Remotely-controlled ice-nucleating particle measurements from the Eastern North Atlantic during autumn and winter

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BACKGROUND

- Ice-nucleating particles (INPs) catalyze heterogeneous formation of ice crystals under ice supersaturation conditions and change cloud characteristics, affecting both weather and climate
- First remote semi-autonomous and continuous multi-season INP concentration measurements from ENA region from October 2020 – March 2021

OBJECTIVES

- Describe on the response of INP concentrations to local and mesoscale dynamics and thermodynamic processes using PINE and other collocated instruments
- Compare marine biological productivity, using satellite-derived chlorophyll a as a proxy for biomass, and INP concentrations
- Compare seasonal differences in meteorological data as it compares with INP concentration data

EASTERN NORTH ATLANTIC SAMPLING SITE

Table 1: Instruments present at Eastern North Atlantic sampling site

Instrument	Products	Company	Model	Sample Time Resolution	Sample Flow Rate (lpm)
Portable Ice Nucleation Experiment Chamber	Ice nucleating particle concentrations	Bilfinger Noell; KIT	PINE-03	~8 m	3
Condensation Particle Counter	Particle concentrations	TSI, Inc	3772	1 s	1
Aerosol Chemical Speciation Monitor	Particle mass for non-refractory aerosols	Aerodyne Resarch, Inc	n/a	30 m	n/a
Particle Soot Absorption Photometer	Three-wavelength aerosol light absorption	Radiance Research	n/a	1 m	1
Integrating Nephelometer	Three-wavelength aerosol light scattering	TSI, Inc	3563	1 m	8.5
Humidified Tandem Differential Mobility Analyzer	Particle size distribution, growth factor	Brechtel Manufacturing, Inc	3002	6 m	1
Cloud Condensation Nuclei Particle Counter	Cloud condensation nuclei particle concentrations	Droplet Measurement Technologies	CCN-100	1 m	0.5
Weather Transmitter	Wind speed, direction, temperature, pressure, relative humidity, and rain	Vaisala	WXT520	1 s	n/a
Ceilometer	Cloud base height, planetary boundary height	Vaisala	CL31	1 m	n/a

- Sampling took place from October 1, 2020 to March 28, 2021 continuously (182 days)
- Results shown here from Autumn 2020 (Oct 1 - Nov 30, 2020) and Winter 2020-21 (Dec 1, 2020 - Feb 28, 2021)
- INP concentrations measured using the Portable Ice Nucleation Experiment chamber described in Möhler et al., 2021
- Other aerosol instrumentation described in Table 1
- All instrumentation operated remotely except for setup period (10 days)

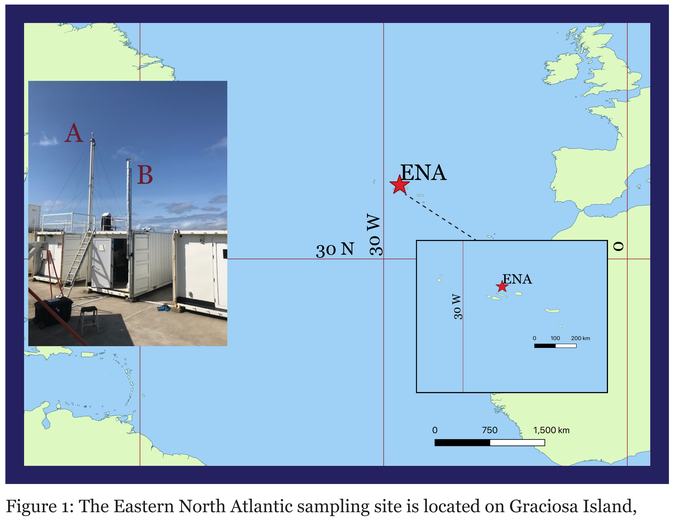


Figure 1: The Eastern North Atlantic sampling site is located on Graciosa Island, Azores at 39.0916 N, 28.0257 W. The aerosol sampling stack (a) and custom-built inlet from which PINE samples (b) are shown in the left image.

