

ICAO Symposium on Non-CO₂ Aviation Emissions

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Speaker

Session 2: Enhancing Scientific Knowledge
Part I – NO_x and Particulate Matter

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Part I: Non-CO2 Emissions and Particulate Matter

Volatile contributions to Particulate Matter: vPM

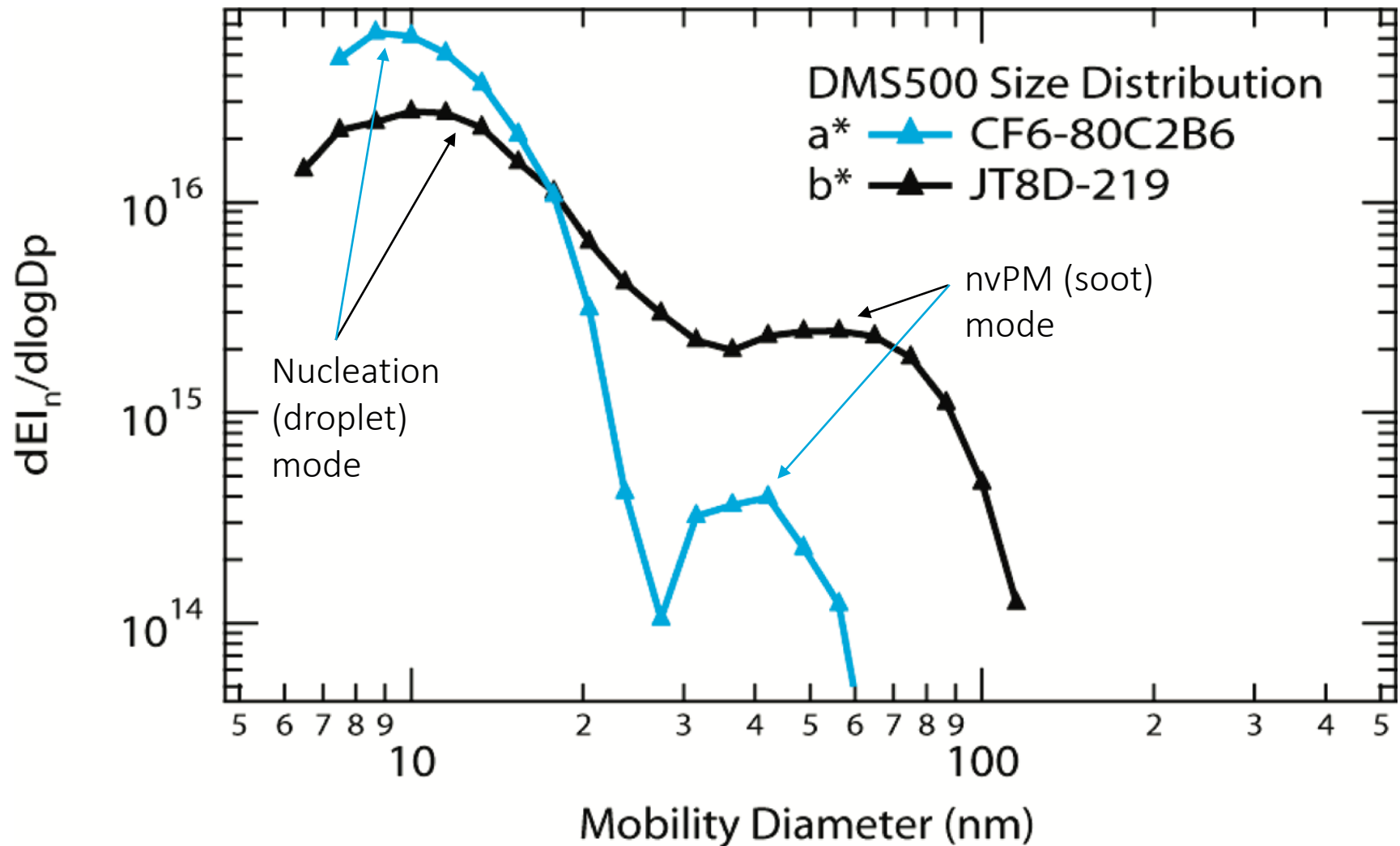
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Presentation Overview

- What is volatile PM: vPM (relative to nvPM)?
 - Why is vPM not part of nvPM standards?
- What species contribute to vPM?
- How is vPM important: LAQ and Contrails?
- What are next steps with vPM?

