Project 021 Improving Climate Policy Analysis Tools

Massachusetts Institute of Technology

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University Participants

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- PI(s): Steven R. H. Barrett, Florian Allroggen (co-PI)
- FAA Award Number: 13-C-AJFE-MIT, Amendment Nos. 004, 017, 024, 037, and 042
- Period of Performance: August 1, 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 tasks, therefore, cover finalization of tasks from previous years only and were funded during the period from September 1, 2018, to October 31, 2018:
  1. Conceptualize a version of Aviation environmental Portfolio Management Tool - Impacts Climate (APMT-IC) that regionalizes the climate physical impacts and computes the costs thereof
  2. Derive and publish marginal climate costs per unit of aviation emissions for rapid assessments of emissions interventions
  3. Support knowledge transfer

Project Funding Level

$600,000 in FAA funding and $600,000 in matching funds. Sources of match are approximately $162,000 from Massachusetts Institute of Technology (MIT), plus third-party, in-kind contributions of $114,000 from Byogy Renewables Inc. and $324,000 from Oliver Wyman Group.

Investigation Team

- Prof. Steven R. H. Barrett, PI, MIT (Tasks 1, 2, and 3)
- Dr. Florian Allroggen, co-PI, MIT (Tasks 1, 2, and 3)
- Dr. Raymond Speth, co-investigator, MIT (Tasks 1, 2, and 3)
- Dr. Mark Staples, co-investigator, MIT (Tasks 1, 2, and 3)
- Dr. Sebastian Eastham, MIT (Tasks 1, 2, and 3)
- Carla Grobler (PhD student), MIT (Tasks 1, 2, and 3)

Project Overview

The objective of ASCENT Project 21 is to facilitate continued development of climate policy analysis tools that will enable impact assessments for different policy scenarios at the global, zonal, and regional scales and will enable FAA to address its strategic vision on sustainable aviation growth. Following this overall objective, the particular objectives of ASCENT 21 are (1) to continue the development of a reduced-order climate model for policy analysis consistent with the latest scientific understanding; and (2) to support FAA analyses of national and global policies as they relate to long-term atmospheric and environmental impacts.

For the current reporting period, no additional funding was provided. The project team subsequently focused on finalizing tasks from previous years under a no-cost extension. These tasks included (1) conceptualizing how regional heterogeneous aviation growth can be captured more accurately in APMT-IC; (2) deriving and publishing marginal climate costs per unit of aviation emissions; and (3) facilitating knowledge transfer to the FAA Office of Environment and Energy (FAA-AEE) and other researchers.

Task 1 - Conceptualization of Regional Physical Impacts in APMT-IC

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Objective(s)

The objective of this task is to conceptualize a potential approach for increasing the spatial resolution of estimating radiative forcing (RF) impacts associated with aviation emissions in APMT-IC. Because APMT-IC is currently set up as a global model, global emissions are used as inputs and globally averaged results are the main output. Although this approach leads to reliable results for current-year assessments, it potentially biases results for future scenarios that assume significantly changed aircraft technologies and/or traffic patterns. More specifically, biases due to changing traffic patterns can result from heterogeneities in atmospheric sensitivities. For example, NO_x emissions are estimated to result in 4 to 5 times more tropospheric ozone formation per unit of NO_x over the Pacific compared with a unit of NO_x emissions over Europe or North America (Gilmore et al., 2013).

In this reporting period, we built on the work completed during the previous reporting period, where we investigated the literature on regionalized emissions-to-impacts pathways. We identified two studies with potentially relevant results. First, Fuglestvedt et al. (2010) presented a review of regionalized physical impacts and found little agreement between the regionalized temperature responses. Second, Lund et al. (2017) analyzed regionalized global warming potential and regionalized temperature potential of aviation emissions. They found that global warming and global temperature potentials varied by a factor of 2 to 4 between different source regions.

During the current reporting period, the objective is to conceptualize a regionalized version of APMT-IC based on the research of Lund et al. (2017).

Research Approach

The current structure of APMT-IC is presented in Figure 1. As inputs, the model requires global fuel burn, CO_2 emissions, and NO_x emissions. Subsequently, global CO_2 radiative impacts are calculated by using impulse response functions and a radiative transfer function included in the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment report (Myhre et al., 2013). The global radiative impacts of the short-lived climate forcers are calculated by scaling the radiative impacts from the aviation climate change research initiative (ACCRI) phase two report (Brasseur et al., 2016) to the global fuel burn of the emission scenario. RF is linked to temperature change through a two-box temperature model based on Berntsen and Fuglestvedt (2008). Finally, global temperature change is linked to damages using the Dynamic Integrated model of Climate and the Economy (DICE) damage function (Nordhaus, 2017).

