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Towards the development of a baseline in ground-based **ice-nucleating particle (INP)** properties at three fixed ARM sites

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2022 ARM/ASR Joint User Facility and PI Meeting – 10/26/2022

ASR
Atmospheric System Research

Acknowledgement

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On-site Technical Support

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Research Collaboration

PNNL:	Aishwarya Raman & Susannah Burrows
AEROICESTUDY:	Daniel Knopf & Nicole Riemer et al.
TAMU:	Xiaohong Liu & Yang Shi
KIT:	Jens Nadolny, Larissa Lacher & Ottmar Möhler

Project Goals

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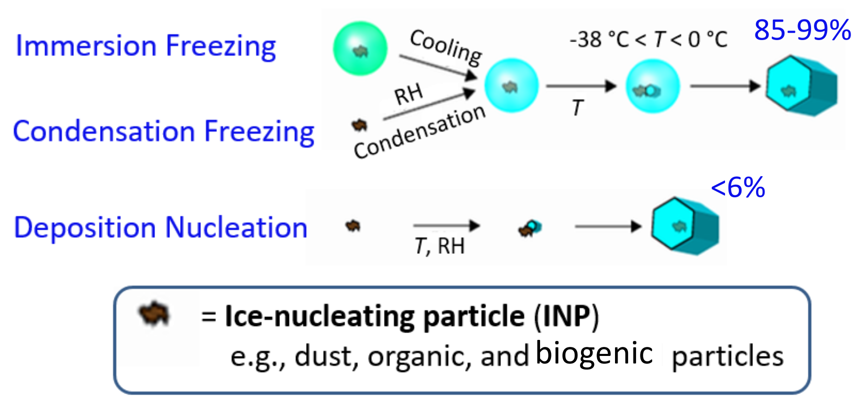
- **Goal 1**: Adapting new INP measurement techniques for long-term ambient INP concentration (n_{INP}) monitoring at T above -33 °C at each Atmospheric Radiation Measurement (ARM) site,
- **Goal 2**: Elucidating sources, chemical composition, and ice nucleation pathways of aerosol particles at the ARM sites,
- **Goal 3**: Developing ice nucleation parameterizations that are useful for n_{INP} prediction and representative of “mixed-phase” clouds at the ARM sites.



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Refs: Hande, L. B. and Hoose, C.: ACP, 14105-14118, 2017; Westbrook, C. D. and Illingworth, A. J.: GRL, 38, L14808, 2011; de Boer, G., et al.:, GRL, 38, L01803, 2011; Cui, Z. et al.: JGR, 111, D05201, 2006; Phillips, V. T. J. et al.: JAS, 64, 738-761, 2007

‘Potential’ Climatic Impact of INPs

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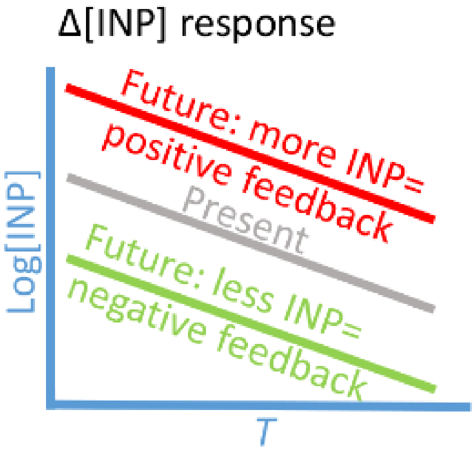
- INPs are quantitatively small but possess the substantial potential to impact climate.
  - *“…INPs are generally not included in CMIP6 models.”*
  - *“…previous studies have produced model estimates of opposing signs.”*
- Model prediction of effective radiative forcing from aerosol-cloud interactions = **–1.0 ± 0.8 W m^{-2}** → **notorious uncertainty**.

[IPCC, 2021: Ch. 7 40-41 pp. & Table 7.6]

1) Snow and ice coverage decreases, leading to greater INPs emissions.
2) Ambient INP concentration may increase in the future in response to warming.
3) INPs are cloud-destroying agents in mixed-phase clouds → back to (1)



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Refs.: IPCC 2021: https://www.ipcc.ch/report/ar6/wg1/; Storelvmo, T.: Annual Review of Earth and Planetary Sciences, 2017; Murray, B. J. et al.: Atmos. Chem. Phys., 21, 665-679, 2021

Methods Summary

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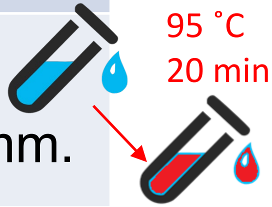
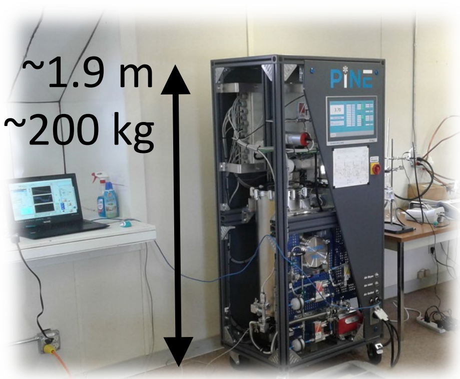
Technique	PINE-3* (Online)	WT-CRAFT** (Offline)
Instrument Type	Mobile Expansion Cooling Chamber	Cold Stage Freezing Assay
Ice Nucleation Mode	Immersion + Condensation + Deposition	Immersion + Heat-treated imm.
Measurable *T* Range	-15 to -33 °C (± 1.0 °C)	0 to -25 °C (± 0.5 °C)



*Calibrated at AIDA, **Calibrated by and co-assessed with INSEKT



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Refs.: **PINE** - Möhler, O. et al.: AMT, 14, 1143–1166, 2021; **WT-CRAFT** - Tobo, Y., Sci. Rep., 6, 32930, 2016; Vepuri, S.H.K. et al.: ACP, 21, 4503-4520, 2021; **INSEKT** - Schneider, J. et al.: Atmos. Chem. Phys., 21, 3899–3918, 2021.

Measurements Summary

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- Total aerosol concentration, $n_{INP}(T)$, and $n_{CCN}(SS\%)$ are higher @ SGP than other ARM sites.

		SGP	ENA	NSA-BRW
		Oct-Nov 2019	**Oct-Nov 2020**	**Oct-Nov 2021**
Total Aerosols, n_{aer} [cm^{-3}]		2896.7 ± 0.9 >	339.0 ± 1.4 >	96.4 ± 2.8
Online $n_{INP}(T)$ x 10^{-3} [cm^{-3}]	-15 °C	0.8 ± 0.3	-	-
	-20 °C	3.4 ± 0.4 >	0.9 ± 0.0_4 >	0.1 ± 0.0_2
	-25 °C	19.6 ± 1.5	5.0 ± 0.3	0.4 ± 0.1
	-30 °C	81.4 ± 10.7	21.8 ± 0.8	7.8 ± 1.5
$n_{CCN}(SS)$ [cm^{-3}]	0.1 %SS	161.6 ± 7.6 >	57.7 ± 3.9	-
	0.2 %SS	510.3 ± 25.1	108.5 ± 7.6	-

$n_{INP}(-20°C)/n_{aer}$ **≈ 1/million** **≈ 1/million** **≈ 1/million**

$n_{CCN}(0.1_{\%}SS)/n_{aer}$ ≈ 1/30 ≈ 1/5

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Online $n_{INP}(T)$ Time Series (6-hour time average)

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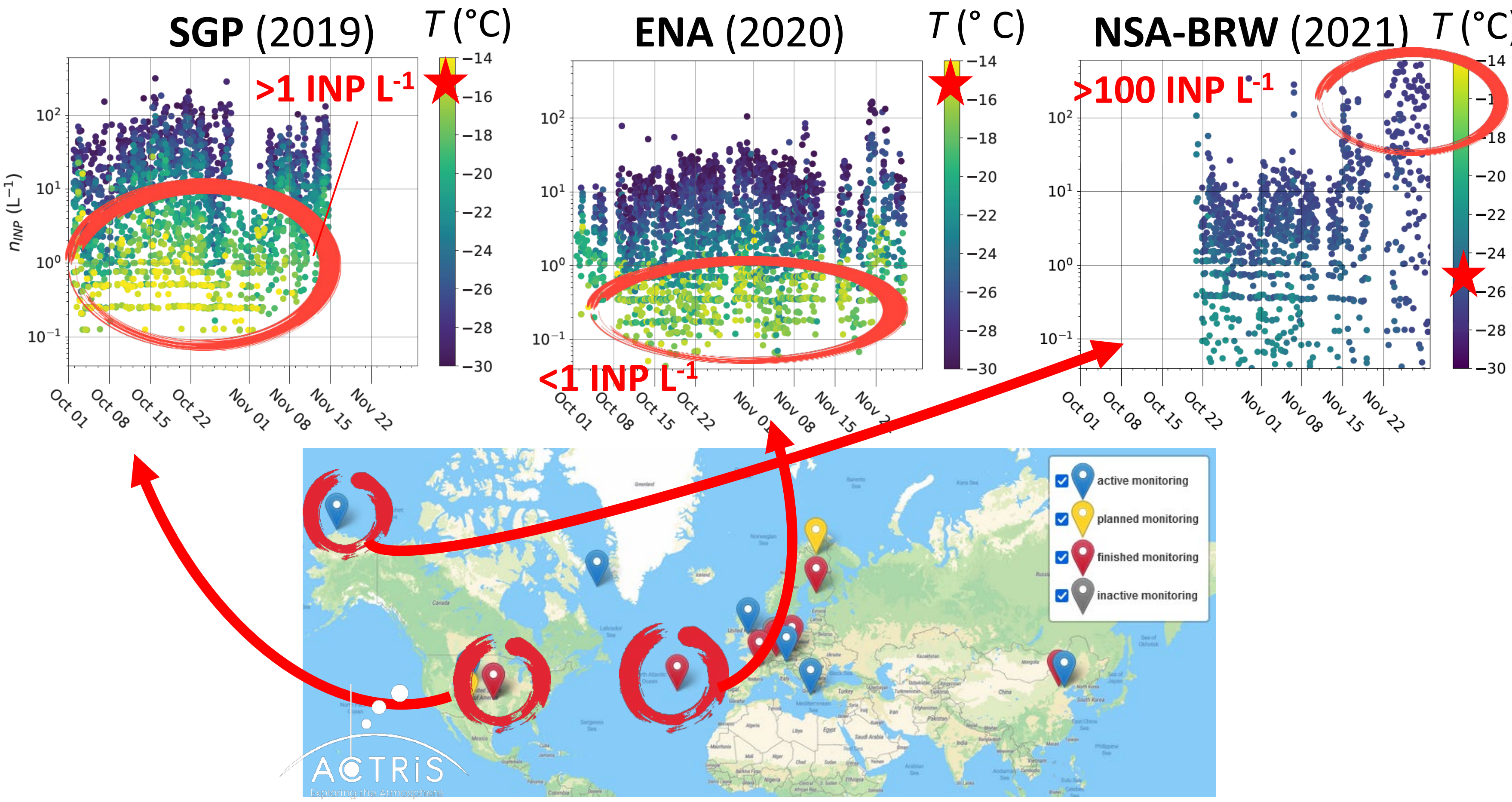

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PINE INP monitoring map - SOURCE: https://www.imk-aaf.kit.edu/pine_inp_monitoring.php
ACTRIS: https://www.actris.eu/

Online $n_{INP}(T)$ Spectra (T-bin = 0.5 °C)

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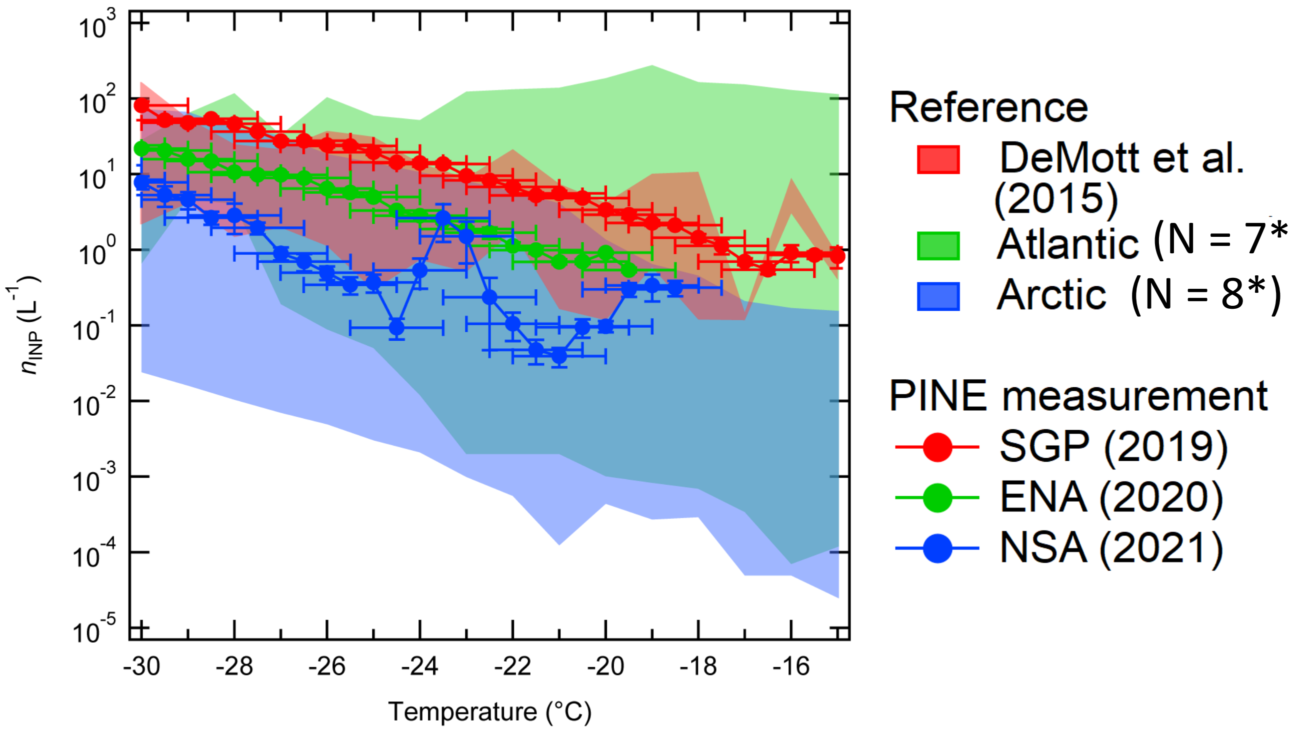

- $n_{INP,SGP} > n_{INP,ENA} > n_{INP,NSA}$
- **NOTE:** NSA High INP episodes during the Chukchi Sea storms → Breakout Session 5 [Eisenhower] @ 2 PM

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Refs.: DeMott, P. J. et al.: , DOE/SC-ARM-15-012, 2015;
*Wilbourn, E. K. et al.: Submitted to J. Chem. Edu.

