Understanding Marine Boundary Layer Aerosol Number Budget Using Airborne Measurements

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INTRODUCTION, BACKGROUND, AND MOTIVATION

Climate change predictions are influenced by uncertainties in marine boundary layer (MBL) cloud condensation nuclei (CCN) concentrations, affecting our understanding of cloud-aerosol interactions and climate sensitivity.

The MBL aerosol composition is controlled by three key sources:

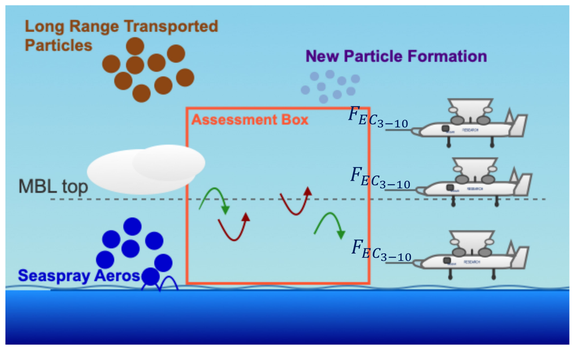
- Long-range transported continental aerosols
- In-situ new particle formation
- Sea spray aerosols from ocean surface bubble-bursting

Accurate modeling of cloud radiative properties depends requires understanding of how these sources contribute to the CCN budget. Current models show significant discrepancies in their representation of these processes.

Vertical turbulent fluxes of particles are a crucial but understudied mechanism that can provide valuable insights into CCN sources and sinks over the oceans.

METHODS

1: CPCs 3025A and 3772 (>3nm and >10nm)
2: Merged aerosol size distribution from 10 nm to ~12 µm
3: Liquid Water Content
4: Balloon Radiosonde Measurements (VAP)



