Impact of Alternative Jet Fuels on Aircraft Emissions in Cruise: Results from the ECLIF2/ND-MAX aircraft campaign

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ECLIF/ND-MAX

Emission and **Cl**imate **I**mpact of Alternative **F**uels
NASA/**D**LR **M**ulti-Disciplinary **A**irborne E**x**periment

Testing the effectiveness of mitigation approaches using alternative jet fuels

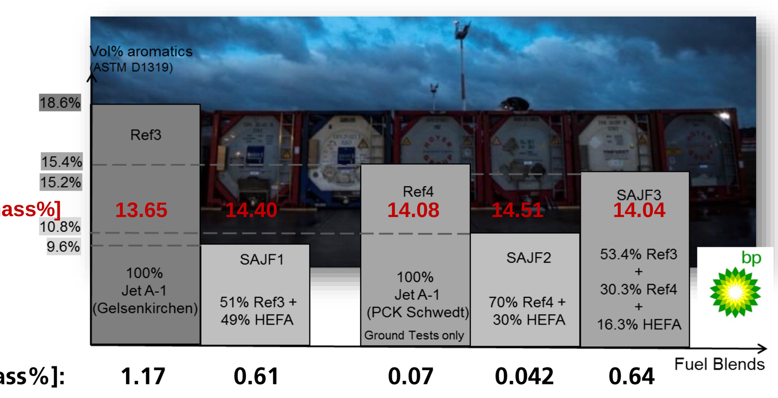
- How are contrails and climate affected by fuel composition, fuel physical and chemical properties, fuel oxidation, and combustion system performance?
- How do alternative jet fuels affect particle and gas emissions in cruise conditions?
- What is the link between soot emissions and contrails?
- Can alternative aviation fuels help mitigate the aviation-induced radiative forcing and its forecasted increase?

Overall ECLIF objective

Study effects of fuel aromatics content and chemical structure on emissions.

ECLIF/NDMAX fuel strategy

- Blends of sustainable HEFA fuel with Jet-A1
- Similar aromatics content but different chemical structure



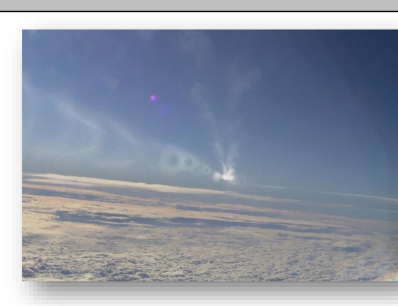
Measurement strategy

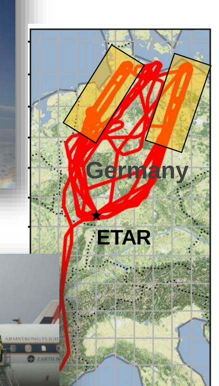
ECLIF2/ND-MAX was the second of two **field experiments** in the framework of ECLIF to sample **emissions** and **contrail** ice particles behind the DLR A320 Advanced Technology Research Aircraft (D-ATRA) **in cruise** burning different **alternative jet fuels**.

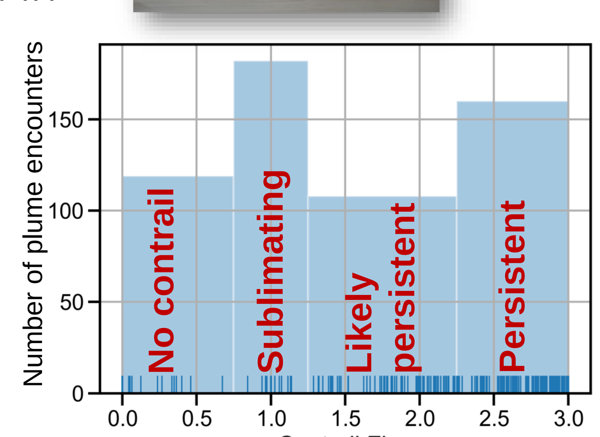
Both aircraft were based at Ramstein Airbase, Germany in Jan/Feb 2018 and the sampling was mainly performed in race-track patterns in restricted airspace over northern Germany. Typical distance to lead aircraft was 3-20nm.

