Long-term Variability in immersion-mode Marine Ice Nucleating Particles from Climate Model Simulations and Observations

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Table S1. INP parameterizations : Potential and Limitations

INP parameterization	Study area	Sample type	Limitations
D15	Saharan and Asian deserts	Mineral dust particles larger than 0.5 μm	Does not distinguish between different dust minerologies.
W15	Arctic (July–August 2013)	Marine Organic Aerosol (MOA)	Does not include the differences in the emission and atmospheric chemistry of INPs between the airborne sea-spray (SSA) and sea surface microlayer water samples ; Entrainment of multiple INP species into a single SSA particle is not considered.
M18	Mace head station (August 2015)	Sea salt aerosol	Derived for clean marine conditions. Only background sea-spray INPs are captured.
M18+D15	Mace Head (August 2015) and Southern Ocean (March-April, 2016)	Dust and Sea salt	Represents only background INPs. Potential variations in marine INPs due to ocean biology or dust mineralogy are not captured.

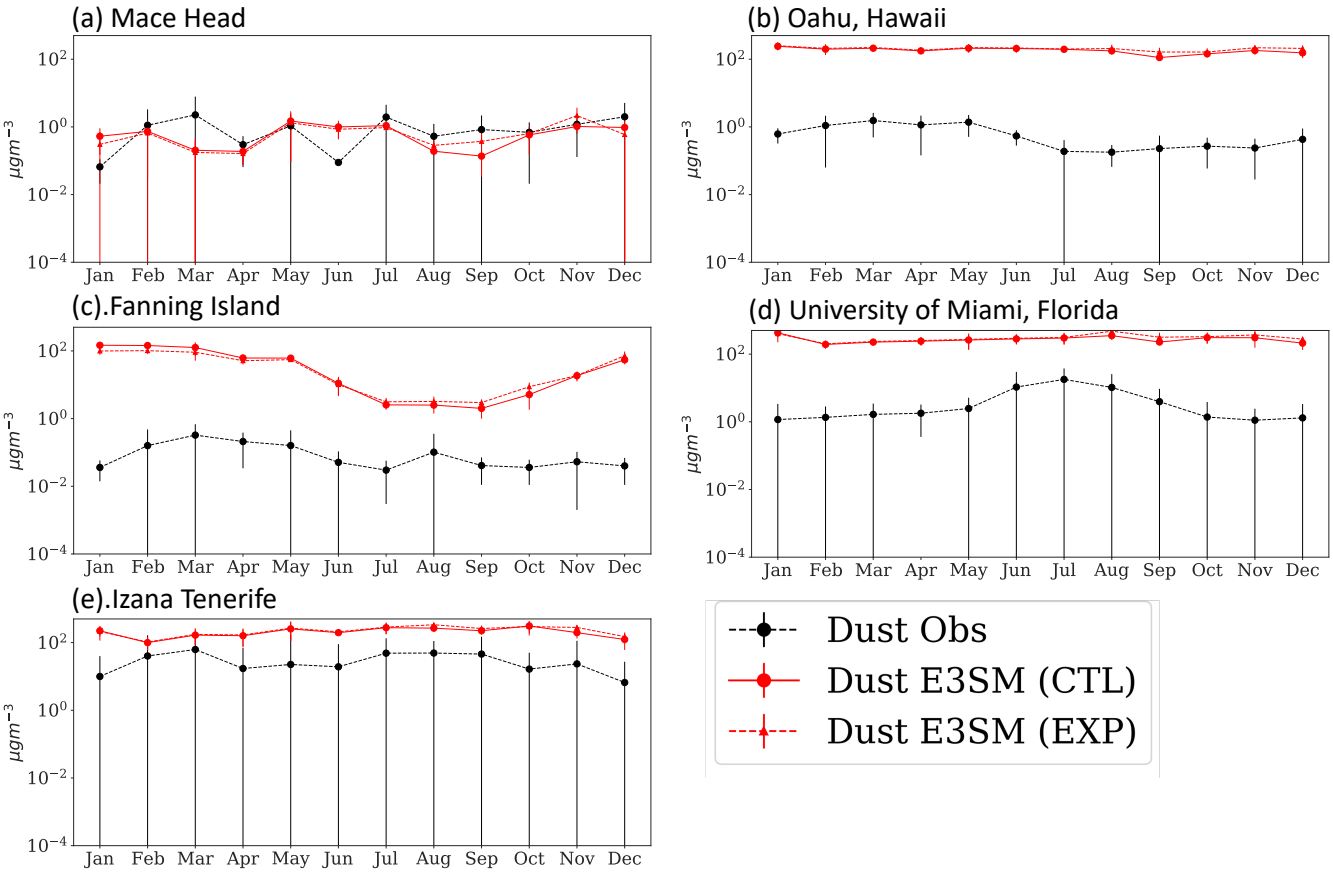

Figure S1. Climatology of dust concentrations from ground stations in the Northern Hemisphere compared against E3SM aerosol climatology. For the model, monthly average dust and sea salt concentrations are shown for the period 2016–2018. Error bars in the model represent standard deviation of aerosol mass concentrations for 2016–2018. Error bars in the observations for each ground station represent standard deviation of measurements. Both CTL and EXP are shown for comparison with observations.

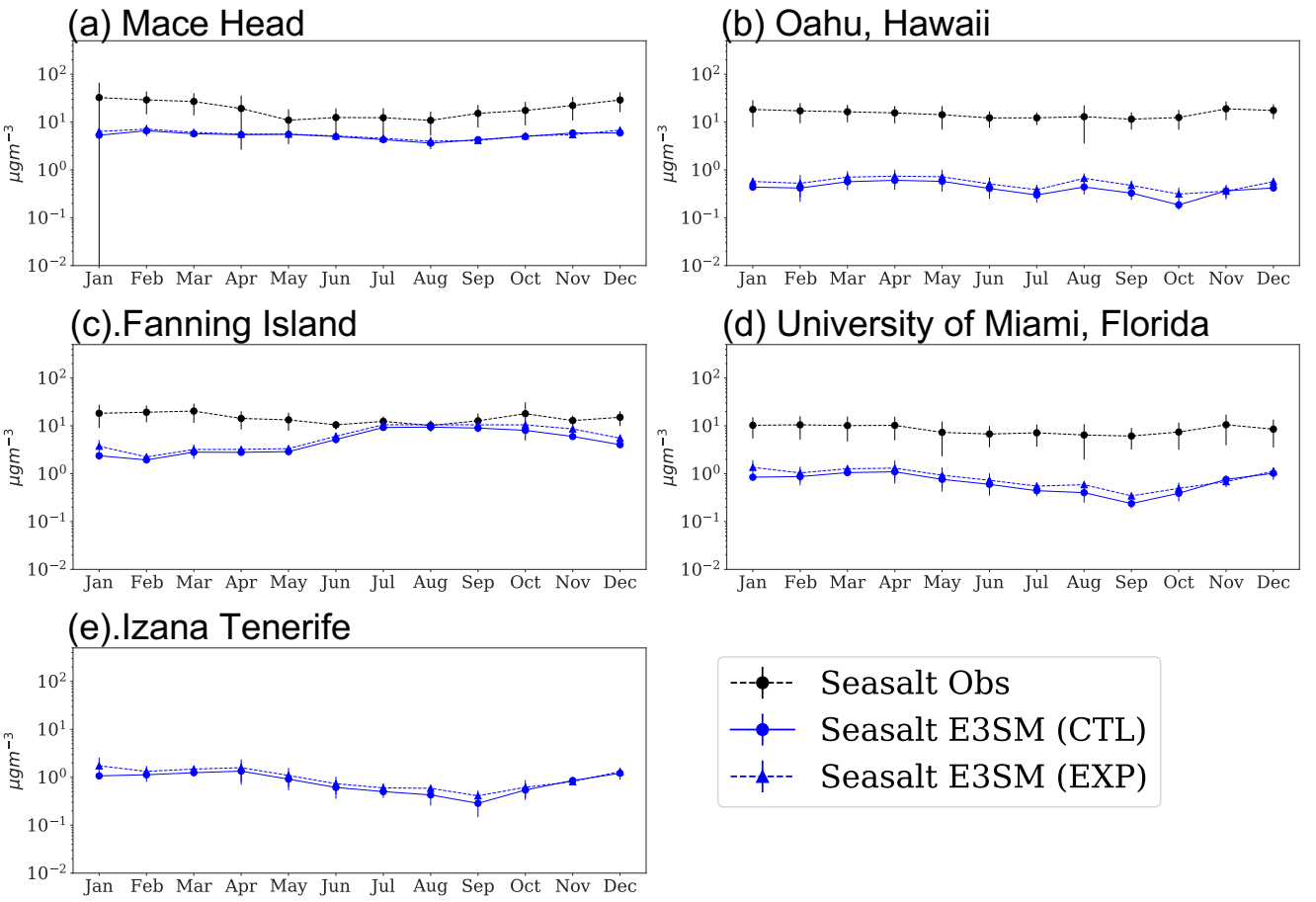

Figure S2. Climatology of sea spray concentrations from ground stations in the Northern Hemisphere compared against E3SM aerosol climatology. For the model, monthly average dust and sea salt concentrations are shown for the period 2016–2018. Error bars in the model represent standard deviation of aerosol mass concentrations for 2016–2018. Error bars in the observations for each ground station represent standard deviation of measurements. Both CTL and EXP are shown for comparison with observations.

