AQMEII Phase 2: Overview and WRF-CMAQ Application over North America

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Abstract In this study, we provide an overview of the second phase of the Air Quality Model Evaluation International Initiative (AQMEII). Activities in this phase are focused on the application and evaluation of coupled meteorology-chemistry models. Participating modeling systems are being applied for annual simulations over both North America and Europe using common emissions and boundary conditions. We present an overview of these common input datasets. In addition, we discuss some of the planned analysis approaches using WRF-CMAQ simulations performed over North America for both 2006 and 2010.

Keywords: Air Quality Model Evaluation International Initiative (AQMEII), coupled meteorology-chemistry models, dynamic evaluation

Introduction

The Air Quality Model Evaluation International Initiative (AQMEII) was launched in 2009 by bringing together scientists from both sides of the Atlantic Ocean (Rao et al., 2011). The first phase of AQMEII culminated in the publication of a special issue of Atmospheric Environment (Galmarini et al., 2012a). Phase 2 of AQMEII was launched at a workshop in Utrecht, The Netherlands in May 2012 with the goal of applying coupled meteorology-chemistry regional models over Europe and North America and assessing feedbacks among aerosols, clouds, and radiation as called for in Alapaty et al. (2012). As in the first phase of AQMEII, it is expected that the model evaluation approaches suggested by Dennis et al. (2010) can provide a common basis for evaluating participating models. Standardized modeling outputs from each modeling group as well as observational data from a number of ground based and upper air networks will be shared on the web-distributed ENSEMBLE system (Galmarini et al., 2012b), facilitating statistical and ensemble analyses to be performed by each group.

Datasets and Model Overview

A common set of input data was provided to all modeling groups to facilitate the interpretation of model-to-model differences. In particular, concentrations from the global MACC reanalysis fields (Inness et al., 2013) were provided at three-hourly resolution over North America and Europe to specify boundary conditions for the regional-scale models for both 2006 and 2010. Anthropogenic emissions over North America and Europe were processed and provided by the U.S. Environmental Protection Agency (U.S. EPA) and the Netherlands Organization for Applied Scientific Research (TNO), respectively, for both 2006 and 2010. Over the U.S., anthropogenic emissions of SO_2 and NO_x decreased by roughly 35% and 20%, respectively, largely due to reductions in power plant and mobile source emissions.

It is expected that a total of about 20 annual regional-scale simulations will be performed as part of AQMEII Phase 2, with about fifteen of these simulations performed over Europe and five over North America. Since model results are still becoming available as of the writing of this paper, we only discuss results from simulations performed by the U.S. EPA using the WRF-CMAQ two-way coupled model (Wong et al., 2012). Annual WRF-CMAQ simulations at a horizontal grid spacing of 12 km were performed for 2006 and 2010 over the continental U.S. considering direct aerosol feedback effects on shortwave radiation. A sensitivity simulation without feedback effects was performed for July 1 – 17, 2006.

Discussion

In this section, we discuss the types of analyses to be performed during Phase 2 of AQMEII using the WRF-CMAQ simulations described above as illustrative example. One of the first steps will be to establish the strength of the simulated feedback effects by performing sensitivity simulations. For the period from July 1 – 17, 2006 when WRF-CMAQ simulations were performed with and without direct feedback effects, results indicated that there was a non-negligible impact of these feedback effects on a number of variables. In particular, when averaged over all daytime hours over all model grid cells with AOD values of at least 0.1, the simulations with direct feedback effects showed lower temperatures (-0.05K), lower PBL heights (-15m) and higher surface $PM_{2.5}$ concentrations (+0.16 µg/m^3). Future analysis will focus on determining the strength of the direct feedback effect for other models, the time periods and regions when the simulated feedback effects are largest, and the relative strength of direct vs. indirect effects.

