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Motivation

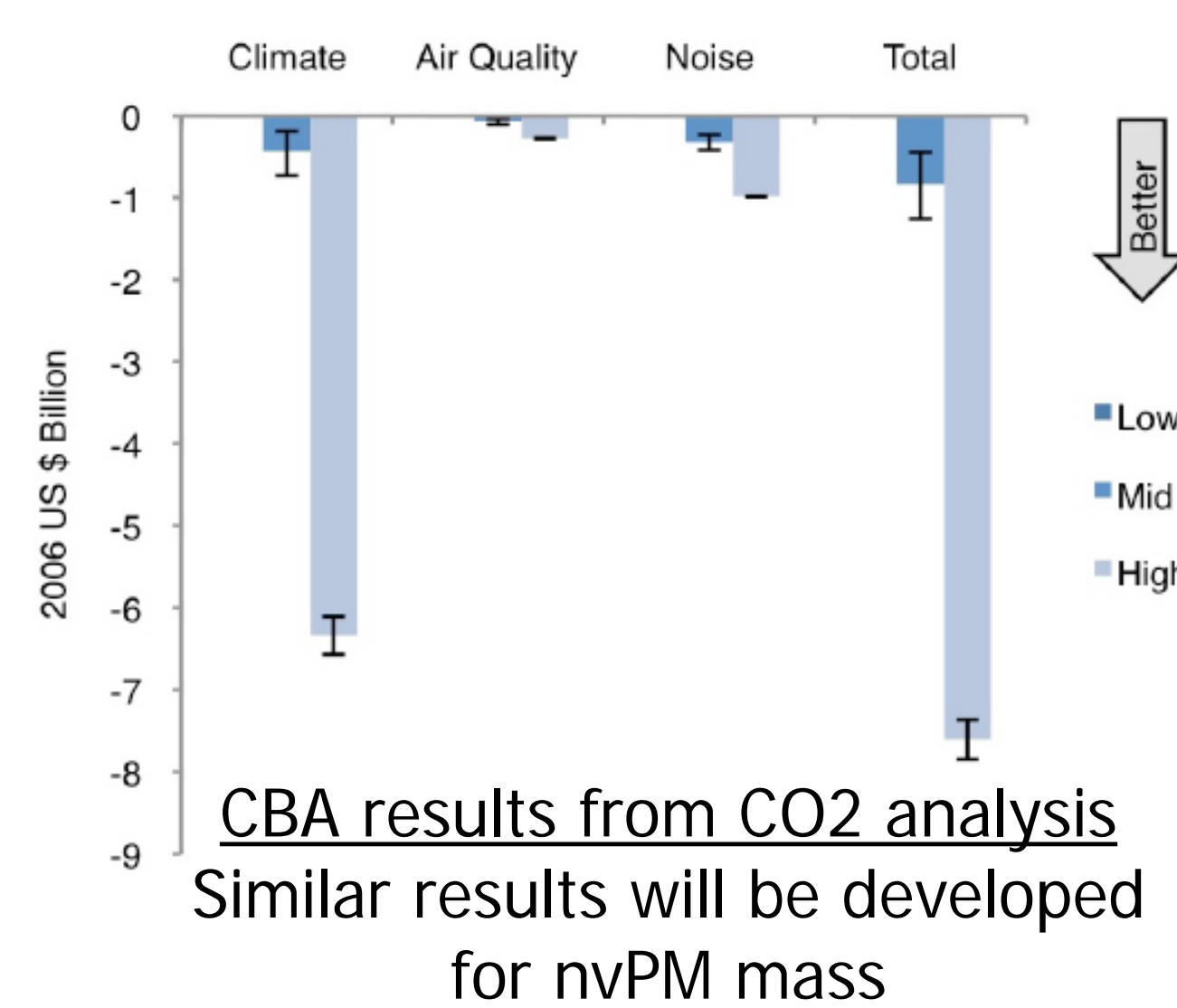
- The combustion of fuel is a source of non-volatile particulate matter (nvPM), with a size less than 2.5 μm ($\text{PM}_{2.5}$). Aircraft engines also emit “ultrafine” particles that are considered to be more harmful more toxic to humans than other sources.
- Exposure to $\text{PM}_{2.5}$ and “ultrafine” particles has been linked to health risks such as cardiopulmonary disease leading to premature mortality.
- Cruise-altitude nvPM emissions contribute to aviation’s climate impact through direct black carbon radiative forcing. They also provide a surface for ice crystals to nucleate, supporting the formation of contrails.

