Utilizing Radiocarbon and Thermo-optical Measurements to Quantify Source Contributions for Aircraft Engine Particulate Emissions

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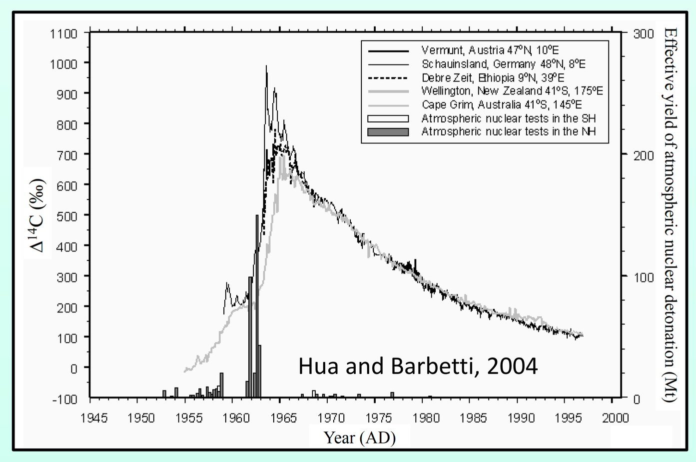
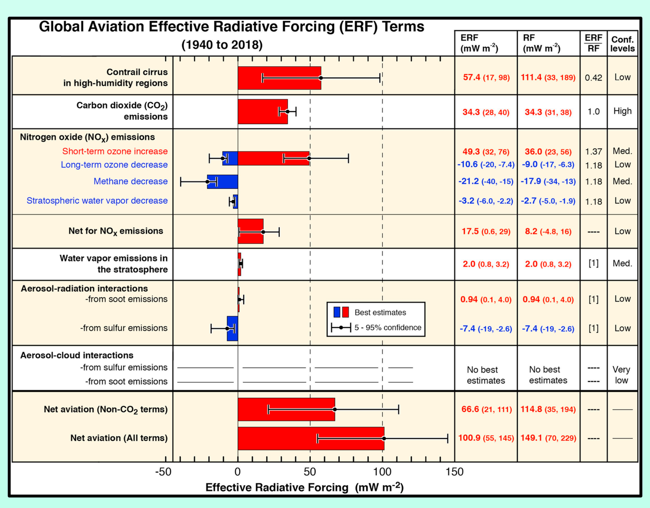
Background

Radiocarbon

Radiocarbon dating provides a unique method to determine carbonaceous aerosol source apportionment. The "Bomb Spike" in radiocarbon causes younger carbon sources (biofuel) to have a much higher radiocarbon content than older carbon sources (Jet-A).



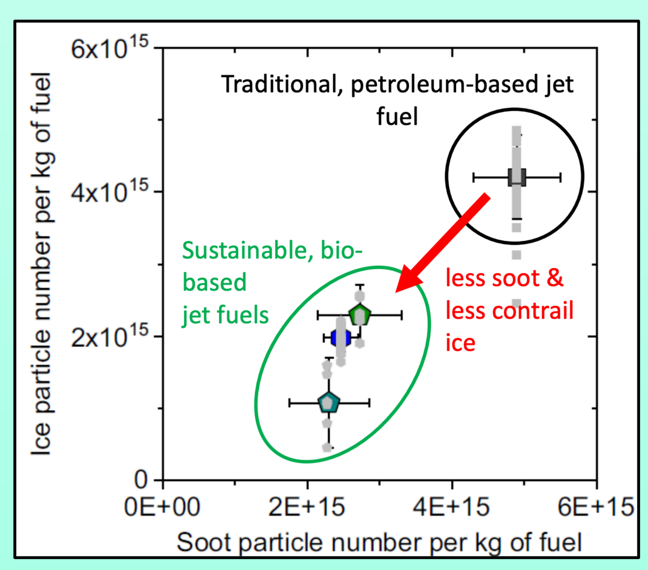


Contrails

Recent assessment from Lee et al., 2021 emphasizes significant climate warming from non-CO2 aviation impacts (i.e., contrails). Options to reduce contrail formation include contrail avoidance, lean combustion aircraft engine technology, and alternative fuels.

