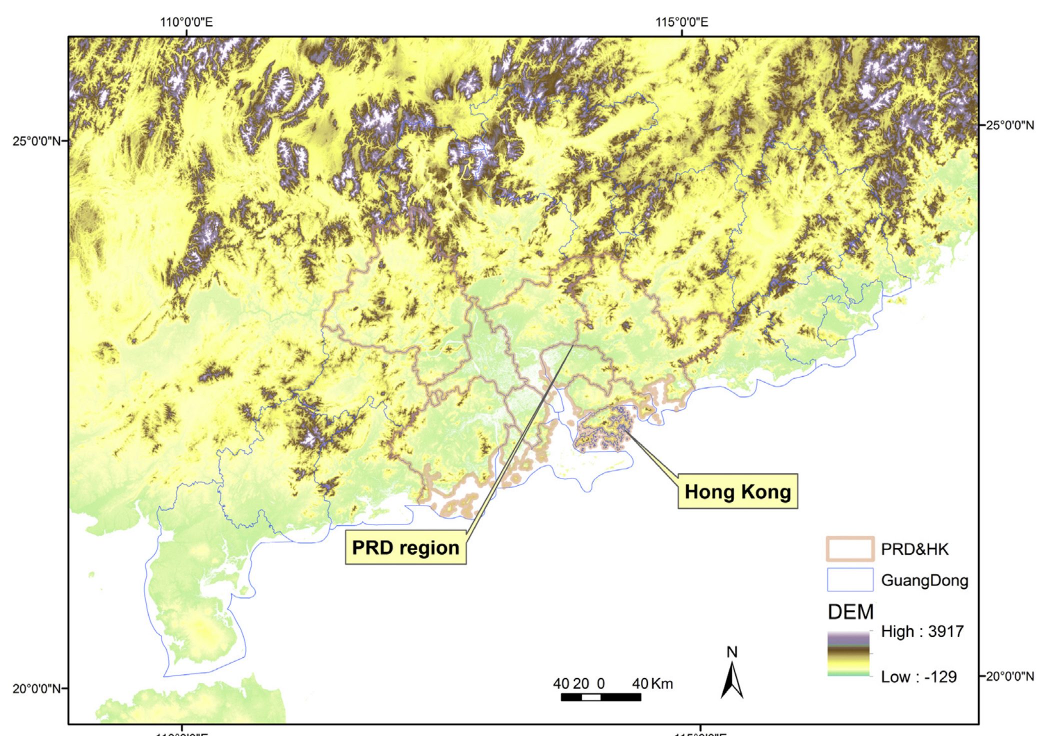

Fig. 1. Complex topography and coastlines of HKSAR and the PRD region.