In order to reduce these environmental impacts, ICAO-CAEP is developing a standard for nvPM mass and number emissions for aircraft engines to reduce aviation’s environmental impact.

Objectives

This projects helps support the FAA decision-making process related to the development of the standard, while providing an independent assessment of the CAEP analyses. The main tasks include:

- Provide independent evaluation of candidate stringency options (SOs).
- Verify estimates of technology responses to different nvPM metrics and stringency options.
- Generate and assess mappings from representative engines to a broader set of engine/airframe combinations accounting for variations in engine technologies.
- Develop advanced, data-driven methods to estimating nvPM mass and number emissions using smoke number (SN).
- Develop tools and processes to be used in cost/benefit analyses of possible nvPM standards including economic, climate, air quality, and noise impacts.
- Conduct CBA to identify the optimum stringency options for the nvPM metrics.



Summary

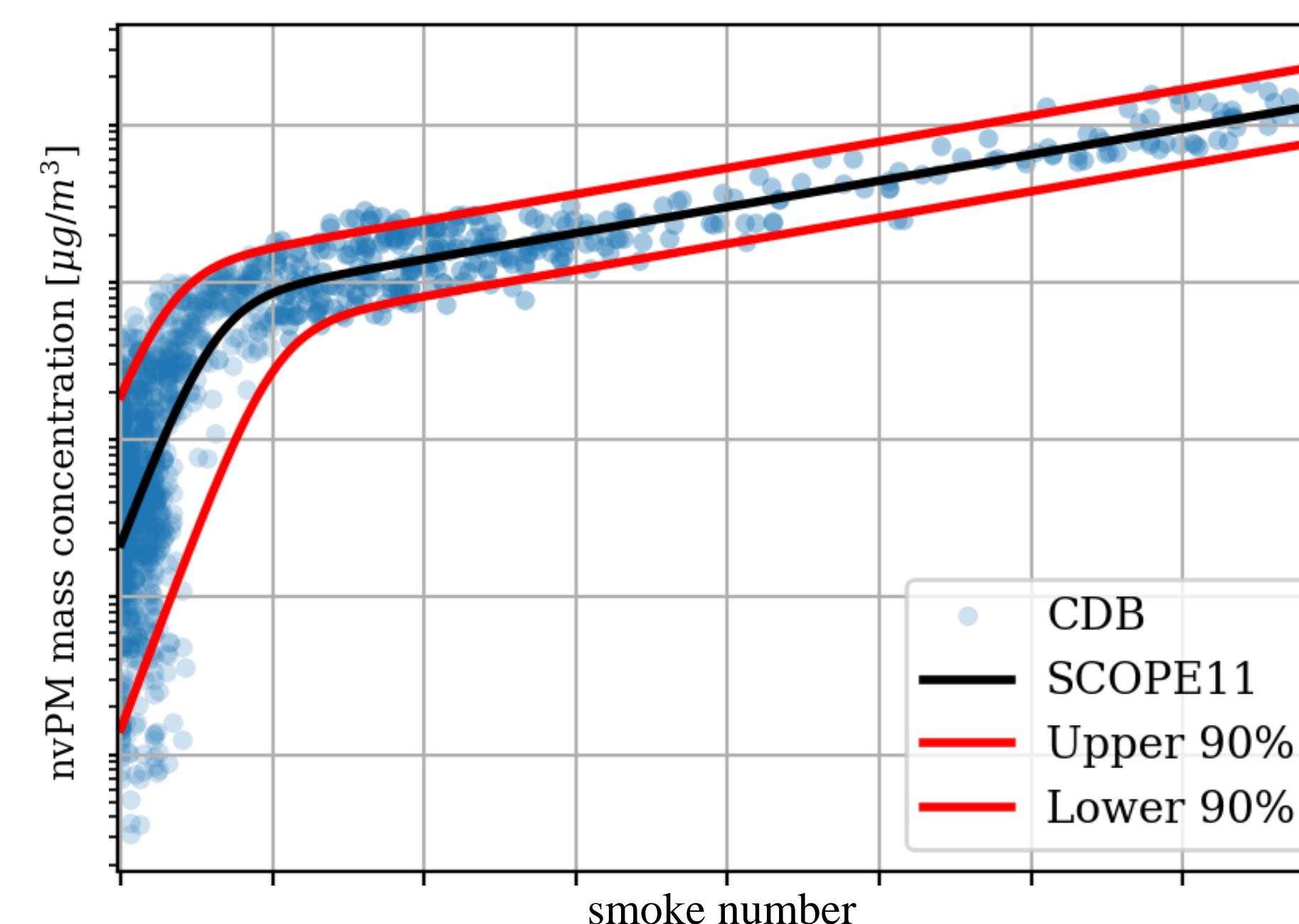
Aviation emissions contribute to air quality and climate impacts. Policies must be developed to direct the technology towards a cleaner future. In the current policy cycle, ICAO-CAEP is developing a standard for nvPM mass and number emissions.

