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Measurements of particle emissions and contrail ice particle properties behind a large passenger aircraft burning 100% sustainable aviation fuel in cruise

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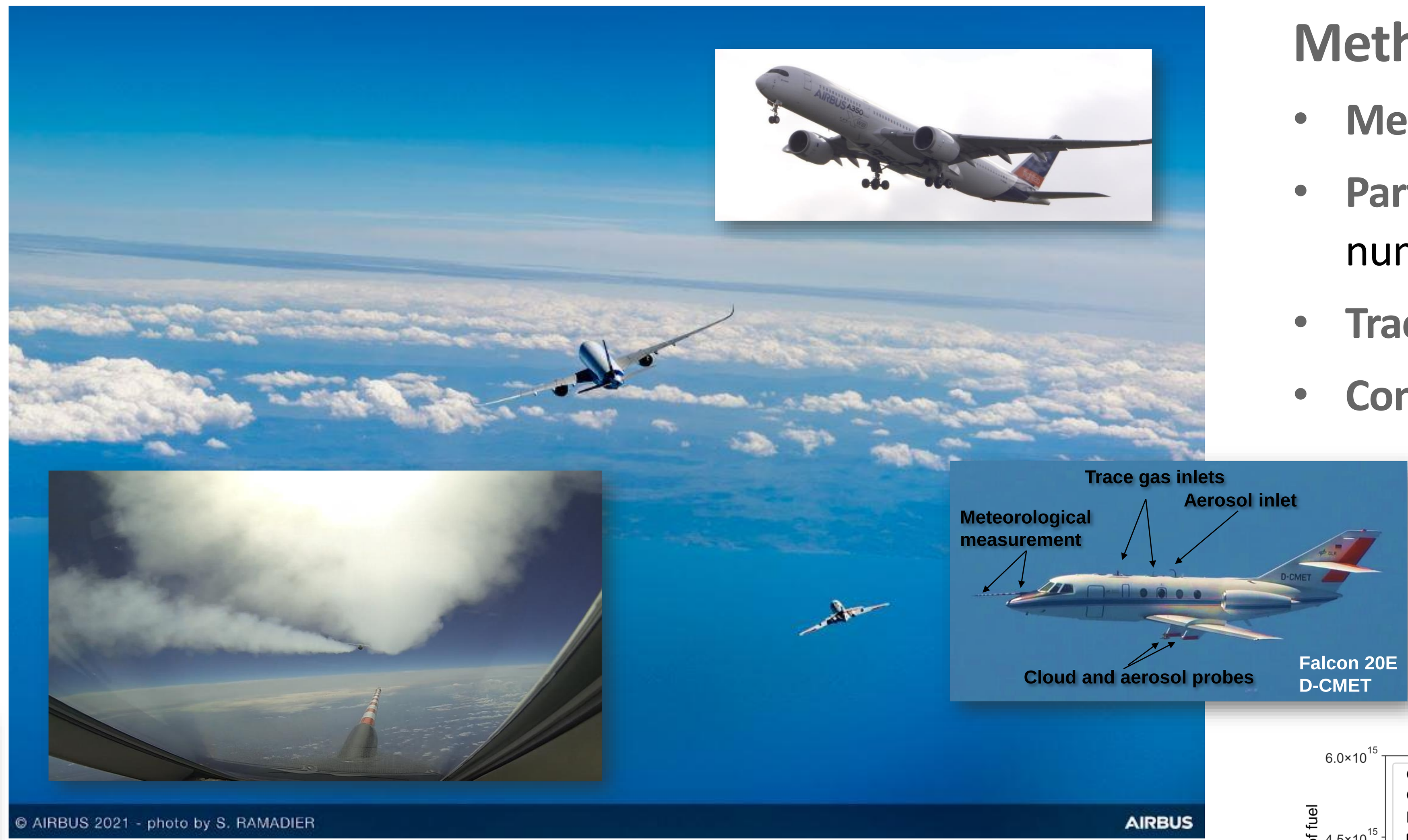
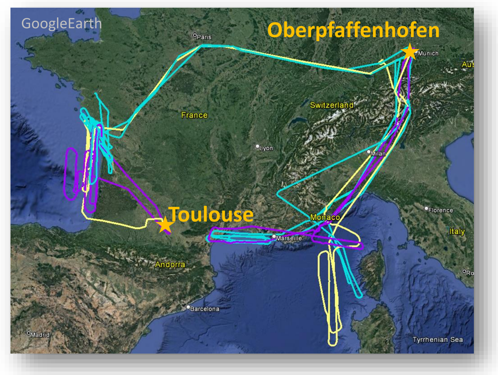
Motivation