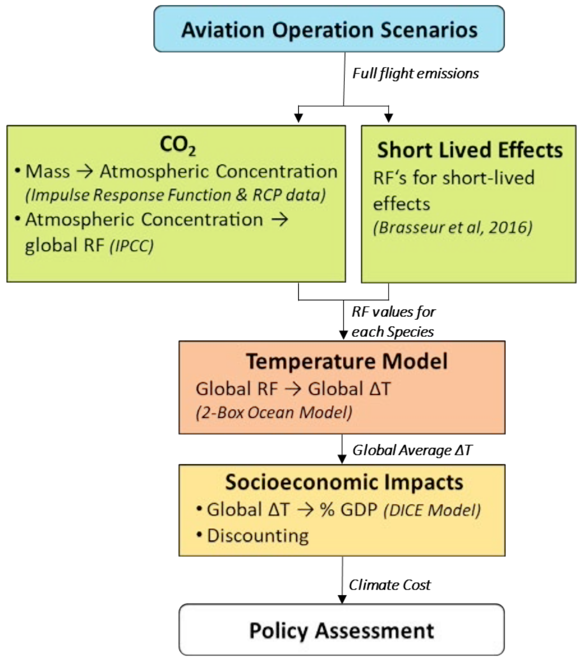

Figure 1. Outline of structure of current version of Aviation environmental Portfolio Management Tool - Impacts Climate (APMT-IC) for one Monte Carlo member. RF, radiative forcing; ΔT, temperature change; GDP, gross domestic product; DICE, Dynamic Integrated model of Climate and the Economy; RCP, representative concentration pathways,

In this task, potential changes to APMT-IC that enable capturing the impacts of regional heterogeneous growth are discussed. Because there is no evidence pointing toward regional heterogeneities of the RF impacts associated with CO_2 emissions, these changes are centered around the modeling of short-lived climate forcers. Changes are not proposed to the damage function. This is because previous work by the project team could not identify consensus on the reduced-order modeling of regionalized damages from regionalized temperature change (Nordhaus, 2017). Therefore, the proposed changes are constrained to linking regional emissions to global mean temperature change, which can subsequently be linked to global damages.

Milestone(s)

The literature study was completed during the previous reporting period, and the proposed concept was completed during this reporting period.

Major Accomplishments

During the current reporting period, the aim of this task of conceptualizing how the impact of different emissions regions can be accounted for in APMT-IC was completed. The proposed structural updates are presented in Figure 2. Most importantly, the proposed modeling structure will require APMT-IC to accept precursor emissions of short-lived forcers broken down by region, where the regions are defined according Lund et al. (2017). The specified local emissions will be linked to local RF in four latitude bands by scaling the local radiative impacts to the local emissions presented by Lund et al. (2017). In turn, these local RF values will be linked to temperature change using the temperature change function and the matrix of regionalized climate sensitivities presented in Lund et al. (2017). Finally, these local temperature changes are converted to a global mean temperature change using an area-weighted average. These steps will be taken individually for each short-lived forcer pathway. Uncertainty estimates for these parameters are presented in Lund et al. (2017) and will also be incorporated into the Monte Carlo simulation.

As a result of these changes, we expect a 17-fold increase in the number of Monte Carlo variables for each short-lived forcer. This will lead to increased run times and memory requirements. Furthermore, the current version of APMT-IC saves results from all Monte Carlo members as output, so further changes might be necessary to reduce the size of the output storage.

Another potential challenge is either a loss of backward compatibility between APMT-IC versions or significant additional implementation costs and loss of flexibility in the current implementation, which result from the fundamentally different architectures. Finally, we note a potential caveat to the proposed approach results from Lund et al. (2017), who calculated their results for year-2006 emissions patterns. The proposed model will subsequently not be capable of capturing the impact of any sub-regional-scale changes in emissions, such as changes in landing and take-off (LTO) and cruise emissions fractions.