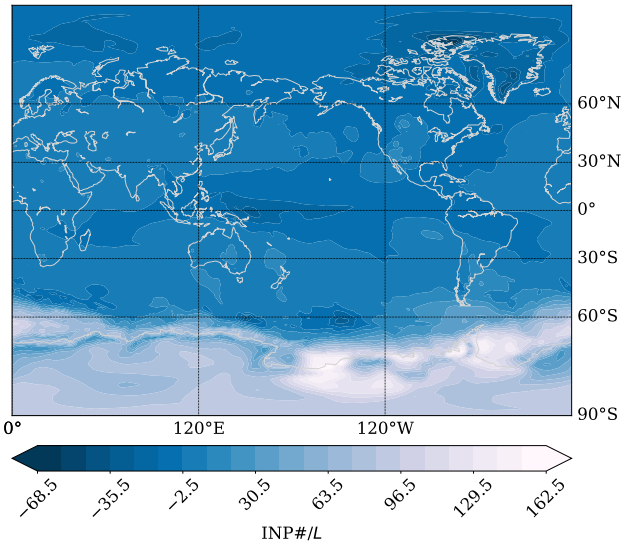

Figure S3. Differences in ratios of CNT and D15 INP parameterizations between $-20^{\circ}C$ and $-28^{\circ}C$

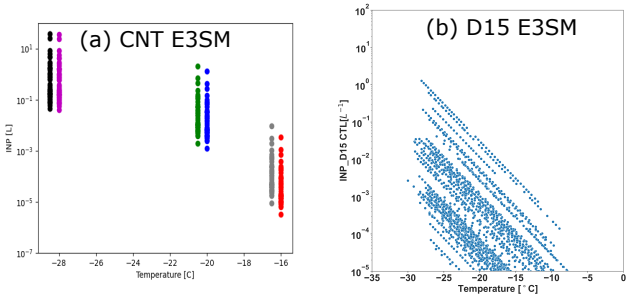

Figure S4. Comparison of INP dependence on temperature in CNT and D15 INP parameterizations from E3SM simulations.