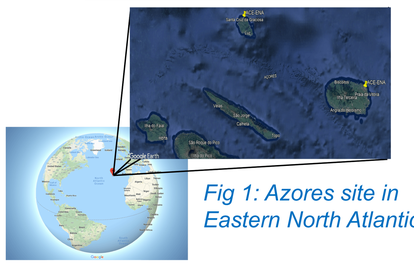


Fig 1: Azores site in Eastern North Atlantic

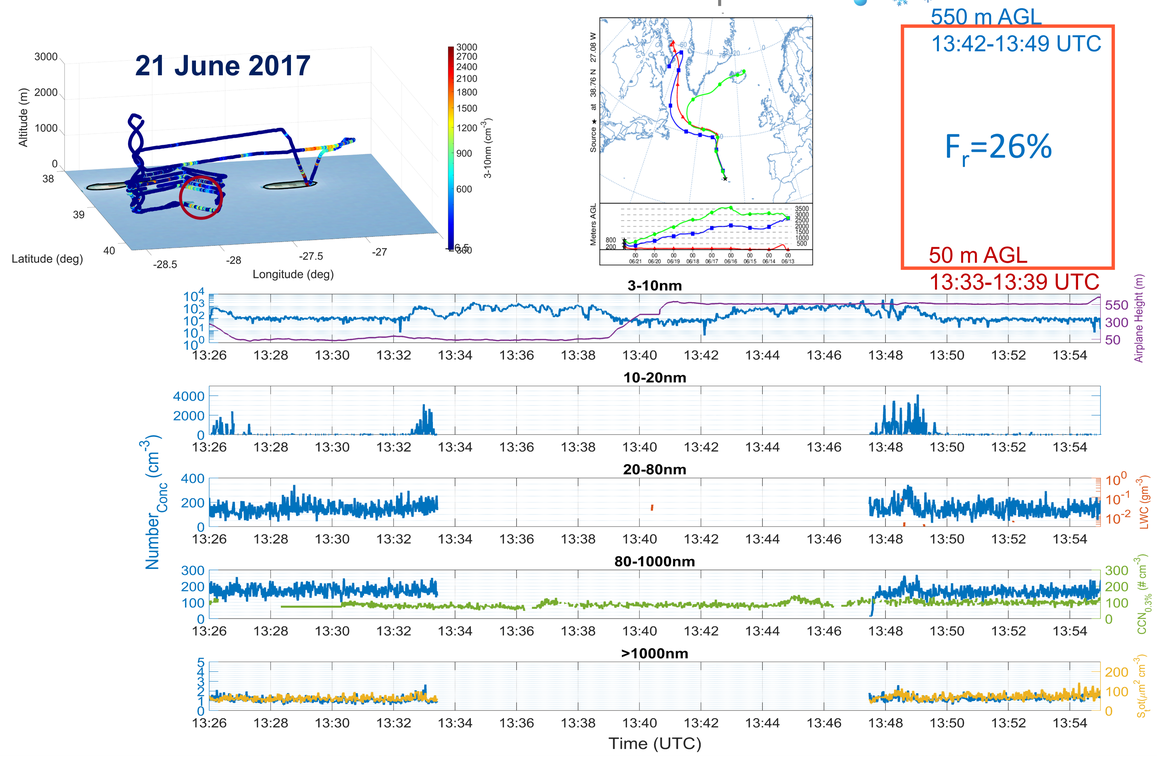
Vertical turbulent flux of particles

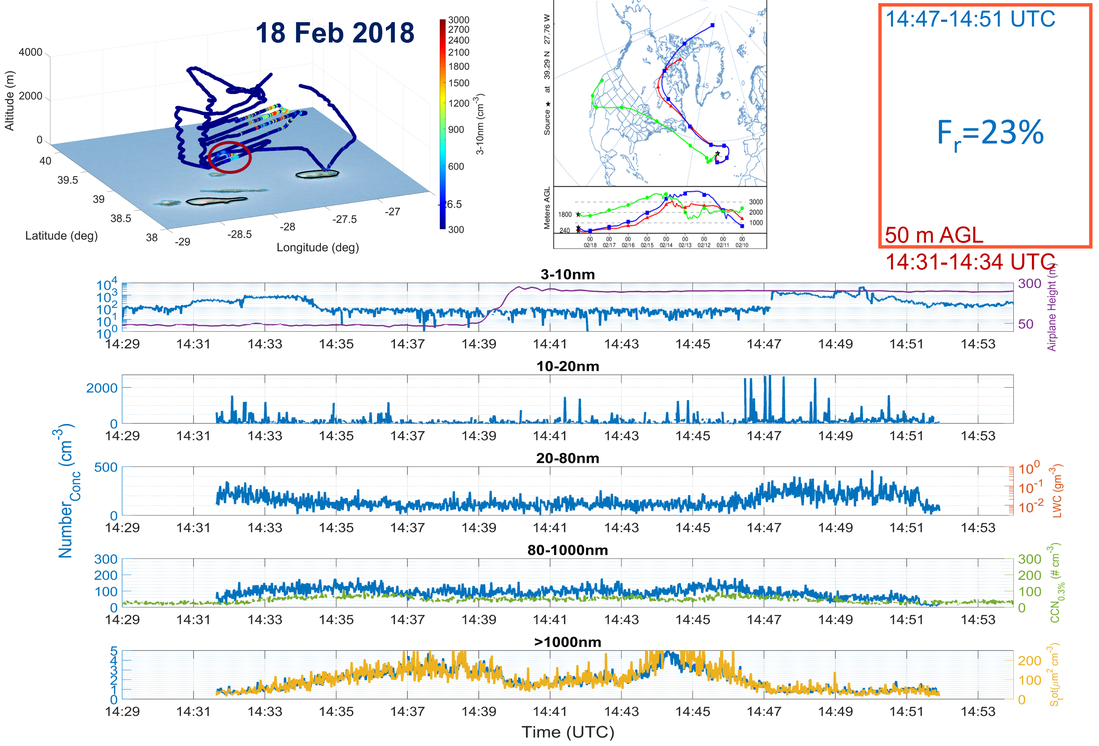
$$F_{EC_{3-10}}(z) = \overline{w'(z)N'(z)}$$

Fractional contribution of 3-10 nm sized particles to total number inside the box

$$\mathrm{Fr} = \frac{F_{EC_{3-10}} \cdot u_*^{-1}}{N_{10} + F_{EC_{3-10}} \cdot u_*^{-1}}$$

RESULTS





KEY FINDINGS AND IMPLICATIONS

- Our observations revealed multiple instances where particle concentrations in the 3-10 nm size range exceeded 5,000 cm^{-3}, indicating substantial new particle formation (NPF) events within the marine environment.
- Eddy covariance measurements revealed both the strength (ranging from 320 to 4,000 particles cm^{-2} s^{-1}) and directionality of 3-10 nm particle fluxes, providing valuable insight into the spatial origin of NPF events.
- Particles in the 3-10 nm size range contributed an average of 25 % to the MBL aerosol number budget.

CONTEXTUAL RESEARCH

- Tower measurements of 3-10 nm sized particle fluxes have helped separate near-surface from residual-layer particle nucleation events (Islam et al., 2022).
- Doppler Lidar measurements have quantified wind-driven emissions of coarse-mode particles in rural (Rasheeda Satheesh et al., 2024), urban (Petters et al., 2024), and marine (Pujiastuti et al., 2025) environments.
- This study used aircraft measurements to estimate the contribution of 3-10 nm size particles to the marine boundary layer aerosol budget.
- CALIPSO satellite retrievals have assessed dry deposition of mineral dust mass over the Caribbean (Rasheeda Satheesh and Meskhidze 2025).

FUTURE DIRECTIONS

- Future studies should integrate flux measurements across different spatial and temporal scales, developing standardized guidelines for scaling particle flux measurements from local to global perspectives.

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