- Long-lived contrails constitute a substantial contribution to aviation's climate impacts – even on long time horizons (Lee et al 2021).
- With conventional aircraft engines, contrail ice particle numbers correlate strongly with engine soot emission
- Use of low-aromatics sustainable aviation fuels (SAF) promise a reduction of ice particles but detailed effects at cruise level are thus far poorly understood and require more research with models and measurements



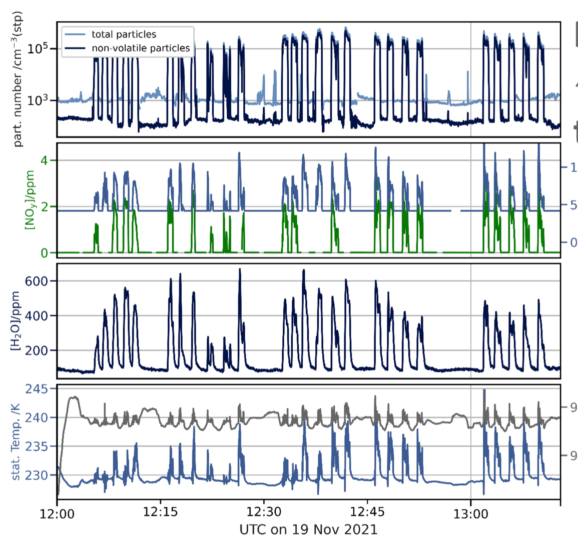
Experiment setup

- Source aircraft:
  A350-941 with Trent XWB-84 engines
  9 flights in Apr and Nov 2021
  near field (~100 m) and far field (20-40 km)
- Different engine power settings and altitudes
- Accompanying ground tests for ground-cruise comparison
- Fuels properties:

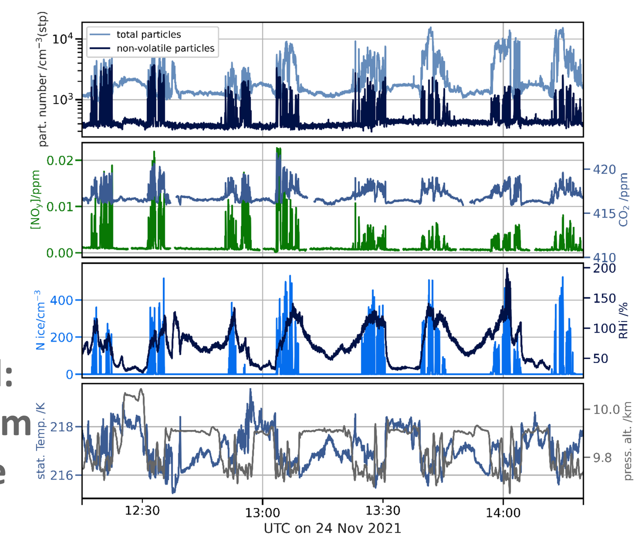


	ECLIF-1 Jet A-1	ECLIF3-1 HEFA	ECLIF3-2 Jet A-1	ECLIF3-2 HEFA	ECLIF3-2 Blend	Jet A-1 world av.
H-content [%m]	14.08	15.11	14.25	15.18	14.39	13.89
S-content [%m]	0.0211	0.0007	0.0125	0.0003	0.0505	0.0460
Naphtalenes [%v]	0.35	<0.08	0.50	<0.08	0.58	1.2
Aromatics [%v]	13.4	N/A	13.4	<0.1	10.8	19.2