Another objective is to compare simulated aerosol and radiation variables against available observations. Based on a comparison of WRF-CMAQ against ground-based AERONET measurements of AOD as well as MODIS satellite AOD retrievals, results indicate that WRF-CMAQ tends to underestimate AOD, especially during summer. In both years, WRF-CMAQ shows an overestimation of total $PM_{2.5}$ during winter and an underestimation during summer at these predominantly rural monitors. While the summertime underestimation of PM mass is consistent with the underestimation of AOD, AOD during wintertime is not overestimated despite an overestimation of $PM_{2.5}$ mass. Future analysis will focus on evaluating $PM_{2.5}$ composition, both at the surface and aloft. In addition, there is a need to study the diurnal cycle of $PM_{2.5}$ mass and components to evaluate whether the models capture the strength and timing of emissions and vertical mixing. To attribute model-to-model differences in AOD to differences in $PM_{2.5}$ composition and distribution vs. differences in aerosol optics calculations, there are plans to employ stand-alone aerosol optics calculation models such as FlexAOD (http://pumpkin.aquila.infn.it/flexaod/) driven by $PM_{2.5}$ concentrations simulated by the different coupled models.

One key consideration when designing the AQMEII Phase 2 activity was to enable dynamic model evaluation as defined in Dennis et al. (2010). To this end, model inputs were prepared for both 2006 and 2010 and groups were encouraged to consider simulating both years. Over North America, such simulations are being performed by at least three models, among them the WRF-CMAQ simulations described above. Results from an analysis of these simulations show a decrease in the observed and modeled concentrations of many gas phase and aerosol concentrations between 2006 and 2010, both during the warm and cold season. In addition, there also is a general decrease in observed and modeled AOD and an increase in simulated clear-sky short wave radiation. For key species such as O_3, NO_x, and SO_4, the percentage reductions in the modeled concentrations tend to be less than the reductions in the observed concentrations (for example, observed May – September SO_4 concentrations decreased by roughly 40% averaged over all rural IMPROVE monitors while modeled concentrations decreased by roughly 35%), but spatial patterns of changes are captured by the WRF-CMAQ simulations.

While the changes in North American anthropogenic emissions between 2006 and 2010 likely are a major driver for these observed and modeled concentration decreases, other factors need to be considered as well. In particular, there are differences in wildfire emissions that affect simulated changes in aerosol concentrations and radiation effects, changes in hemispheric background concentrations as represented by MACC that influence the regional-scale simulations through lateral boundary conditions, and changes in meteorology that affect pollutant transport, transformation and removal. For example, wintertime average mid-tropospheric O_3 concentrations in MACC decreased between 5 and 15 ppb from 2006 to 2010 near the western and northern boundaries of the regional scale simulations. Similarly, an initial analysis of meteorological fields indicates that changes in meteorology likely counteracted some of the effects of reduced anthropogenic emissions on summertime ozone in parts of the Eastern U.S. and enhanced them in the Western U.S. Future work will be aimed at separating the various effects influencing year-to-year changes in pollutant concentrations and conducting such analyses for other modeling systems besides WRF-CMAQ.

Summary

AQMEII Phase 2 focuses on evaluating and intercomparing online coupled meteorology/chemistry modeling systems. By preparing inputs for 2006 and 2010 and by collecting a large observational dataset, it will be possible to perform operational, diagnostic, dynamic, and probabilistic evaluation of these models (Dennis et al., 2010). WRF-CMAQ simulations were used to illustrate some of the planned analysis approaches. Through these analyses and a planned journal special issue, it is envisioned that AQMEII Phase 2 will document the state of science in coupled regional-scale modeling and help to determine the value of including feedback effects in different model applications.

Acknowledgments and Disclaimer

Although this work has been reviewed and approved for publication by the U.S. Environmental Protection Agency, it does not reflect the views and policies of the agency. We gratefully acknowledge the contribution of various groups to the second Air Quality Model Evaluation international Initiative (AQMEII) activity: U.S. EPA, Environment Canada, Mexican Secretariat of the Environment and Natural Resources (Secretaría de Medio Ambiente y Recursos Naturales-SEMARNAT) and National Institute of Ecology (Instituto Nacional de Ecología-INE) (North American national emissions inventories); TNO (European emissions processing); ECMWF/MACC project & Météo-France/CNRM-GAME (Chemical boundary conditions).

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