Online ice-nucleating particle measurements in the Southern Great Plains (SGP) using the Portable Ice Nucleation Experiment (PINE) chamber

Hemanth S. K. Vepuri[1], Larissa Lacher[2], Jens Nadolny[2], Ottmar Möhler[2], and Naruki Hiranuma[1]

[1]Dept. of Life, Earth and Environmental Sciences, West Texas A&M University (WTAMU), Canyon, TX, USA; [2]Institute of Meteorology and Climate Research, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

West Texas A&M

Karlsruher Institut für Technologie

Objectives & Motivation

- Performing ground-based Ice-Nucleating Particle (INP) measurement using PINE at WTAMU, Canyon, TX ('TxTEST', Jul–Aug, 2019) and the ARM-SGP, Lamont, OK ('ExINP-SGP', Oct-Nov, 2019) site, where we repeatedly observe ice crystals & clouds below 20 km AGL[1], connecting the aerosols at ground level to higher altitudes (**Fig. 1**).
- Remotely controlling PINE via network for a semi-autonomous INP measurement on a 24/7 basis, filling a current deficit in ambient online INP measurements (n_{INP})[4].
- Complementing PINE data with offline n_{INPs} from the aerosol particles collected using the polycarbonate filters & liquid impinger suspensions.
- Examining if immersion is a more predominant ice nucleation mechanism at the SGP site.
- Developing a variety of INP parameterizations representing the U.S. intra-continental dust from various sources (e.g. agricultural soil dust, biomass burning etc).

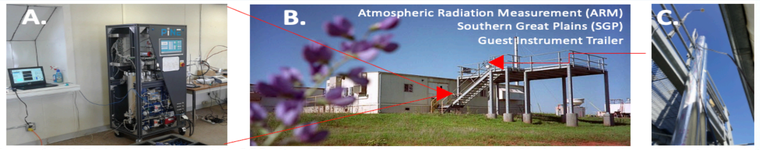


Figure 1. PINE (A) deployed at the SGP site, (B) Guest Instrument Trailer (C). A semi-laminar flow stack inlet (17.5' AGL), built by Daniel Knopf, was used to intake aerosols to PINE. *Photo B* – courtesy of Michael Ritsche.

Methods

- In both campaigns, PINE made semi-autonomous INP measurements at a high time resolution of 8 minutes for individual adiabatic expansions with continuous temperature scans from -5 to -35°C in 90 minutes[7]. PINE Level-1 & Level-2 data represents n_{INP} at the end of each run & for every 0.5°C *T*-bins for each run at a high time resolution.
- Furthermore, a 47mm polycarbonate filter sampler was used to collect aerosol particles next to PINE. At SGP site, the filter samplings were carried out for an average period of ~2 days.
- A liquid impinger sampler was also used to collect aerosol particles at SGP site. An initial liquid (HPLC grade) volume of 20mL was used for sampling over an average period of ~2 hours.
- A semi-laminar stack inlet was used to intake aerosols to all our instruments at SGP site (**Fig. 1c**).
- Offline-droplet freezing assays were later conducted for aerosol particles collected on the filter and impinger samples for immersion freezing mode using WT-CRAFT[3] and INSEKT[9-10].

Results - SGP Field Campaigns

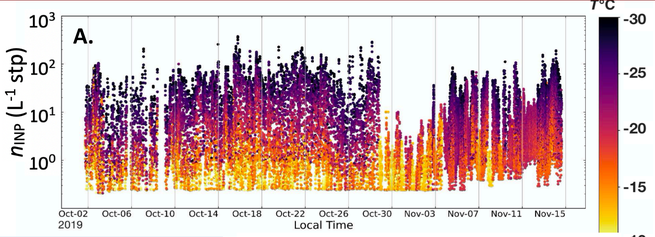
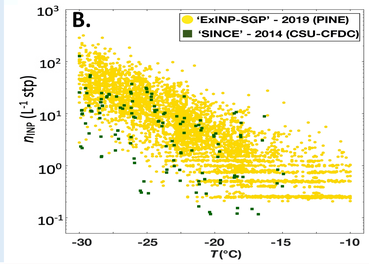


Figure 2. (A) Time series of the PINE measured n_{INP} at ARM SGP site. (B) comparison of PINE INP data from ExINP-SGP 2019 with CSU-CFDC SINCE-2014.