- Total of 7 flights behind ATRA, (~33h hours)
- 1 survey flight to sample emissions from A320-class aircraft with new, low-emission engines

→ ~750 successful plume encounters at various speeds altitudes with and without contrails



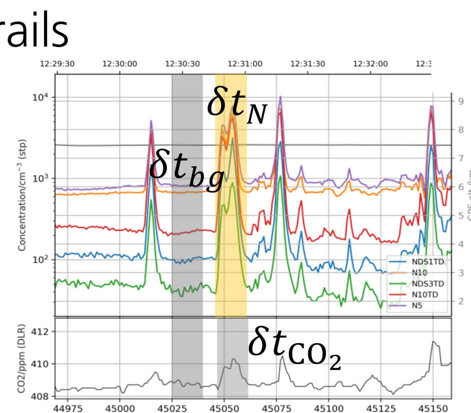




Particle number emission index

→ Particles emitted per kg fuel burnt

$$EI_x = \frac{n_x}{[CO_2]} \frac{RT}{p(M_c + \alpha M_H)}$$

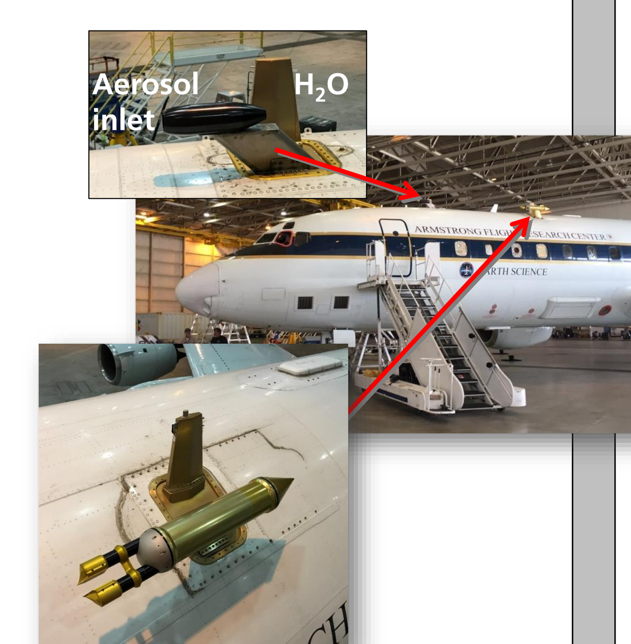


M_c, M_H: molar mass
p, T: std pressure and temperature
α: H/C ratio of the fuel
$[CO_2]$: mixing ratio of CO_2
n_x particle number concentration
CO_2 and n_x are determined as integrated, background subtracted peak areas.

Analysis following Moore et al 2017

Aerosol, trace gas and cloud particle instrumentation onboard the NASA DC8

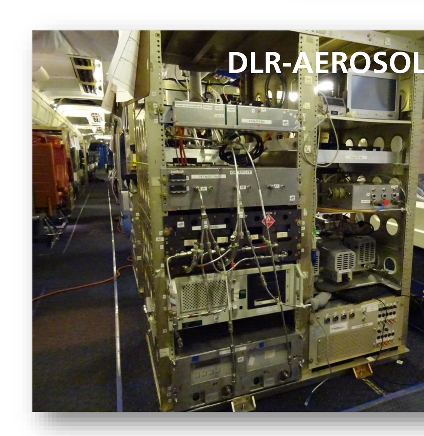
An extensive payload for measurement of aerosol microphysical and chemical properties was installed on board the NASA DC8.



Instruments for particle emissions (selection): Various condensation particle counters with **different size cutoffs**, some behind a **heated sample** line (thermodenuder) to evaporate volatile components → **non-volatiles** as proxy for **soot emissions**

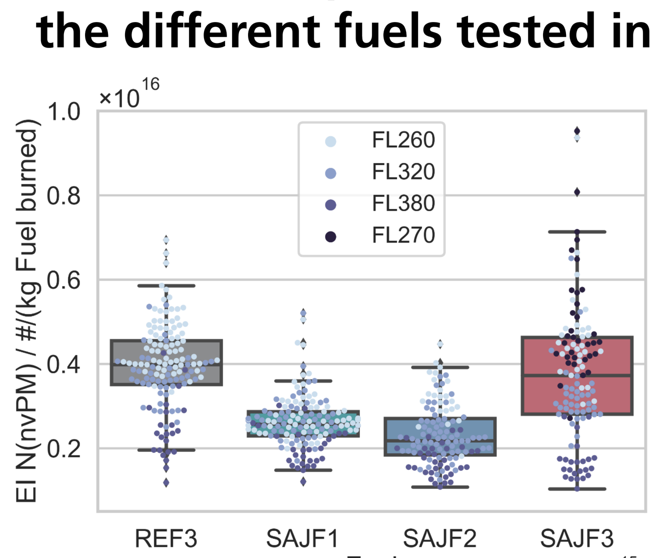
Contrail ice particle measurements: FastFFSP on 62° port on top of fuselage, CAPS, CDP, CAS-DPOL, 2D-S on wings.