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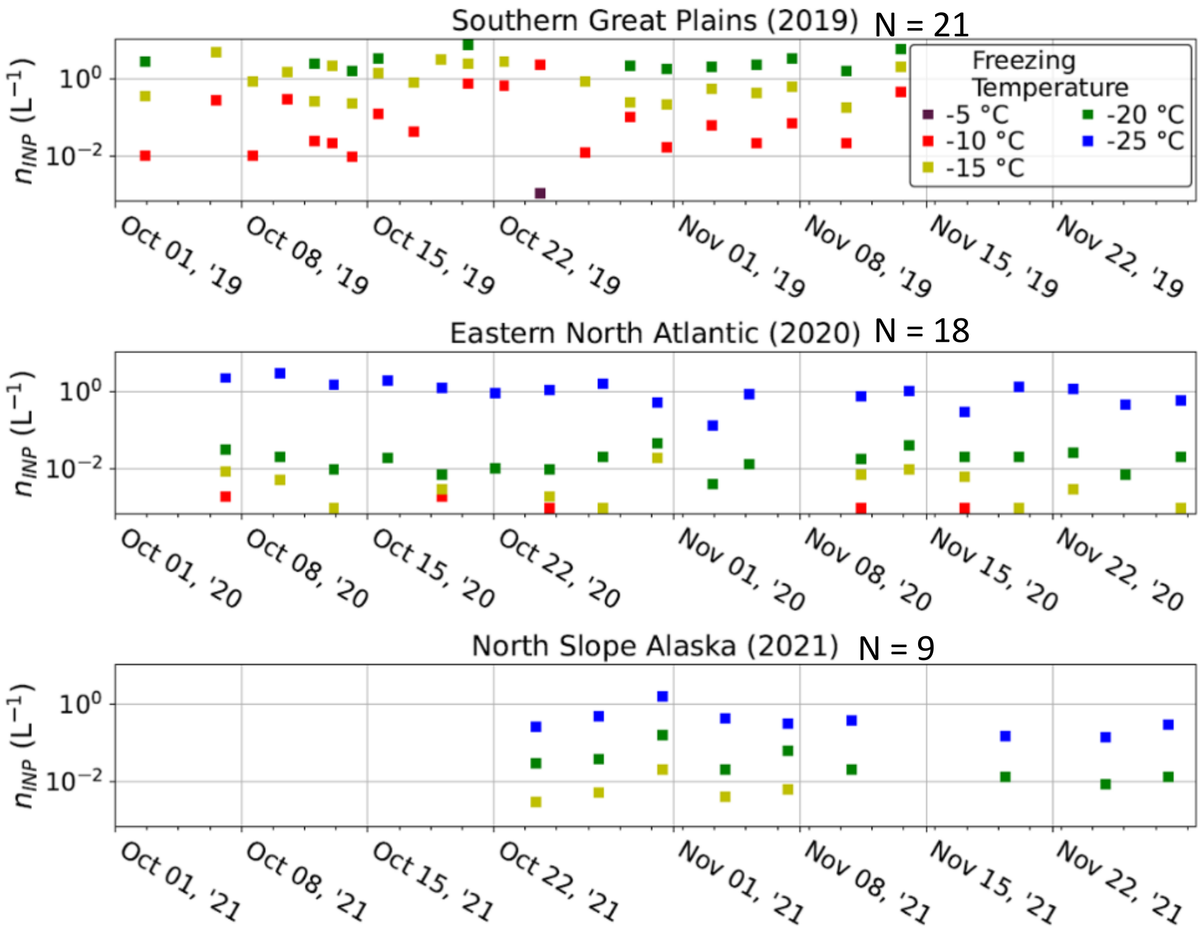
Offline n_{INP} Time Series



❑ $n_{INP,SGP} > n_{INP,ENA} > n_{INP,NSA}$

Note: SGP measurements were co-assessed with INSEKT: Schneider, J. et al.: Atmos. Chem. Phys., 21, 3899-3918, 2021.

Offline $n_{INP}(T)$ Heat Sensitivity

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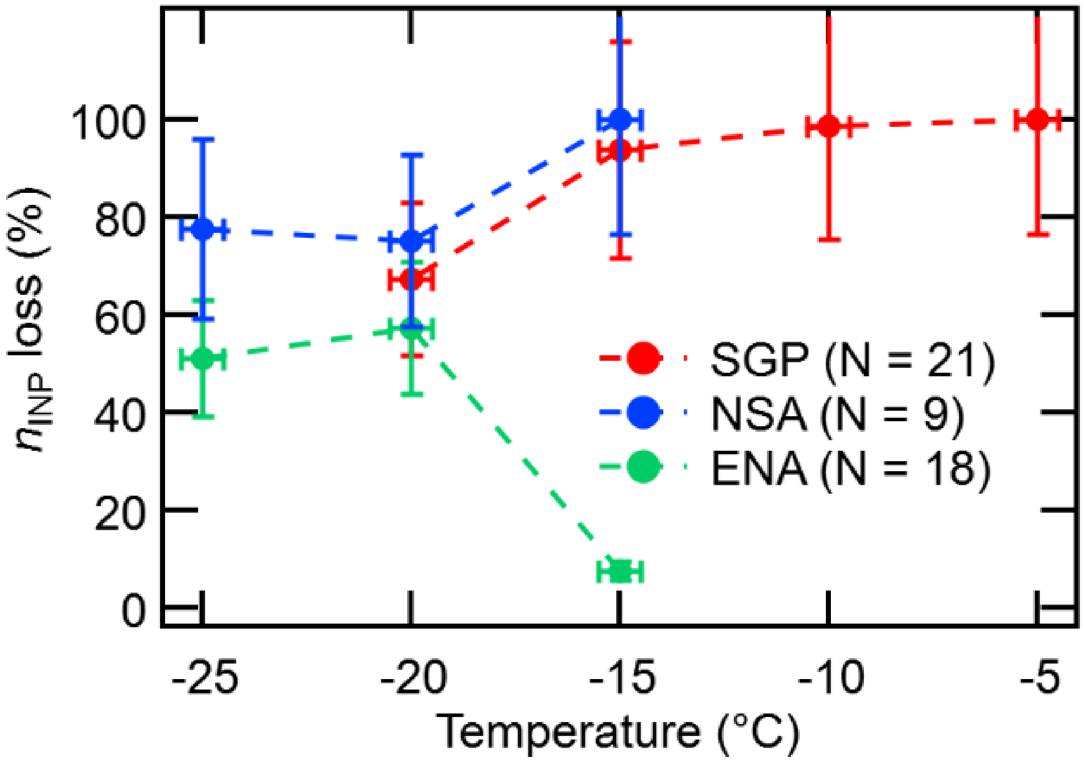

- ❑ SGP & NSA INPs are heat-sensitive (>67% loss across).
- ❑ Presence of biogenic INPs is seen at all ARM sites.

Online vs. Offline n_{INP} Comparison

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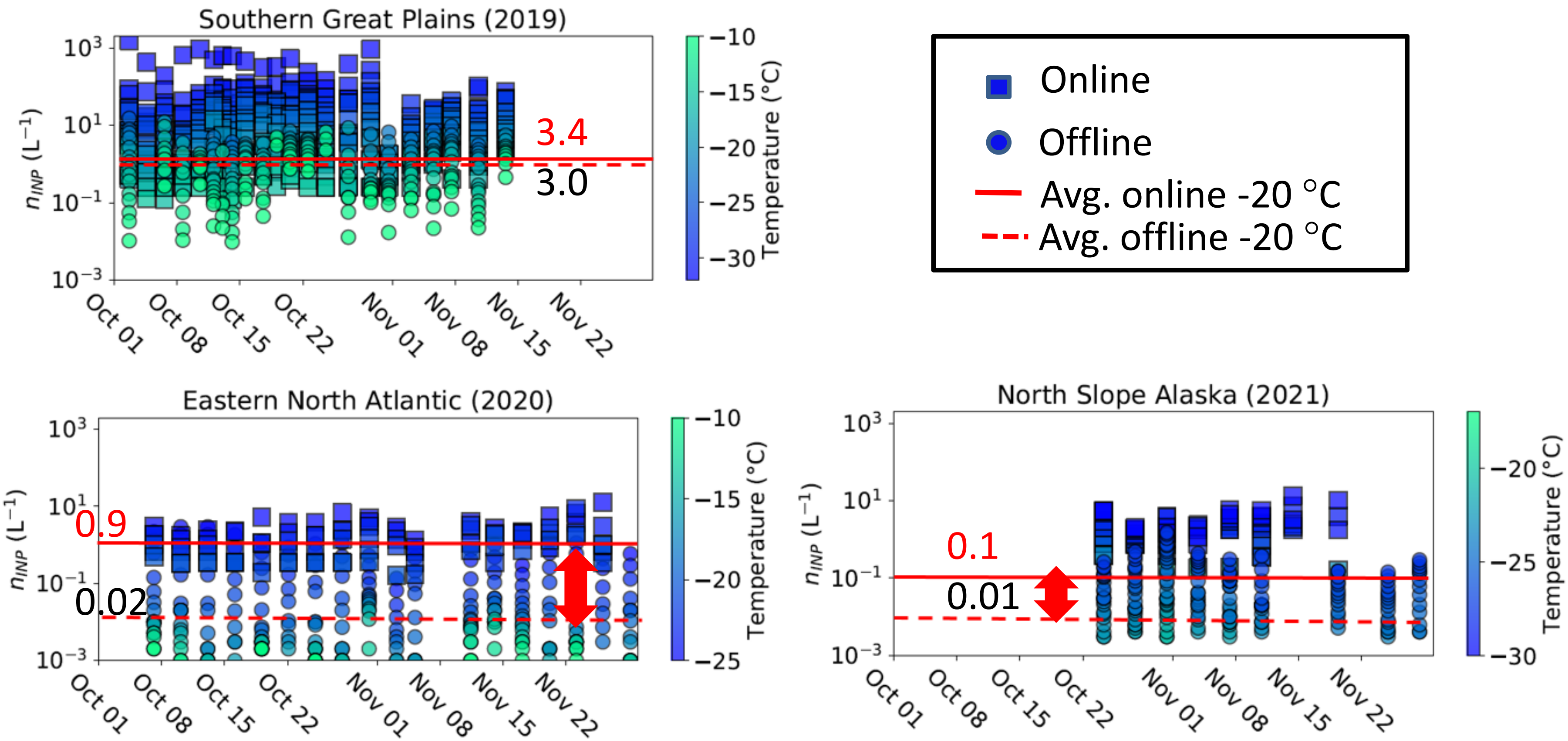

❑ Online – Offline = Condensation & Deposition >> Immersion?*

Refs.: *Rinaldi, M. et al.: Atmos. Chem. Phys., 21, 14725–14748, 2021;
Note: SGP measurements were done with INSEKT: Schneider, J. et al.: Atmos. Chem. Phys., 21, 3899-3918, 2021.

INP Properties: SGP vs. ENA

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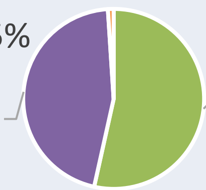
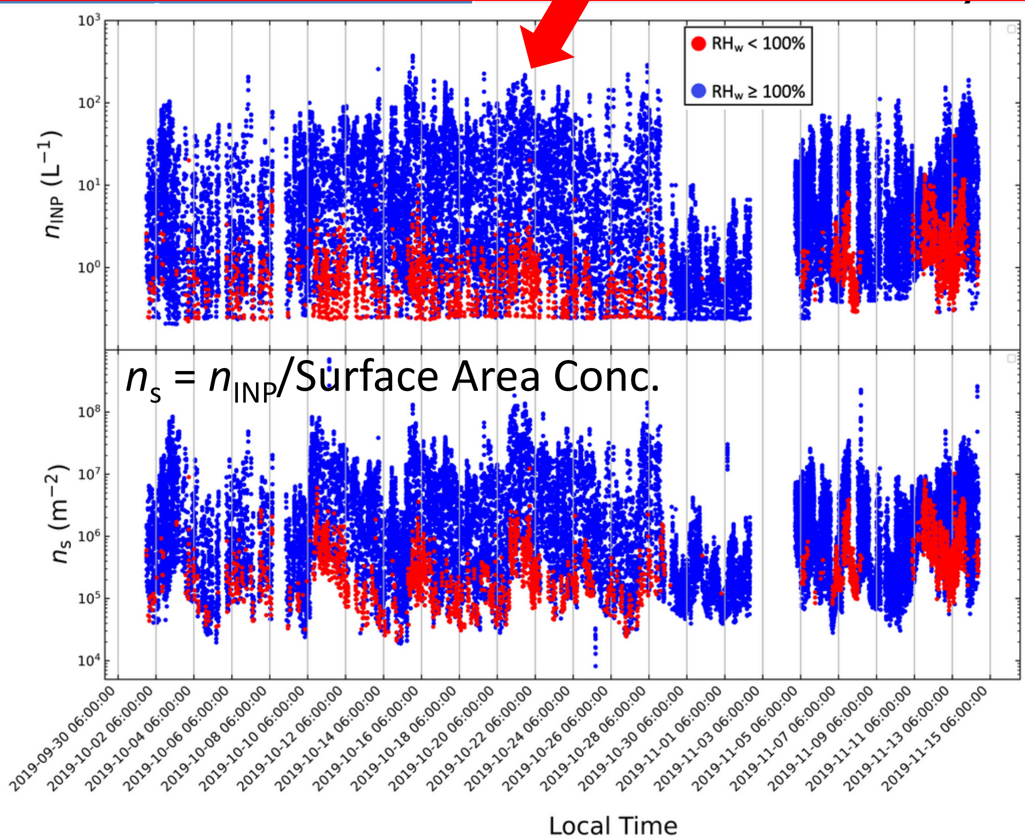
Site	SGP	ENA
Major IN mode	Immersion-dominant (<3% deposition)	Probable condensation freezing (**$n_{INP} \propto n_{CCN}$**)
		m_{ORG} = 0.94 µg m^{-3} **m_{Cl} = 0.14 µg m^{-3}** **m_{BC} = 0.90 ng m^{-3}
		Arctic air mass (54.8%)
		Na/Cl = 1.91-2.73
		In-progress





Session 5 [Eisenhower] @ 2 PM

Knopf, D. A. et al.: Bull. Amer. Meteor., *102*, E1952-E1971., 2021;
** Any data during m_{BC} of ≥50 ng m^{-3} were removed.

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n_{INP} & n_{CCN} Correlation @ ENA

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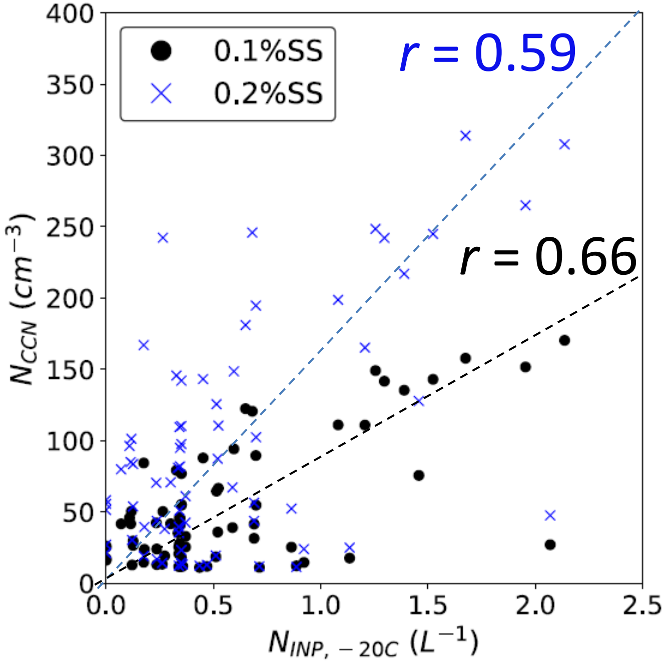

ENA Campaign			
Temperature (°C) / Supersaturation (%)	-30 °C	-25 °C	-20 °C
0.1	-0.14	0.17	**0.66**
0.2	-0.06	0.14	**0.59**
SGP Campaign			
Temperature (°C) / Supersaturation (%)	-30 °C	-25 °C	-20 °C
0.1	-0.03	0.05	0.001
0.2	0.12	0.001	0.06

- ❑ Probable marine contribution for both INP and CCN at ENA
- ❑ Predominance of condensation freezing at around -20 °C, explaining the gap between online and offline measurements?

