Carbonaceous aerosols from aircraft engine exhaust: chemical characterization, optical properties and climate effects

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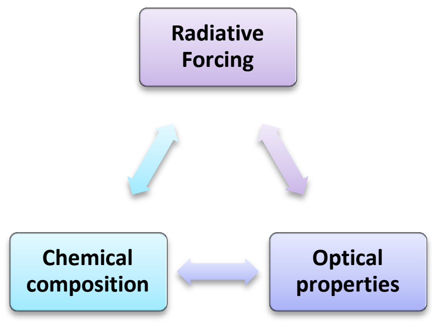
Introduction

- Aircraft engine exhaust consists of (in order of abundance): CO_2, H_2O, NO_x, SO_2, CO, HC, soot.
- Although aircraft are only a minor source of soot, the radiative effects of the particles emitted at cruising altitude might be enhanced. The aerosol radiative effects are strongly dependent on the optical properties of the particles, which, in turn, are related to their chemical composition.
- Biofuels have been introduced in the recent years in an attempt to decrease the aviation emissions. However, the effects of using biofuels on the emissions is still not well understood.
- The lack of experimental data on optical properties contributes significantly to the high uncertainties in the radiative effects from aircraft soot in global models.



Results & discussion

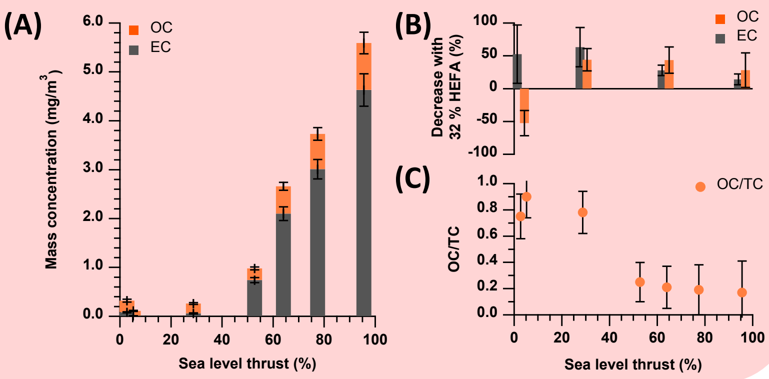
Chemical composition

- **Elemental Carbon (EC) and Organic Carbon (OC) from quartz filter samples using TOT method**

A. EC and OC mass concentrations both increasing with thrust level

B. Decrease in mass with the use of a 32 % HEFA fuel:
- EC mass decreases at all thrust levels, with maximum decrease of 60 % at 30 % thrust
- OC mass decreases at all thrust levels except for 3 %, where it increases by 50 %

C. OC/TC ratio: Unexpected high OC fraction at low thrust levels (up to 90 %) and more moderate at thrust above 50 % (OC ~ 20 %)



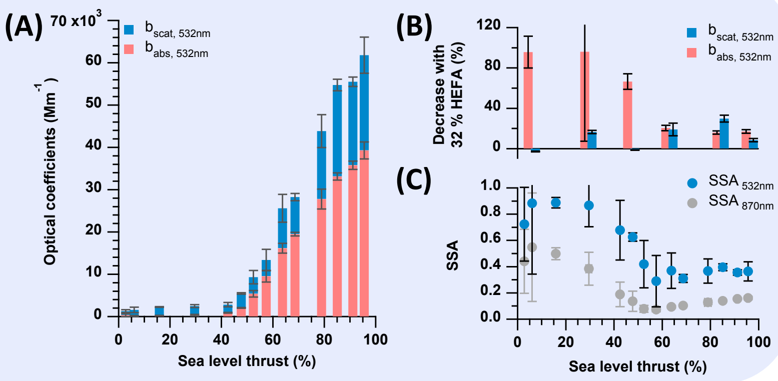
Optical properties

- **Online measurement of optical properties with CAPS (λ = 532 nm) and PAX (λ = 870 nm)**

A. Absorption and scattering coefficients (b_{abs} and b_{scat}) both increasing with thrust level

B. Decrease in b_{abs} and b_{scat} with the use of a 32 % HEFA fuel:
- b_{abs} decreases at all thrust levels, with maximum decrease < 90 % at 7% and 30 % thrust
- b_{scat} decreases (or unchanged) at all thrust levels but effect is more moderate

