Sep 15, 2014

FINAL REPORT

Title: Assessment of the Indirect and Semi-Direct Aerosol Effects During ISDAC Through Integrated Observational and Modeling Studies

Project ID: 0015141

Award Register#: ER64773

Program Manager: Ashley D. Williamson

Submitted by: P.I. Zafer Boybeyi

Associate Professor
Department of Atmospheric, Oceanic, and Earth Sciences
College of Science
George Mason University, Fairfax, VA

1. Introduction

The Department of Energy (DOE) awarded George Mason University (GMU) with a research project. This project started on June, 2009 and ended July 2014. Main objectives of this research project are; a) to assess the indirect and semi-direct aerosol effects on microphysical structure and radiative properties of Arctic clouds, b) to assess the impact of feedback between the aerosol-cloud interactions and atmospheric boundary layer (ABL) processes on the surface energy balance, c) to better understand and characterize the important unresolved microphysical processes, aerosol effects, and ABL processes and feedbacks, over meso-γ spatial (~1-2 km) and temporal scales (a few minutes to days), and d) to investigate the scale dependency of microphysical parameterizations and its effect on simulations.

Towards these goals, we have been using measurements from ISDAC field campaign, measurements from the extended ARM-SGP sites, and coupled Weather, Research, and Forecasting – Chemistry (WRF/CHEM) modeling system for an integrated observational and modeling study.

This project has provided research topic for two Ph.D. students at GMU to create educated professionals who have the requisite training to support the future climate research. Two greaduate students (Mrs Roy and Mr. Stofferhan) have been studying aerosol effects over the

CONUS and Alaska regions using WRF-Chem model under supervision of Dr. Boybeyi. A postdoc (Dr. John Lindeman) has also worked on this project.

Dr. Lindeman published a journal article in Journal of Geophysical Research, Mrs. Roy has completed her Ph.D. research and graduated in Fall 2011. Currently, Mr. Stofferahn is actively working on this project pursuing his Ph.D. research on semi-direct and indirect aerosol effects on cloud physics. It is expected that Mr. Stofferahn will graduate in 2014. It is also expected that he will produce two journal articles from his Ph.D. research. In addition, several conference presentations and abstracts are produced from this project. For example, one of these conference papers presented by Mrs. Roy at the 91st Annual American Meteorological Society (AMS) Meeting, 23-27 January, Seattle, WA received the best student poster award (cf., the list publications below).

2. Summary of Major Findings

Numerical simulations are employed to supplement the ISDAC field experiment data. In particular, aerosol effects are studied by comparing the WRF/CHEM simulations (with aerosols) to baseline WRF simulations (without aerosols) to obtain a better understanding of the direct, semi-direct, and indirect effects of aerosol species on the surface energy balance. Many different aerosol species such as black carbon, sulfates and different size regimes can be represented in WRF/CHEM. ISDAC field experiment and ARM data from Barrow and Atqasuk, Alaska are employed for model validation. Two case studies from the ISDAC field experiment time frame are examined closely: a 7-8 April, 2008 'clean' atmospheric environment study, and a 'polluted' case study lasting from 16-21 April, 2008.

Numerical simulations have been examined for the clean case using WRF/CHEM with background aerosol concentrations representative of northern hemispheric, mid-latitude clean environment conditions. WRF/CHEM and the baseline WRF model results compare favorably to ARM surface observations and sonde data. The WRF/CHEM simulations show only small differences when compared to the baseline WRF simulations. These results indicated that aerosols play an important role in cloud/radiative/precipitation processes. These results also indicated aerosols have a significant impact on the surface energy balance.

