Project 022 Development and Evaluation of Climate Metrics for Aviation Based on Climate-Chemistry Modeling Analyses

University of Illinois at Urbana-Champaign

Project Lead Investigator

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FAA Award Number: 10-C-NE-UI amendment 007
Period of Performance: September 30, 2014 – September 30, 2015

Project Funding Level

$100K
$50k of in kind support from the University of Illinois

Investigation Team

Don Wuebbles, PI
Arezoo Khodayari, Postdoctoral Research Associate
Daniel Phoenix, Graduate Student

Project Overview

In this project, we will continue to 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.

Our primary efforts on the project to this point have been to further evaluate the much more complex 3-D chemistry-climate model to further our understanding of the chemistry and climate effects from aviation emissions. As part of this effort we have used CAM5Chem, the atmospheric component of Community Earth System Model (CESM) and did series of studies to evaluate aviation impact both on surface air quality in 2006 and on climate in 2050. These findings will be useful in our evaluation of the APMT model later this year.

Task and Research Approach

1. We have contributed to a report and a companion journal paper led by Andrew Gettleman investigating the effects of aviation cruise emissions on climate in 2050. The study found that a growth in the climate impact of aviation by 2050, including positive radiative forcing from contrails up to ~80mWm^{-2} and enhanced upper

tropospheric and lower stratospheric ozone (O3), due to nitrogen oxide (NOx) emissions of ~60mWm^{-2}. Changes in methane (CH4) forcing resulting from changes in the CH4 lifetime induced by aviation are estimated at -25mWm^{-2} in 2050.

2. We have also contributed to a report lead by Mark Jacobson investigating the effects of aviation cruise emissions on air quality. This study found that all models (Three-dimensional chemical-transport models (CTMs) and Climate Response Models (CRMs)) show increases in near-surface ozone (0.4 to 1.9% globally), perturbations in the Northern Hemisphere that are highest in winter (when ambient ozone levels are lower and potentially of not as much concern to human health compared to the higher ozone in the summer months). In the CTMs, the response was highest in high-altitude regions and large-scale subsidence regions, with maximum annual perturbations ranging from ~1.1 to 2.8 ppbv over the Tibetan Plateau. Horizontal transport of ozone and its precursors, rather than chemistry, is shown to dominate the surface ozone response. A similar response is seen in the CRMs. The study also found the contribution of aviation emissions to the increase in PM2.5 concentration near the surface and compared the response between CTMS and CRMs. Changes in surface-level PM2.5 in the CTMs (0.14 to 0.4%) and CRMs (-1.9 to 1.2%) may depend on highly-varying background aerosol fields among models and the inclusion of feedbacks between aircraft emissions and changes in meteorology. The CTMs tend to show an increase in surface PM2.5 primarily over high-traffic regions in the North American mid-latitudes. The CRMs, on the other hand, demonstrate the effects of changing meteorological fields and potential feedbacks on aviation emission impacts, and exhibit large perturbations over regions where natural emissions (e.g., soil dust and sea spray) are abundant. Excluding these emissions in the CRMs results in a smaller-in-magnitude surface change due to aviation.

3. We also evaluate the impact of using different year-to-year meteorological fields on derived changes in aviation induced ozone in CAM5Chem. CTM studies of human effects on the atmosphere, including those of aircraft, have typically employed a single representative year of atmospheric meteorology to drive the model (i.e simulations have been run in a specified dynamics mode). The current and likely near-future aircraft fleets operate mostly near the tropopause, a region sensitive to changes in dynamics that are likely among different years. We evaluated the variation in aviation induced ozone perturbations using CAM5Chem over eleven years of meteorological fields which represent eleven years of interannual variability. Meteorology to drive the model was supplied by eleven years of MERRA (Modern Era Retrospective-Analysis for Research and Applications) reanalysis for years 2000-2011. The aviation emissions used were obtained from the Aviation Environmental Design Tool (AEDT) for the year 2006.Results indicate a very little year to year variation (less than 10%) in the derived changes in aviation-induced ozone. This result led to the conclusion that aircraft effects modeling under a single meteorology year should suffice within current model uncertainties. It can be further concluded that aviation induced signals obtained in coupled simulations could not be entirely masked by the model interannual variability.

4. Our paper investigating the sensitivity of NOx emissions from lightning on aviation-induced ozone production has been submitted to Atmospheric Environment.

5. Our paper titled "Aviation NOx-induced CH_4 effect: Fixed mixing ratio boundary conditions versus flux boundary conditions" was published in Atmospheric Environment in May.