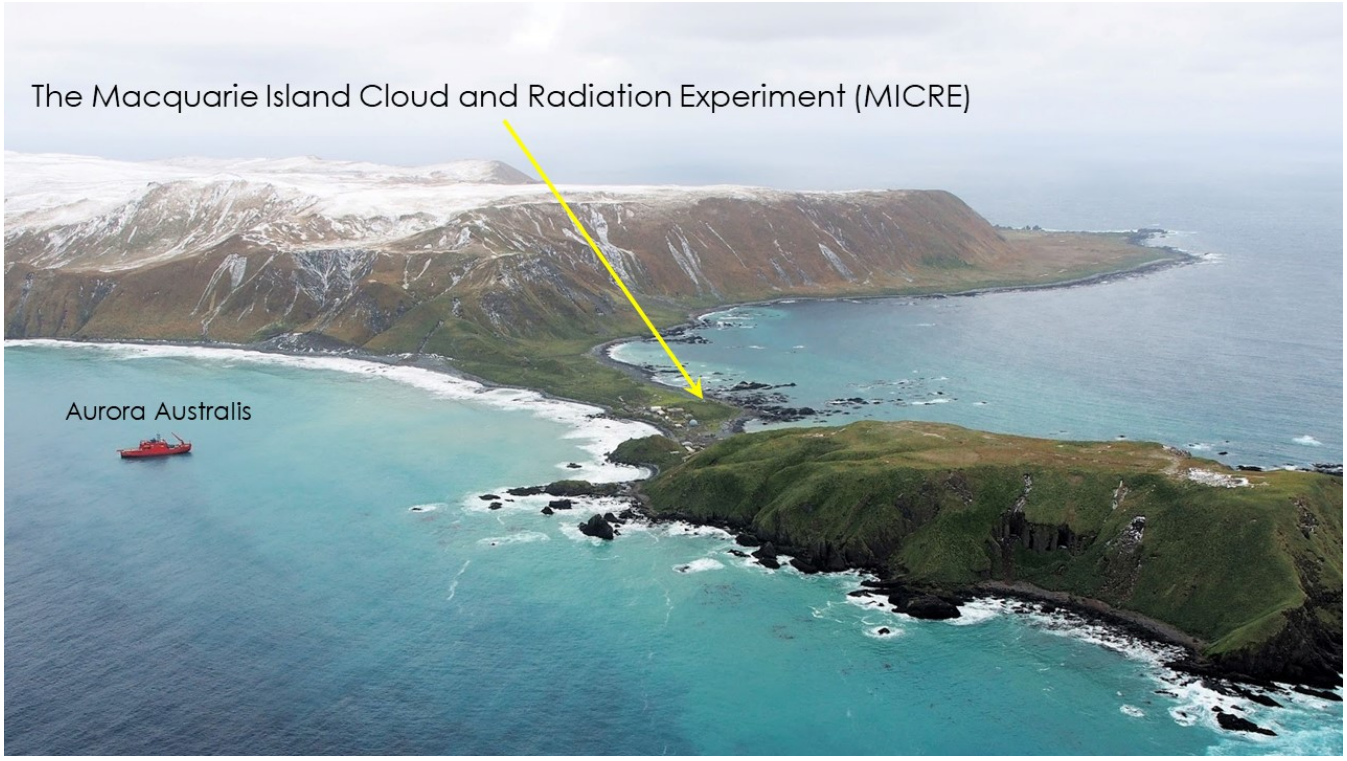

Figure S5. Aerial shot of Macquarie Island and MARCUS ship

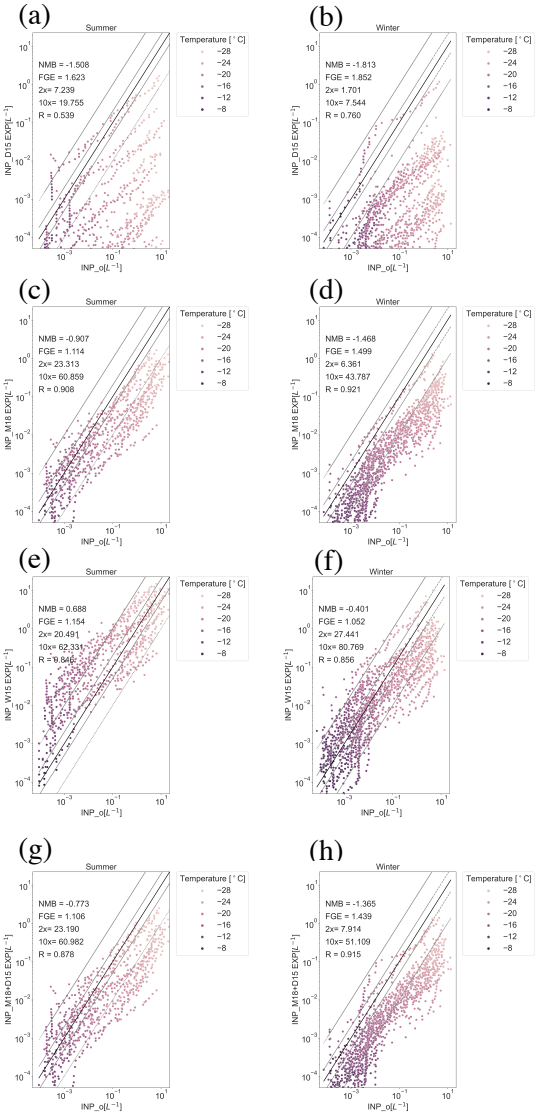

Figure S6. Comparison of observed versus predicted INP concentrations (L^{-1}) at the Macquarie Island for E3SMv1 simulations using the updated dry deposition parameterization. Left and right panels show scatter plots for austral summer (October-February) and austral winter (March - September) respectively. In this plot, we show model observation comparisons for for different INP parameterizations : (a) and (b) D15, (c) and (d) M18, (e) and (f) M18+D15, (g) and (h) W15. INP concentrations are colored by INP measurement temperatures. The solid line in each panel represents 1:1 equivalence, while dashed lines represent a factor of 2 and 10 difference from the observations, respectively. Error metrics in each panel include the normalized mean bias (NMB), Spearman correlation (R), percentage of model INPs within a factor of two from observations (2x), and percentage of model INPs within a factor of 10 from observations (10x).