Aircraft total PM size distributions



- Advected plumes at airport (100s of m)
- Bimodal distributions indicate both soot mode and a smaller mode
- Smaller mode can be 1 to 2 orders of magnitude more numerous than soot mode
- Many additional engine and airport studies

from: Herndon et al., *Environ. Sci. Technol.* **2008**, 42, 1877–1883, 26 - 29
September 2004, MS&T (UMR) measurements at Hartsfield-Jackson International Airport, *with annotation added.*

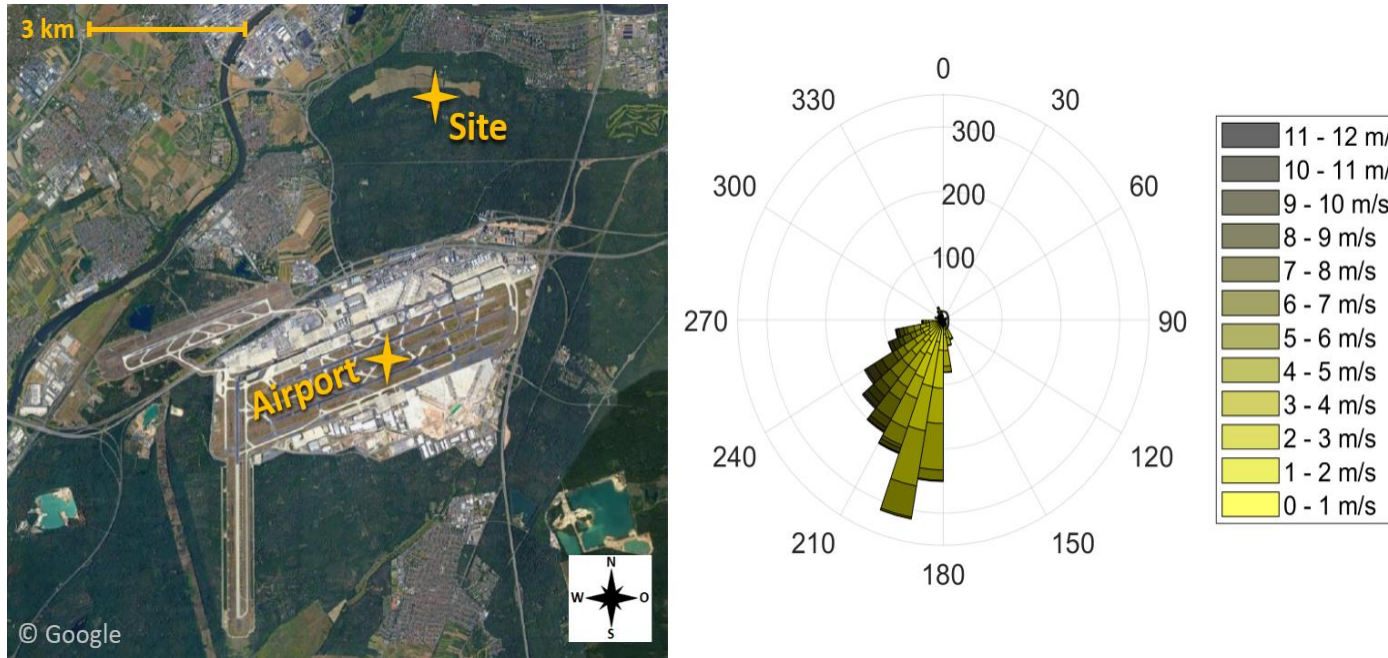
What is vPM?

