Project 022 Evaluation of FAA Climate Tools: APMT

University of Illinois at Urbana-Champaign

Project Lead Investigator

Dr. Donald Wuebbles (Dr. Robert Rauber has been acting as Principal Investigator while Dr. Wuebbles was on special assignment with the National Science Foundation and the Office of Science and Technology Policy of the Executive Office of the President; we are in process of changing Dr. Wuebbles back to being the PI)
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University Participants

University of Illinois at Urbana-Champaign
P.I.(s): Dr. Donald Wuebbles

- Period of Performance: October 16, 2016 to October 15, 2017
- Task(s):
    1. Evaluate version 23 of APMT
    2. Provide Feedback on plans for APMT version 24
    3. Using the CESM chemistry-climate model, update our earlier analyses of regional effects from aviation based on latitude bands and regions
    4. Evaluate the GTP concept for aviation that is being developed by the CICERO research team

Project Funding Level

Support from the FAA over this time period was $75,000 with an additional $75,000 in matching support, including about $10,000 from the University of Illinois, but also as in-kind support from Reading University.

Investigation Team

Dr. Donald Wuebbles: project oversight
Dr. Arezoo Khodayari (post doc; most recently on subcontract) and Jun Zhang (graduate student): analyses of APMT and 3-D atmospheric climate-chemistry modeling analyses

Project Overview

The primary objective of this project was to evaluate the capabilities of the APMT-I model, particularly the Climate module, to ensure this FAA policy analysis tool uses the current state of climate science. Regional climate impacts of aviation were also evaluated using the 3D atmospheric climate-chemistry model. Findings from these studies were reported at several meetings and in special reports to the FAA.

Task #1: APMT-I Climate Evaluation and Review of Requirements Document

University of Illinois at Urbana-Champaign

Objective(s)

In this project, we act as a resource to FAA for analyses relating to metrics and to model development and evaluation of FAA modeling tools and datasets, with special emphasis on testing the Aviation Environmental Portfolio Tool (APMT) model and the further development and evaluation of its climate component to ensure that the underlying physics of the model is addressed properly. A specific focus of this project is on analyses of zonal and regional effects of aviation on climate and testing the resulting incorporation of such effects within APMT. As such, we want to make sure the APMT linking of aviation emissions with climate impacts and the representation of the various components of the cause–effect chain (i.e., from emissions to climate effect) properly represents the state-of-the-science.

Research Approach

We have focused on (1) evaluating the climate component of the Aviation Environmental Portfolio Tool (APMT) for three main aspects of the model, mainly its treatment of the carbon cycle, short-lived species, and NOx-related impacts, (2) regional climate impacts from aviation using the 3D atmospheric climate-chemistry model. We also test the APMT model following the cause-effect chain from aviation emission to temperature change. The project evaluates the APMT components relative to state-of-the-art modeling that fully considers the physics and chemistry important to the various processes. Our aim is to ensure that the physics and chemistry underlying the treatments in APMT are addressed properly based on our and others published modeling studies.

Milestone(s)

Milestone	Milestone reached
Feedback on plans for APMT version 24	December 15, 2016
Getting started to evaluate the newly developed APMT version 24.	September 30, 2017

Major Accomplishments

Most relevant to this project is the feedback we provided on the plans for development of APMT version 24. Our aim is to ensure that the physics and chemistry underlying the treatments in APMT are addressed properly based on our and others published modeling studies. We recommend that the stratospheric water vapor induced by methane oxidation and nitrates induced by NOx emissions should be included in the model. For the carbon cycle, APMT should couple the impulse response functions (IRF) of atmosphere, ocean and biosphere presented in Joos et al (2013) instead of just using a linear atmospheric IRF. For energy balance model, feedbacks from ocean and temperature need to be considered to get more accurate simulated temperature change under different emission background scenarios. The nonlinearity impacts of the background atmosphere also needs to be taken into account. As a result of making these changes, APMT should be better able to link the various components of aviation emissions with climate impacts relative to the findings from ACCRI.

Publications

Zhang and Wuebbles, Evaluation of FAA Climate Tools: APMT. Report for the FAA, December 2016

Outreach Efforts

ASCENT Advisory Committee Meeting – April 18-19, 2017 (Presentation)
ASCENT Advisory Committee Meeting – September 26-27, 2017 (Presentation)
Bi-weekly meeting with project manager Daniel Jacob

Awards

None

Student Involvement

Graduate Student: Jun Zhang
Ms. Zhang is responsible for the analyses and modeling studies within the project, and leading the initial preparation of the project reports.

Plans for Next Period

Evaluate the new version of APMT (version 24). The following modules of APMT will be tested to evaluate the model performance:
1) the carbon cycle in APMT to simulate the aviation CO2 concentration on different background scenarios;
2) the energy balance model to calculate the temperature change induced by all aviation emissions;
3) the NOx-induced effects and how they are represented in APMT model.

