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Atmospheric adjoint sensitivity analysis of aviation emissions impacts

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A critical challenge for the aerospace industry in the 21st century is to understand and reduce the environmental impacts of aviation. Aviation emissions contribute to the formation of Particulate Matter ($PM_{2.5}$) and ozone (O_3) in the atmosphere, thus degrading surface air quality and causing adverse health impacts. Although aviation emissions constitute only a small percentage of the total anthropogenic emissions today, studies predict that the aviation industry and market will grow by 2-3 fold by 2050. This work aims to advance the understanding of the environmental impacts of aviation and to contribute to the sustainable growth of the aviation sector, through the development of tools that help us assess and mitigate these impacts.

Conventional ways of modeling environmental impacts include 3D chemistry transport models, which simulate the chemistry, transport and deposition processes in the atmosphere. These models are computationally expensive, especially when run multiple times for the assessment of different policy scenarios or policy optimization. This work uses an adjoint sensitivity approach to overcome this inherit computational cost of the modeling process. Specifically, we use the adjoint of a chemistry transport model (GEOS-Chem adjoint) to calculate sensitivities. These sensitivities quantify how much a quantity of interest (e.g. population exposure to pollutants) changes for a perturbation in the emissions. They allow us to capture, in a computationally efficient way, the impacts of changes in emissions species, location or time, and to examine the entire design space of impacts.

The air quality and human health impacts of the 2006 aviation activity in the US will be presented. We attribute these impacts to species, location and time of emission. The impacts of aviation are placed into context by applying the sensitivities to combustion emissions from other sectors of the economy (e.g. road transportation, rail, industrial processes etc.) and comparing the impacts. We analyze the temporal variation of the sensitivities and find that NO_x emissions during July create $\sim$5 times more population exposure to $PM_{2.5}$ than NO_x emissions in January. Additionally, we find that the use of low-sulfur aviation fuels (e.g. alternative fuels) in the summer would be $\sim$2 times more effective than in the winter.

The presentation will also discuss current work, which involves extending the model to be able to capture impacts of emissions at higher altitudes. As aircraft CO_2 emissions decrease, due to technological advancements in aircraft weight, design and engine efficiency, aircraft cruise at higher altitudes to be able to attain the increased overall efficiency. Additionally, modern engine and aircraft designs have made supersonic aviation technologically feasible for a variety of routes, by largely overcoming the noise (sonic boom) restrictions, one of the aspects that prohibited supersonic aviation in the past.

High altitude aircraft emissions could result in the degradation of the ozone layer. The stratospheric ozone layer protects life on the ground from DNA-damaging ultraviolet (UV) light and since the late '80s is protected under the Montreal Protocol and its revisions. Even though significant effort is invested in assessing the environmental impacts of the current aircraft fleet, by employing state-of-the-art atmospheric models, only preliminary efforts have so far been made to assess the impacts of flying at higher altitudes. The investigation of the environmental impacts of high altitude aircraft is also part of my PhD.