ASCENT 20
Development of NAS wide and Global Rapid Aviation Air Quality Tools

Motivation and Objectives

Aviation emissions contribute to the formation of particulate matter ($PM_{2.5}$) and ozone (O_3) in the atmosphere. Long term exposure to $PM_{2.5}$ and O_3 can lead to cardiopulmonary diseases and lung cancer. Health impacts have been shown to exist on local, regional and global scale.

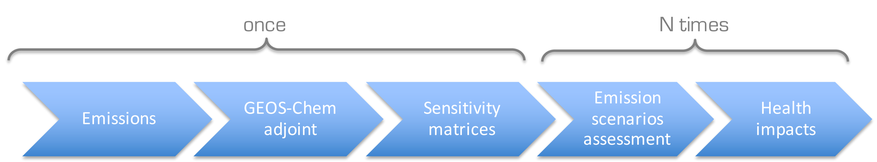
The assessment on the impacts of aviation on air quality usually rely on **chemical transport models** that tend to be computationally expensive. In a policy context however, many scenarios need to be evaluated and compared in a short period of time. The adjoint approach is designed to alleviate the burden of computation and render chemical transport models compatible with policy applications.

The long-term objective of this project is to provide a validated tool for both the US and the global domain, that enables the **rapid air quality assessment** ($PM_{2.5}$ and O_3) of aviation emissions scenarios.

As of now, the tool is operational for $PM_{2.5}$ on the global domain and the fine resolution US domain, and for O_3 on the US domain. A major objective in the short-term is to include the global ozone capability to the adjoint tool.

In parallel, we are also conducting an analysis of the second-order sensitivities in order to quantify the impact of changes in background emissions on our results.

Methods and Materials



Sensitivity matrices give us the gradient of the objective function (e.g. human exposure) with respect to multiple inputs. It allows detailed analysis of spatial, temporal and speciated variations.

Population exposure to $PM_{2.5}$ or O_3

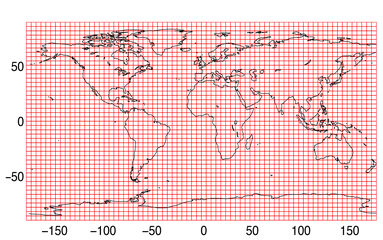
Origin of impacts (spatial)

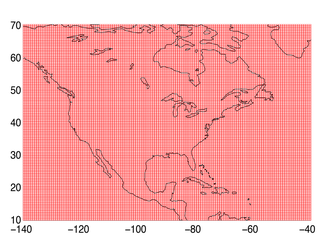
$$\frac{\partial \mathrm{J}}{\partial \mathrm{E}_w}(i,j,k,t)$$

For each emissions species

Time of emission

The adjoint tool allows to rapidly assess the **effects of perturbations** (i.e. assess policy scenarios) (linear relationship assumed).
Two grids are currently available: global domain (4°x5°) and nested NA domain (0.5°x0.667°)





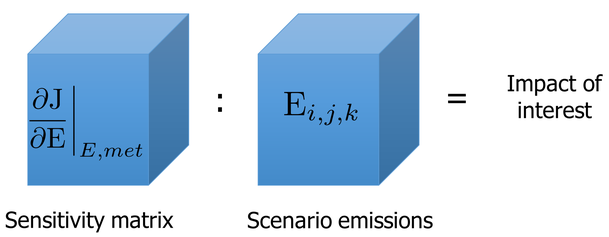
Summary

Aviation emissions have both present and future air quality and health impacts that need to be understood in order to be controlled. In a policy context, the number of scenarios to be assessed does not allow traditional modeling, due to the computational cost of those models.

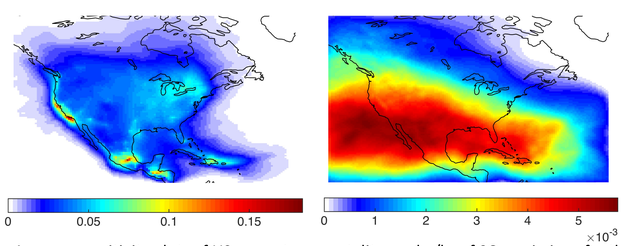
This project aims to develop the adjoint tool that provides policymakers with a rapid air quality assessment tool, which is computationally fast but does not compromise the underlying chemistry and transport calculations.

The sensitivity matrices allow detailed analysis of the spatial and temporal origin of emissions impacting the quantity of interest (e.g. population exposure in a given area) and highlight the importance of each species on the overall result.