Example time series of measurement data



Near field: ~100 m behind the engine

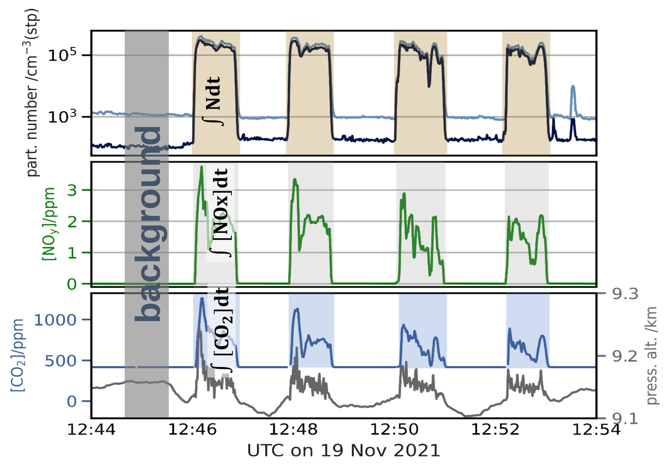


Far field: 20 -40 km distance

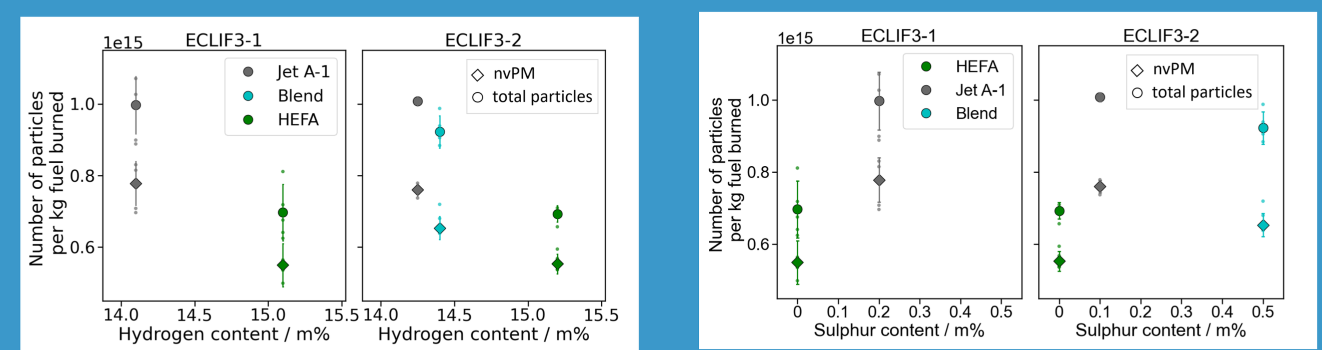
Emission index for species X based on tracer Tr:

$$EI_X = \frac{\Delta X}{\Delta \mathrm{Tr}} \frac{M_{\mathrm{air}}}{M_{\mathrm{Tr}} \rho_{\mathrm{air}}} EI_{\mathrm{Tr}}$$