By aiding the CAEP analyses and FAA decision-making process, we aim to identify cost beneficial nvPM regulations that can reduce aviation’s environmental impact using the APMT-I tools. In the process, we aim to motivate and convince CAEP to adopt CBA in addition to cost-effectiveness analysis (CEA).

Results & Discussion

Methods to estimate nvPM mass and number emissions

- FAA and ICAO require an inventory of nvPM mass & number emissions to conduct CBA and CEA
- We have developed a correlation between SN and nvPM mass that improves upon current practice (Wayson et al (2009)¹) by using:
 - A dataset of concurrent SN and nvPM mass measurements that used standardized, certification-compliant measurement systems; and
 - A novel relationship that can explain the trend of nvPM mass at low and high SNs.
- This correlation is referred to as the Smoke Correlation for Particle Emissions – CAEP 11 (SCOPE11) and includes upper and lower confidence intervals for uncertainty quantification.



- For number emissions, we must estimate the geometric mean diameter (GMD). Current methods assume a fixed GMD for each mode of operation. This is used to estimate a number emissions index (EI-n) as below, where $\sigma = 1.8$ is the geometric standard deviation:

$$EI_{\#} = \frac{8EI_m}{\pi\rho(GMD)^3 e^{4.5(\ln\sigma)^2}}$$

- We have developed a new method using mass concentration (C_{BC}). A higher C_{BC} increases coagulation rates, and so larger GMDs, which our method attempts to model.
- This method is currently being tested and compared with the mode-dependent alternative.

SCOPE11 and the proposed GMD method can be combined to estimate nvPM mass and number emissions knowing only the SN. These will be used to calculate an emissions’ inventory for all historic engines where nvPM measurements do not exist. This work is currently being written for peer-review publication.

Evaluation of stringency options (SOs)

- Using the agreed upon SOs (5 for mass, 3 for number), we have estimated the margins of a set of engines to each SO.
- This provides guidance on technically achievable target to help ICAO-CAEP push manufacturers toward cleaner engines.

Replacement of SN with mass concentration limit line

- The SN limit line was developed as a visibility standard in the 1980s. During CAEP10, a mass concentration limit line was developed using the original SN limit line.
- ICAO-CAEP is now considering the possibility of replacing SN with the CAEP10 limit.
- We have conducted a statistical analysis of a range of representative engines to understand the implications of this replacement.

Future Work

As emission inventories are being developed, our main focus is 2 fold:

- Prepare the SCOPE11 and C_{BC} – GMD relationship for publication.
- Assimilate the various tools required to conduct the CBA. This includes sensitivities from adjoint simulations for air quality impacts and the APMT-I climate model

Contributors & Collaborators:

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