Trace gas measurements (selection): CO_2: Picarro CRDS instrument (airborne) NO_y:SO_2, H_2SO_4, Formic Acid: CIMS

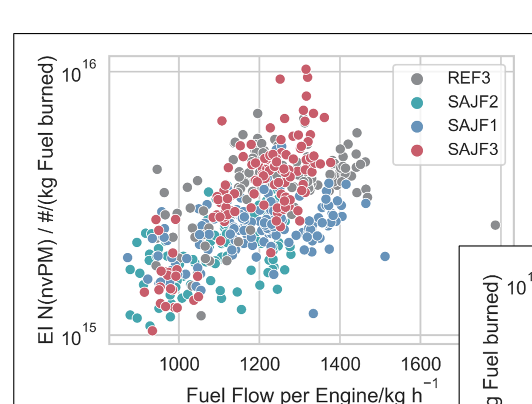


Results from particle measurements

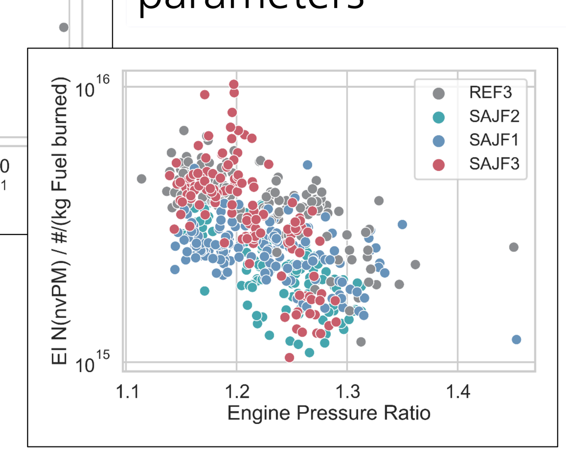
Non-volatile particle numbers for the different fuels tested in flight



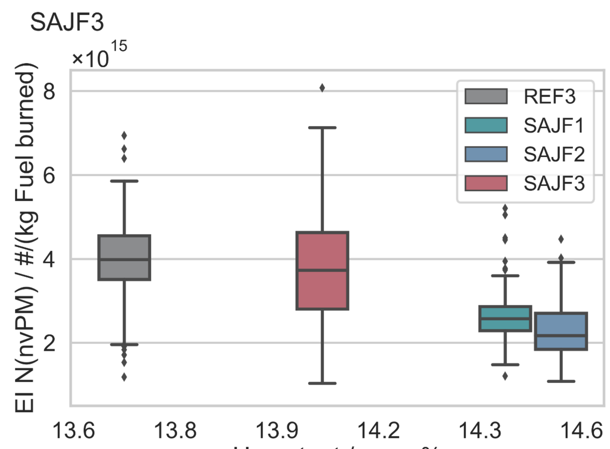
Spread in data shows that emissions are also controlled by other parameters.



Example for correlations of EI(nvPM) with engine parameters



As a function of fuel H-content

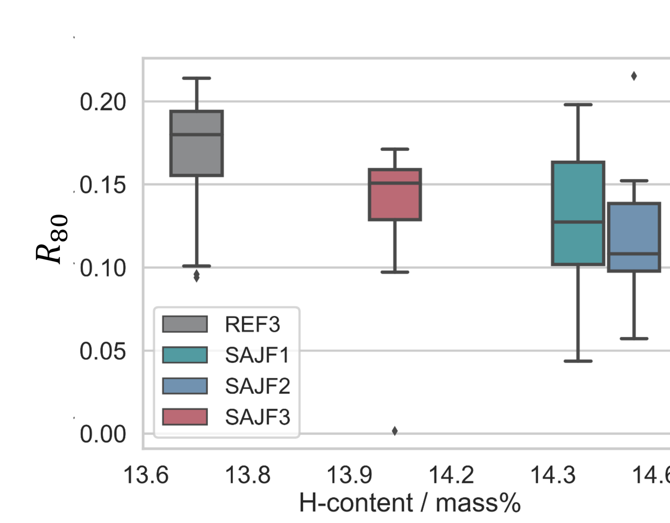


→ **Aromatics content** of fuel drives soot emissions
→ **Aromatics structure** further controls the soot formation in a non-linear way: more double cyclic aromatics → more soot
→ Summarized in the hydrogen-content parameter for the respective fuel (e.g., Lobo et al 2015)