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Courtesy of Elise K. Wilbourn

INP Properties: SGP vs. ENA

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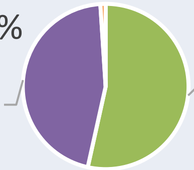
Site	SGP	ENA
Major IN mode	Immersion-dominant (<3% deposition)	Probable condensation freezing ($n_{INP} \propto n_{CCN}$)
Aerosol Composition	**m_{ORG} = 1.26 μg m^{-3}** m_{Cl} = 0.02 μg m^{-3} m_{BC} = 0.74 ng m^{-3}	m_{ORG} = 0.94 μg m^{-3} **m_{Cl} = 0.14 μg m^{-3}** **m_{BC} = 0.90 ng m^{-3}
Aerosol & INP Source	*Ag soil dust	Arctic air mass (54.8%)
Mixing State	In-progress (EMSL-LSR)	 Na/Cl = 1.91-2.73 (N = 490)
IN Parameterization	n_s & *ABIFM	In-progress

NOTE: NSA Data → Breakout Session 5 [Eisenhower] @ 2 PM

- ❑ Will further explore the mixing state and IN parameterization

Knopf, D. A. et al.: Bull. Amer. Meteor., *102*, E1952-E1971., 2021;
** Any data during m_{BC} of ≥50 ng m^{-3} were removed.

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Summary & Outlook

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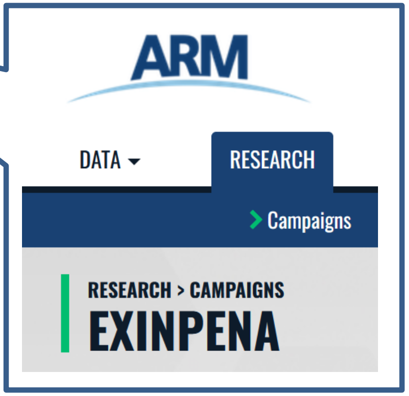
- We implemented PINE-3 & WT-CRAFT for short-term & long-term campaigns.
- Given the predominance of heat-sensitive biogenic particles at all ARM sites, **systematic measurements of biological aerosol particles** would be a great addition to the ARM program.
- **Co-located measurements of INP and CCN** might be meaningful for the INP community.
- We have many more things to look into – e.g., aerosol size distribution (esp. **supermicron range**), **particle chemical speciation** (esp. organics) etc. What is the priority for the modeling community?

ARM Archived Data

ExINP-SGP: https://www.arm.gov/research/campaigns/sgp2019exinpsgp
ExINP-SGP II: https://www.arm.gov/research/campaigns/sgp2020exinpsgpii
ExINP-ENA: https://armweb0-stg.ornl.gov/research/campaigns/ena2020exinpena



Publications

1. *Möhler, O.* et al.: Atmos. Meas. Tech., 14, 1143–1166, https://doi.org/10.5194/amt-14-1143-2021, 2021
2. *Vepuri, H. S. K.* et al.: Atmos. Chem. Phys., 21, 4503–4520, https://doi.org/10.5194/acp-21-4503-2021, 2021
3. *Hiranuma, N.* et al.: Atmos. Chem. Phys., 21, 14215–14234, https://doi.org/10.5194/acp-21-14215-2021, 2021
4. *Knopf, D. A.* et al.: Bull. Amer. Meteor., *102*, E1952-E1971., 2021

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$ Funding

DOE ECRP (DE-SC0018979) *2018-2023*

DOE Office of Science FAP (DE-SC0020006) *2019-2021* [PI: Knopf]

EMSL-LSR (60345) *2022* [PI: Knopf]

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Supplemental Information: Data

SGP: Methods – Community Atmospheric Model 6 (CAM6), Community Earth System Model 2 (CESM2)

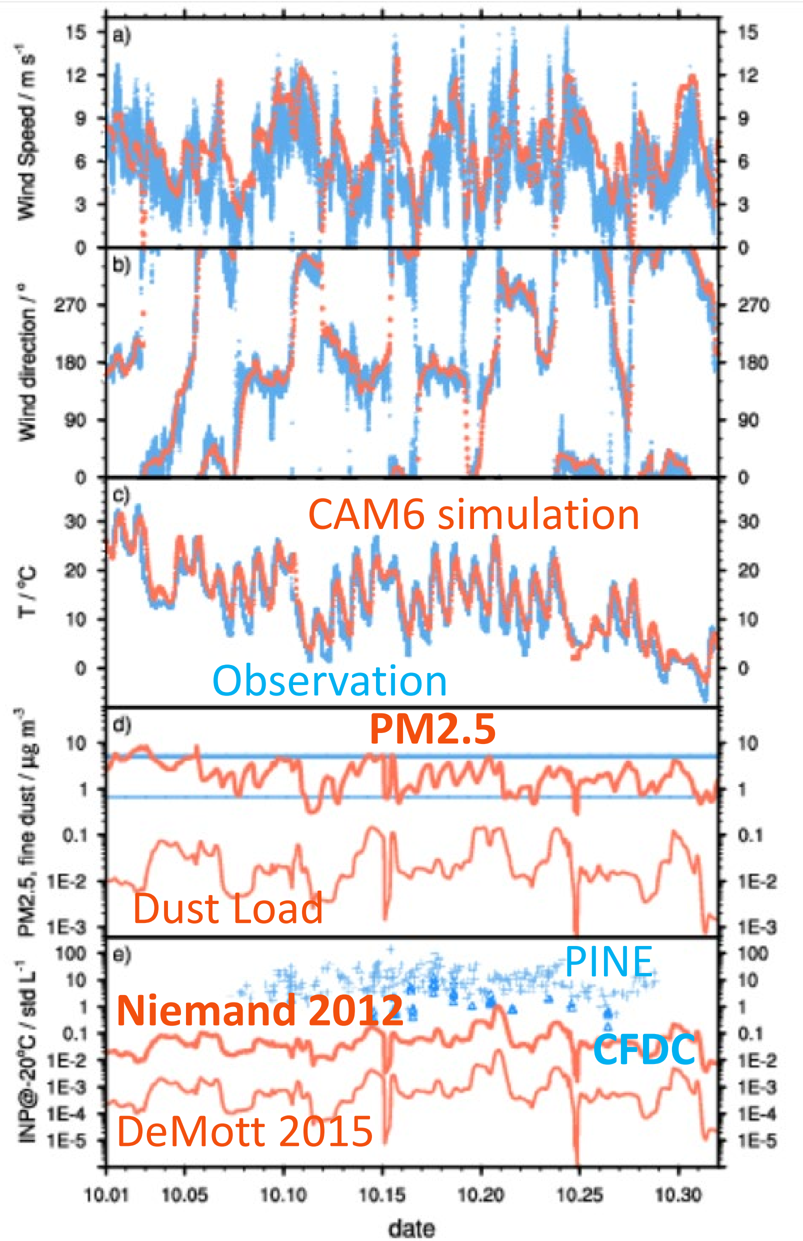
Runtime period: October to November 2019

Resolution: 0.9° x 1.25°, 56 vertical layers

Meteorology: Horizontal winds and temperature nudged to MERRA2 data

Aerosol module: Four-mode version of Modal Aerosol Module (MAM4; Liu et al., 2016)

Aerosol emissions: Shared Socioeconomic Pathways (SSP) 2-4.5



These data are the courtesy of Xiaohong Liu and Yang Shi

Refs.: *Knopf, D. A*. et al.: Bull. Amer. Meteor., *102*, E1952-E1971., 2021; Niemand, M. et al.: J. Atmos. Sci., 69, 3077-3092, 2012; DeMott, P. J. et al.: Atmos. Chem. Phys., 15, 393-409, 2015

ENA: Methods – Energy Exascale Earth System Model (E3SM)

Runtime period: October to November 2020

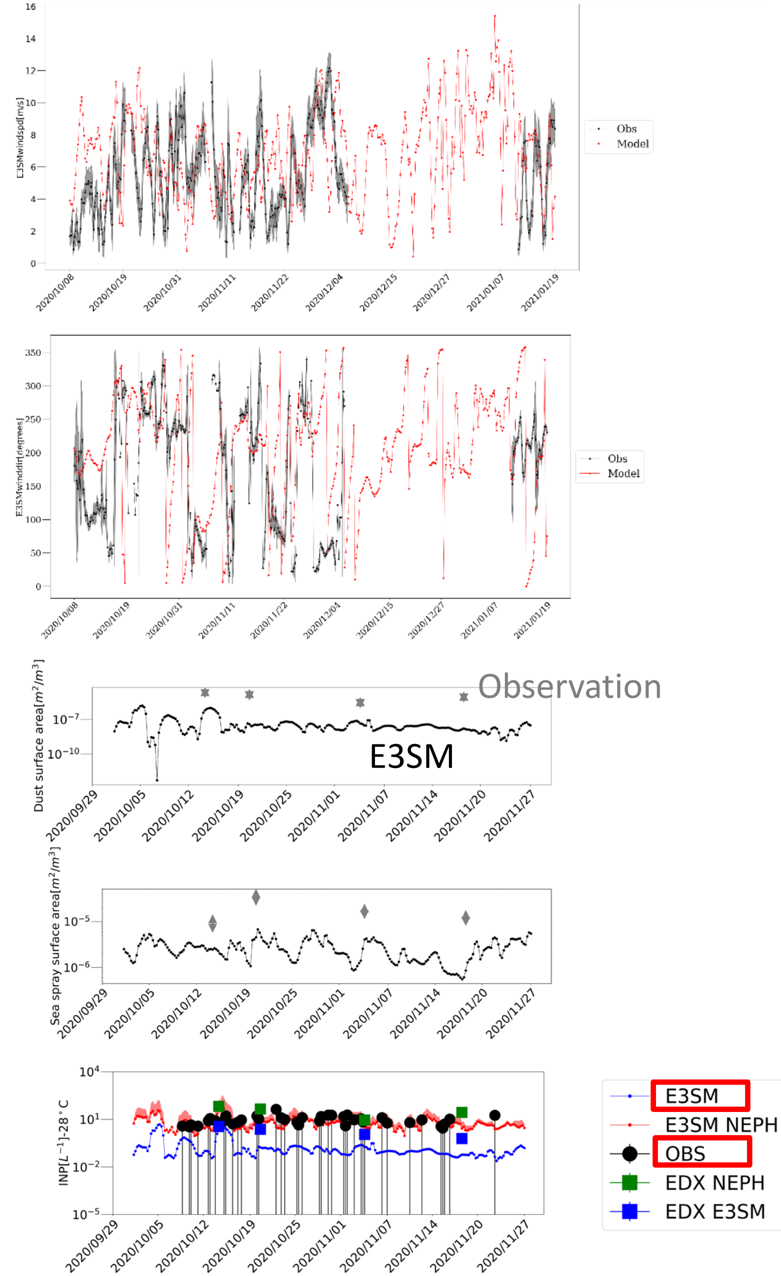
Resolution: 1°, 72 vertical layers

Meteorology: Horizontal winds and temperature nudged to MERRA2 data

Aerosol module: Four-mode version of Modal Aerosol Module (MAM4; Liu et al., 2016)

Sea salt emissions: OCEANFILMS

Dust emissions: Zender et al. (2003)



These data are the courtesy of Aish Raman and Susannah Burrows

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Refs.: Liu, X. et al.: Geoscientific Model Development , 9 (2), 505–522, 2016;
Zender, C. S. et al.: JGR-A, 108 (D14), 2003.

E3SM

ENA Closure Study

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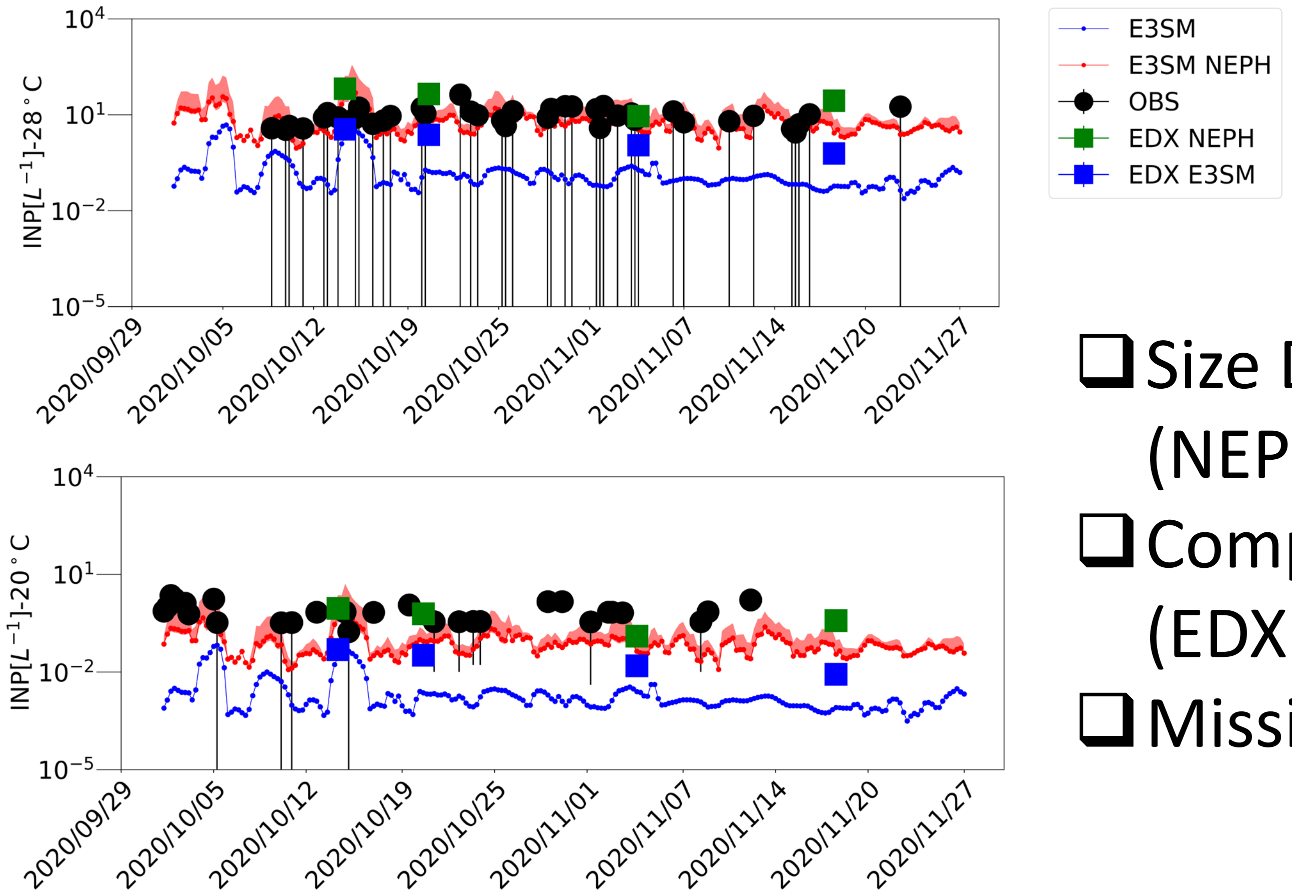

- ❑ Size Distribution (NEPH)?
- ❑ Composition (EDX)?
- ❑ Missing INPs?

