Atmospheric Environment 45 (2011) 3424–3433

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

An assessment of Aviation's contribution to current and future fine particulate matter in the United States

Matthew Woody [a,b], Bok Haeng Baek [a], Zachariah Adelman [a], Mohammed Omary [a], Yun Fat Lam [c], J. Jason West [b], Saravanan Arunachalam [a,*]

[a] Institute for the Environment, University of North Carolina at Chapel Hill, Chapel Hill, NC 27599, USA
[b] Department of Environmental Sciences and Engineering, Gillings School of Global Public Health, University of North Carolina at Chapel Hill, NC 27599, USA
[c] Department of Civil and Environmental Engineering, University of Tennessee at Knoxville, Knoxville, TN 37996, USA

ARTICLE INFO

Article history:
Received 4 November 2010
Received in revised form
15 March 2011
Accepted 21 March 2011

Keywords:
Aviation emissions
$PM_{2.5}$
CMAQ
NextGen
Inorganic $PM_{2.5}$ change
Free ammonia

ABSTRACT

The impacts of aviation emissions on current and future year fine particulate matter ($PM_{2.5}$) were investigated using the Community Multiscale Air Quality model, accounting for aviation emissions from 99 airports and below 3 km during landing and takeoff (LTO) cycles. Results indicated that current year aviation emissions increased annual average $PM_{2.5}$ concentrations by 3.2 ng m^{-3} (0.05%) in the continental U.S. while projected 2025 aviation emissions increased annual average $PM_{2.5}$ by 11.2 ng m^{-3} (0.20%). Ammonium nitrate aerosol was the largest contributor to the increase in $PM_{2.5}$ concentrations, particularly in the future year. Using an indicator of inorganic $PM_{2.5}$ change, we attributed ammonium nitrate aerosol contributions in both years to excess free ammonia (8% higher NH_3 and 35% lower NO_x emissions from non-aviation sources in 2025 than 2005), and higher aircraft emissions of NO_x (which when converted to HNO_3 forms ammonium nitrate aerosol) than SO_2 (a precursor of ammonium sulfate aerosol). Our findings highlight the critical role that non-aviation emissions play in assessing the air quality impacts of aviation emissions in a future year scenario.

1. Introduction

Aviation is a vital component of the U.S.'s infrastructure, transporting on average 2.1 million passengers and 190,500 metric tons of freight daily (Federal Aviation Administration, 2009). Furthermore, the U.S. aviation sector continues to grow and the Federal Aviation Administration (FAA) projects U.S. passenger enplanements to increase 2.5% annually between 2011 and 2030, with 1 billion passengers expected to fly in 2023 (FAA, 2010a). While important economically, aircraft activities are of environmental concern for air quality due to emissions of CO, NO_x, Volatile Organic Compounds (VOCs), SO_x, $PM_{2.5}$ (fine particulate matter less than 2.5 μm in diameter), and numerous hazardous air pollutants (HAPS). Considering projected growth and environmental concerns, it is critical to understand the effects of aircraft on air quality from both an environmental and public health perspective. Here we present an investigation of the simulated impacts of aviation emissions on current (2005) and future year (2025) surface air quality, using the Community Multiscale Air Quality (CMAQ) model with the goal of quantifying the contribution of aviation emissions on ambient $PM_{2.5}$ concentrations.

$PM_{2.5}$ is one of six criteria air pollutants regulated by the U.S. Environmental Protection Agency (EPA) under the National Ambient Air Quality Standards (NAAQS) section of the Clean Air Act (Federal Register, 1997). It has been linked to adverse health effects, decreasing life expectancy by irritating the cardiovascular and respiratory systems due to its small size and ability to penetrate deep into the lungs (McMurry et al., 2004). The EPA has set annual average and 24-hour average primary standards for $PM_{2.5}$ of 15.0 μg m^{-3} and 35.0 μg m^{-3}, respectively, as a means of protecting public health. Here, we quantify the contribution of aircraft emissions to annual $PM_{2.5}$ concentrations because the annual average standard is seen as more restrictive.

Numerous recent studies have attempted to better quantify and characterize aircraft emissions (Wood et al., 2008; Timko et al., 2010a, 2010b) as well as the impacts of LTO aircraft emissions on local air quality (Unal et al., 2005; Hu et al., 2009). Ratliff et al. (2009) investigated the impacts of 2005 aircraft emissions below 1 km on $PM_{2.5}$ and ozone concentrations in U.S. NAAQS non-attainment areas. Results indicated aircraft emissions increased annual average wet $PM_{2.5}$ post processed using the Speciated Modeled Attainment Test

* Corresponding author. Institute for the Environment, University of North Carolina at Chapel Hill, 137 E. Franklin Street, #656, Chapel Hill, NC 27599-6116, USA. Tel.: +919 966 2126; fax: +919 843 3113.
E-mail address: sarav@email.unc.edu (S. Arunachalam).

1352-2310/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.atmosenv.2011.03.041