- Condensable gases (low vapor pressure) form new particles and coat the existing soot particles as exhaust mixes with ambient air
 - vPM is both coatings on soot **and** new (smaller) totally volatile particles with no soot core. nvPM is the "uncoated" soot that leaves the engine.
- vPM depends on:
 - engine combustion processes (as does nvPM)
 - fuel composition (aromatic species, S, hydrocarbon matrix) (as does nvPM)
 - vented oil
 - ambient conditions (especially Temperature)
 - time after emission
- vPM not amenable to current engine exit-plane certification approach: vPM not currently regulated

What species contribute to vPM?

- Gaseous products of incomplete combustion
 - Complete combustion: $\text{Fuel} + \text{Air} \rightarrow \text{CO}_2 + \text{H}_2\text{O}$
 - Any raw fuel (very small and mostly at idle conditions)
 - Partially combusted fuel species (also small, but vPM particles are very small)
- Sulfuric Acid (H_2SO_4) from oxidized fuel S
 - Few % of total fuel S (ppmm) is H_2SO_4 , most is emitted as SO_2
 - But H_2SO_4 (with H_2O) is exceptionally able to nucleate new particles.
- Engine oil: totally separate from engine combustion processes
 - Unlike piston engines (cars, trucks, small airplanes), oil is not exposed to combustor conditions in an aircraft gas turbine engine.
 - Emitted gas turbine oil is indistinguishable from new oil (not significantly oxidized)
 - Oil can be vented in hot exhaust or in cold ambient stream, greatly affecting how oil contributes to vPM. Various engine manufacturers vent differently.

Airport PM studies: focus on vPM



E.g.: Ungeheuer, F., van Pinxteren, D., and Vogel, A.L., *Identification and source attribution of organic compounds in ultrafine particles near Frankfurt International Airport*, Atmos. Chem. Phys., 21, 3763–3775, 2021

Also:

Mueller, S.C., Hudda, N., Levy, J.I., Durant, J.L., Patil, P., Lee, N.F., Weiss, I., Tatro, T., Duhl, T., and Lane, K., *Changes in Ultrafine Particle Concentrations near a Major Airport Following Reduced Transportation Activity during the COVID-19 Pandemic*. Env. Sci. & Tech. Letters, 9, 706-711, 2022.

