Project 020 Development of NAS-Wide and Global Rapid Aviation Air Quality Tools

Massachusetts Institute of Technology (MIT)

Project Lead Investigator

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University Participants

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- PI(s): Steven R. H. Barrett
- FAA Award Number: 13-C-AJFE-MIT, Amendment Nos. 007, 018, 025, 032, and 041
- Period of Performance: August 19, 2014, to August 31, 2020 (via no-cost extension)
- Tasks for current period (September 1, 2018, to August 31, 2020):
  No additional funding was provided for the project for this reporting period. The work therefore covers finalization of tasks from previous years only and was funded during the period September 1, 2018, to November 30, 2018:
  - Provide surface air quality analysis and quantify the effects of aviation on surface air quality
  - Continue work on development of nested domains and provide tool validation
  - Incorporate the nested domains into a single user-friendly framework
  - Support and assist the non-volatile particulate matter (nvPM) standard team on consistency checking of input data and interpreting results
  - Finalize and project uncertainty in ammonia emissions onto aviation impact sensitivities
  - Perform scoping of work for developing a multi-scale adjoint tool

Project Funding Level

$800,000 FAA funding + $50,000 Transport Canada funding = $850,000 total sponsored funds, of which only the FAA-funded portion requires matching funds. Sources of match are that same $50,000 Transport Canada funding (it constitutes both matching funds itself and sponsored funds that do not need to be matched), plus approximately $215,000 from MIT, and third-party in-kind contributions of $114,000 from Byogy Renewables Inc. and $421,000 from Oliver Wyman Group.

Investigation Team

- PI: Professor Steven Barrett, MIT: Tasks 1 and 2
- Co-PI: Dr. Raymond L. Speth, MIT: Task 2
- Co-investigator: Dr. Florian Allroggen, MIT: Task 2
- Research scientist: Dr. Sebastian Eastham, MIT: Tasks 1 and 2
- Postdoctoral associate: Dr. Irene Dedoussi, MIT: Tasks 1 and 2
- Graduate student: Guillaume Chossière, MIT: Task 1

Project Overview

The aim of this project is to develop tools that enable the rapid assessment of the health impacts of aviation emissions. The focus of the project is aviation-attributable particulate matter ≤2.5 μm ($PM_{2.5}$) and ozone on the National Airspace System

(NAS)-wide and global scales. These tools allow for rapid policy analysis and scenario comparison. The adjoint method on which these tools are based provides a computationally efficient way of calculating sensitivities of an objective function with respect to multiple model inputs. The project enhances existing tools in terms of the domains and impacts covered, and in terms of uncertainty quantification. The enhanced tools support the FAA in its strategic vision to reduce the health impacts of aviation emissions and allow for detailed and quantified policy analyses.

Project work for AY2018–2019 was covered under a no-cost extension. Therefore, the tasks that were listed for the previous period of performance (AY2017–2018) and that were worked on during the September 1, 2018, to November 30, 2018, period are reformulated as:

- Task 1: Continue work on the development of nested domains and provide tool validation.
- Task 2: Operationalize the rapid assessment tool for internal use by the FAA.

Task 1 - Nested Domains and Tool Validation

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Objective(s)

The objective of this task is to continue to work on the development of nested domains and provide tool validation. This includes code development and testing to develop a high-resolution simulation for Europe. This task was completed during the previous period of performance with additional progress during the no-cost extension.

Research Approach

As documented in previous reports, the central tool for this project is the GEOS-Chem adjoint. This reporting period has been dedicated to applying the operationalized tools for quantification of the air quality impacts of aviation in two projects. The first, relevant to this task, was to quantify impacts of aviation in Asia and compare them to impacts from other, non-aviation sectors. Using tools developed under ASCENT 20, the impacts of landing and take-off emissions on Asian air quality in 2015 were quantified as part of a project to determine changes in sources of air quality-related mortality across Asia. This project separated impacts by country, sector, and year, isolating the effects of policy change in various Asian countries on air quality across the region.