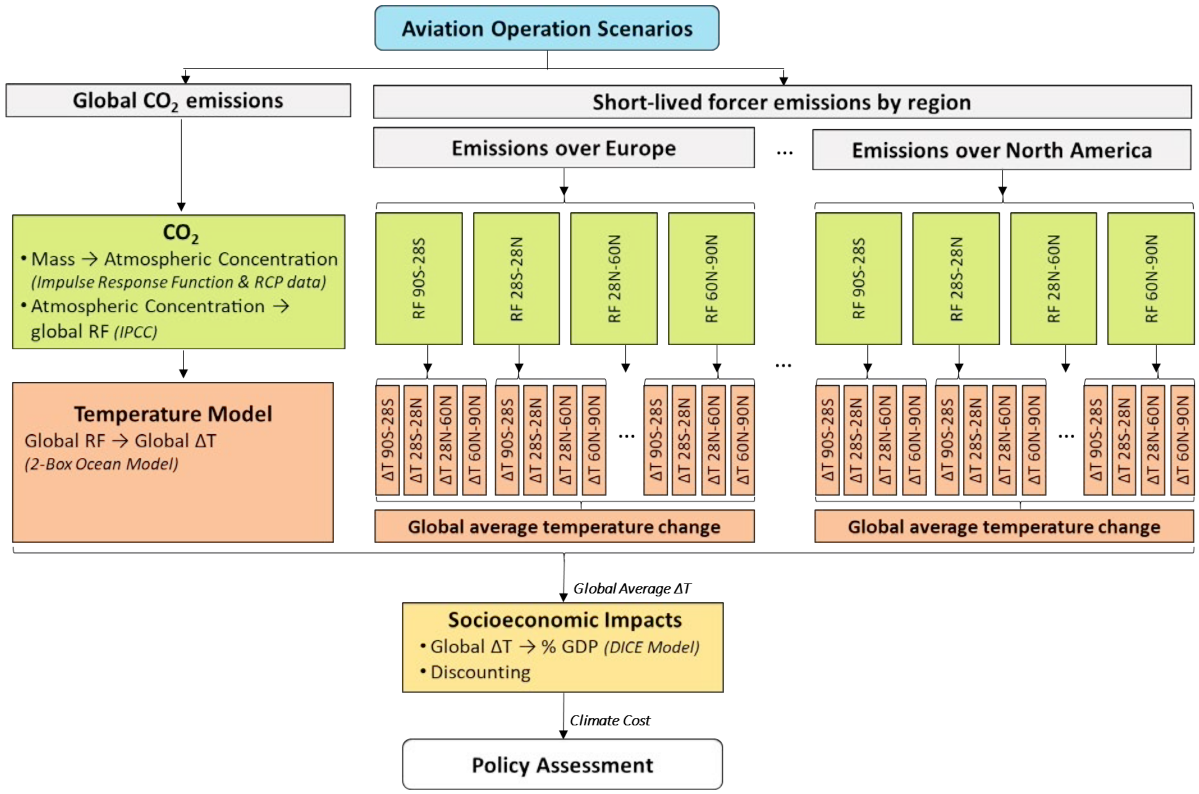

Figure 2. Conceptualization of structure for Aviation environmental Portfolio Management Tool - Impacts Climate (APMT-IC) using regionalized results from Lund et al. (2017) for one Monte Carlo member. RF, radiative forcing; ΔT, temperature change; GDP, gross domestic product; DICE, Dynamic Integrated model of Climate and the Economy.

Publications
N/A

Outreach Efforts
N/A

Student Involvement
The literature study and conceptualization of methods were prepared by Carla Grobler (PhD student, MIT).

Plans for Next Period
N/A

References
Berntsen, T.K. & Fuglestvedt, J.S. (2008). Global temperature responses to current emissions from the transport sectors. Proceedings of the National Academy of Sciences of the United States of America, 105 19154–9 Online: http://www.ncbi.nlm.nih.gov/pubmed/19047640

Brasseur, G.P., Gupta, M., Anderson, B.E., Balasubramanian, S., Barrett, S., Duda, D., Fleming, G., Forster, P.M., Fuglestvedt, J., Gettelman, A. & Halthore, R.N. (2016). Impact of aviation on climate: FAA's aviation climate change research initiative (ACCRI) phase ii. Bulletin of the American Meteorological Society, 97(4), pp.561-583

Fuglestvedt, J. S., Shine, K. P., Berntsen, T., Cook, J., Lee, D. S., Stenke, A., Waitz, I. A (2010). Transport impacts on atmosphere and climate: Metrics. Atmospheric Environment, 44(37), pp. 4648–4677. doi: 10.1016/j.atmosenv.2009.04.044

Gilmore, C.K., Barrett, S.R.H., Koo, J., & Wang, Q. (2013) Temporal and spatial variability in the aviation NO_x-related O_3 impact. Environmental Research Letters, 8 034027

Lund, M. T., Aamaas, B., Berntsen, T. K., Bock, L., Burkhardt, U., Fuglestvedt, J. S. and Shine, K. P. (2017). Emission metrics for quantifying regional climate impacts of aviation. Earth System Dynamics, 8(3), pp. 547–563. doi: 10.5194/esd-8-547-2017

Myhre, G., Shindell, D., Bréon, F., Collins, W., Fuglestvedt, J., Huang, J., Koch, D., Lamarque, J., Lee, D., Mendoza, B., Nakajima, T., Robock, A., Stephens, G., Takemura, T., Zhang, H. (2013). Anthropogenic and natural radiative forcing. Contribution of Working Group I Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., Qin, D., Plattner, G.K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., & Midgley, P.M. (eds.). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press] https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter08_FINAL.pdf.