Sustainable Aviation Fuel

Sustainable aviation fuel (SAF) produces much lower soot and ice particle numbers per kg of fuel compared to traditional jet fuel and may be a potential pathway to reduce contrail induced climate warming. Fuel mixtures of SAF and Jet-A are beginning to be used in aircraft to reduce contrails. However, the relative contributions from SAF, Jet-A, and aircraft engine oil to carbonaceous aerosol engine emissions are difficult to accurately quantify using traditional approaches.



We use radiocarbon to determine carbonaceous aerosol contributions from oil, Jet-A, and SAF in aircraft engine emissions

Methods

2022 Boeing EcoDemonstrator Ground Test with NASA

During the fall of 2022, we parked the NASA LARGE MACH-2 mobile lab behind a Boeing 777-200ER with Rolls Royce TRENT-892 engine (conventional combustor) to collect aircraft engine emissions. We conducted tests using four types of fuel: high sulfur Jet-A, low sulfur Jet-A, pure SAF, and a 50/50 blend of SAF and Jet-A. Each test consisted of a sequence of varying engine conditions with dwell times of 8-10 minutes.

Aerosol Sample Collection & Analysis

We used 47mm quartz fiber filters to collect carbonaceous aerosols during the 2022 ground test. We collected one filter per condition for EC/OC analysis using Sunset Laboratories Thermal/Optical methods for each test. For radiocarbon, we collected four total filters per test to optimize loading. Radiocarbon filters spanned over conditions representative of idle, takeoff/landing, and cruise conditions, plus an additional filter than spanned all conditions. The radiocarbon samples were analyzed using UC-Irvine's Keck accelerator mass spectrometer.

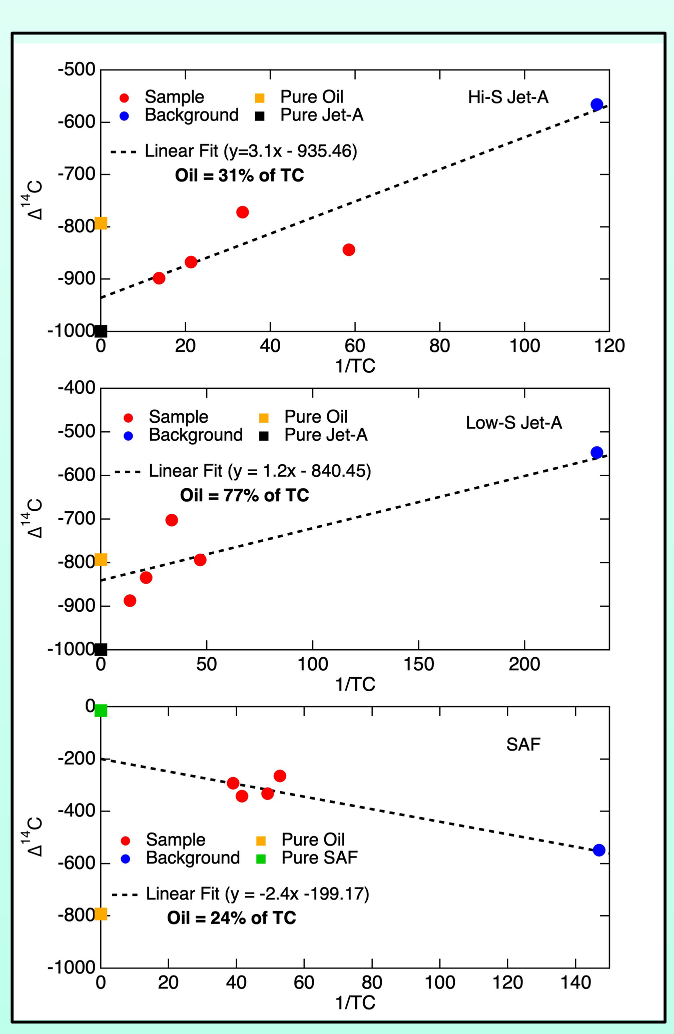
Results

Radiocarbon

We can use the intercept from a Keeling plot & known $\Delta^{14}C$ of fuel and oil to compute oil contribution to total carbon (TC) for each test. Note we added an oil diversion vent to the engine during the high sulfur Jet-A test and the SAF test.