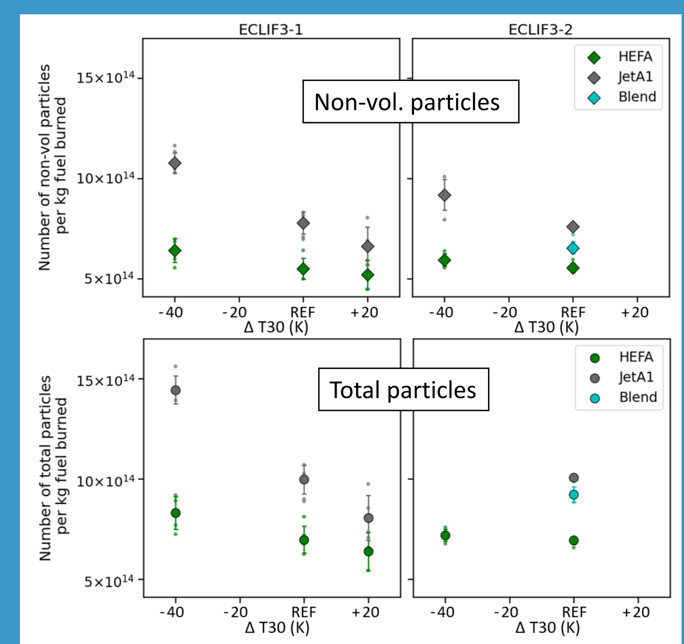
Tracers used are CO_2 and NO_y



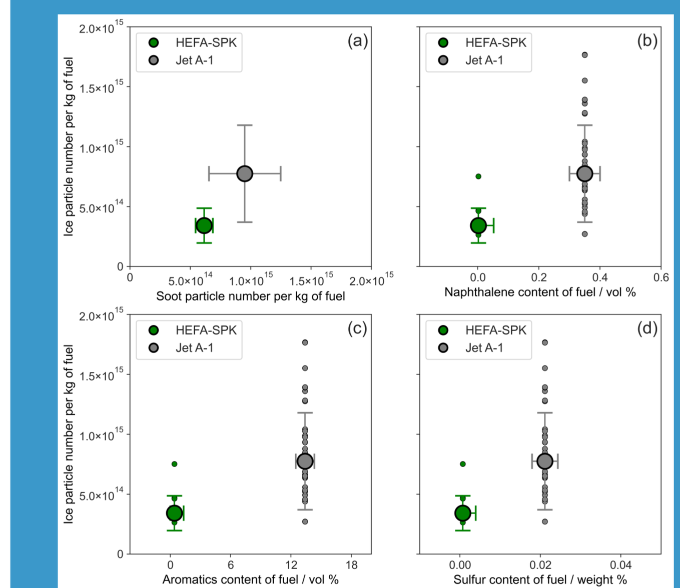
Results



Observed particle emissions as a function of fuel properties



Observed particle emission indices versus changes in the engine combustor inlet temperature T30

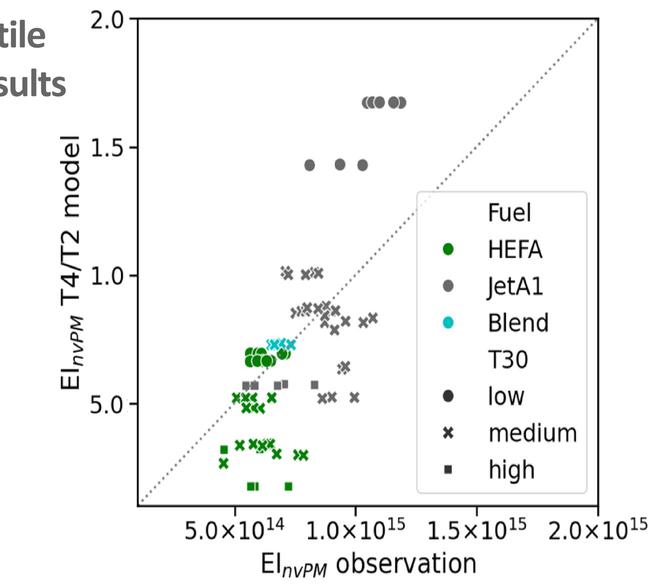


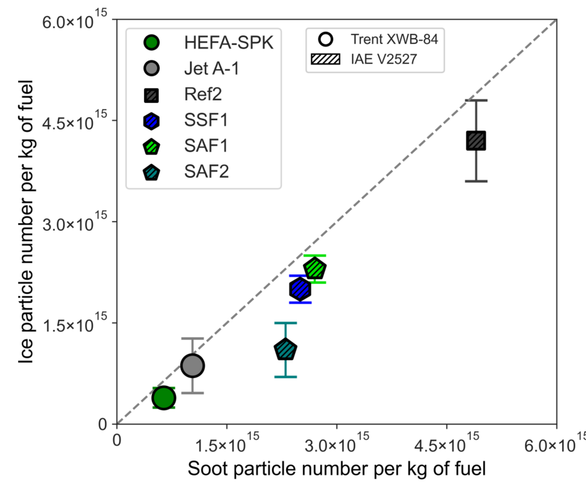
Observed ice particle apparent emission index as a function of observed soot emissions and fuel properties

Methods and Instrumentation

- **Measurement platform:** DLR Falcon 20 research aircraft
- **Particle measurements:** total and non-volatile particle number in different size ranges down to 5 nm
- **Trace gas measurements:** CO_2, NO_y, CO, CH_4, H_2O
- **Contrail ice particles:** particle size distributions 0.6 to 50 µm

Comparing observed non-volatile particle emissions to model results using the T2T4 model [2]:





Observed non-volatile particle emissions and ice particles compared to measurements from ECLIF2/NDMAX [3]

Conclusions

- Use of 100% HEFA-SPK fuel reduces ice particle numbers by ~56% compared to Jet A-1 in cruise
- The measured 35% reduction in soot particles suggest reduced ice activation by the low sulfur HEFA fuel
- Detailed reductions in particle emissions depend on fuel but also engine power settings
- In addition to a reduction of CO_2 emission the use of HEFA-SPK can reduce aerosol and contrail particle numbers and provide an added climate benefit.

References

Details of this work are presented in:
Märkl et al, 2023, [preprint], https://doi.org/10.5194/egusphere-2023-2638
Dischl et al 2024, in prep.

[1] Lee et al, 2021, https://doi.org/10.1016/j.atmosenv.2020.117834
[2] Teoh et al, 2022, https://doi.org/10.5194/acp-2022-169
[3] Voigt et al, 2021, https://doi.org/10.1038/s43247-021-00174-y