Nordhaus, W.D. (2017). Revisiting the social cost of carbon Proceedings of the National Academy of Sciences of the United States of America, 114 1518–23 http://www.pnas.org/lookup/doi/10.1073/pnas.1609244114

Task 2 - Derivation of Marginal Climate Costs Per Unit Aviation Emissions

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Objective(s)

Aviation emissions have been found to cause 5% of global anthropogenic RF and ~16,000 premature deaths annually due to impaired air quality (Eastham & Barrett, 2016; Lee et al., 2009; Yim et al., 2015). When aiming to reduce these impacts, decision makers often face trade-offs between different emission species or impacts in different times and locations. To inform rational decision-making, the objective of this task is to compute aviation's marginal climate and air quality impacts per tonne of species emitted during different flight stages and by emission location. This task has been completed in collaboration with the ASCENT 20 project.

Research Approach

The research approach involves applying APMT-IC to calculate costs for full flight emissions by running APMT-IC for an emissions pulse in 2015. Impacts per unit of precursor emissions are derived by normalizing each of the short-lived forcers by its respective precursor emissions.

Full flight results are derived using the APMT-IC model, and LTO and cruise impacts are derived by modifying the LTO and cruise RF per unit of fuel burn. LTO RF results are based on the global warming potential values for ground emissions from the IPCC report (Myhre et al., 2013), whereas cruise radiative impacts are calculated as the difference between the ACCRI (Brasseur et al., 2016) full flight radiative impacts and the LTO results. Climate results are derived for discount rates ranging from 2% to 7%.

A detailed description of the research approach can be found in the publication (see below).

Milestone(s)

Results were derived as described above. The journal paper was prepared and submitted to *Environmental Research Letters*, where it was reviewed, accepted, and published (Grobler et al., 2019).

Major Accomplishments

Results were successfully derived using APMT-IC. Our results indicate that three components are responsible for 97% of climate and air quality damages per unit fuel burn, with individual contributions of NO_x at 58%, CO_2 at 25%, and contrails at 14%. Air quality impacts account for 64% of total impacts. 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 the climate sensitivity and the DICE damage function to be the largest drivers in the output uncertainty. Furthermore, this work was submitted and published in *Environmental Research Letters*.

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

A summary of the paper approach and results were presented to the FAA.

Student Involvement

The derivation of the climate metrics, validation, and paper drafting were completed by Carla Grobler (PhD student, MIT).

Plans for Next Period

N/A

References

Brasseur, G.P., Gupta, M., Anderson, B.E., Balasubramanian, S., Barrett, S., Duda, D., Fleming, G., Forster, P.M., Fuglestvedt, J., Gettelman, A. & Halthore, R.N. (2016). Impact of aviation on climate: FAA's aviation climate change research initiative (ACCRI) phase ii. Bulletin of the American Meteorological Society. 97(4), pp.561-583

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. 144 17–23

Lee, D.S., Fahey, D.W., Forster, P.M., Newton, P.J., Wit, R.C.N., Lim, L.L., Owen, B., & Sausen, R. (2009). Aviation and global climate change in the 21st century. Atmospheric Environment, 43 3520–37, http://dx.doi.org/10.1016/j.atmosenv.2009.04.024

Myhre, G., Shindell, D., Bréon, F., Collins, W., Fuglestvedt, J., Huang, J., Koch, D., Lamarque, J., Lee, D., Mendoza, B., Nakajima, T., Robock, A., Stephens, G., Takemura, T., & Zhang, H. (2013). Anthropogenic and natural radiative forcing. Contribution of Working Group I Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., Qin, D., Plattner, G.K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., & Midgley, P.M. (eds.). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press] https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter08_FINAL.pdf.

Yim, S.H.L., Lee, G.L., Lee, I.H., 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

Task 3 - Support Knowledge Transfer

Massachusetts Institute of Technology

Objective(s)

The objective of this task is to support FAA analyses of national and global policies as they relate to long-term atmospheric impacts. APMT-IC version 24 builds upon the tool that was used to assess international aircraft and engine stringencies at Committee on Aviation Environmental Protection (CAEP) 8, 9, and 10. Under ASCENT 21 (together with its predecessor, PARTNER 46), the ASCENT 21 team was directly involved in the analysis of all three standards. A further objective of this task is to ensure results are made available to a wider audience.

Research Approach

During this reporting period, a publication was prepared and published in *Environmental Research Letters* (Grobler et al., 2019). This publication includes a model description of APMT-IC version 24b. The research was also summarized and presented to the FAA.

Milestone
Research results were published, and a summary of the publication was presented to the FAA.

Accomplishments
Knowledge transfer was supported through our reporting and communication activities.

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

Student Involvement
Carla Grobler (PhD student, MIT), who was responsible for updating APMT-IC to version 24 during the previous reporting period, co-authored the publication and compiled the summarized briefing of the publication presented to the FAA.

Plans for Next Period
N/A