Fuel Type	$\Delta^{14}C$ (‰)
Jet-A Fuel	-999.5
SAF Fuel	-14.7
Oil	-792.6

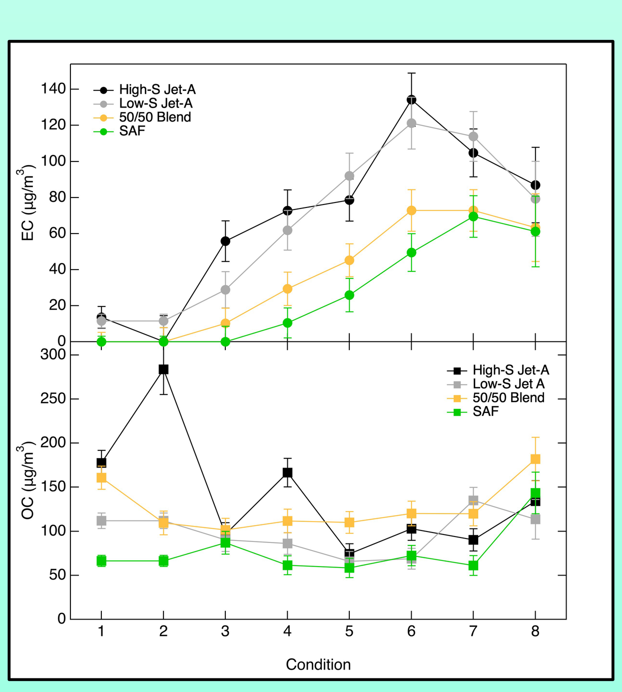
High-Sulfur Jet-A Test: Oil = 31% of TC (VENTED)
Low-Sulfur Jet-A Test: Oil = 77% of TC
SAF Test: Oil = 24% of TC (VENTED)



We find significant oil contributions to carbonaceous aircraft engine emissions

Condition Legend

1 = Idle
2 = 35% N1
3 = 50% N1
4 = 60% N1
5 = 70% N1
6 = 75% N1
7 = 85% N1
8 = MAX N1



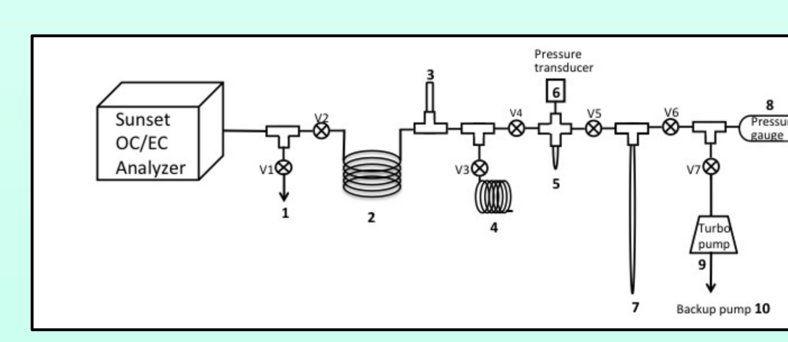
Sunset EC/OC

We find EC and OC are higher for Jet-A and lower for SAF and the 50/50 blend. The EC from the 50/50 blend was not halfway between Jet-A and SAF EC concentrations. EC increased with engine condition until 85% N1 and MAX, for all fuels. OC is very noisy for the high sulfur Jet-A test, but generally remains constant except for idle and the highest conditions, where it increases relative to other conditions.

Future Work

We plan to use radiocarbon to determine the relative contributions of black carbon aerosol aircraft engine emissions from SAF and Jet-A using a 50/50 fuel blend

BC aerosol will be separated from total carbonaceous aerosols by using a vacuum line connected to a Sunset EC/OC analyzer developed at UC Irvine and demonstrated by Mouteva et al., 2015. The black carbon will then by analyzed for their radiocarbon content using the Keck AMS.



Sunset Vacuum Line Approach to Isolate Black Carbon from Total Carbon for subsequent radiocarbon analysis.

References

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