Correlations of emitted particle sizes

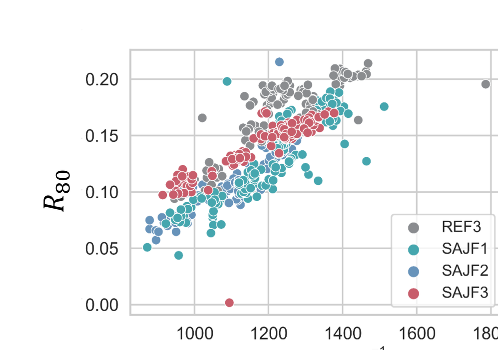
Fraction of non-volatile particles with D>80nm:

$$R_{80} = \frac{EI(N_{\mathrm{nvPM}}|D > 80\mathrm{nm})}{EI(N_{\mathrm{nvPM}}|D > 14\mathrm{nm})}$$



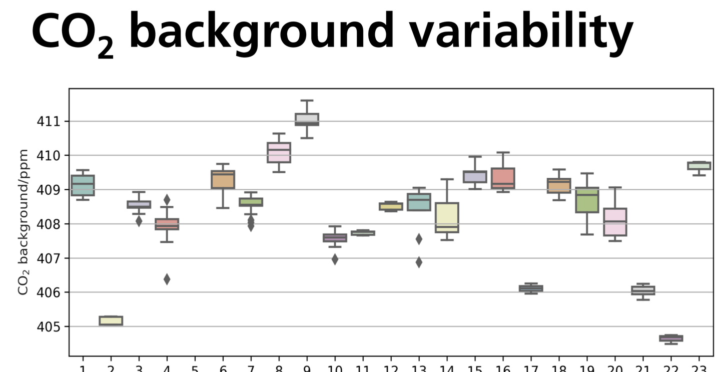
Particle size distribution moves to smaller particles with higher H-content

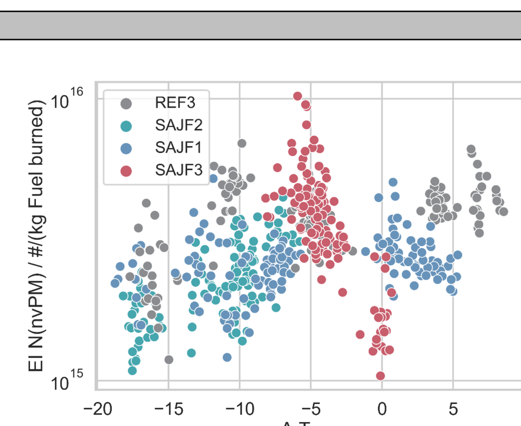
Particle size also correlates with engine parameters



Uncertainties

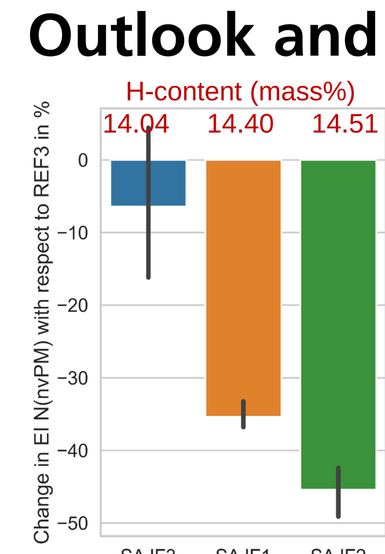
CO_2 background variability



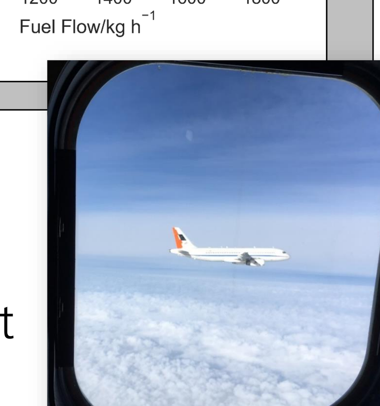


Correlation with Schmidt-Appleman threshold temperature e.g.Schumann (1996)
Contrail formation might affect particle measurements → effect seems small.

Outlook and conclusions



- Extensive data set with very good plume statistics for all fuel types with many data points for different engine settings and flight conditions
- Reduction of soot particle number emissions by up to 45% for alternative jet fuels tested here
- Reduction dependent on chemical fuel properties
- Effects on contrail formation is work in progress → upcoming publications Bräuer et al and Voigt et al



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Lobo et al. (2015) DOI:10.1016/j.atmosenv.2015.01.020
Schumann (1996), MetZ, 5, 4