Available online at www.sciencedirect.com
ScienceDirect
Atmospheric Environment 42 (2008) 3218–3237
ATMOSPHERIC ENVIRONMENT
www.elsevier.com/locate/atmosenv

Modeling agricultural air quality: Current status, major challenges, and outlook

Yang Zhang[a,*], Shiang-Yuh Wu[b,c], Srinath Krishnan[a], Kai Wang[a], Ashley Queen[a], Viney P. Aneja[a], S. Pal Arya[a]

[a]Department of Marine, Earth and Atmospheric Sciences, North Carolina State University, Raleigh, NC 27695-8208, USA
[b]Department of Environmental Quality, Richmond, VA 23240, USA
[c]Clarke County, Nevada Department of Air Quality and Environmental Quality, Las Vegas, NV 89155, USA

Received 19 September 2006; accepted 31 January 2007

Abstract

Agricultural air quality is an important emerging area of atmospheric sciences that represents significant challenges in many aspects of research including measurements, modeling, regulations, emission control, and operation managements. This work presents a review of current status, major challenges, and future research needs and opportunities of several important aspects of agricultural air quality modeling including chemical species, concentration and deposition measurements for model verification, emission inventories, major physical and chemical processes, model application and evaluation, and policy implications.

Keywords: Agriculture; Air quality; Ammonia; Reduced nitrogen; 3-D modeling

1. Introduction

Air quality research in the past half century focuses largely on criteria pollutants such as nitrogen oxides (NO_x), sulfur dioxide (SO_2), ozone (O_3), and particulate matter with an aerodynamic diameter equal or less than 2.5 μm ($PM_{2.5}$). Limited attention has been given to non-criteria air pollutants such as reduced nitrogen- and sulfur-containing compounds from agricultural sources (e.g., ammonia (NH_3), hydrogen sulfide (H_2S), nitrous oxide (N_2O)) that may play important roles in the formation of tropospheric O_3, SO_2, acids, and $PM_{2.5}$, and the eutrophication of the ecosystems. Agriculture provides a major source of those nitrogen- and sulfur-containing compounds (e.g., livestock, fertilizer, soils, and biomass burning). For example, 90% of the atmospheric NH_3 emission results from animal production and emissions from slurries and manures in the US (Davison and Cape, 2003) and many European countries (Van Der Hoek, 1998; Hutchings et al., 2001; Sotiropoulou et al., 2004). Growing evidence has shown that the increased size and geographical concentration of animal-feeding operations (AFOs) and agricultural crop production are increasing the emissions of odor (e.g., organic acids) and trace gases (e.g., carbon dioxide (CO_2), methane (CH_4), NO_x, NH_3,

*Corresponding author. Tel.: +1 919 515 9688; fax: +1 919 515 7802.
E-mail address: yang_zhang@ncsu.edu (Y. Zhang).

1352-2310/$ - see front matter
doi:10.1016/j.atmosenv.2007.01.063

and H_2S) to the atmosphere (e.g., NRC, 2003; Aneja et al., 2006). Increases in the emissions of those agriculturally emitted compounds in the US and abroad and their adverse impacts on the quality of the air, water, soil, the biodiversity, and the entire agro-ecosystem have raised growing public and regulatory concerns. For example, atmospheric nitrogen deposition has been considered to be one of the top three causes for global biodiversity loss in this century following land use and climate change (Sala et al., 2000); and it will post serious threat to biodiversity (Phoenix et al., 2006) and ecosystem (Sanderson et al., 2006). In addition, NH_3 likely plays an increased role in $PM_{2.5}$ formation as the emissions of sulfur oxides (SO_x) and NO_x are reduced in the coming years and the promulgation of a more stringent 24-h average National Ambient Air Quality Standard (NAAQS) of $35\,\mu g\,m^{-3}$ by the US EPA for $PM_{2.5}$. Recognizing the growing needs in this research area, a number of governmental agencies such as the US Department of Agriculture (USDA), the National Science Foundation (NSF), the US Environmental Protection Agency (EPA), the North Carolina Division of Air Quality (NCDAQ) and several universities and research organizations such as the North Carolina State University (NCSU), Duke University, Purdue University, the Air and Waste management Association (A&WMA), and the Ecological Society of America co-sponsored the first workshop on agricultural air quality (WAAQ) in the US during June 3–8, 2006 to synthesize existing measurements and modeling results and identify emerging research needs for agricultural air quality (AAQ) (http://www.esa.org/AirWorkshop). As indicated at the WAAQ by the keynote speaker, Dr. Ralph Cicerone, the president of the US National Academy of Sciences, the research on agricultural air quality in the US is much behind compared with countries in Europe such as the Netherlands, Denmark, the UK, Scotland, and Spain.

Air quality models (AQMs) accounting for emissions, transport, transformation, and removal of air pollutants provide a powerful tool to simulate the fate, distributions, and impact of agriculturally emitted air pollutants. National Research Council has clearly identified a need for three-dimensional (3-D) transport/transformation models in providing scientific basis for the development of relevant mitigation strategies (NRC, 2003). In this paper, current status and major challenges associated with AAQ modeling are reviewed. The deficiencies and uncertainties in current AQMs, model inputs, and measurements will be indicated along with recommendations regarding potential model improvements and data needs. Finally, the important implications of results from 3-D AQMs in developing relevant regulations and control strategies for agricultural air quality as well as future research opportunities for studying agriculture-related pollutants and their impacts on air quality, human health, and regional climate will be discussed.

2. Current status

The development of feasible regulations of air emissions from AFOs requires a scientific basis that is currently lacking due largely to inadequate funding from governmental agencies, little attention from scientific communities for AAQ research, and the fact that many producers do not want to report emissions from their operations because of the potential for increased scrutiny. The National Air Emissions Monitoring Study (NAEMS) has recently been established to measure emissions from all major types of AFOs including broiler systems, dairy farms, and swine/poultry houses and related manure storage facilities. Knowledge gaps and critical needs for agricultural air quality research have been recently identified by National Research Council (NRC, 2003) and the USDA Agricultural Air Quality Task Force (http://www.airquality.nrcs.usda.gov/AAQTF/). Significant uncertainties lie in nearly all aspects of research including the sparseness of monitoring stations and observational data of emissions, concentrations, and deposition fluxes, the lack of accurate emission inventories and reliable measurement methodologies, poorly-quantified health-effect associated with the AFOs-emitted species, and the needs for process-based emissions models and 3-D transport/transformation models to support regulation and policy-making.

2.1. Species of concern

Many species can be emitted from confined animal feeding operations and burning of crop residue (Aneja et al., 2006). Table 1 lists some major agriculturally-relevant reduced nitrogen and sulfur species that should be considered in AAQ modeling along with their reaction constants and lifetimes against oxidation reactions by the hydroxyl radical (OH). NH_3 is a major basic gas in the atmosphere and plays an important role in neutralizing acids.