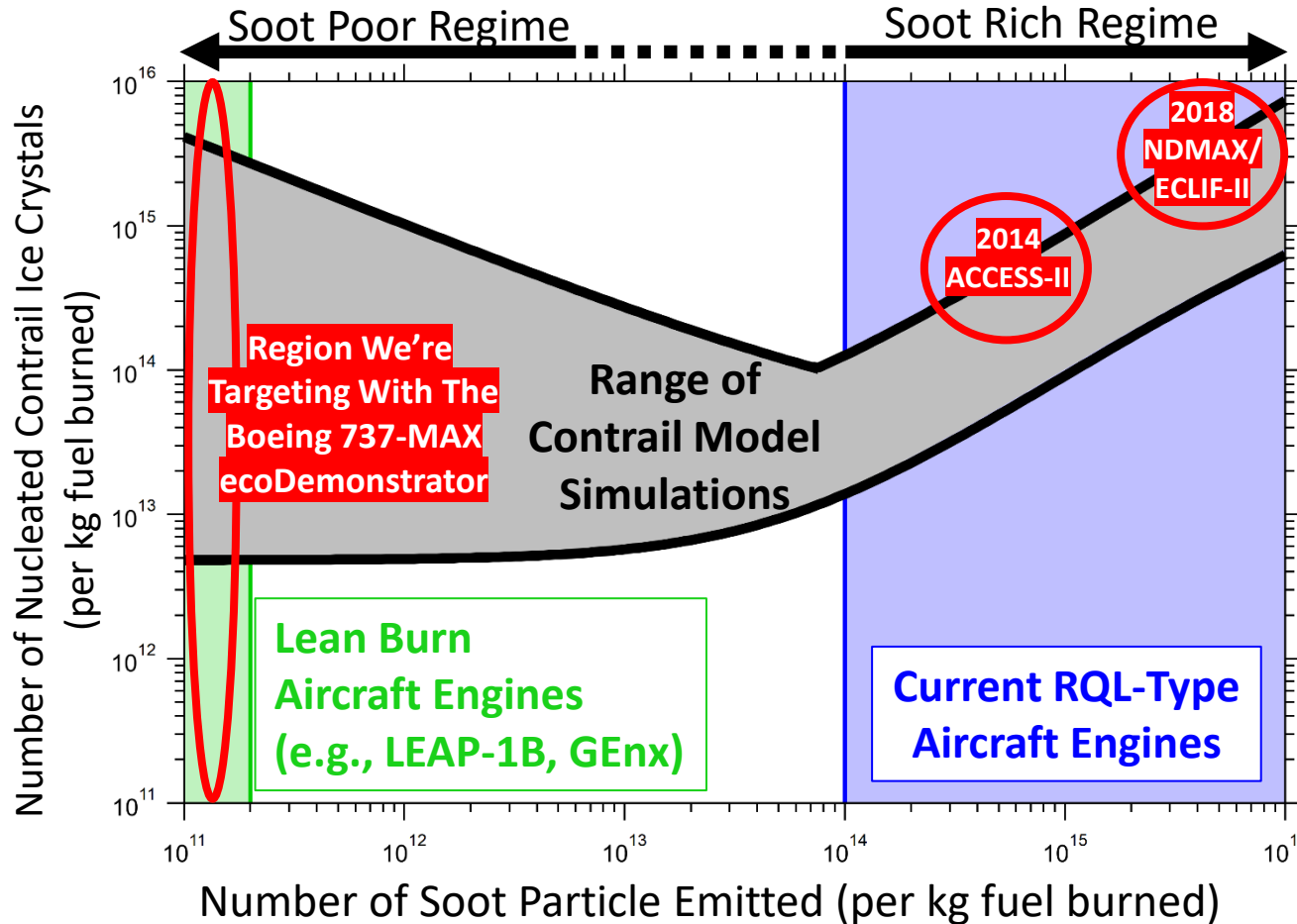
Fushimi, A., Saitoh, K., Fujitani, Y., and Takegawa, N., *Identification of jet lubrication oil as a major component of aircraft exhaust nanoparticles*, Atmos. Chem. Phys., 19, 6389–6399, 2019

Hudda, N., Gould, T., Hartin, K., Larson, T.V., Fruin, S.A., *Emissions from an international airport increase particle number concentrations 4-fold at 10km downwind*. Environ. Sci. Technol 48, 6628e6635, 2014.

and many more . . .

vPM role in contrail formation?

Great Potential of SAF and Advanced Combustor Technology



Need to understand engine particle emissions in the “soot-poor” regime in order to connect to contrail formation and climate impacts

Emissions reductions also beneficial for air quality

Figure adapted from Kärcher, *Nature Communications*, 2018.

Red circles show the approximate Number EIs observed during the 2014 ACCESS-II and 2018 ND-MAX/ECLIF-II flight test series.