The data in the courtesy of Aish Raman and Susannah Burrows

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SGP Closure Study

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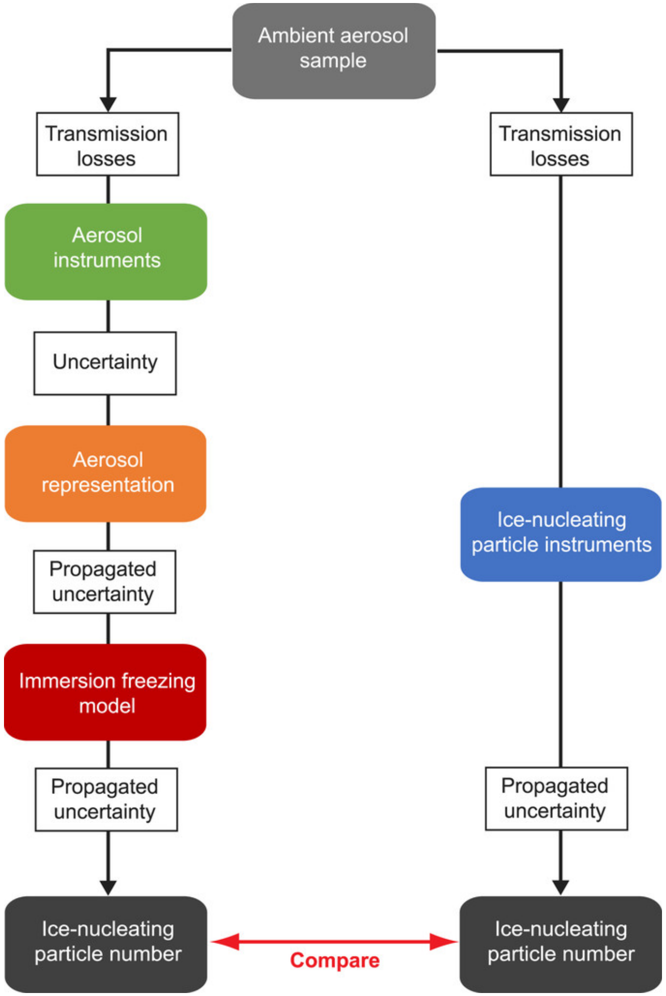
Can we predict n_{ice} from…

- Aerosol size (i), surface area (S), and number conc. (n_{aer}) based on SMPS-APS
- Composition (mineral dust, organic, & soot) based on CCSEM-EDX
- n_s or J_{het} parameterization



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Ref.: *Knopf, D. A.* et al.: Bull. Amer. Meteor., *102*, E1952-E1971., 2021

SGP INAS parameterization

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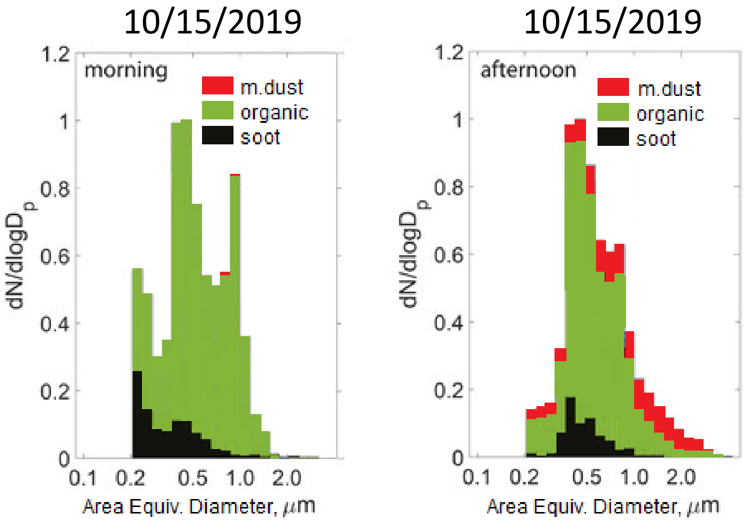


$$n_{ice,i} = n_{aer,i}\,(1 - e^{-S_i n_s(T)})\ [L^{-1}]$$

Mineral Dust (N12) -36 °C < T < -12 °C

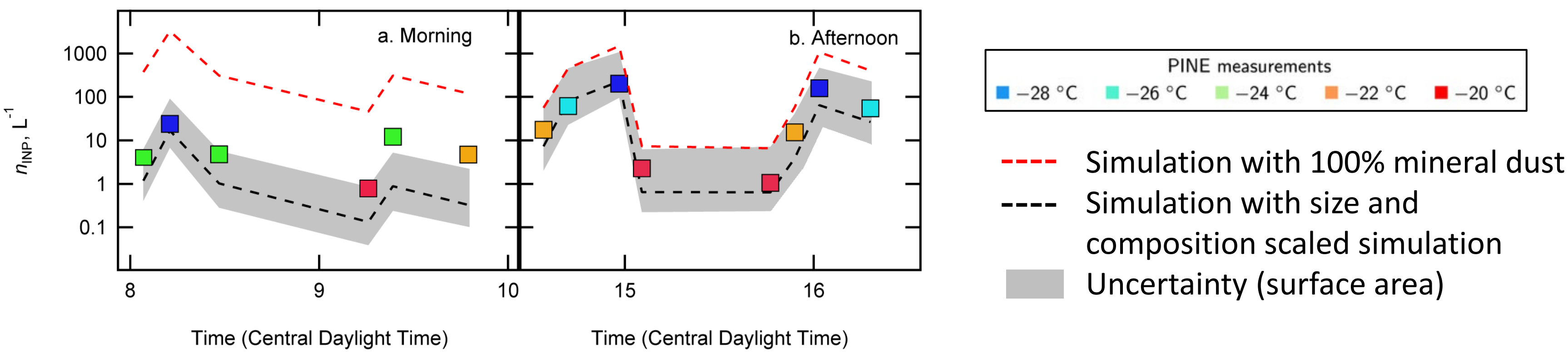
$$n_{s,\ desert\ dust}(T) = \exp[-0.517(T-273.15) + 8.934]\ [m^{-2}]$$

Organic (R13) 215 K < T < 273 K

$$n_{s,\ peat}(T) = 2.59 \times 10^{-4} \times (T - 245.80)^2\ [m^{-2}]$$

Soot (S20) -36 °C < T < -11 °C

$$n_{s,\ soot}(T) = \exp(1.844 - 0.687 \times T - 0.00597 \times T^2)\ [m^{-2}]$$



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Ref.: *Knopf, D. A.* et al.: Bull. Amer. Meteor., *102*, E1952-E1971., 2021

SGP ABIFM parameterization

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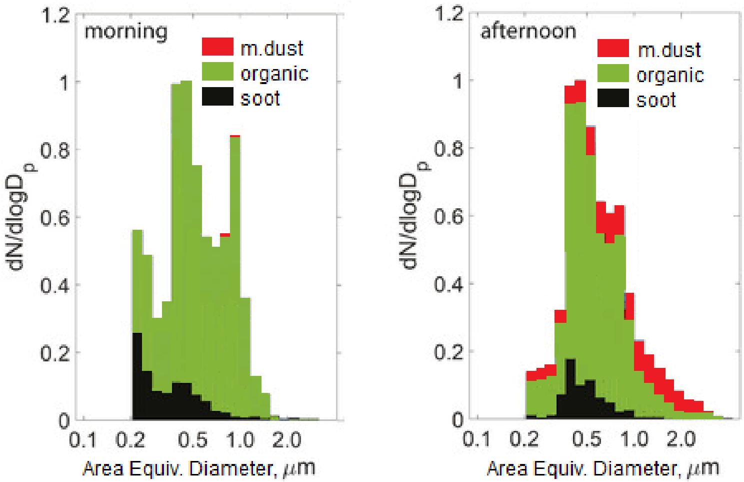
$$n_{\text{ice},j} = n_{\text{aer},j}\left(1 - e^{-S_j J_{\text{het}}(aw)\, t}\right)\ [\text{L}^{-1}]$$

(NOTE: t = 13 to 48 s)

10/15/2019 10/15/2019



Mineral Dust (A&K16)

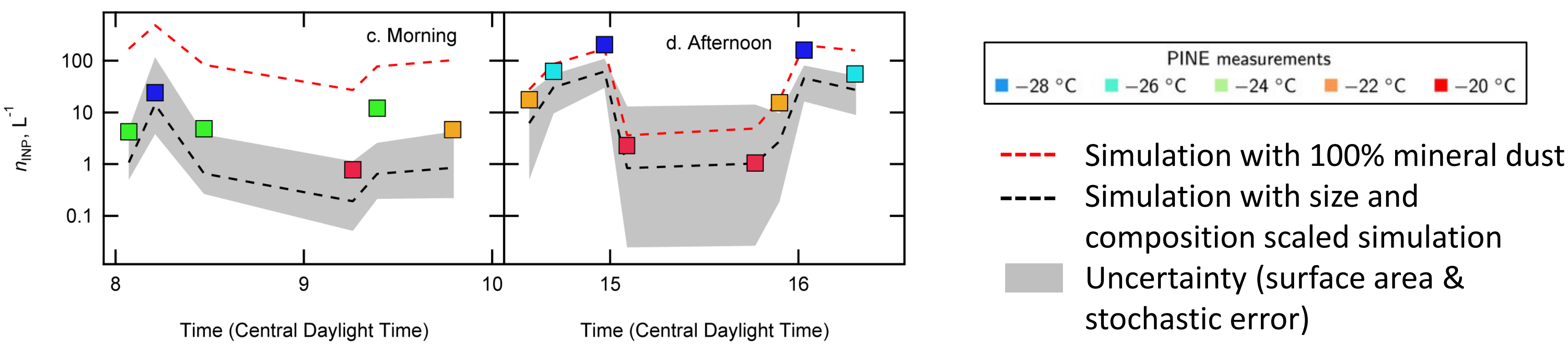
$$J_{\text{het, illite}}(\Delta aw) = 10^{-10.66873 + 54.48075 \times \Delta aw}\ [\text{cm}^2\ \text{s}^{-1}]$$

Organic (K&A13)

$$J_{\text{het, leonardite}}(\Delta aw) = 10^{-13.40148 + 66.90259 \times \Delta aw}\ [\text{cm}^2\ \text{s}^{-1}]$$

Soot (K21)

$$J_{\text{het, soot}}(\Delta aw) = 10^{-2.0847 + 18.0679 \times \Delta aw}\ [\text{cm}^2\ \text{s}^{-1}]$$



Ref.: *Knopf, D. A.* et al.: Bull. Amer. Meteor., *102*, E1952-E1971., 2021

$BC_{SGP} \leq BC_{ENA}$

$AE_{SGP} >> AE_{ENA}$

Aerosol Abundance (6-hour time average)

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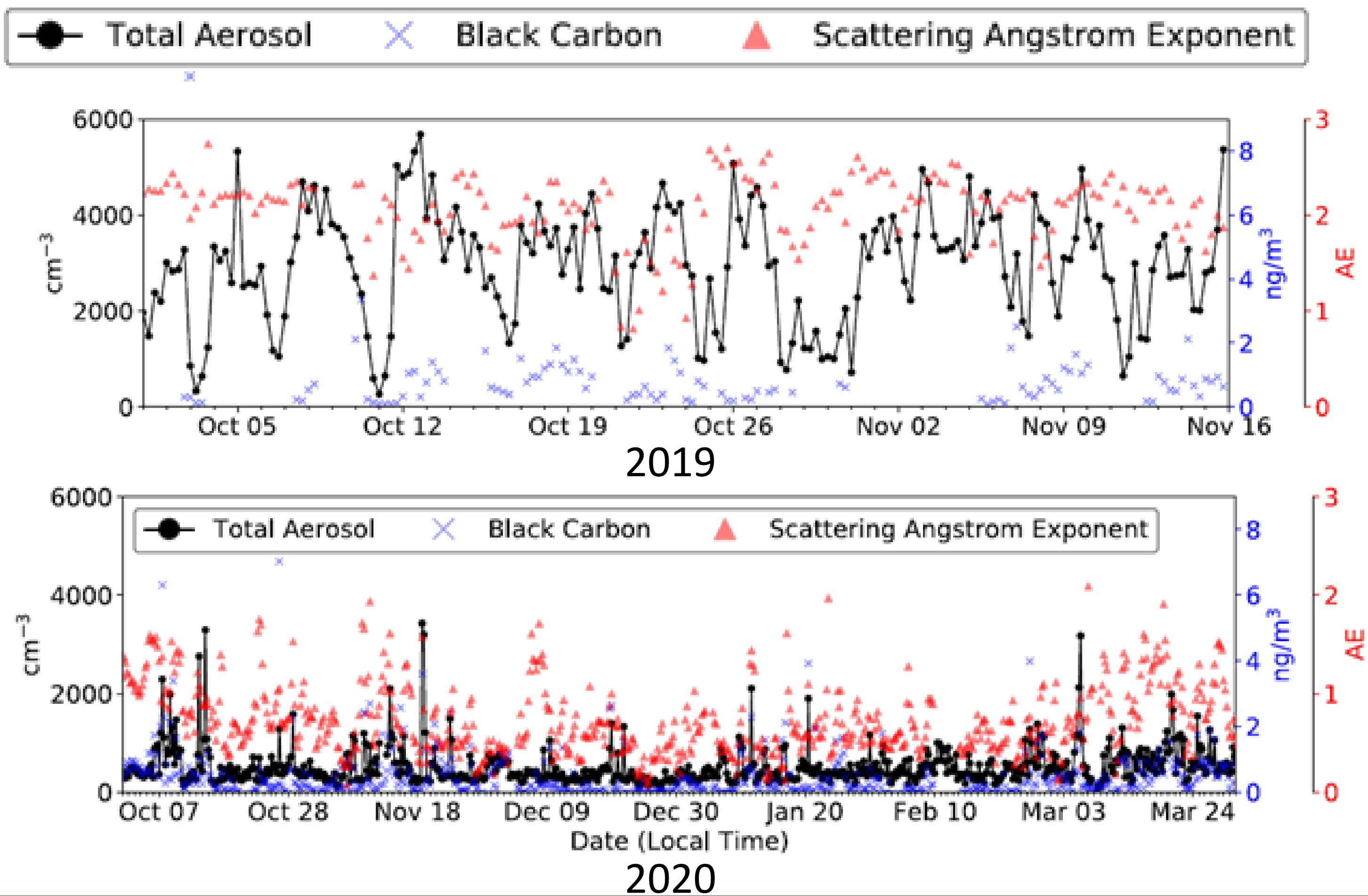
SGP

ENA



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Refs.: Russell, P. B. et al.: Atmos. Chem. Phys., 1155-1169, 2010; DeMott et al., 0.1073/pnas.1514034112, PNAS, 2016.