To apply the adjoint tool to analysis, one needs to choose the sensitivity matrix corresponding to the quantity of interest, for instance US population exposure to $PM_{2.5}$, and multiply it element-wise by the matrix containing the emissions that result from the proposed scenario. The summation of the obtained matrix corresponds to the impact of the scenario under scrutiny.



Results so far include the assessment of the relative air quality impacts of aviation and of other sectors in the US, the identification of seasonality phenomena that change the impacts of potential policies or the evaluation of tradeoffs and co-benefits of the ICAO CAEP CO_2 standard.



Average sensitivity plots of US premature mortality per kg/hr of SO_2 emissions for the LTO levels (left) and the cruise levels (right)

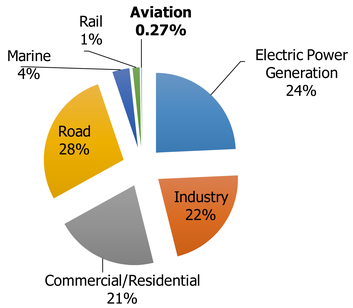
Lead investigator: S. Barrett, Massachusetts Institute of Technology
Project manager: N. Didyk, D. Jacob, FAA

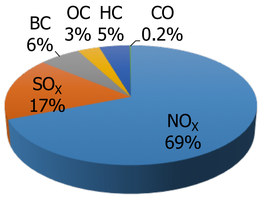
April 26-27, 2016

This work was funded by the US Federal Aviation Administration (FAA) Office of Environment and Energy as a part of ASCENT Project 20. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the FAA or other ASCENT Sponsors.

Results and Discussion

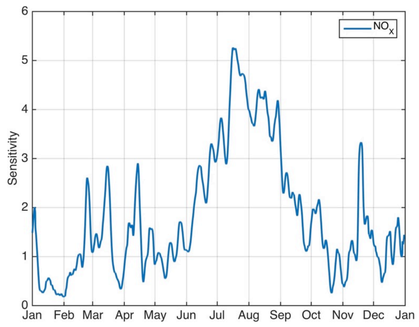
The adjoint sensitivities were used to **put aviation into context** and compare its impacts to those of other sectors. Combustion emissions in the US lead to ~170,000 premature mortalities annually attributable to $PM_{2.5}$. The sectoral breakdown of these impacts is shown on the left. We also attributed aviation's impacts to aviation emissions species, as shown on the right.

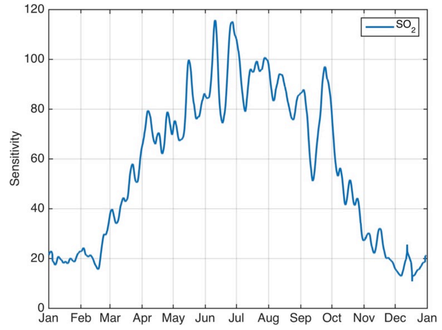




[Dedoussi and Barrett (2015)]

We also found that the sensitivities exhibit **seasonality**. The following two graphs show the sensitivity of US $PM_{2.5}$ exposure to NO_x (left) and SO_2 (right) emissions. Policies controlling these emissions are found to be more effective during summer than winter.





[Dedoussi and Barrett (2015)]

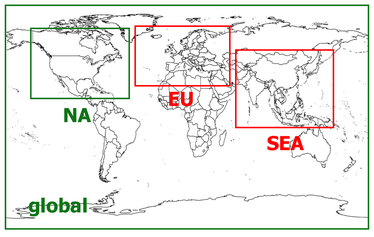
The adjoint tool was recently applied in the ICAO CAEP CO_2 standard analysis.

Conclusions and Next Steps

The adjoint air quality tool is a powerful rapid assessment model that allows the analysis of a large number of scenarios in a computationally practical manner, as required to inform policymaking. It has recently been used to inform the US FAA on the AQ effects of different proposed stringencies for the **CO2 emissions standard** under development at the International Civil Aviation Organization.

Next steps include:

- Development of ozone capability (in progress)
- Second order sensitivities analysis (in progress)
- Spatial capability (Europe, South-Eastern Asia)



Contributors: I. Dedoussi, G. Chossière, R.Malina, R. Speth, S. Barrett

References

1. Dedoussi, I. C., & Barrett, S.R.H. (2014). Air pollution and early deaths in the United States. Part II: Attribution of $PM_{2.5}$ exposure to emissions species, time, location and sector. Atmospheric Environment, 99, 610–617.
2. Dedoussi, I. C., & Barrett, S.R.H. (2015). US aviation air quality impacts and comparison with other sectors. Presentation given that Aiircraft Noise and Emissions Reduction Symposium, September 22-25 2015, La Rochelle, France..