Task #2: Three-Dimensional Atmospheric Climate-Chemistry Modeling Studies for Aviation Regional Effects on Climate

University of Illinois at Urbana-Champaign

Objective(s)

The aim in this work was to have a better understanding of the climate impacts from aviation emissions on a zonal and regional basis. Since the aviation emissions have significant spatial variability in the sign and magnitude of response, the strength of regional effects is highly likely hidden due to the global averaging of climate change. Thus, it is important to look at the impact of aviation emission on climate on a regional scale rather than global scale. We continued using a complex 3-D chemistry-climate model to further our understanding of the chemistry and climate effects from aviation emissions and to do our regional analysis and compare our results with the earlier findings. As part of this effort, we used CAM5-Chem, the atmospheric component of Community Earth System Model (CESM), and did a series of studies to evaluate aviation impact on climate both in 2006 and 2050.

Research Approach

In this study, the chemistry-climate model Community Atmosphere Model (CAM-chem5) is carried out to examine the regional climate effects based on 4 different latitude bands (90°S- 28°S, 28°S-28°N, 28°S-28°N, 60°N-90°N) and regions (contiguous United States, Europe and East Asia). We have completed the studies modeling of aviation effects on global atmospheric composition and on climate we did with FAA support that were published as FAA reports. We have derived the regional effects of NOx-induced species (short-lived O_3, CH_4, long-lived O_3 and stratospheric water vapor) and direct aerosols (black carbon and sulfates) under different latitude bands and regions using CESM.

Milestone(s)

Completed master thesis referenced below. Also made presentations of findings at ASCENT meetings.

Major Accomplishments

We have updated our earlier analyses of regional effects from aviation based emissions on latitude bands and regions using the CESM chemistry-climate model. The short-lived agents are more regionally important than the long-lived species. For NOx-induced effects (including O3-short, CH4, O3-long and Stratospheric water vapor), we found that the short-term O3 forcing is the major contributor to the overall net NOx-induced forcing from aviation. Although the global mean values of net NOx forcing can be very small, forcings over high latitudes in the Northern Hemisphere can be up to 140 mW/m^2 in the future scenarios (shown in Figure 1).