- We have successfully completed our INP measurements for 45 consecutive days with a turnover time of ~8 min scanning from -5 to -35°C. Overall, the ExINP campaign produced more than 30,000 meaningful PINE-measured INP data points (**Fig. 2a**).
- We observed a reasonable agreement of our PINE INP measurements with previous SINCE-2014[2] campaign at SGP site for *T*s ≤-20°C (**Fig. 2b**).



Online vs. Offline INP Measurements

- Reasonable agreement between PINE and other offline measured INPs was found for most of the sampling days. But, a substantial deviation was observed at higher *T*s (i.e., ≥ -15°C) (**Fig. 3**).
- Collection efficiency, transmission losses, & meteorological conditions may explain the observed deviation among PINE and offline measured INPs.

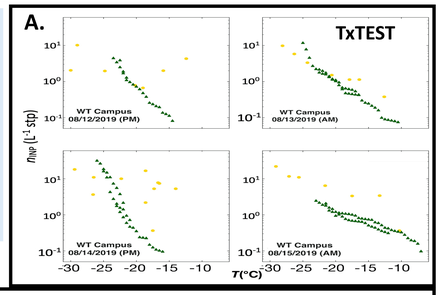
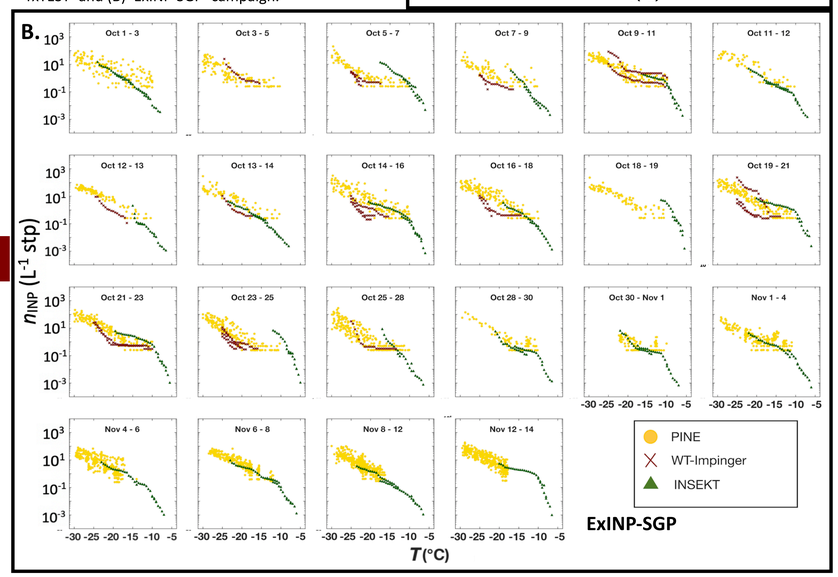


Figure 3. Comparison of PINE & offline n_{INP} for (A) 'TxTEST' and (B) 'ExINP-SGP' campaign.

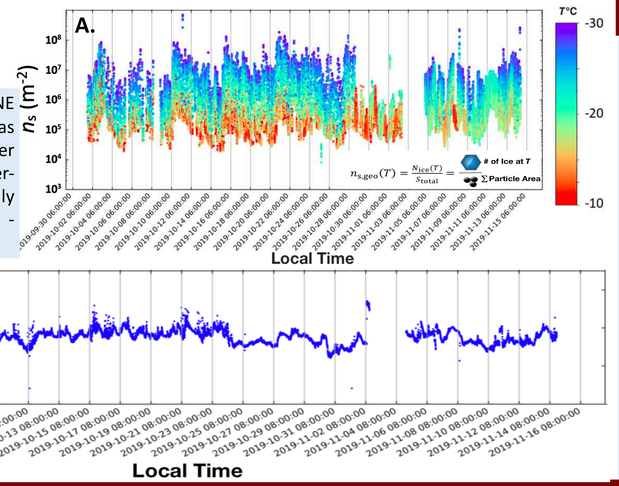


SGP INP Parameterizations

- We have successfully developed INP parameterizations, such as ice nucleation active surface site density ($n_s(T)$)[8] for 45 consecutive days based on our PINE INP data (**Fig. 4a**).
- Compared to n_{INP}, the surface area based parameterization may minimize the spread of uncertainty in n_s at a given *T*.