C. SSA = (b_{scat}/b_{ext}): Unexpected high scattering fraction at low thrust levels (SSA_{532nm} up to 0.9) and more moderate at thrust above 50 % (SSA_{532nm} ~ 0.4)



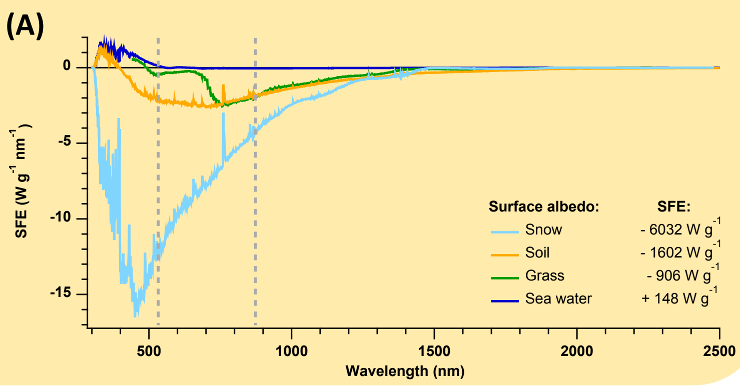
Radiative efficiency

- **Direct radiative effect estimate using simple forcing efficiency (SFE)**

$$SFE\ (\lambda) = \frac{S_0(\lambda)}{4} T_{atm}^2(\lambda, z)\left[2\left(1 - a_s(\lambda)\right)^2 \beta(\lambda) MSC(\lambda) - 4 a_s MAC(\lambda)\right]$$

where: S_0: Solar radiation at the top of the atmosphere
T_{atm}: Atmospheric transmission at the height over sea level z (SMARTS model)
a_s: Ground surface albedo ; β: Backscattered fraction
MSC & MAC: Mass scattering and mass absorption cross section

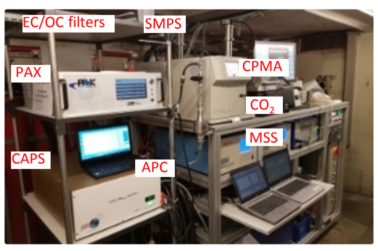
A. SFE spectra for various a_s : Aircraft soot has a very strong warming effect if emitted over snow-covered surfaces, a more moderate warming if emitted over other land surfaces (grass or soil) and a slight cooling effect when emitted over sea water



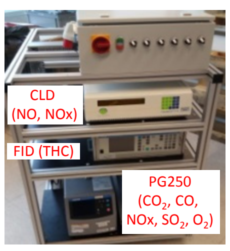
Methods

SR Technics Test Cell at Zurich Airport

Particle phase analyzers
Sampling: Diluted (1:10), 60 °C



Gas phase analyzers
Sampling: Undiluted, 160 °C



Engine type: CFM56-7B/26 turbofan
Fuel: Jet A-1 and 32 vol. % HEFA (Hydro-processed Ester and Fatty Acids) blend

TOT: Thermo Optical Transmission method (modified NIOSH 5040 protocol)
CAPS: Cavity Attenuated Phase Shift-based single scattering albedo monitor (λ = 532 nm)
PAX: Photo-Acoustic Extinctiometer (λ = 870 nm)

Conclusions

- Substantial decrease in the particulate emissions at all thrust levels with HEFA biofuel blend; No visible effect on the intensive properties (EC/OC ratios, SSA…)
- Link between chemical composition and optical properties: Corresponding trends in OC/TC and SSA with thrust level
- Large effect from surface albedo on SFE; Large warming effect when cruise emissions occur above highly reflective sources (snow, clouds)

Outlook

- Plume evolution study: Simultaneous measurements at engine exit plane, silencer and stack exit to study the evolution of the particles after emission

Acknowledgments: *This work was supported by the Swiss Federal Office of Civil Aviation (FOCA). We further acknowledge SR Technics AG for operating the engine testing facility and AVL GmbH for loaning the PAX instrument.*

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