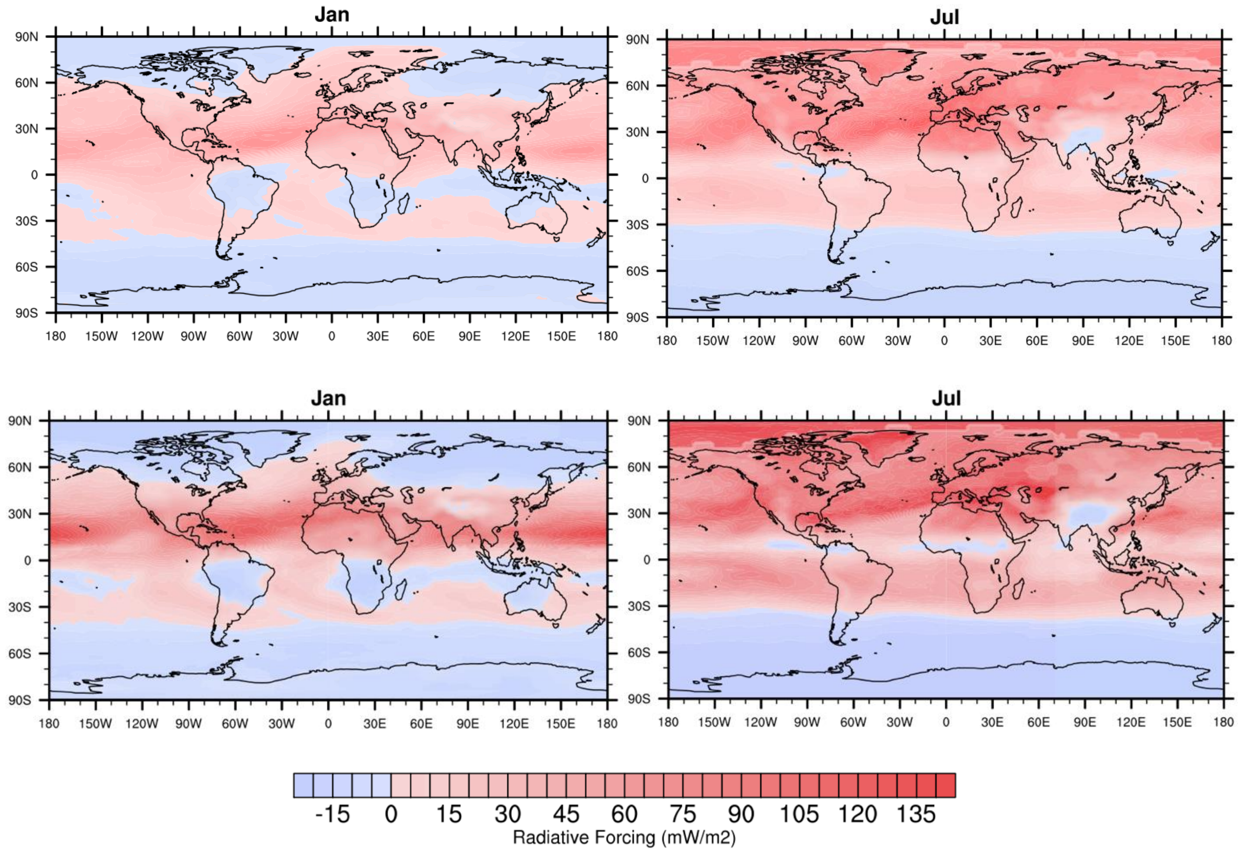

Figure 1. Simulated radiative forcing (mW/m²) for net radiative forcing (mW/m²) of aviation NOx emissions for January (left) and July (right). The present-day scenario (2006) is on the top panel and future scenario (2050 S1) is on the bottom. Blue bar indicates negative radiative forcing (cooling effect) while the red bar indicates positive radiative forcing (warming effect).

We also found that the radiative forcings of short-lived agents indicate a large hemispheric asymmetry. Radiative forcings are mainly distributed over the latitude band from 28°N – 60°N where most of aviation emission occurs (Table 1). The radiative forcings for short-lived agents over the United States, Europe and East Asia is approximately 4 times of its corresponding global values. The climate impact over the US has the most information loss and the forcing will be highly underestimated when looking at the climate impacts from aviation emissions using globally-averaged values and ignoring the regional heterogeneity (shown in Table 2).

This regional analysis suggests that the globally-averaged metrics are not able to capture the significant spatial variability induced by aviation emissions since global averaging will lead to cancellations between warming and cooling effects such that the strength of regional impacts is hidden. Thus, the climate impacts from aviation emissions could be much more intense over regional areas than over the globe.

Table 1. Radiative forcing (in mW/m^2) of short-lived species (O_3, BC and sulfates) over different latitude bands compared with global values for the present-day scenario (2006) and future scenarios (2050 S1 and 2050 S2).

2006 Radiative forcing (mW/m^2)	90°S-28°S	28°S-28°N	28°N-60°N	60°N-90°N	Global
O_3	12.6	27.5	67.1	45.6	37.3
BC	0.06	0.14	0.86	0.63	0.3
Sulfate	-1.15	-2.7	-11.37	-7.86	-4.4

2050 S1 Radiative forcing (mW/m^2)	90°S-28°S	28°S-28°N	28°N-60°N	60°N-90°N	Global
O_3	23.4	63.3	82.6	57.5	56.3
BC	0.15	0.22	1.80	1.37	0.6
Sulfate	-4.86	-6.88	-33.2	-25.51	-13

2050 S2 Radiative forcing (mW/m^2)	90°S-28°S	28°S-28°N	28°N-60°N	60°N-90°N	Global
O_3	23.7	65.4	87.2	61.1	58.3
BC	0.07	0.11	0.91	0.67	0.3
Sulfate	-	-	-	-	-

Table 2. As in Table 1, but for different subregions (United States, Europe and East Asia).

2006 Radiative forcing (mW/m²)	United States	Europe	East Asia	Global
O_3	69.5	68.5	52.7	37.3
BC	0.8	1.1	0.7	0.3
Sulfate	-12.0	-13.2	-8.5	-4.4

2050 S1 Radiative forcing (mW/m²)	United States	Europe	East Asia	Global
O_3	95	82.7	74.9	56.3
BC	1.6	2.3	1.1	0.6
Sulfate	-31.4	-39.4	-22.1	-13

2050 S1 Radiative forcing (mW/m²)	United States	Europe	East Asia	Global
O_3	99.5	87.7	78.4	58.5
BC	0.8	1.1	0.6	0.3
Sulfate	-	-	-	-

Publications

Zhang and Wuebbles, Evaluating the regional impact of aircraft emissions on climate and the capabilities of simplified climate model. Master's thesis, University of Illinois, July 2017

Outreach Efforts

Results presented at ASCENT meetings. Journal paper to be prepared.

Awards

None

Student Involvement
Graduate student Jun Zhang is responsible for the analyses and modeling studies within the project, and leading the initial preparation of the project reports.

Plans for Next Period
We will do more analysis of regional climate effects from aviation emissions toward completing these studies for publication. We want to explore the impact of global and regional aviation emissions on global-mean radiative forcing response and the regional radiative forcing response to global and regional aviation emissions. More chemistry-climate runs will be performed as part of this study if needed.