Dust Abundance

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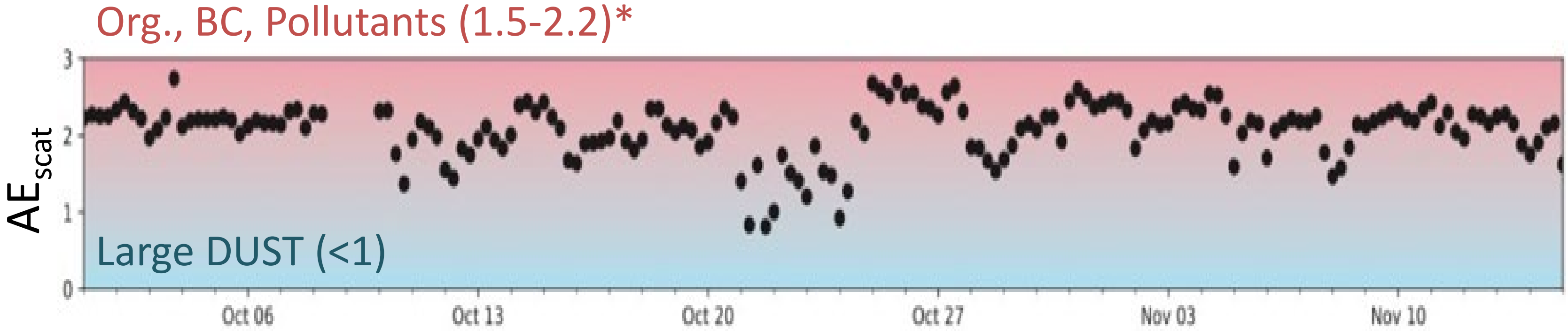
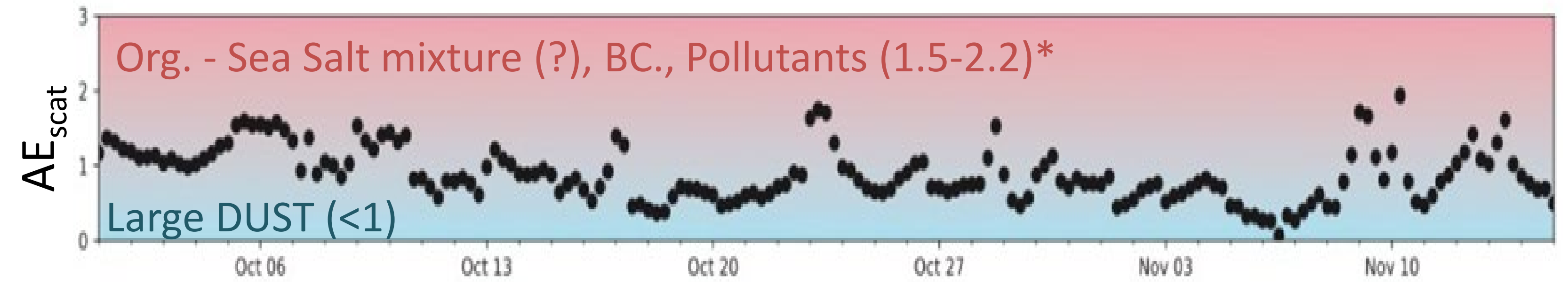
- $Org_{SGP} >> Org_{ENA}$ (AE_{scat} of 1.5 – 2.2)
- $Dust_{SGP} << Dust_{ENA}$ (AE_{scat} < 1) with greater variability!

SGP



2019

ENA



2020

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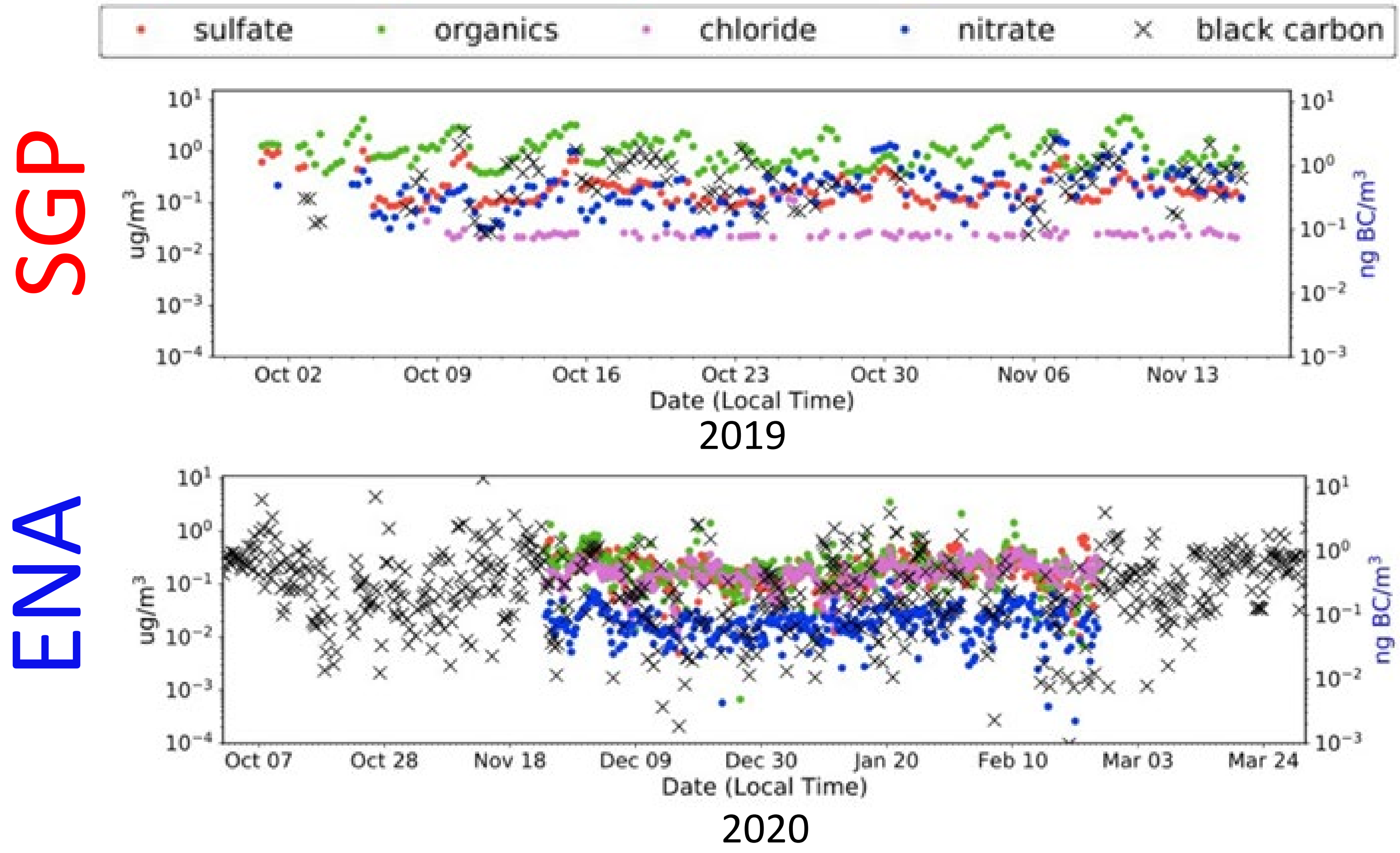
Refs.: *Russell, P. B. et al.: Atmos. Chem. Phys., 1155-1169, 2010; DeMott et al., 0.1073/pnas.1514034112, PNAS, 2016.

Aerosol Composition

- $Org_{SGP} >> Org_{ENA}$
- $Nitrate_{SGP} >> Nitrate_{ENA}$



10-day HY-SPLIT Back-trajectory (sampling height)

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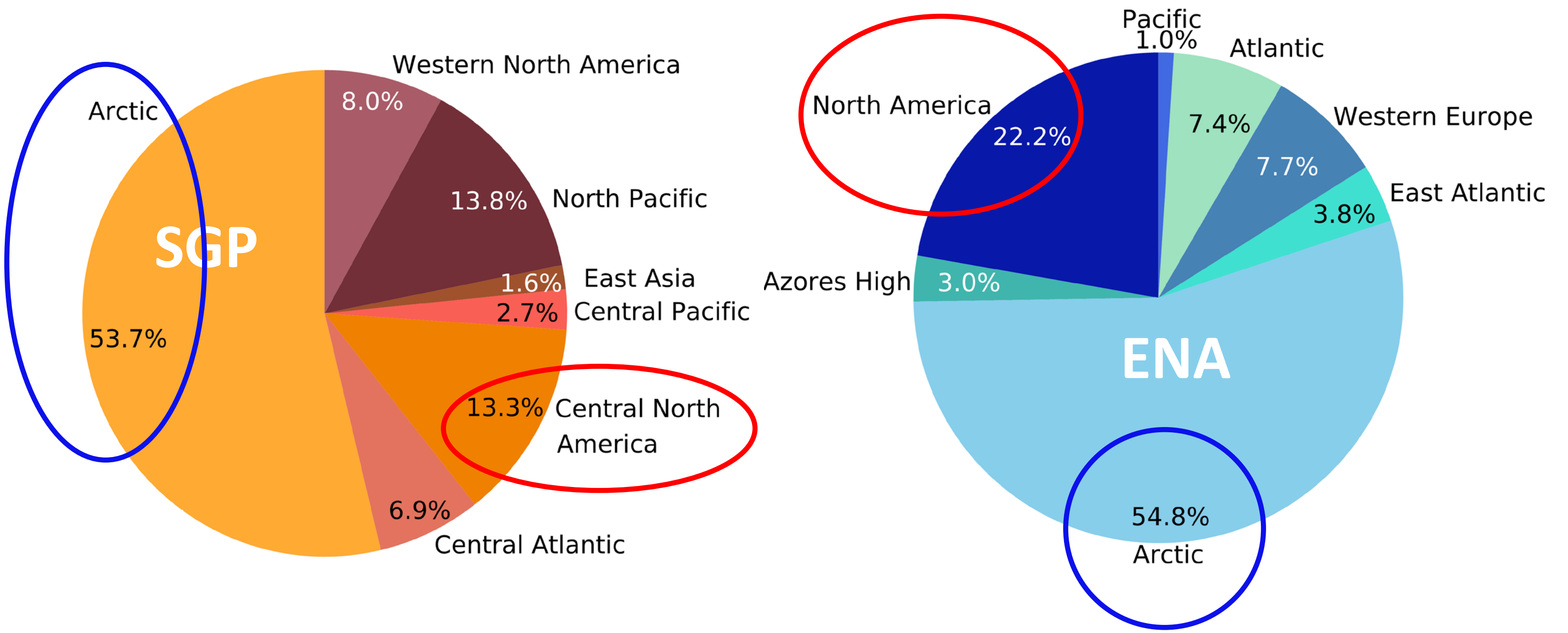
- Air mass of high INP events came from the **Arctic**.
- Air mass of high CCN (at 0.1-0.2 SS%) events came from North America (NA).
- Seasonal variability: More Arctic air mass in autumn;
  More NA in winter in our study period [ENA].



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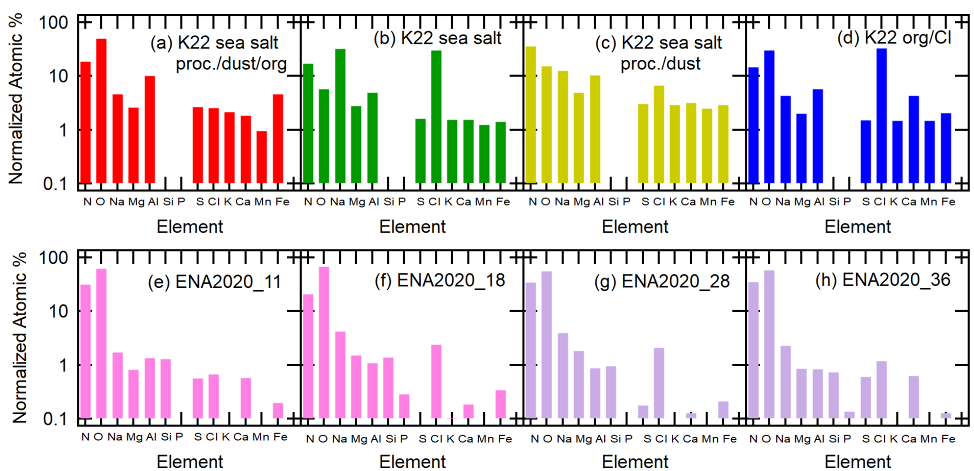
Courtesy of Elise K. Wilbourn

ENA Particle Composition

Filter name	Start Date/Time (UTC)	End Date/Time (UTC)	Salt-dominant particle	Dust-dominant particle	Na-to-Cl ratio
Unit	mm/dd/yy hh:mm	mm/dd/yy hh:mm	% ± std. err.	% ± std. err.	n/a
ENA2020_11	10/11/20 14:24	10/14/20 15:30	29 ± 21	68 ± 14	2.73 ± 0.20
ENA2020_18	10/17/20 15:24	10/20/20 14:24	70 ± 16	30 ± 16	1.94 ± 0.08
ENA2020_28	11/1/20 13:47	11/4/20 16:03	85 ± 13	15 ± 18	1.91 ± 0.06
ENA2020_36	11/15/20 16:42	11/18/20 13:24	56 ± 16	42 ± 16	2.00 ± 0.09



Ref.: Knopf, D. A.: Atmos. Chem. Phys., 22, 5377–5398, 2022.

