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Impact of Projected Emission and Climate Changes on Air Quality in the U.S.: from National to State Level

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Abstract

Future ambient air quality will respond to changes in anthropogenic and biogenic emissions as well as climate changes, which may vary at national and state levels in different regions of the world. In this work, we applied an advanced online-coupled meteorology and chemistry model, the Weather Research and Forecasting Model with Chemistry (WRF/Chem), to the continental U.S. for current (2001-2010) and future (2046-2055) decades under four climate scenarios including the Representative Concentration Pathways (RCP) 4.5 and 8.5 and the Technology Driver Model (TDM) A1B and B2. Our goal is to quantify the impact of projected changes in anthropogenic and biogenic emissions and climate on future air quality under various climate scenarios for policy analysis for emission control and mitigation of adverse climate change. The simulations are performed at 36-, 12-km, and 4-km over North America, Continental U.S., and selected states, respectively. A comprehensive evaluation has been performed for the current simulation period using available observations from surface networks and satellites and shows an overall good performance in reproducing climatic and chemical observations at all grid scales. Future air quality features greater reduction in $PM_{2.5}$ by RCP 4.5/8.5 than TDM B2/A1B and decreased O_3 over most areas in the U.S. by RCP4.5 and TDM B2, indicating the benefits of carbon policy and technology changes with greater emission reductions. Air quality responds differently to projected changes in anthropogenic emissions in different states and seasons, indicating a need to develop state-specific emission control strategies for different seasons.

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Keywords: Air quality modeling; climate scenarios; regional and urban scales

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1. Introduction

Changes in anthropogenic emissions and climate will impact future ambient air quality and human health. Fiore et al. (2012)[1] reported that annual mean surface O_3 levels increase by 2050 under the Fifth Assessment Report (AR5) of the IPCC Representative Concentration Pathways (RCP) 8.5 scenario but decrease with RCP 2.6, 4.5 and 6.0 over North America (NA). Penrod et al. (2014)[2] found that future anthropogenic emissions have a greater influence compared to climate change alone on future air quality. IPCC AR4 and AR5 projected future anthropogenic emissions based on possible pathways of economic development considering socioeconomic factors. However, these projections do not account for changes in future technologies that essentially determine air pollutant emissions. Yan et al. (2014)[3] developed a new Technology Driver Model (TDM) that accounts for changes in future technologies. In this work, TDM is used to project anthropogenic emissions under two of the four climate and emission scenarios (i.e., IPCC AR4 A1B and B2).

In this work, an advanced online-coupled meteorology and chemistry model, the Weather Research and Forecasting Model with Chemistry (WRF/Chem), has been applied to NA for current (2001-2010) and future (2046-2055) years under four climate and emission scenarios including the RCP 4.5 and 8.5, and the TDM A1B and B2. The period of 2001-2010 is selected to represent current climate conditions because of availability of U.S. EPA National Emissions Inventory and also observations for model validation. The period of 2046-2055 is selected to represent future climate conditions because we are interested in projected changes around the year 2050 and this period is 45-year apart from the current decade, which allows an assessment of climate change from the current decade. Different from offline-coupled models, WRF/Chem can simulate complex feedbacks between air pollutants and climate, thus can more realistically represent the atmosphere. Nested simulations are performed at higher horizontal grid resolutions over continental U.S. (CONUS) and selected states for 2005 and 2050. The goal of our study is to quantify the impact of projected changes in emissions (both anthropogenic and biogenic) and climate on future air quality under various scenarios in support of policy making for air quality attainment and adverse climate change mitigation.

2. Model Configuration and Evaluation Protocol

In this study, we have applied the WRF/Chem v3.6.1 with updates in Wang et al. (2015)[4] to simulate air quality and climate under the two RCP scenarios and WRF/Chem v3.7 under the two TDM scenarios. In both versions, the physics options include the Rapid and accurate Radiative Transfer Model for GCM (RRTMG) for both shortwave and longwave radiation, the Yonsei University (YSU) planetary boundary layer scheme and the Morrison double moment microphysics scheme. For cumulus parameterization, the Grell 3D Ensemble is used for RCP simulations whereas the multi-scale Kain Fritsch (MSKF) scheme is used for TDM simulations. Both versions of WRF/Chem use the modified version of 2005 Carbon Bond (CB05) gas-phase chemical mechanism with chlorine chemistry, the aqueous-phase chemistry module, and the Model for Aerosol Dynamics in Europe with the Volatility Basis Set (VBS) module for secondary organic aerosol (SOA).

The simulations are performed under the four climate scenarios for current (2001-2010) and future (2046-2055) years over NA with a horizontal resolution of 36×36 km^2. Nested simulations are performed at 12×12 km^2 over CONUS, and 4×4 km^2 over California (CA) and North Carolina (NC) for 2005 and 2050 under the TDM scenario with changes in anthropogenic emissions only (assuming the same climate in 2050). Figure 1 shows the triple-nested domains. Given different emissions during 2001-2010 between RCP4.5 and 8.5, two sets of 2001-2010 simulations are performed for RCP scenarios. For TDM A1B and B2, only one set of 2001-2010 simulation is performed because their emissions are very similar. The anthropogenic emissions for current period RCP and TDM simulations are based on those of RCP and the U.S. National Emission Inventories (NEI), respectively. Biogenic, dust, and seal-salt emissions are calculated online. The chemical and meteorological initial and boundary conditions (ICONs/BCONs) are generated based on the simulations of Glotfelty et al. (2007)[5] and Glotfelty and Zhang (2007)[6] using the modified Community Earth System Model. For the current decade, a comprehensive climatological evaluation for both climatic and chemical predictions at 36-km resolution is performed using available observations from surface networks and satellites. The evaluation is performed in terms of performance statistics, spatial distributions, and temporal variations based on 10-year averaged results during 2001-2010 at 36-km, and 2005 at