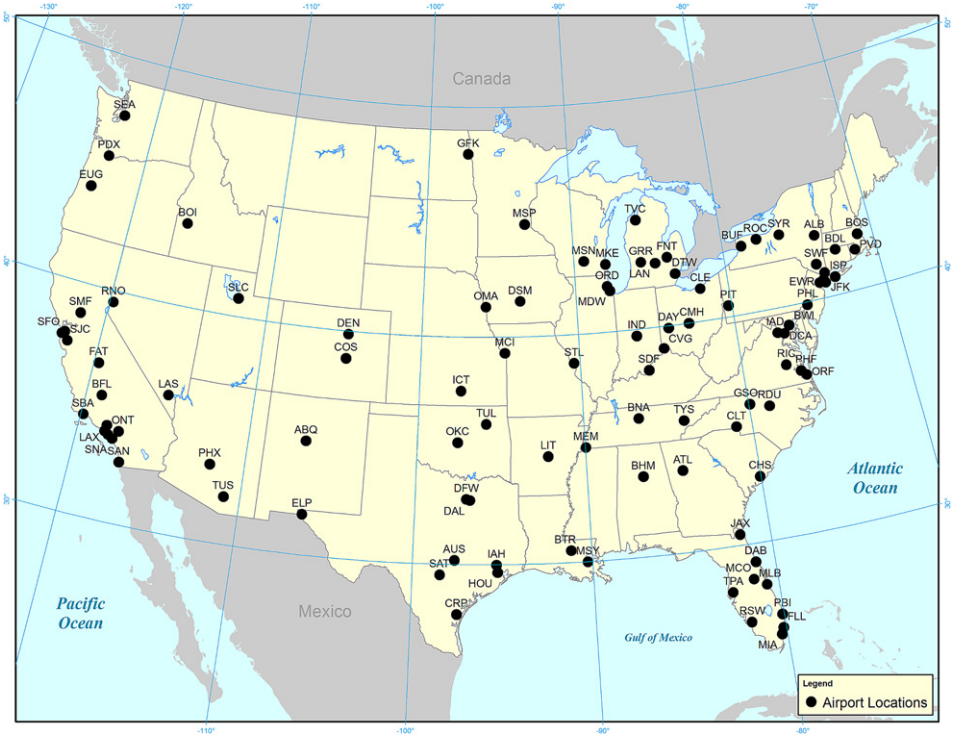

Fig. 1. Modeling domain and 99 airports modeled.

(SMAT) (EPA, 2007a) and maximum 8-hour average ozone concentrations by 10 ng m^{-3} and 0.11 ppb, respectively, although the increase in ozone concentrations was not uniform as aircraft emissions decreased concentrations in some areas. A similar study by Arunachalam et al. (2008, 2011) focused on the Atlanta Hartsfield (ATL), Chicago O'Hare (ORD), and Providence T.F. Green (PVD) airports using a multiscale (36-km, 12-km, and 4-km) modeling approach. There, the EDMS2Inv tool (Baek et al., 2007) was developed and implemented as an interface to process aviation emissions from the FAA's Emissions and Dispersion Modeling System (EDMS) (Federal Register, 1998) and through the Sparse Matrix Operator Kernel Emissions (SMOKE) model (Houyoux et al., 2000) to provide a three-dimensional representation of aircraft emissions. Aircraft emissions were based on landing and takeoff (LTO) cycles, which include startup, taxiing, queuing, takeoff, climb-out, and approach, and account for emissions below 3 km. Results indicated aircraft emissions increased total $PM_{2.5}$ contributions overall both at and downwind of the three airports considered. While the concentrations of most $PM_{2.5}$ species increased in the immediate vicinity of the airport, nitrate and secondary organic aerosol (SOA) concentrations decreased near the airports but increased downwind of them. The reduction in SOA concentrations was attributable to aircraft NO_x emissions reacting with and removing free radicals from the total radical budget thereby lowering the amount available to oxidize SOA precursors.

This study aims to model contributions of aircraft emissions to ground level $PM_{2.5}$ in the continental U.S. in a current and future year. We use a similar approach to that of Arunachalam et al. (2008, 2011) to quantify the emissions of aircraft below 3 km but expand from localized impacts at three airports to national impacts by including emissions from 99 major U.S. airports in 2005 and 2025. We simulated the impacts of aircraft emissions on current year $PM_{2.5}$ concentrations, determined how the impacts may change in a future year, and compared contributions from changes in non-aviation and aviation emissions in both years.

2. Methodology

2.1. Model and non-aviation emissions description

The Pennsylvania State University/NCAR mesoscale v3.7 model (MM5) (Grell et al., 1994), SMOKE v2.5 model, and CMAQ (Byun and Ching, 1999) v4.6 model, which includes the ISORROPIA v1.7 thermodynamic equilibrium model (Nenes et al., 1998) for inorganic particulate matter, were used to estimate the effects of aircraft emissions on surface air quality within the continental U.S. (Fig. 1). Particulate matter is treated as the sum of three modes – Aitken (diameters up to approximately 0.1 microns for the mass distribution), accumulation (mass distribution in the range of 0.1–2.5 microns) and coarse (particles of size 2.5–10 microns). Additional details on the treatment of particulate matter in CMAQ is described elsewhere (Binkowski and Roselle, 2003). The focus for this study is on all speciated components of dry PM (ammonium nitrate [NH_4NO_3], ammonium sulfate [$(NH_4)_2SO_4$], elemental carbon (AEC), primary organic (POA), SOA, and "other" aerosols (A25)) in the Aitken and accumulation mode. The post-processing of CMAQ results to compute ammonium nitrate and ammonium sulfate is based upon Arunachalam et al. (2011). The treatment of HAPS in CMAQ was also included for this application, but the results are not presented here. Five annual simulations were performed at a 36-km horizontal grid resolution with 21 vertical layers (Table 1). Meteorological inputs based on 2005 conditions were held constant across all model scenarios. Initial and boundary conditions (IC/BCs) for current and future years were based on output generated by the Goddard Earth Observing System-CHEMistry (GEOS-Chem) global model (Bey et al., 2001; Lam and Fu, 2010). In the absence of 2025 specific GEOS-Chem simulations, IC/BCs from 2000 to 2050 simulations based on the Intergovernmental Panel on Climate Change's A1B emission scenario were interpolated to obtain 2025 IC/BC concentrations (Lam et al., 2011). Current year base case (base05) emissions were estimated using the EPA's 2005 National Emissions Inventory (NEI) (EPA, 2007b) and excluding NEI reported commercial