Supplemental Information: Methods

Portable Ice Nucleation Experiment (PINE-3) Chamber

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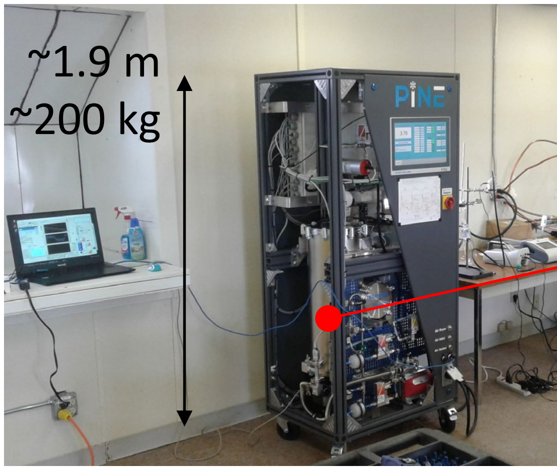
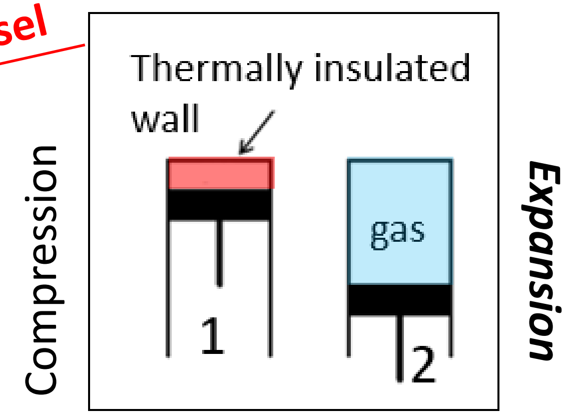
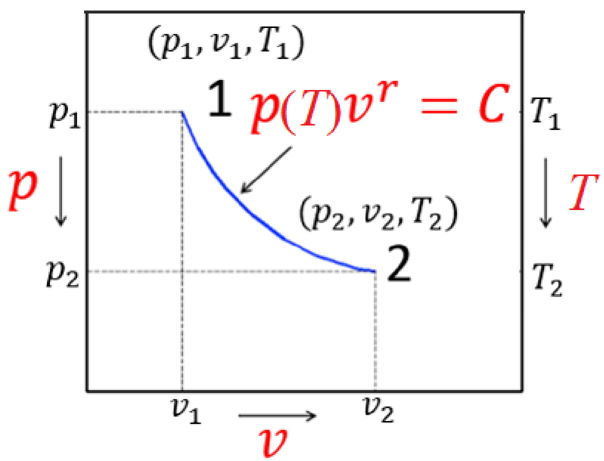


Simulated adiabatic ***expansion*** cooling





$\Delta T_{gas} \approx -4$ °C

$\Delta P \approx -200$ to -250 mb

$\Delta v \approx +2.2$ to $+2.5$ L

$\Delta T/\Delta t \approx 4$ °C min^{-1}

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Ref: mechanicalbooster.com

Portable Ice Nucleation Experiment (PINE-3) Chamber

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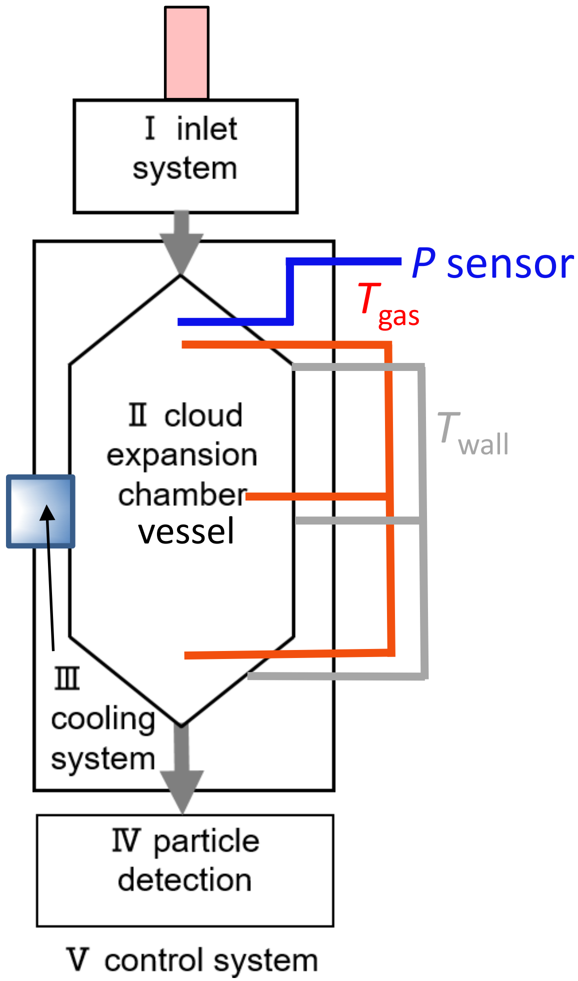
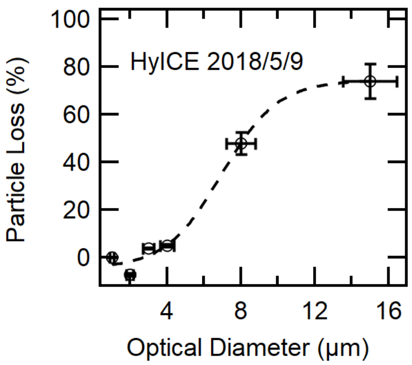


- **I. Nafion dryer:** as a part of the inlet system
- **II. Vessel with multiple sensors:** 3 T_{gas} thermocouple, 3 T_{wall} pt-100, P sensor (± 1 °C accuracy)
- **III. Cryo-cooler:** controlling T_{gas} in the vessel between 0 °C and -60 °C (T_{wall} cooling = 0.6 °C min^{-1})
- **IV. Optical particle counter:** for n_{INP} measurement (± 20% accuracy) for ≈ 0.7 - 220 µm (≈ 0.4 INP L^{-1} detection limit)
- **V. LabView console:** autonomously controlling 'expansion' experiment **every ≈12 min** with 3 pumps, 3 mass flow controllers & 6 valves

NOTE: The measured particle loss: ≤5% at ≤3 µm D_{opt}



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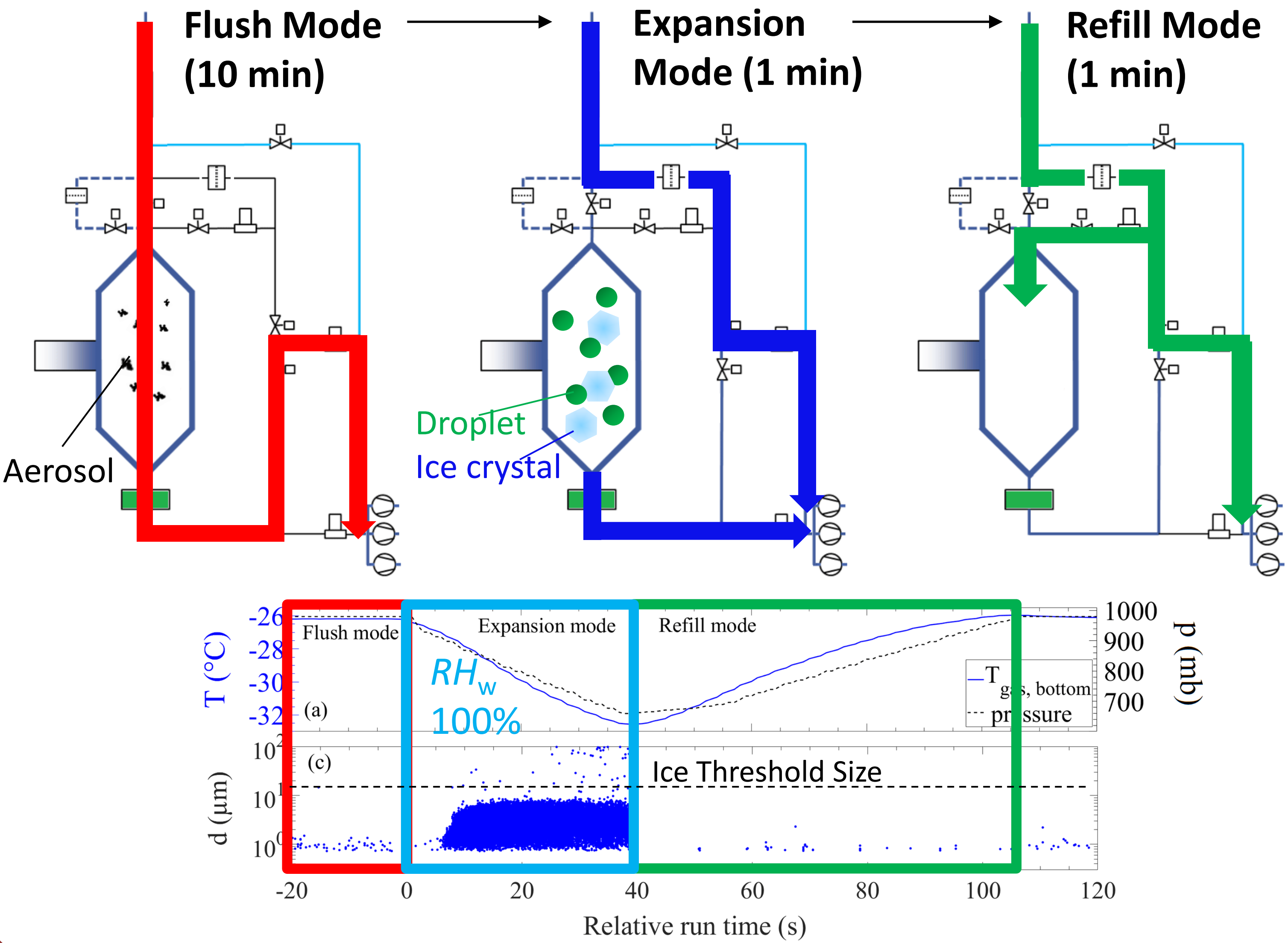
Ref.: Möhler, O. et al.: Atmos. Meas. Tech., 14, 1143–1166, 2021

PINE-3 Run-Mode



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Ref.: Möhler, O. et al.: Atmos. Meas. Tech., 14, 1143–1166, 2021

PINE-3 Operation

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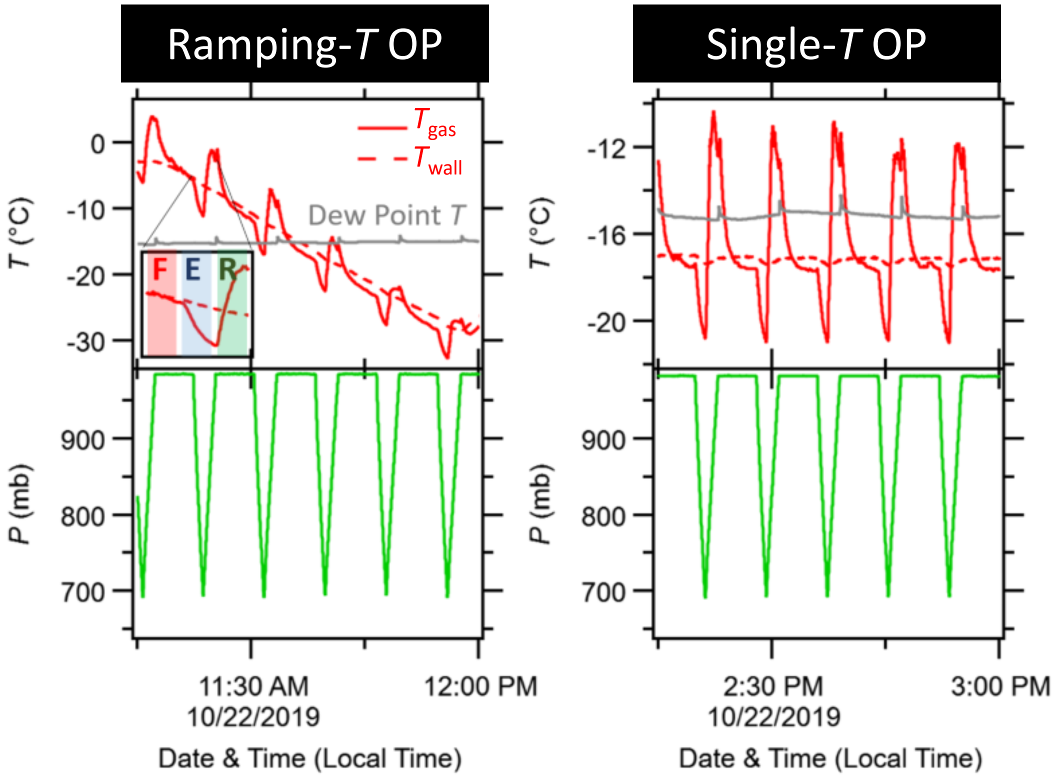
- **Ramping-*T* Operation**: T_{wall} cycles of -5 °C ←→ -35 °C every 90 min with automated sequence of Flush → Expand → Refill
- **Single-*T* Operation**: Measurements at a fixed T_{wall}
- **Background Operation**: Expansions with filtered air are carried out daily for ~1 hour to ensure a zero-INP background



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PINE-3 Calibration

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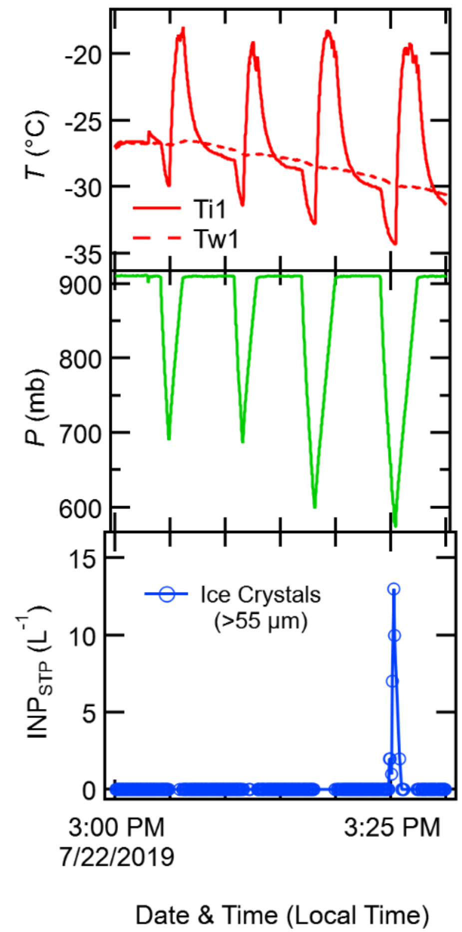
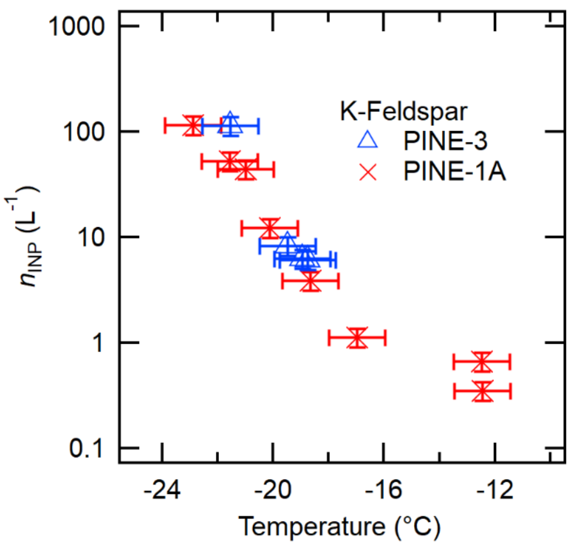
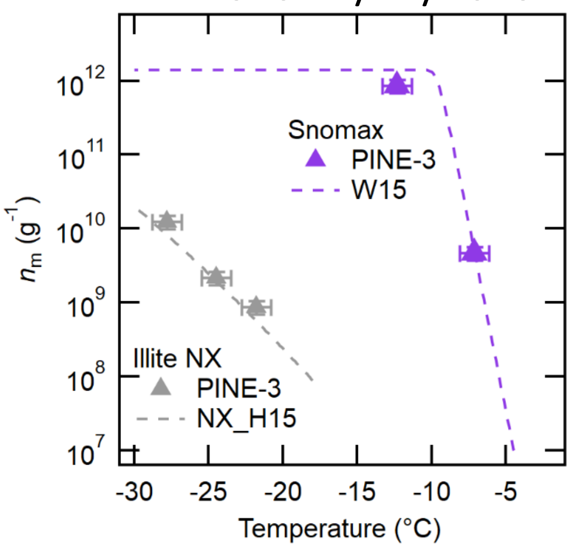
Homogeneous Freezing with Ammonium Sulfate < -33 °C



CAL01 5/21/2019



TxTEST01 7/24/2019



$$n_{INP}(T) = \frac{Ice\ Crystal\ Counts}{Expanded\ Air\ Vol.}\ [L^{-1}]$$

$$n_m(T) = \frac{n_{INP}(T)}{Particle\ Mass}\ [\mathrm{g}^{-1}]$$

Refs.: Wilbourn , E. K. et al., in prep.; Wex, H. *et al.*: Atmos. Chem. Phys., 15, 1463-1485, 2015; Hiranuma, N. *et al.*: Atmos. Chem. Phys., 15, 2489-2518, 2015