METEOROLOGICAL CONDITIONS

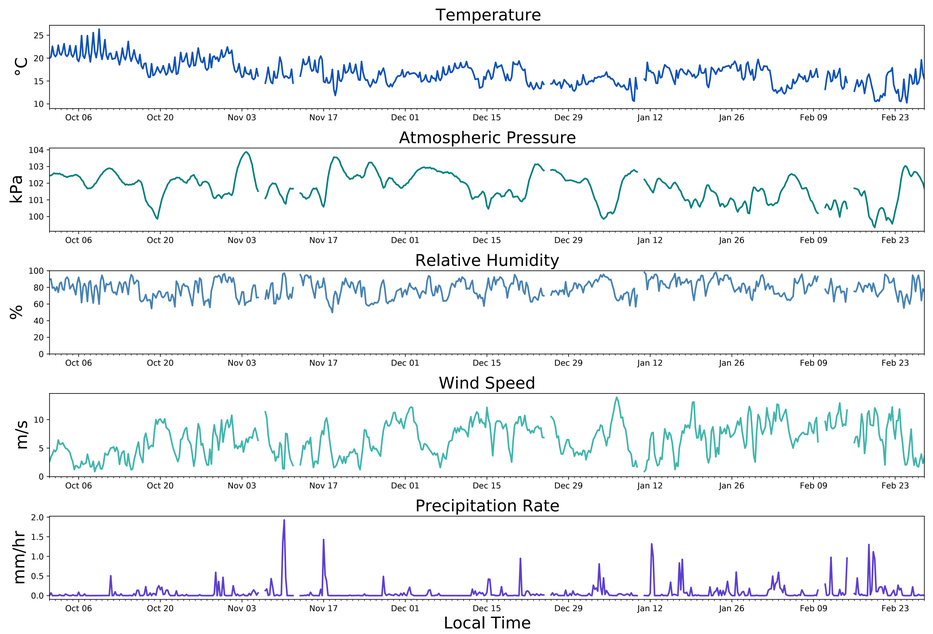


Figure 2: From top to bottom, atmospheric pressure, atmospheric temperature, relative humidity, mean wind speed, and precipitation rate measured at the ENA sampling site during the study (6-hour averages).

- Graciosa Island in both autumn and winter had high relative humidity values (>50%) and moderate temperatures ranging from 28 °C to 7.5 °C
- Only temperature showed any seasonal trends (decreasing as time progressed)
- INP concentrations did not correlate with any single meteorological variable

AIR MASS ORIGINS

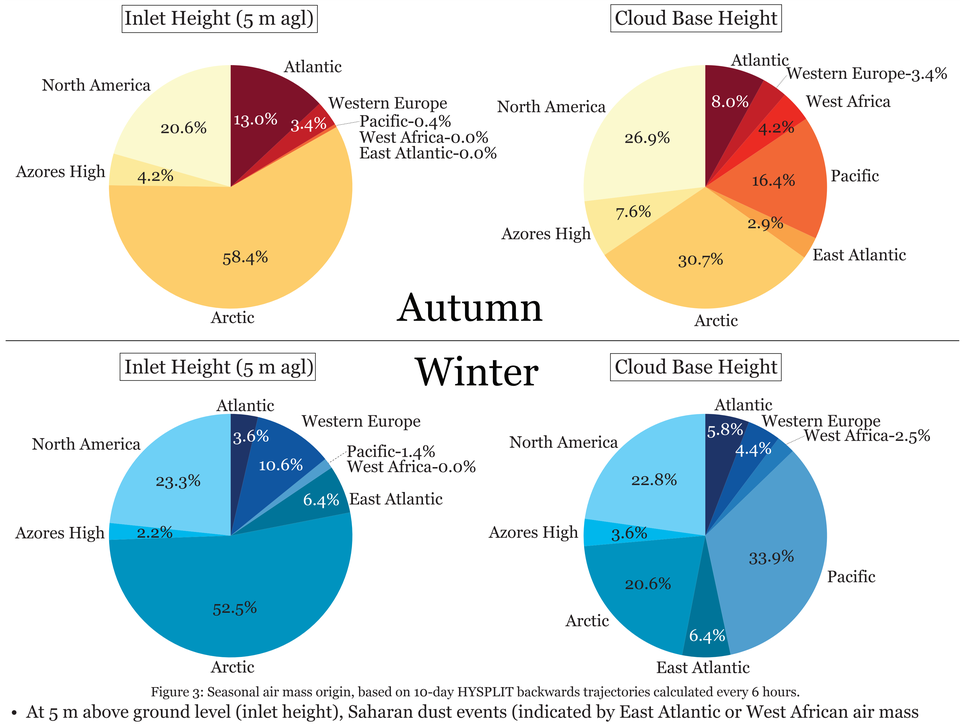


Figure 3: Seasonal air mass origin, based on 10-day HYSPLIT backwards trajectories calculated every 6 hours.

- At 5 m above ground level (inlet height), Saharan dust events (indicated by East Atlantic or West African air mass source) only occurred during winter months
- Cloud base height air masses traveled further than inlet height air masses during both seasons as indicated by the presence of air masses originating in the Pacific ocean
- For autumn and winter, median first level cloud base height at 1541 m above ground level and median planetary boundary layer height at 335 m above ground level
- Less active INPs associated with Arctic air masses, especially during wintertime

AEROSOL TIME SERIES

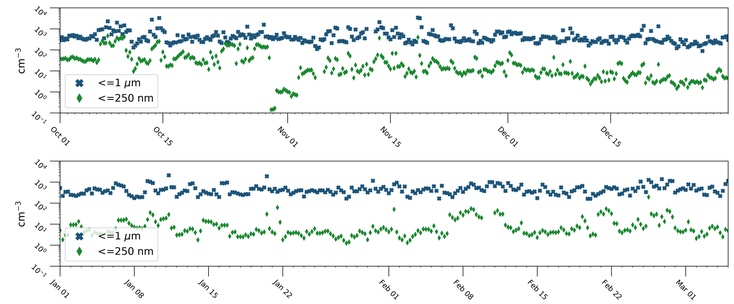
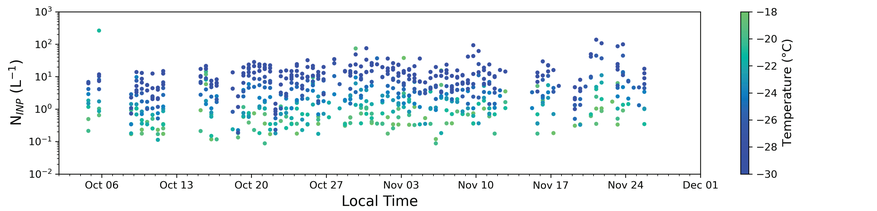


