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Air quality impacts of distributed power generation in the South Coast Air Basin of California 2: Model uncertainty and sensitivity analysis

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Abstract

Uncertainty and sensitivity of ozone and $PM_{2.5}$ aerosol to variations in selected input parameters are investigated with a Monte Carlo methodology using a three-dimensional air quality model. The selection of input parameters is based on their potential to affect concentration levels of ozone and $PM_{2.5}$ predicted by the model and to reflect changes in emissions due to the implementation of distributed generation (DG) in the South Coast Air Basin (SoCAB) of California. Numerical simulations are performed with the CIT air quality model. Response of the CIT predictions to the variation of selected input parameters is investigated to separate the potential air quality impacts of DG from model uncertainty. This study provides a measure of the model errors for selected species concentrations. A spatial sensitivity analysis is used to investigate the effect of placing DG in specific regions of the SoCAB. In general, results show that confidence in the model results is greatest in locations where ozone and $PM_{2.5}$ concentrations are the highest. Changes no greater than 80% in the nominal values of selected input variables, cause changes of 18% in ozone mixing ratios and 25% for $PM_{2.5}$ aerosol concentrations. Sensitivity analysis reveals that nitrogen oxides (NO_x) emissions and side boundary conditions of volatile organic compounds (VOC) are the major contributors to uncertainty and sensitivity of ozone predictions. An increase in NO_x emissions leads to reductions in ozone mixing ratios at peak times and sites where the maximum values are located. $PM_{2.5}$ aerosol is most sensitive to changes in NH_3 and NO_x emissions. Increasing these emissions leads to higher aerosol concentrations. Sensitivity analyses show that the impacts of DG implementation are highly dependent on both space and time. In particular, ozone concentrations are reduced during the nighttime nearby locations where DGs are installed. However, during the daytime ozone concentrations increase downwind from the sources. A major finding of this study is that the emissions of DG installed in coastal areas produce a significant impact on the production of ozone and $PM_{2.5}$ aerosol in the eastern regions of the SoCAB.

Keywords: Distributed power generation; Uncertainty and sensitivity analysis; Monte Carlo analysis; Spatial sensitivity

1. Introduction

Distributed energy resources (DER) have the potential to provide a considerable portion of the

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increased power demands in California and elsewhere. California is one of the first regions in the world to reorganize its electric power industry, becoming one of the first places where widespread adoption of DER is expected. The use of these distributed generation (DG) resources results in multiple stationary power generators spatially distributed throughout an urban basin, whereas new central-generation sources are typically placed outside the basin. DG implementation may result in significantly different emissions profiles with increased and widely dispersed stationary sources. Therefore, it is important to determine any adverse effects on the air quality of urban centers that may result from additional DG pollutant emissions. Rodriguez et al. (2006) examined the impacts of DG implementation on the air quality of the South Coast Air Basin of California (SoCAB). This study, however, left some outstanding questions unanswered. Namely, are the observed impacts greater than the numerical uncertainties of the model? Are those impacts real? How uncertainties in the input variables that represent DG implementation scenarios will affect the model predictions? Which of these variables are responsible for most of the model uncertainty? How will the placement of DG emissions in specific locations throughout the basin affect the model results?

Russell and Dennis (2000) found that numerical predictions of mathematical models are subjected to various sources of uncertainty. For instance, emissions inventories usually represent the largest uncertainties associated with output concentrations in three-dimensional urban models (Griffin et al., 2002a). Different approaches have been used to evaluate the uncertainty of air quality models (Yang et al., 1997; Hanna et al., 1998, 2001; Moore and Londergan, 2001; Hanna and Davis, 2002; Vardoulakis et al., 2002; Hakami et al., 2003; Sax and Isakov, 2003). Also, Monte Carlo analyses have been used extensively in regional-scale gas-phase mechanisms to address uncertainty assessment (Derwent and Hov, 1988; Gao et al., 1996; Phenix et al., 1998; Bergin et al., 1999; Grenfell et al., 1999; Hanna et al., 2001; Vuilleumier et al., 2001).

This manuscript presents the first study in which unique aspects are considered to include the impacts of DG implementation in the uncertainty and sensitivity analysis of a three-dimensional air quality model. This work examines the response of specific air quality model predictions in order to separate the DG air quality impacts from model uncertainties. It also provides a measure of the error bounds for simulated concentrations of ozone and particulate matter less than 2.5 μm ($PM_{2.5}$). However, the most innovative contributions are the characterization of the spatial variation of the model's errors to determine those areas in the SoCAB where the predictions display the largest uncertainties and the systematic development of scenarios for a thorough spatial sensitivity analysis that investigates the effects of placing DG in specific regions of the SoCAB.

2. Description

Sensitivity results presented in this study are based on the baseline emissions inventory described in Rodriguez et al. (2006). A base line scenario is established with this inventory that accounts for the increase in population by the year 2010. Additionally, an improved model is used in the present work. For instance, the current CIT model incorporates the Caltech atmospheric chemistry mechanism (CACM) (Griffin et al., 2002a,b; 2003; Pun et al., 2002), a detailed atmospheric chemical mechanism that explicitly predicts the formation of semi-volatile products with the potential to be constituents of secondary organic aerosol (SOA). The current study is motivated by the potential air quality effects of DG implementation by the year 2010. After performing various model evaluations, statistical analysis methods are used to identify the input parameters with the largest effect on both, concentrations of selected key species and their associated variance. This section describes the chosen statistical sampling, the multiple regression methodology used to estimate the sensitivity coefficients, and the corresponding uncertainty assessment for the simulation conditions established.

2.1. Latin hypercube sampling

Monte Carlo methods examine the changes in the model's output (species mixing ratios) when a preselected set of input parameters varies by repeated sampling from an assumed joint probability distribution. The probability distribution of species mixing ratios along with the mean and other relevant statistics are evaluated from each sample of model output. Monte Carlo analyses using simple random sampling yield reasonable estimates for probability distributions if the sample size is large. However, a large number of sampled cases are