6. Our paper on aviation metrics is finally near completion. Don is working on it and will send to the other authors towards completing it.

7. We are preparing an individual paper that examines the global impacts of aviation non-LTO emissions on surface air quality for present day and mid-century (2050). Our results from the present day simulations show a northern hemisphere (NH) mean surface O_3 increase of 1.3 ppb (2.7% of the background) and a NH maximum surface PM 2.5 increase of 1.4 μg/m^3 in January. Mid-century simulations show slightly greater surface O_3 increases (mean of 1.9 ppb (4.2%) for both scenarios) and greater $PM_{2.5}$ increases (maximum of 3.5 μg/m^3 for SC1 and 2.2 μg/m^3 for Alt). We conclude that these perturbations do not significantly increase the frequency of extreme air quality events (increase is less than 1.5%), although they do contribute to the background concentrations of O_3 and $PM_{2.5}$, making it easier for urban areas to surpass these standards.

8. We are preparing a second individual paper on the evaluation of the aviation impact at mid-century with two fuel scenarios. Our results show that the impact of aviation on climate in mid-century shows a short-term O_3 radiative forcing (RF) of 62.1 mWm^{-2} for both mid-century scenarios, which while still quite small, is a 111% increase relative to present day simulations. The main differences between the two fuel scenarios are the SO_4^{2-} and black carbon (BC) direct radiative forcings. The SO_4^{2-} direct RF is -15.3 and -8.1 mWm^{-2} in SC1 and Alt, respectively while the BC direct RF is 1.1 and 0.5 mWm^{-2} in SC1 and Alt, respectively.

Milestone(s)

All the milestones have been reached.

Major Accomplishments

Evaluated the impact of aviation emissions on the surface air quality in 2006 and on climate in 2050 and contributed to 7 research papers that either have been published, submitted for publication or are in preparation phase.

Publications

Gettleman, A., M. Z. Jacobson, and D. J. Wuebbles, Climate forcing effects from 2050 Projected Aviation, FAA Report, submitted to FAA for review, 2015.

Gettleman, A., C.-C. Chen, M. Z. Jacobson, M. A. Cameron, D. J. Wuebbles, A. Khodayari, D. B. Phoenix, Climate effects from 2050 Projected Aviation Emissions, Atmos. Environ., submitted.

Jacobson, M. Z., S. R. H. Barrett, A. Gettleman, H. B. Selkirk, N. Unger, and D. J. Wuebbles, Surface Air Quality Effects of Cruise Emissions, FAA Report, submitted for review by FAA, 2015.

Khodayari, A., S. C. Olsen, D. J. Wuebbles, and D. B. Phoenix, Aviation NOx-induced CH4 effect: Fixed mixing ratio boundary conditions versus flux boundary conditions, Atmospheric Environment 113 (2015): 135-139.

Khodayari, A., D. B. Phoenix, and D. J. Wuebbles, Effect of NOx emissions from lightning on the production of aviation-induced ozone, J. Geophys. Res.-Atmos., submitted.

Phoenix, D. B., A. Khodayari, and D. J. Wuebbles, Aviation impact on air quality in present day and mid-century simulated in the community atmosphere model (CAM), in preparation to be submitted to Atmos. Chem and Phys.

Phoenix, D. B., A. Khodayari, and D. J. Wuebbles, Evaluation of Aviation Effects with Alternative Fuels on Climate in Mid-Century (2050) in the Community Atmosphere Model (CAM), in preparation to be submitted to Atmos. Environ.

Outreach Efforts

Dan Phoenix attended and gave presentations at the AEC Roadmap meeting in Washington DC on May 19-20, 2015.

Arezoo Khodayari gave seminars on our findings both at the University of Birmingham and Cambridge University in UK in Aug, 2015.

Don Wuebbles had numerous phone discussions with FAA leadership on project developments and related science issues.

Awards

None.

Student Involvement

Daniel Phoenix was the graduate student who has been involved in this project and contributed in all the analyses. He graduated this summer and moved to the University of Oklahoma to do his doctorate study.

Plans for Next Period

If there is funding the plan for the next phase would be to investigate the relationship between the CRMs and CTMs, chiefly in balancing an accurate representation of atmospheric processes with computational cost. Overall, aviation-induced perturbations to ground level ozone and PM2.5 in this study are found to occur globally, not only near airports, although primarily in the Northern Hemisphere. Global chemistry-climate models such as those used in this study are critical for further narrowing the estimated range of impacts of aircraft on surface ozone and PM2.5 and potentially, their effects on human health.