West Texas Cryogenic Refrigerator Applied to Freezing Test (WT-CRAFT) System

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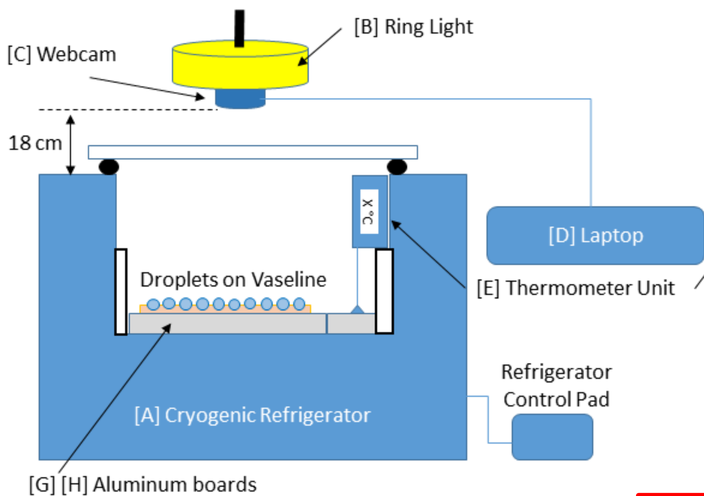
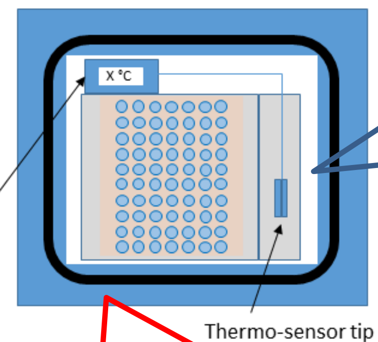
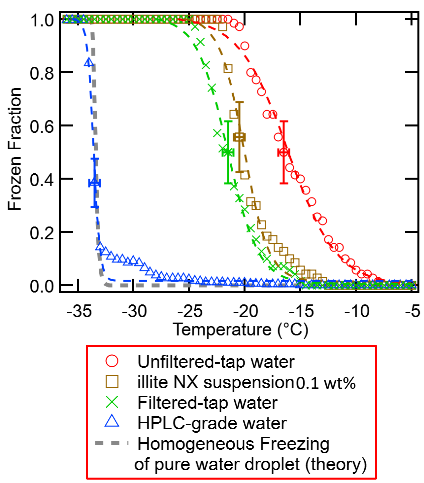
a. Side View

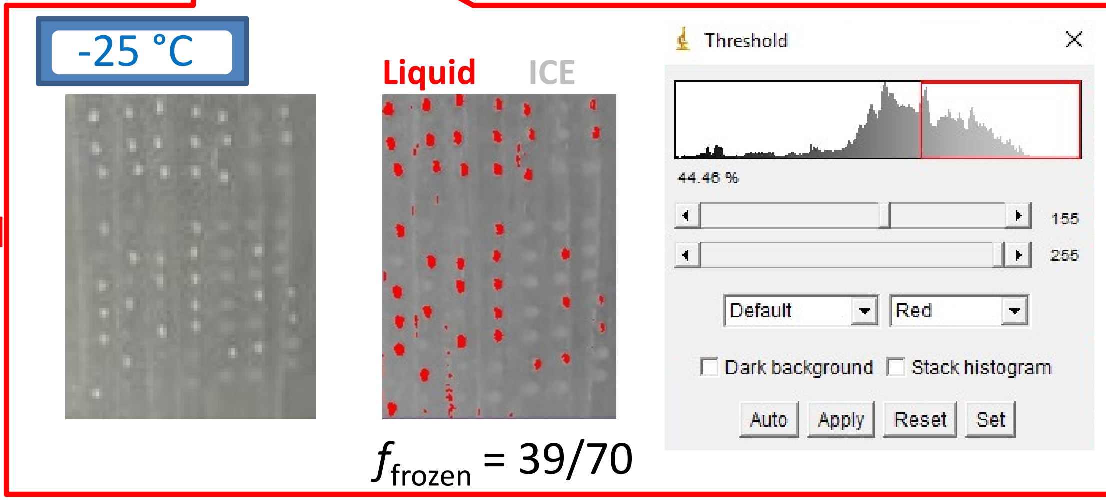


b. Top View



- ❑ 70 of 3μL droplets containing particles
- ❑ 1 °C min^{-1} cooling for -25 °C < T < 0 °C
- ❑ Frozen fraction (f_{frozen}) at each 0.5 °C





ARM ASR Atmospheric System Research

Refs.: Tobo, Y., Sci. Rep., 6, 32930, 2016; Vepuri, H. S. K.: Atmos. Chem. Phys., 21, 4503–4520, 2021; Wilbourn E. K. et al. submitted to J. Chem. Edu.

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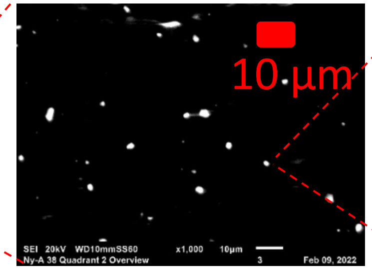
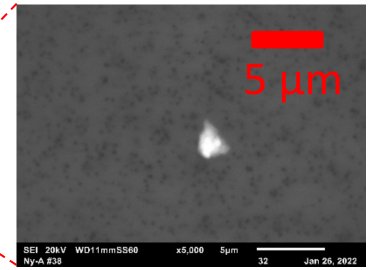
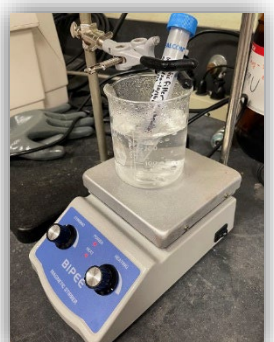
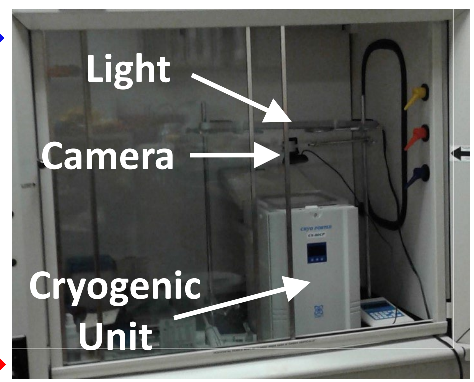
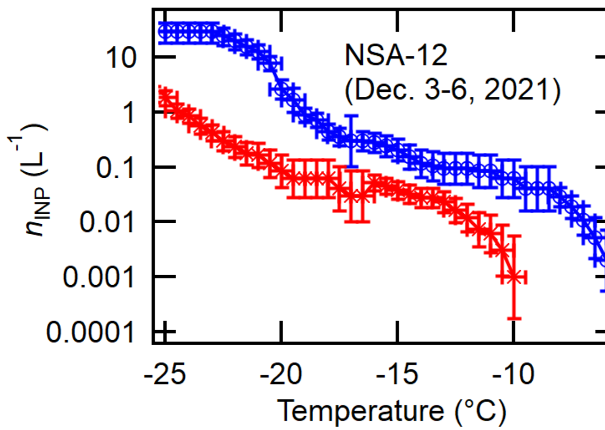




~95 °C
20 min







$$C_{INP}(T) = -\frac{\ln\left(1 - f_{frozen}(T)\right)}{Droplet\ Vol.}\ [L^{-1}\ liq.]$$

$$n_{INP}(T) = C_{INP}(T) \times \frac{Suspension\ Vol.}{Sampled\ Air\ Vol.} [L^{-1}\ \text{air}]$$

ARM ASR Atmospheric System Research

Refs.: Rinaldi, M. et al.: Atmos. Chem. Phys., 21, 14725–14748;
Hiranuma, N. et al.: Atmos. Chem. Phys., 21, 14215–14234, , 2021.

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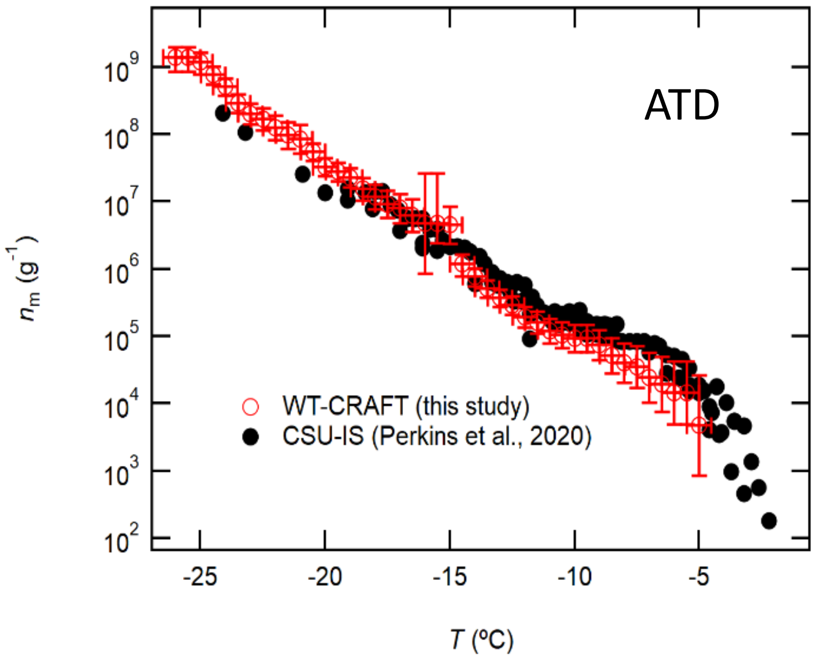

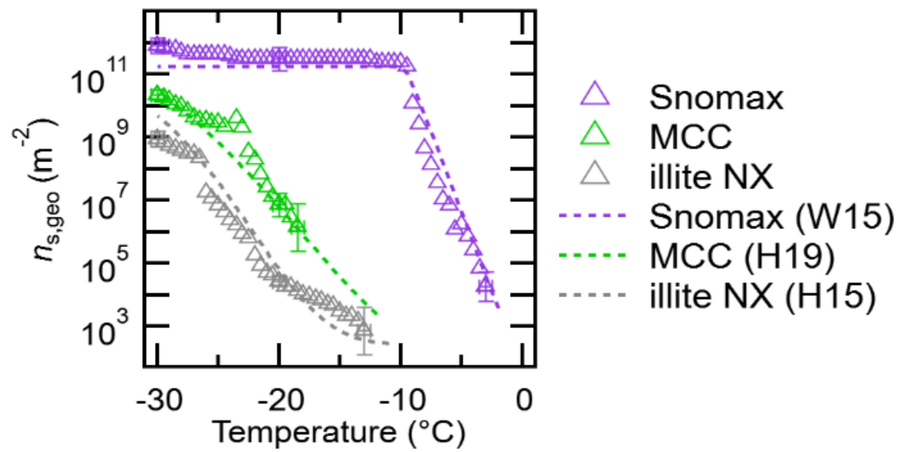

$$n_m(T) = \frac{n_{INP}(T)}{Particle\ Mass}\ [\mathrm{g}^{-1}]$$

$$n_{s,geo}(T) = \frac{n_m(T)}{Specific\ Surface}\ [\mathrm{m}^{-2}]$$

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Refs.: Hiranuma, N. et al.: Atmos. Chem. Phys., 21, 14215–14234, 2021;
Wilbourn, E. K. et al.: Submitted to J. of Chem. Edu.

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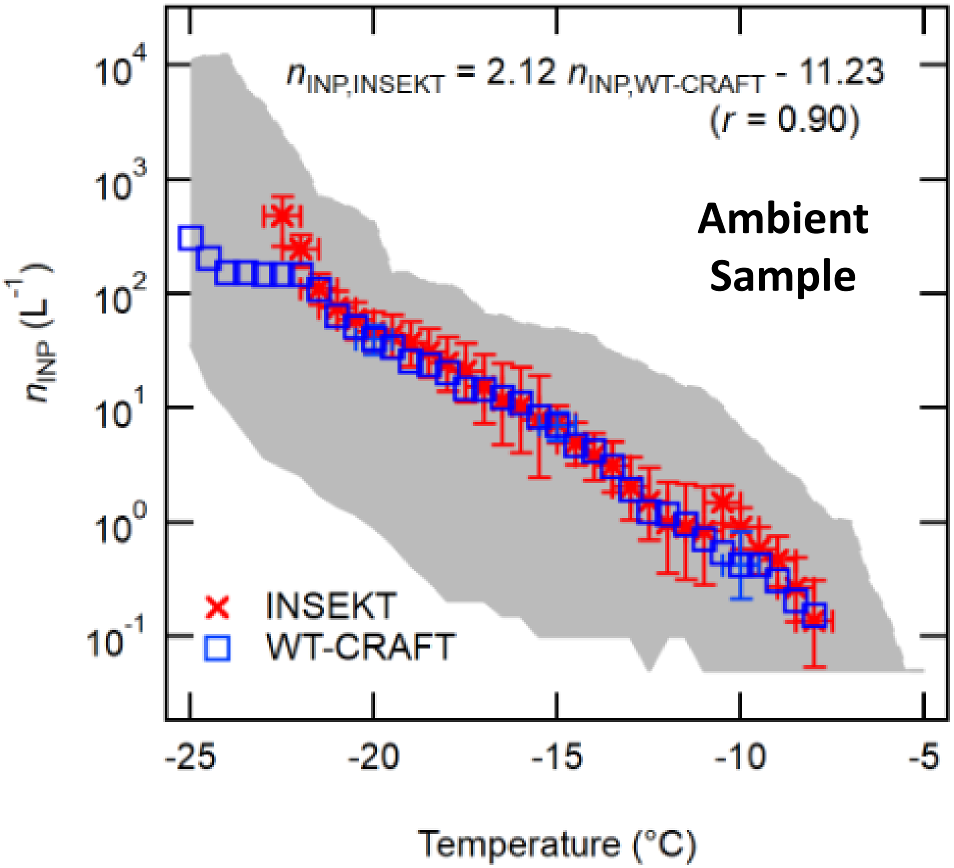

Refs.: Hiranuma, N. et al.: Atmos. Chem. Phys., 21, 14215–14234, 2021;
Wilbourn, E. K. et al.: Submitted to J. of Chem. Edu.