Figure 4: Aerosol particle concentration per cm³ of air. Values from the CPC are reported as blue crosses, while values from the HTDMA are reported as green diamonds.

- Particles <= 1 μm measured with CPC (TSI 3772), <250 nm calculated based on total aerosol count from HTDMA (Brechtel Manufacturing, Inc 3002)
- Particles <250 nm decrease over time from October 1, 2020 to February 28, 2021 (ρ = -0.55 to -0.67, p<0.001, n = 180)
- Autumn median count, <250 nm = 24.32 ccm while winter median count, <250 nm = 5.15 ccm
- Autumn median count, <1 μm = 297.6 ccm while winter median count, <1 μm = 369.4
- Difference between seasons is greatest at smaller diameters (measured by HTDMA)

INP SUMMARY AND CONCLUSIONS



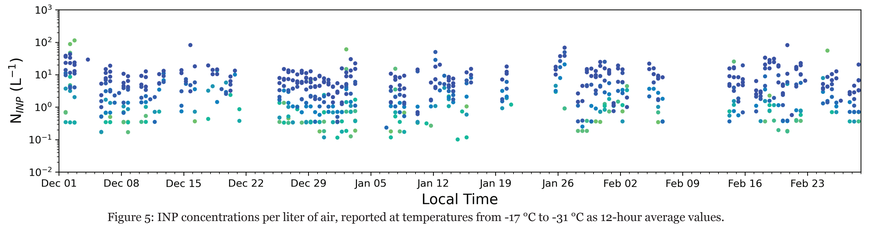


Figure 5: INP concentrations per liter of air, reported at temperatures from -17 °C to -31 °C as 12-hour average values.

- Median INP concentrations are lower in winter than autumn at all temperature ranges, but datasets are not significantly different (1-way ANOVA, p>0.05)
- Cold-temperature INPs (-25, -30 °C) decrease over time in winter (ρ = -0.58 to -0.6, p<0.001, n = 180)
- Highest measured single N_{INP} was 315.18 INP L^{-1} on December 20, 2020 at -29.3°C
- Saharan dust events lead to high INP concentrations, as do air masses that pass over Western Europe
- No relationship seen between ocean chlorophyll *a* and INP concentrations
- INP concentrations are comparable to past studies that measured INP concentrations at sites influenced by the Atlantic Ocean, but lower than terrestrial INP studies both with PINE and other instruments

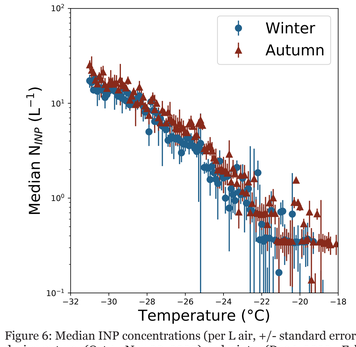


Figure 6: Median INP concentrations (per L air, +/- standard error) during autumn(Oct 1 - Nov 30, 2020) and winter (Dec 1, 2020 - Feb 28, 2021)

FUTURE WORK

- Comparison of samples taken at ENA with samples taken by PINE at U.S. Southern Great Plains site in Oklahoma
- Statistical analysis of error at temperatures from -15 °C to -30 °C
- Analysis of high-temperature INPs present at ENA using offline measurement techniques
- Sampling by PINE at North Slope Alaska site (Utqiagkvik, AK) in 2021-2023
- Further comparison of INP concentrations and marine biological activity

REFERENCES

• Möhler, O., Adams, M., Lacher, L., Vogel, F., Nadolny, J., Ullrich, R., . . . Murray, B. J. (2021). The Portable Ice Nucleation Experiment (PINE): a new online instrument for laboratory studies and automated long-term field observations of ice-nucleating particles. Atmos. Meas. Tech., 14(2), 1143-1166. doi:10.5194/amt-14-1143-2021

• Rolph, G., Stein, A., & Stunder, B. (2017). Real-time Environmental Applications and Display sYstem: READY. Environmental Modelling & Software, 95, 210-228. doi:10.1016/j.envsoft.2017.06.025

• Stein, A. F., Draxler, R. R., Rolph, G. D., Stunder, B. J. B., Cohen, M. D., & Ngan, F. (2015). Noaa's Hysplit Atmospheric Transport and Dispersion Modeling System. Bulletin of the American Meteorological Society, 96(12), 2059-2077. doi:10.1175/Bams-D-14-00110.1

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