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Current status and future trends of SO_2 and NO_x pollution during the 12th FYP period in Guiyang city of China

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HIGHLIGHTS

► Current status of SO_2 and NO_x pollution are assessed for base year 2010.
► CALPUFF modeling is evaluated by comparing observed and simulated concentrations.
► Three emission scenarios are analyzed for the projected year 2015.
► Reasonable air pollutant emission control targets are proposed during the 12th FYP.
► Comprehensive countermeasures must be implemented to ensure air quality improvement.

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ABSTRACT

In order to investigate the future trends of SO_2 and NO_x pollution in Guiyang city of China, the MM5/CALMET/CALPUFF modeling system is applied to assess the effects of air pollution improvement that would result from reduction targets for SO_2 and NO_x emissions during the 12th Five-Year Plan (2011–2015). Three scenarios are established for the objective year 2015 based on the reference emissions in base year 2010. Scenario analysis and modeling results show that emissions are projected to increase by 26.5% for SO_2 and 138.0% for NO_x in 2015 Business-As-Usual (BAU) relative to base year 2010, respectively, which will lead to a substantial worsening tendency of SO_2 and NO_x pollution. In comparison, both the 2015 Policy Reduction (PR) and 2015 Intensive Policy Reduction (IPR) scenarios would contribute to improve the urban air quality. Under 2015 PR scenario, the maximum annual average concentration of SO_2 and NO_x will reduce by 54.9% and 31.7%, respectively, relative to the year 2010, with only 2.1% of all individual gridded receptors exceed the national air quality standard limits; while the maximum annual average concentrations of SO_2 and NO_x can reduce further under 2015 IPR scenario and comply well with standards limits. In view of the technical feasibility and cost-effectiveness, the emission reduction targets set in the 2015 PR scenario are regarded as more reasonable in order to further improve the air quality in Guiyang during the 12th FYP period and a series of comprehensive countermeasures should be effectively implemented.

1. Introduction

With the continuous population inflow into large metropolitan areas, the large-scale industrialization and the increase of vehicle's fleet, China has been suffering significant environmental problems and public health is being seriously threatened (Kan et al., 2012; Tian et al., 2010). Therein, both of SO_2 and NO_x emissions reduction have been listed as two restrictive indicators in the 12th Five-Year Plan (FYP) for the national and local governments of China mainly because of their substantial contribution to regional air quality deterioration (MEP, 2011). For Guiyang, the capital of Guizhou Province, continuous development of regional economy and coal-dominated energy structure have caused very complex air pollution problems (Guiyang EPB, 2011a; Xie et al., 2005; Wang et al., 2007; Tian et al., 2012a,b). Especially, non-attainment of SO_2 concentration and the rapidly rising tendency of NO_x concentration in Guiyang have received great concerns, and a series of regulations and policies have been implemented to reduce SO_2 emissions during the 11th FYP, such as shutting down or renovating inefficient and heavy polluting enterprises, as well as application of flue gas desulfurization (FGD) in coal-fired power plants. However, 5.5% of daily SO_2 concentration by the year 2010 still exceed the Grade II National Ambient Air Quality Standards (NAAQS, GB3095-1996) (MEP, 1996) and the annual average concentration of NO_x tends to increase obviously year by year owing to few actions to

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diminish NO_x emissions (Guiyang EPB, 2011a). Moreover, regional economic growth and energy demand will prompt air pollutants emissions to keep increasing in the future and the regional air quality will get worsening, if none of effective countermeasures were taken timely. Therefore, a better understanding of the current status and future trends of typical air pollutants emissions and their potential impacts on the urban air quality in the period of 12th FYP (2011–2015), especially in the downtown of Guiyang city with high density of populations and industries, is of great significance.

Several studies have investigated the regional air quality for the present (Hao et al., 2007; Salcedo et al., 2012) and the future (Xing et al., 2011; Herron-Thorpe et al., 2010; Dacre, 2011). Overall, a combination of air quality model and scenario analysis is an effective method to assess the current regional air quality and forecast its changes in the future (Wang et al., 2010a,b; Saikawa et al., 2011; Yi et al., 2012). Therein, CALPUFF modeling system (Scire et al., 2000a,b) has been broadly used to study the formation and transport of multiple air pollutants (Zhou et al., 2003; MacIntosh et al., 2010; Poplawski et al., 2011; Song et al., 2008, 2009), and the MM5/CALMET/CALPUFF system has been utilized in a number of studies to investigate pollutant concentrations in different regions. For example, Lonati et al. (2010) applied CALPUFF modeling system to assess the impact on local air quality at base-case and worse-case emission scenarios for a new freight port in project in the Mediterranean Sea; Yim et al. (2010) employed the MM5/CALMET/CALPUFF system to analyze the SO_2 apportionment to air quality in Hong Kong. However, previous researches about air pollution in Guiyang were mostly concentrated on the mercury speciation, emission and distributions (Feng et al., 2003; Tang et al., 2007; Liu et al., 2011) or the characteristics of individual pollutant in Guiyang (Xiao and Liu, 2004; Xie et al., 2005), and fewer studies have been conducted to systematically address the current air pollution in Guiyang and the potential trends in the future.