Later the semidirect aerosol effect is examined separately during a polluted episode of the Indirect and Semi-Direct Aerosol Campaign (ISDAC) with the use of WRF/Chem model. The results of this study have been published (Lindeman et al., 2011). The WRF/Chem model was initialized with chemical and aerosol reanalysis data from a global chemistry model to simulate a polluted event over Alaska on 18-21 April. WRF/CHEM and WRF comparisons show that the atmosphere is sensitive to changes the black carbon concentration, even though it comprises only a small fraction (less than 1 percent) of the total aerosol mass. When compared to a corresponding meteorology-only simulation, the atmosphere at 850 hPa warms by 0.2 K in regions where black carbon is concentrated. A sensitivity test where the initial distribution of black carbon is doubled leads to an additional 0.1 K of heating. When black carbon is zeroed-out initially, the heating is much reduced. The simulations also show that vertical profiles of the black carbon concentration at Barrow, Alaska vary considerably with altitude and simulation time. The amount of warming also varies considerably, with some individual altitudes warming by as much as 0.3 K for certain times. The lower tropospheric heating increases the stability of the boundary layer, and causes a redistribution and a reduction in the liquid water content of around 0.004 km m^{-2} in the daylight hours. A doubling of black carbon leads to further reductions in the cloud optical thickness and liquid water content. The cloud redistribution also affects the amount of shortwave radiation and surface temperature at Barrow. A series of numerical sensitivity tests are also conducted to allow for better quantification of the aerosol effects. The results show that the differences between WRF/CHEM and the baseline WRF simulations are greater in polluted cases than in clean cases.

The effect of anthropogenic aerosols on the radiation, cloud, and precipitation processes over the *CONUS* region is also being studied using WRF/CHEM model. Mesoscale Convective System (MCS) are frequent occurrences during summer months in mid-west USA and bring almost 30% rainfall to the region. This work investigates the effects of anthropogenic aerosols, like sulfate and black carbon, and natural aerosols like dust on a MCS. The coupled meteorology and chemistry Weather Research and Forecasting– Chemistry (WRF–Chem) version 3.1.1 model was employed for the numerical study of the MCS. The selected MCS occurred on June 20, 2007 covering large parts of Kansas, Oklahoma and northern Texas. The aerosol effects are analyzed by inputing the aerosol optical properties into the shortwave scheme and physical properties into the microphysics scheme. The interaction of aerosols with the incoming shortwave radiation is higher due to the wavelength being similar to particulate sizes found in the atmosphere. The spatial resolution which resolves the features of the MCS reliably well was found by conducting sensitivity studies at coarse and fine resolution. At the coarse resolution (18 km) the MCS was not very well resolved, with delays in cloud and precipitation. However, the direct and indirect effects of anthropogenic aerosols were prominent, by showing large scale scattering of the shortwave radiation and by suppressing the precipitation, respectively. The nested domain simulations have higher inner domain resolutions (6 and 1.5 km) and as a result resolved the MCS better than the single coarse resolution simulation. The combined aerosol effects are investigated by increasing the amount of the sulfate, black carbon and dust aerosols, and considering their dominant characteristics. Sulfates are the major constituents of the anthropogenic emissions, and they are scattering and reflecting in nature. On the other hand, black carbon and dust absorb radiation, evaporating clouds and also warming the atmosphere. The dust particulates form giant cloud condensation nuclei (CCN), which can enhance precipitation in the presence of moisture in the atmosphere. The combination of the radiative effects due to each of these aerosols have shown, that scattering due to aerosols is a dominant factor for all the types of aerosols. The presence of aerosols interacting with the microphysics and radiation schemes produces a more organized MCS structure, as well as more liquid and ice clouds. The black carbon particulates do not solely warm the atmosphere, but also prevent a large amount of the solar radiation from reaching the surface. The giant CCN due to dust particles instead of suppressing the precipitation, enhances it.

3. Publications, Presentations & Dissertations

3.1) Journals

Lindeman, J., Z. Boybeyi & I. Gultepe (2011): An Examination of the aerosol semi-direct effect for a polluted case of the ISDAC field campaign. *J. Geophysical Research*, Vol. 116, 15 pp, doi:10. 1029/2011JDO15649.

