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Robust climate optimal flight planning toward identifying "win-win" solutions: concept of equivalent CO_2 emissions

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Abstract

The aviation-induced non-CO_2 climate effects, being responsible for 66% of aviation radiative forcing, have a strong dependency on the location and time of emissions [1]. A first step toward mitigating their associated impact is to identify regions with significant climate effects, called climate-sensitive areas. Such information should then be used by flight planning tools to generate climate-friendly trajectories [2]. Among other sources, meteorological uncertainty can seriously affect the reliability of the identified climate hotspots and, consequently, the predicted aviation-induced climate effects. In this respect, generating flight plans robust to relevant sources of uncertainty is crucial. Besides, as the avoidance of climate-sensitive areas results in longer flights and, consequently, higher operating costs, climate policies are required to make climate-optimal trajectories economically reasonable to aviation stakeholders. Current market-based instruments, such as the emission trading scheme (ETS), include the emission of CO_2. In contrast, despite being under exploration in recent years, no restriction has been imposed so far on the aviation-induced non-CO_2 climate effects. One possibility is to convert the non-CO_2 emissions to CO_2 equivalents and then apply the taxes planned for CO_2 emission to non-CO_2 species. The conversions are generally made using constant conversion factors, e.g., based on the climate impact quantified using global warming potential. Due to the spatiotemporal dependency of non-CO_2 climate effects, fixed conversion factors cannot properly represent the climate effects of non-CO_2 emissions as, in this case, only the amount of CO_2 emission, and consequently, its climate effect is restricted.

In this study, we propose spatiotemporal-dependent conversion factors for each non-CO_2 species by determining the ratio of their corresponding climate effects to that of CO_2 emission. Then, by using the tax of CO_2 emission and the conversion factors, spatial-dependent taxes are derived for the non-CO_2 climate effects. The climate impacts are quantified using the prototype algorithmic climate change functions (version 1.1), providing spatially-resolved information on the climate impact of aviation [3]. As the quantification of aviation-induced non-CO_2 climate effects requires meteorological variables retrieved from standard weather forecasts, the conversion factors (or taxes) are associated with uncertainty. We perform robust aircraft trajectory optimization considering both climate impacts and operating costs (without including costs of climate effects) as objectives. By varying the weights of the climate effects, different sets of trajectories are generated. It is shown through analyzing Pareto-frontier that mitigating climate effects can only be achieved at the expense of higher operating costs. In addition, the net climate impact is highly uncertain due to the effects of meteorological uncertainty characterized by employing the ensemble prediction system weather forecast. In the next step, the generated trajectories are assessed by adding the costs of non-CO_2 climate effects to the operating cost. The results indicate possibilities of finding "win-win" scenarios in which both climate impact and operating costs are reduced. In addition, meteorological uncertainty affects the operating cost through the quantified climate effects. This implies one difficulty associated with setting-up climate policy for the non-CO_2 climate impact. Finally, the effects of changing the climate metric (e.g., time horizon, emission scenario, and efficacy factors) used to derive conversion factors are explored on the quantified operating cost. It is shown that the operating cost and the identified "win-win" scenarios vary with the selected climate metric.

References

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