Inlet Loss

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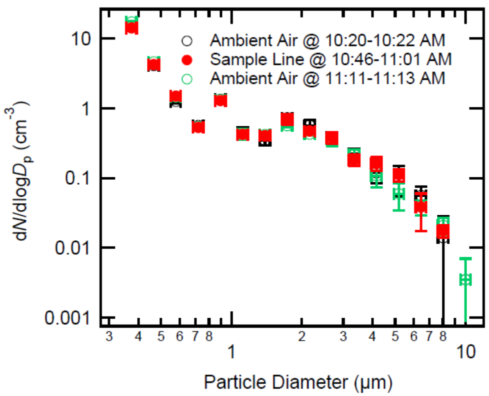
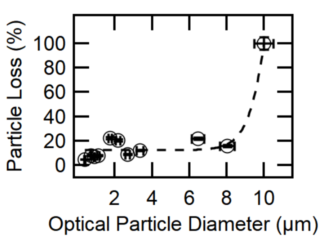
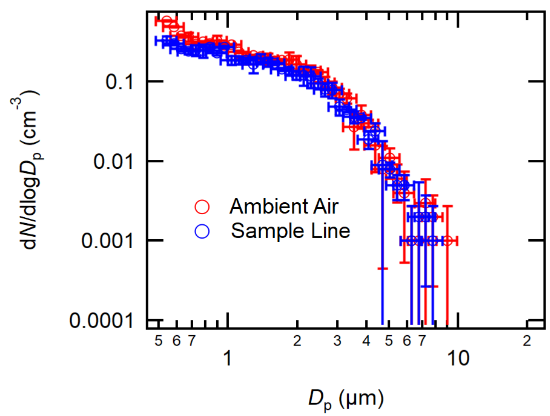
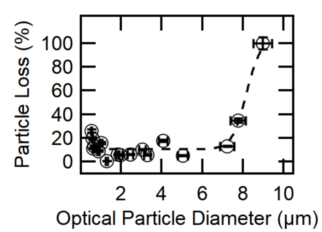
SGP



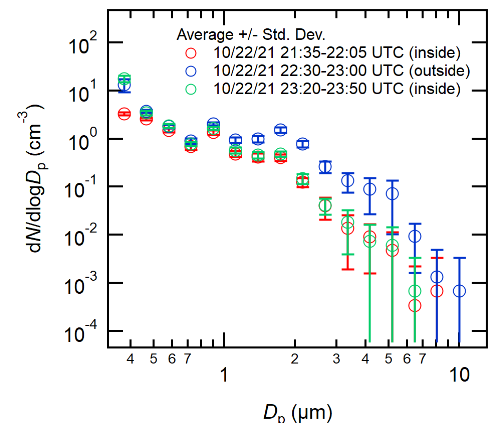


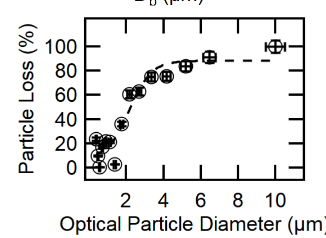
ENA



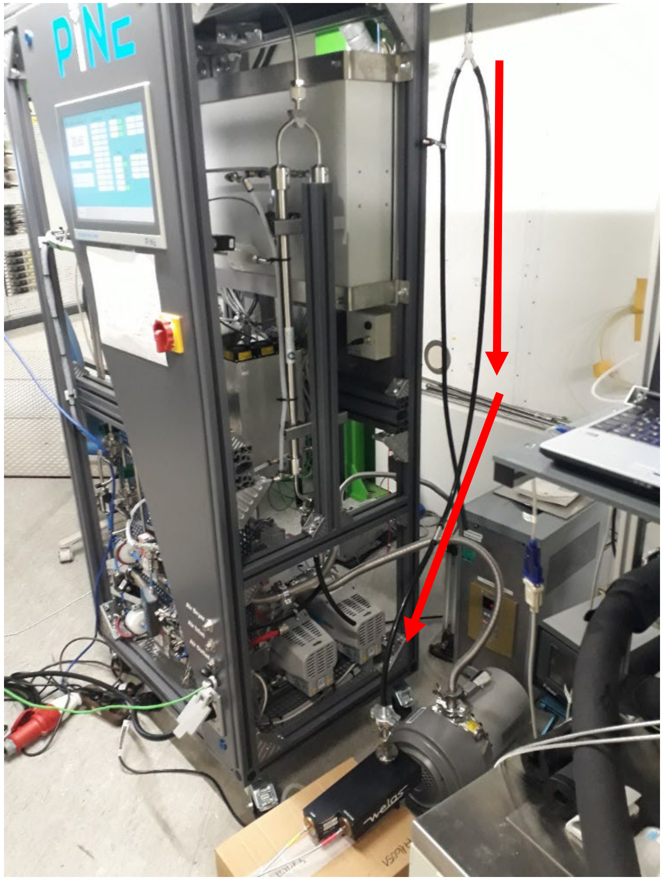


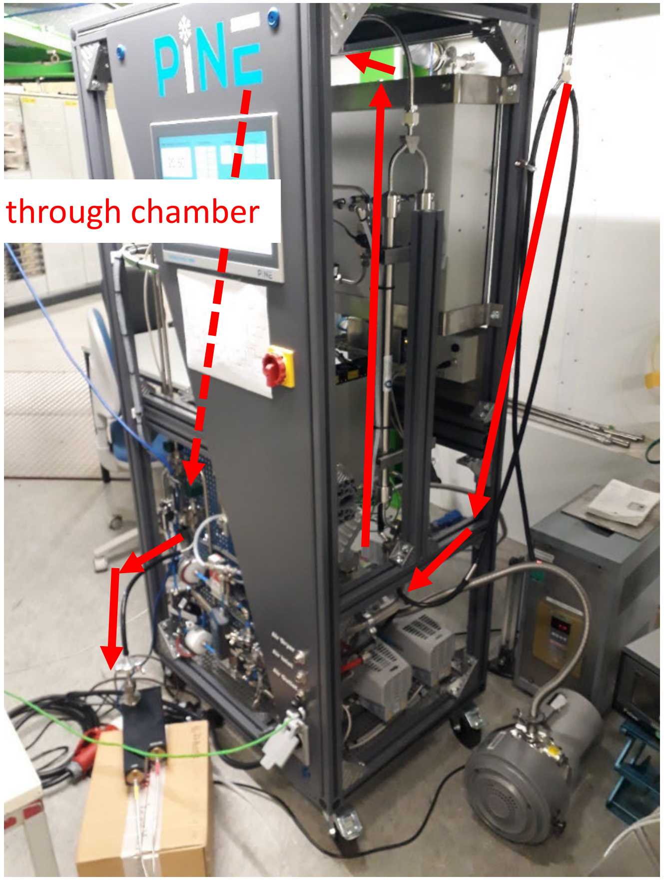
NSA-BRW





Particle Loss in PINE





"Memory Effect" Tests

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- Can we clean up the chamber by introducing "filtered-air" for 300 sec or 600 sec?
- We did a series of expansion with the following sequence:

  Expansion w/ filtered air (F) → Expansion w/ ambient sample air (S) → S → F

- We repeated this sequence at 4 different set point *T*s: -16, -21, -26, and -31 °C

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Poisson Analysis

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To estimate n_{INP} errors as a function of T = memory effect

- Suggested by CSU – see Kathryn Moore's M.S. thesis - https://mountainscholar.org/handle/10217/208435
- Based on equations from Krishnamoorthy and Lee, 2013
- Poisson mean:
- $\hat{\lambda}_s - \hat{\lambda}_f + \frac{3.84}{2}\left(\frac{1}{n_s} - \frac{1}{n_f}\right)$ where $\hat{\lambda}_s = \frac{N_s}{n_s}$ and $\hat{\lambda}_f = \frac{N_f}{n_f}$
- N_s = $n_{\text{INP,sample}}$ with ambient air
- N_f = $n_{\text{INP, filtered}}$
- n_s = number of expansions with ambient air
- n_f = number of expansions with filtered air
- $CI_{95\%} = \hat{\lambda}_s - \hat{\lambda}_f + \frac{1.96^2}{2}\left(\frac{1}{n_s} - \frac{1}{n_f}\right) \pm 1.96 * \sqrt{\left(\frac{\hat{\lambda}_s}{n_s} + \frac{\hat{\lambda}_f}{n_f}\right) + \frac{1.96}{4}\left(\frac{1}{n_s} - \frac{1}{n_f}\right)^2}$
- For the Poisson mean to be applicable, Z_m must be greater than 1.96 for a 95% confidence interval
- $Z_m = \frac{\hat{\lambda}_s - \hat{\lambda}_f}{\sqrt{\hat{\lambda}\left(\frac{1}{n_s} + \frac{1}{n_f}\right)}}$ where $\hat{\lambda} = \frac{N_s + N_f}{n_s + n_f}$

K. Krishnamoorthy & M. Lee, Journal of Statistical Computation and Simulation, 83, 2232-2243, DOI: 10.1080/00949655.2012.686616, 2013

Preliminary "Memory Effect" Results [12/14/20]

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We need an aerosol concentrator or further data processing (e.g., time average or cumulative INP counting analysis) to diagnose nINP above -16 °C

300 Second Flush Time										
Temperature (°C)	Flush Time (s)	λ_f	t_f	λ_s	t_s	λ	Mean	CI	Z_m	Mean ± 95% CI
-16	300	0.18350168	4	0.06060606	6	0.10976431	-0.2829623	0.4905715	-0.5746607	n/a
-21	300	0.09090909	4	0.12012987	6	0.07272727	-0.1308459	0.43571273	0.1678606	n/a
-26	300	0.25423729	4	3.98964218	6	0.10844156	3.57533823	1.68054328	17.5729806	3.58 ± 1.68
-31	300	3.90053763	4	29.5157765	6	0.17377284	25.4551722	4.76126722	95.194769	25.46 ± 4.76
600 Second Flush Time										
Temperature (°C)	Flush Time (s)	λ_f	t_f	λ_s	t_s	λ	Mean	CI	Z_m	Mean ± 95% CI
-16	600	0.41168629	12	0.21783849	8	0.33414717	-0.1138145	0.49275337	-0.7347044	n/a
-21	600	0.58256018	12	2.14063641	12	0.4366715	1.55807623	0.93369481	5.77546426	1.56 ± 0.93
-26	600	0.54963303	12	6.61994079	14	1.36159829	6.04744109	1.41173315	13.2237362	6.05 ± 1.41
-31	600	3.45739366	8	26.7392024	8	1.34513472	23.2818088	3.80793979	40.1479914	23.28 ± 3.81

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Positive aspect of Poisson

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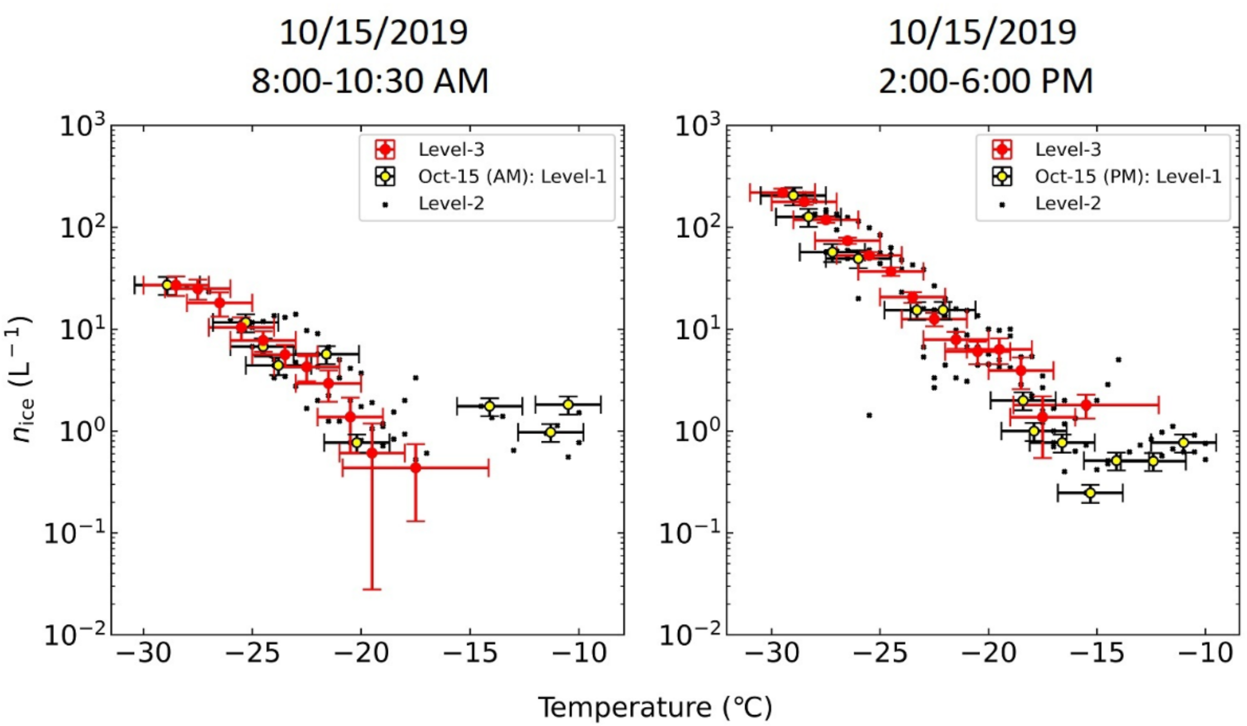
The Poisson analysis processed data (red) **exclude high *T* humps & reasonable $CI_{95\%}$** as compared to the raw data (yellow).



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Offline-droplet freezing results

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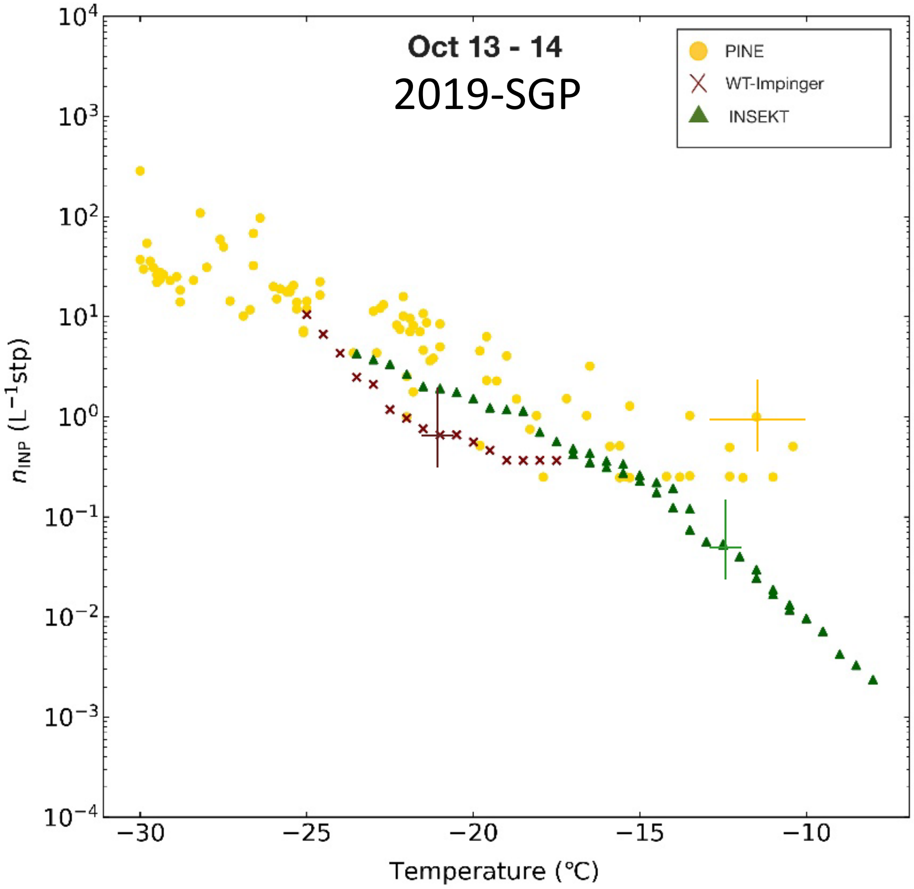

INSEKT Technique Ref.: Schneider, J. et al.: Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2020-683, in review, 2020.