3.2) Conferences/Presentations

Stofferahn E. & Z. Boybeyi (2014): A Study of the semi-direct and indirect aerosol effects on the Arctic region during the ISDAC campaign using WRF-CHEM. American Meteorological Society Annual Meeting, February 2-6, Atlanta, Georgia.

Stofferahn E. & Z. Boybeyi (2013): A Study of the semi-direct and indirect aerosol effects on the Arctic region during the ISDAC campaign using WRF-CHEM. The 2013 Science Team Meeting will be March 18-21, Potomac, MD.

Boybeyi Z. & P Roy (2012): A Numerical Investigation of the Aerosol Effects on a Mesoscale Convective System. Presented at 3rd Atmospheric System Research (ASR) Science Team Meeting. Arlington, VA.

Stofferahn E. & Z. Boybeyi (2012). A Study of the Semi-Direct and Indirect Aerosol Effects on the Arctic Region during the ISDAC Campaign Using WRF-CHEM. Presented at Fall American Geophysical Union Meeting, San Francisco, CA.

Boybeyi Z. (2011): WRF/Chem simulations of aerosol transport and dispersion for the ISDAC field campaign. DOE Atmospheric System Research (ASR) Science Meeting, September 12-16, Annapolis, Maryland.

Lindeman J. & Boybeyi Z., (2011): Aerosol Semi-Direct effect on surface energy balance. 15th Annual George Mason University Transport and Dispersion Modeling Workshop. July 12-14, Fairfax, Virginia.

Roy P. & Z. Boybeyi (2011): Numerical Study of the Impact of Aerosol-Could Interactions during Mesoscale Convective. 91st Annual AMS Meeting, 23-27 January, Seattle, WA.

Boybeyi Z., J. Lindeman, P. Roy, E. Stofferhan & I. Gultepe (2010): WRF/Chem simulations of aerosol transport and dispersion for the ISDAC field campaign. DOE Atmospheric System Research (ASR) Science Meeting, October 11-15, Boulder, Colorado.

Boybeyi Z., J. Lindeman, Eric Stofferahn, Priyanka Roy & I. Gultepe (2010): Numerical Studies of Aerosol Effects During the ISDAC Experiment. First Science Team Meeting of the Atmospheric System Research (ASR) Meeting. March 15-19, Bethesda, Maryland.

Roy P. & Boybeyi Z., (2010): A Numerical Study of Aerosol-Cloud Interaction Over CONUS Area During a Deep Convective Episode. First Science Team Meeting of the Atmospheric System Research (ASR) Meeting. March 15-19, Bethesda, Maryland.

Lindeman J. & Boybeyi Z., (2010): Effects of Black Carbon Concentration on the Surface Energy Budget. First Science Team Meeting of the Atmospheric System Research (ASR) Meeting. March 15-19, Bethesda, Maryland.

Boybeyi, Z., J. Lindeman, P. Roy, I. Gultepe and N. Shantz, March 2010: Studying Aerosol-cloud Interaction by Solution Adaptive Modeling Technique, 1st Science Team Meeting of the Atmospheric System Research (ASR), U.S. Department of Energy climate research program, Bethesda, Maryland, USA.

Boybeyi Z., J. Lindeman & I. Gultepe (2009): A Preliminary Numerical Case Study: Impact of Aerosols on Surface Energy Budget During ISDAC Field Campaign. ARM CMWG & AWG Meeting. September 29-October 2, Boulder, Colorado.

3.3) Ph.D. Thesis

Priyanka Roy (2011): A Numerical Investigation of the Aerosol Effects on a Mesoscale Convective System. *A dissertationsubmitted to thegraduate facultyofGeorge Mason UniversityIn partial fulfillment ofthe requirements for the DegreeofDoctor of Philosophy Earth Science and Geoinformation Systems* **(completed).**

Eric Stofferhan (2013): Studying Aerosol Effects on Clouds & Radiation During ISDAC **(in-progress)**.