Vertical Mixing of Commercial Aviation Emissions in the Upper Troposphere and Lower Stratosphere

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Introduction
Commercial aviation is a rapidly growing and energy intensive industry. Therefore, it is important to identify the potential impacts of aviation on climate and public health. Several previous studies have identified commercial aviation as a source of anthropogenic climate change and a few others have identified airports as a source of air pollution. Only recently, however, have cruise-altitude emissions been suggested to enhance ground level air pollution. This study uses both data analysis and numerical modeling to investigate the vertical transport and mixing of cruise-level aviation emissions due to dynamical processes. This is a first step towards understanding the impacts of cruise-altitude emissions on surface-air quality.

Data Analysis
We collocated the aviation emissions in time and space with static stability (N² > g/θ) where p₀ = 1000 hPa. We used data from the 2006 emissions inventory described in Wilkerson et al. [2010], tropopause heights from the NASA Atmospheric Infrared Sounder (AIRS), and vertical temperature and pressure profiles from the Challenging Minisatellite Payload (CHAMP) and Constellation Observing System for Meteorology, Ionosphere and Climate (COSMIC). The annual data were plotted in Figure 1 and statistics were tabulated in Figure 2.

Numerical Modeling
We simulated two tracer release experiments with the gas, aerosol, transport, radiation, general circulation, mesoscale and ocean (GATOR-GCMOM) computer model. The model was initialized with reanalysis data on January 1, 2006 and July 1, 2006. In both cases, an inert tracer was released globally and instantaneously in a tight Gaussian distribution centered at 11 km (the peak of the vertical distribution of commercial aviation emissions) and transported by dynamical processes, including vertical transport in sub-grid convective clouds. The model was run without any data assimilation. Moreover, we turned off chemistry and removal processes in order to isolate and analyze the dynamical processes alone. Zonally averaged mixing ratios are plotted in Figure 3. In addition, we compared modeled static stability with static-stability data derived from the satellite data in Figure 4.

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References

Figure 1. Commercial aircraft burned 188 Tg of jet fuel in 2006. We plotted the zonal sum of these emissions over all latitudes with contours of static stability (N²) (left) and potential temperature (θ) (right). All variables are plotted in tropopause relative coordinates.

Figure 2. Globally, we found that 188 Tg of jet fuel were burned in 2006, 14.94 Tg were burned in January, and 16.86 Tg were burned in July. We found that 82.8 Tg were burned in the extra-tropical northern hemisphere (latitude > 40° N) and 2.35 Tg were burned in the arctic circle (latitude > 66.56° N).

Figure 3. Zonally-averaged tracer mixing ratios obtained from GATOR-GCMOM were plotted at the following days after the tracer release: 7, 21, 49, 77 (left to right). Vertical mixing was slower in January (top) than July (bottom) by several metrics.

Figure 4. January (left) and July (right) zonally-averaged static-stability derived from satellite data (top) and GATOR-GCMOM (bottom).

Figure 5. The summer and winter zonally averaged e-folding lifetime, τ, (plot A) and the boundary-layer to cruise-altitude tracer mixing ratio fraction (MRF) (plots B and C) show slower mixing in the winter (B) than the summer (C). MRF is a measure of tropospheric well-mixing time.