The purpose of this paper is to use the MM5/CALMET/CALPUFF modeling system and scenario analysis to investigate current status of urban air quality in Guiyang city and to forecast the potential future trends during the 12th FYP. Further, reasonable emission control targets are proposed and comprehensive control policy recommendations are provided for further improving urban air quality in Guiyang.

2. Methodology

In this study, the MM5/CALMET/CALPUFF modeling system is employed. First, using MM5 to generate a large-scale wind field as a first guess field, and then utilizing the CALMET model to produce real wind fields in Guiyang by adjusting the meteorological fields to reflect the complex terrain and land use data. The meteorological fields generated from MM5/CALMET then drive the CALPUFF for simulating the ambient air pollutants concentration in the whole Guiyang city.

The emission inventories of SO_2 and NO_x in the base year 2010 are established according to the Comprehensive Annual Report of Environmental Statistics Data (Guiyang EPB, 2011b) and Pollution Source Census during the 11th five-year plan (Guiyang EPB, 2011c). Based on the current status in base year 2010, anthropogenic emissions of SO_2 and NO_x in target year of 2015 are forecasted in light of the trends of regional economic development, population growth and energy use increase, which are proposed in the Guiyang Economic and Social Development 12th Five-Year Plan (The People's Government of Guiyang Municipality, 2011).

Three emission scenarios in 2015 are established: the first scenario applies current economy growth and energy demand trend with no additional controls utilized (called 'Business-As-Usual' or '2015 BAU scenario'); the second scenario sets a policy emission reduction plan – 8% reduction for SO_2 and 10% reduction for NO_x, respectively, relative to the year of 2010 according to the emission reduction targets of the 12th FYP in China which were promulgated by the Chinese central government in the year 2011 (MEP, 2011) (called 'Policy Reduction scenario' or '2015 PR scenario'); and the third scenario assumes an intensive policy reduction plan aiming to examine the air quality improvement from strengthening emission reductions – 12% reduction for SO_2 and 15% reduction for NO_x, respectively, relative to the year of 2010 (called 'Intensive Policy Reduction scenario' or '2015 IPR scenario'), as shown in Table S1 in the Supplementary Information (SI).

Ambient concentrations of SO_2 and NO_x are then simulated by applying CALPUFF modeling system for the base year 2010 and the three scenarios in projected year 2015. The National Ambient Air Quality Standards GB3095-1996 (MEP, 1996), and GB3095-2012 (MEP, 2012) which was newly issued in the early of 2012, are served as the reference standards for the base year 2010 and projected year 2015, respectively.

2.1. MM5 configuration

In this study, MM5 is configured with two two-way interactive nested grids (Fig. 1). The first domain (D01) covers almost all over the Guizhou Province providing the boundary conditions for the second domain (D02). This domain has 34 × 36 grid points with a horizontal resolution of 9 km. The second domain D02 contains 64 × 70 grid points with a horizontal resolution of 3 km. The computational domain in MM5 consists of 23 sigma (σ) vertical levels from bottom to top. Each σ level is defined by $\sigma = (p_0 - p_{top})/(p_{surface} - p_{top})$, where p is the atmospheric pressure, and the top pressure is100 hPa (Grell et al., 1994; Dudhia et al., 2005). The major physics options used in the MM5 simulations include the Grell cumulus scheme (Grell et al., 1994), the medium-range forecast (MRF) planetary boundary layer scheme (Hong and Pan, 1996), Dudhia's simple ice explicit moisture scheme (Dudhia, 1989), cloud-radiation scheme (Dudhia, 1989) and the Five-layer soil model (Dudhia, 1996). Initial conditions and boundary conditions are provided by the 1.0° National Centers for Environmental Prediction (NCEP) Final Analyses (FNL) at 6-h intervals. The MM5 simulations are input as initial-guess field in CALMET to simulate the wind field over the modeling domain. Notably, same meteorological field generated by MM5 for the base year 2010 is used for all three 2015 scenarios, and future climate change is neglected in this study.

2.2. CALMET configuration

CALMET (Scire et al., 2000a) is configured with domain covering the whole Guiyang city and with the horizontal grid spacing of 3 km and 10 vertical layers which correspond to the physical heights of 10 m, 25 m, 40 m, 75 m, 150 m, 350 m, 750 m, 1500 m, 2500 m and 3150 m. Land use categories and associated geophysical parameters are obtained from the U.S. Geological Survey Land Use Classification System. The wind field outputs from the D02 of MM5 model are horizontally and vertically interpolated to the CALMET grid as an initial-guess wind field (Scire et al., 2000a).

2.3. CALPUFF configuration

CALPUFF is an advanced non-steady state puff Lagrangian Gaussian dispersion model to simulate the transport, dispersion, chemical reaction and deposition of air pollutants in the time- and space varying meteorological conditions, and requires each source