Milestone

The task has been completed and a paper published.

Major Accomplishments

We found that aviation was responsible for <0.3% of all air quality-related impacts associated with regional emissions (see Table 1), which is less than half the total impacts from railroad emissions in 2015. This finding was published in Dasadhikari et al. (2019). This work also included validation of the capability of the GEOS-Chem nested tool to reproduce observed surface-level $PM_{2.5}$ concentrations (see Figure 1).

Table 1. Total regional deaths attributed to each sector in 2015; results are truncated to two significant figures.

Aviation	Agriculture	Energy	Fuel Processing	Industry	Residential	Rail Transport.	Road Transport.	Shipping
4,600	580,000	290,000	57,000	440,000	490,000	10,000	69,000	30,000

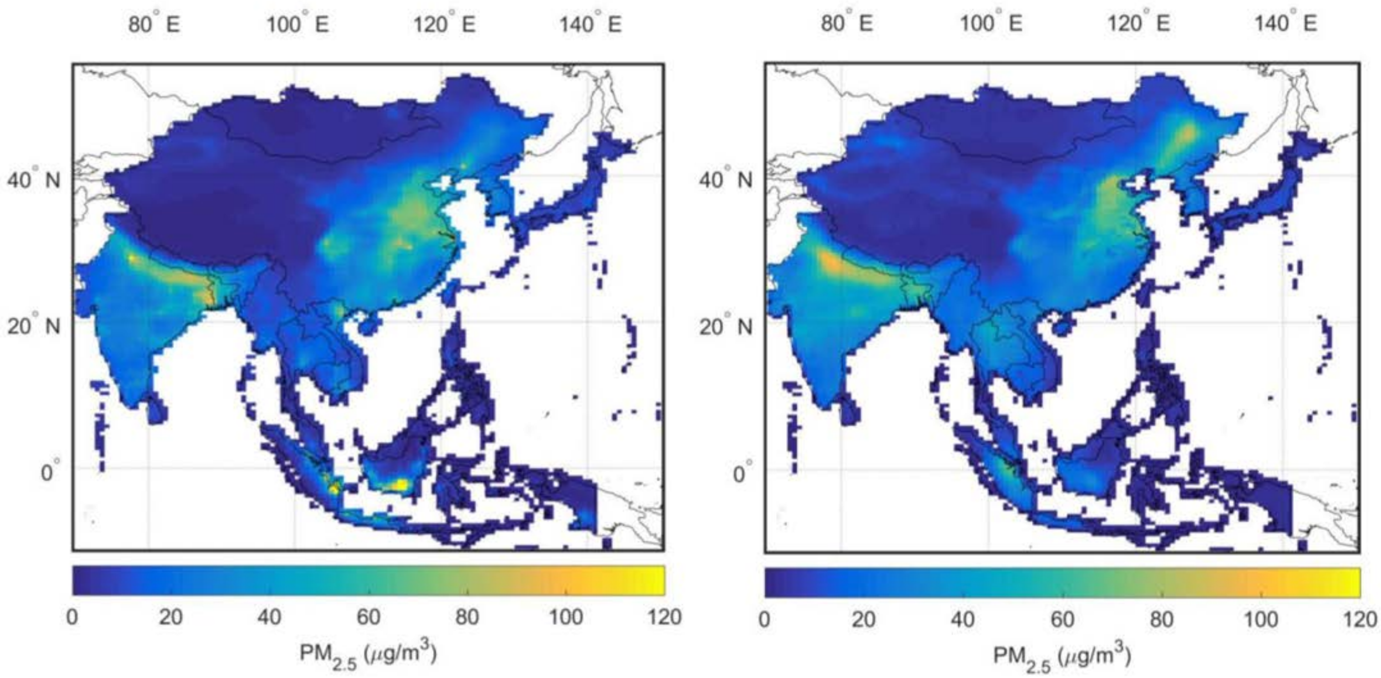

Figure 1. Simulated (left) versus "observed" (right) surface-level concentrations of particulate matter ≤2.5 µm ($PM_{2.5}$) in 2015; the observed values are from a machine learning–based reconstruction that incorporated MODIS satellite observation data.