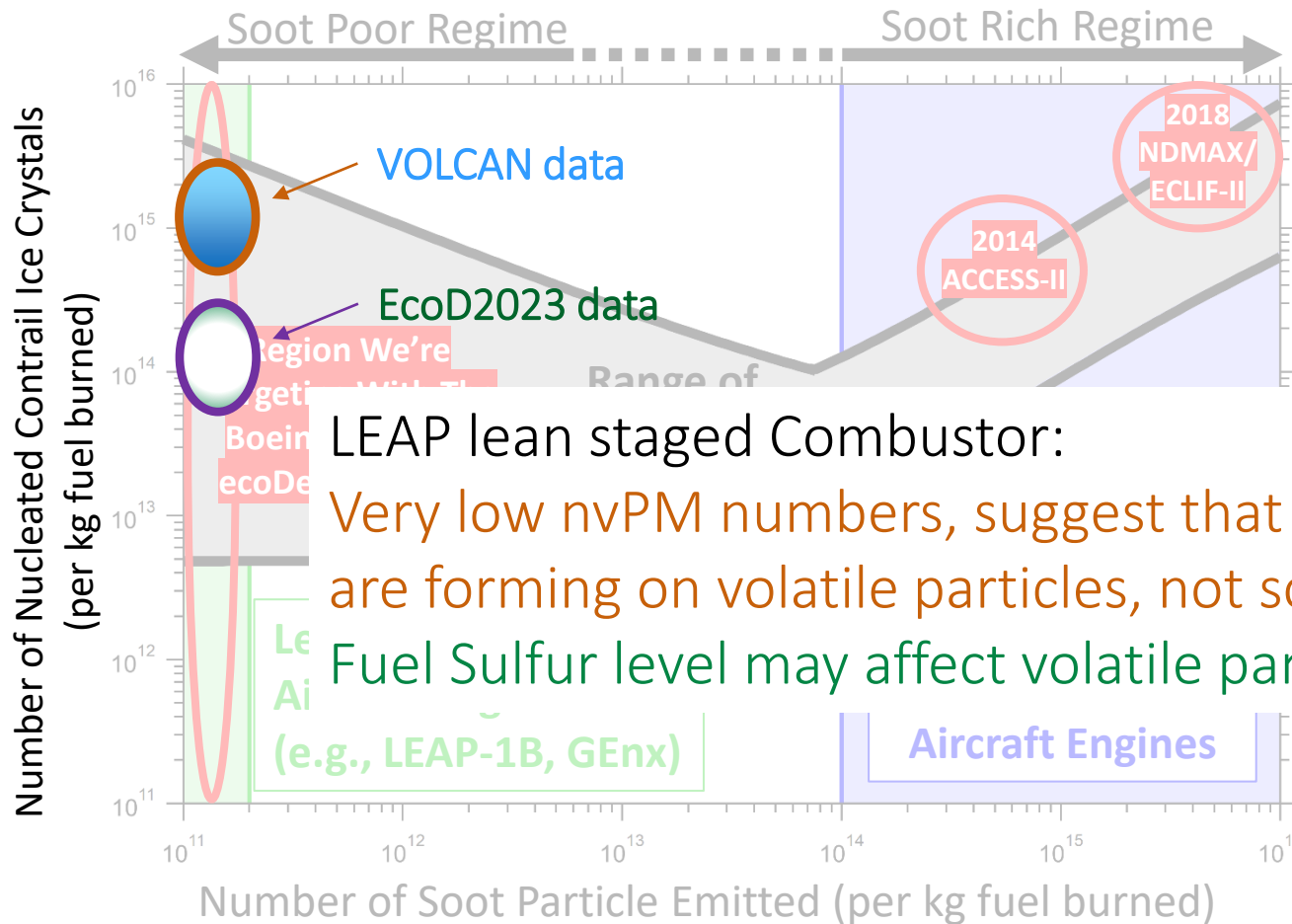
Moore et al., *Nature*, 2017; Voigt et al., *Nature Comms. Earth & Environ.*, 2021

Rich Moore (NASA) TAC-5 talk 2022

When nvPM is very low, contrails form on vPM?



Great Potential of SAF and Advanced Combustor Technology



Need to understand engine particle emissions in the "soot-poor" regime in order to connect to contrail formation and climate

LEAP lean staged Combustor:

Very low nvPM numbers, suggest that contrail particles are forming on volatile particles, not soot

Fuel Sulfur level may affect volatile particle properties

Red circles show the approximate Number Eis observed during the 2014 ACCESS-II and 2018 ND-MAX/ECLIF-II flight test series.

Moore et al., Nature, 2017; Voigt et al., Nature Comms. Earth & Environ., 2021

What are next steps with vPM?

- What are health impacts and contrail impacts?
- Need better understanding of mechanisms for new particle formation (especially for very low nvPM & sulfur)
 - Role of S vs organic species vs oil, especially as engines emit fewer particles, fuel sulfur decreases, and fuel composition evolves (SAFs)
- What can be done to control vPM?
 - Control of fuel composition and oil emissions are (mostly) independent of combustor design: aromatics vs cyclo-paraffins, S level, etc.
 - Jet fuel standards have no lower limit on sulfur content
 - Current driver for control of oil is simply mechanical usage, oil not evaluated or regulated as an emission. What venting approach is better?
- What changes to fuel and engines (including oil venting) are warranted to affect vPM emissions?

Thank You