Publications

Peer-reviewed journal publications:

Dasadhikari, K., Eastham, S. D., Allroggen, F., Speth, R. L., & Barrett, S. R. H. (2019). Evolution of sectoral emissions and contributions to mortality from particulate matter exposure in the Asia-Pacific region between 2010 and 2015. Atmospheric Environment, 116916.

Outreach Efforts

N/A

Student Involvement

Guillaume Chossière, then and currently a PhD candidate in the Department of Aeronautics and Astronautics at MIT, was involved in this study.

Plans for Next Period

This task is complete and no additional funding has been provided.

Task 2 - Operationalization of the Rapid Assessment Tool

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Objective

The objective is to apply the tools developed under ASCENT 20 to quantify the surface air quality impacts of aviation. This task was completed during the no-cost extension.

Research Approach

The second subproject completed during the no-cost extension was to produce metrics of the marginal air quality costs of aviation. This provide a set of metrics which can be used directly to perform rapid policy assessment. Previous MIT research found that aviation emissions result in ~16,000 premature deaths annually due to impaired air quality (Eastham & Barrett, 2016; Yim et al., 2015). When aiming to reduce these impacts and those from climate change, decision makers often face trade-offs between different emission species or impacts in different times and locations. To inform rational decision-making, the sensitivity data computed for ASCENT 20 were applied to compute aviation's marginal air quality impacts per tonne of species emitted, while accounting for the altitude and chemical composition of the emissions. Uncertainty in chemistry transport modeling was incorporated using scaling factors based on prior literature. Uncertainty in climate, health impact, and economic factors was also quantified.

Milestone

The task has been completed and a paper published.

Major Accomplishments

We found that air quality impacts accounted for 64% of combined climate and air quality impacts, based on fuel burn in 2015, and that the majority of these impacts were associated with cruise-level NO_x emissions. A sensitivity study was conducted to find the contribution of each of the uncertain Monte Carlo input variables to the observed output variance. We found uncertainty in climate sensitivity and the DICE (Dynamic Integrated Climate-Economy model) damage function to be the largest drivers of total output uncertainty.

A detailed description of the research approach and results can be found in a paper which was published as a result of work under both ASCENT 20 and 21 (Grobler et al., 2019).

Publications

Peer-reviewed journal publications:

Grobler, C., Wolfe, P.J., Dasadhikari, K., Dedoussi, I.C., Allroggen, F., Speth, R.L., Eastham, S.D., Agarwal, A., Staples, M.D., Sabnis, J. & Barrett, S.R.H. (2019). Marginal climate and air quality costs of aviation emissions. Environmental Research Letters, 14 114031, https://doi.org/10.1088/1748-9326/ab4942

Outreach Efforts

Results were presented to the FAA.

Student Involvement

N/A

Plans for Next Period

This task is complete and no additional funding has been provided.

References

Eastham, S. D. & Barrett, S. R. H. (2016). Aviation-attributable ozone as a driver for changes in mortality related to air quality and skin cancer. Atmospheric Environment, doi:10.1016/j.atmosenv.2016.08.040.

Grobler, C., Wolfe, P. J., Dasadhikari, K., Dedoussi, I. C., Allroggen, F., Speth, R. L., Eastham, S. D., Agarwal, A., Staples, Sabnis, J., & Barrett, S. R. H. (2019). Marginal climate and air quality costs of aviation emissions. Environmental Research Letters, 14 114031, https://doi.org/10.1088/1748-9326/ab4942.

Yim, S. H. L., Lee, G. L., Lee, I. W., Allroggen, F., Ashok, A., Caiazzo, F., Eastham, S. D., Malina, R. & Barrett, S. R. H. (2015). Global, regional and local health impacts of civil aviation emissions. Environmental Research Letters, 10 034001.