Figure 4. Time series of (A) $n_s(T)$ from PINE INP data and (B) AOS-APS total (>2µm) particle conc. at SGP site.

- At SGP, an increase in PINE measured n_{INP} was observed with the number concentration of super-micron particles, especially for diameters > 2µm (@ -25°C, r = 0.37) (**Fig. 4b**).



Supermicron Particles - INP Abundance at SGP

- Relatively high daily averaged n_{INP} @ -25°C (**35.6 ± 8.4 L^{-1}**) was coincided with the supermicron particle laden condition observed on **10/21** (**Fig. 5**).
- The low n_{INP} @ -25°C on **10/25** (**4.7 ± 1.2 L^{-1}**) may be due to decrease in total concentration of supermicron particles.

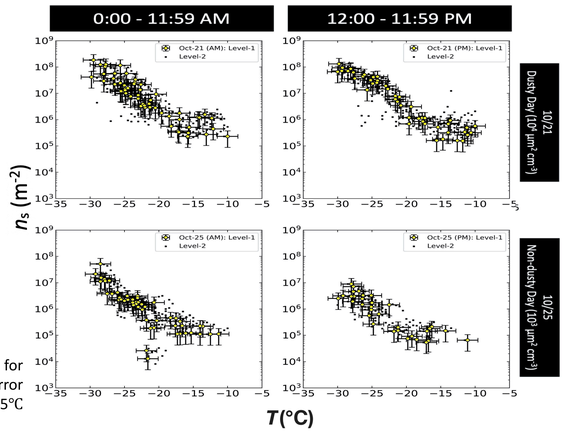


Figure 5. $n_s(T)$ based IN spectra for 10/21 & 10/25 days at SGP site. Error bars are systematic errors of ± 1.5°C (X-axis) & ±62% (Y-axis).

Immersion Freezing Predominance at SGP ?

- Our preliminary results suggested that the immersion freezing was the dominant ice-nucleation mechanism at the SGP site compared to the deposition mode. (**Fig. 6**).
- We observed no substantial correlation between cloud condensation nuclei (CCN) at SS = 0.2% and n_{INP} (-20°C) during our campaign period (r=0.002).

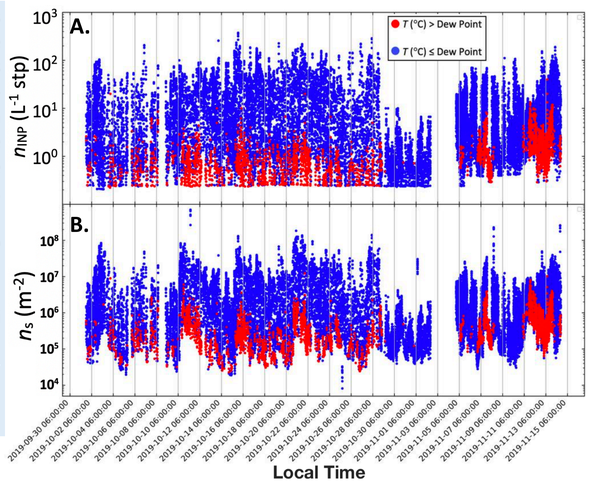


Figure 6. Time series of (A) n_{INP} and (B) $n_s(T)$ separated based on dew point temperature.

Summary & Outlook

- Unattended remote operation of PINE at SGP was successful, and we have processed 45 days of PINE data for Level-0 → Level-1 → Level-2.
- PINE is susceptive to the high *T* INP detection for INP > 0.2 L^{-1} with ~8 min time resolution.
- We observed that aerosol particle surface area is not a sole factor determining ice nucleation efficiency at SGP in 2019. Other factors like aerosol particle composition, mixing-state etc. should also be examined in the future.
- Comparison of PINE and the offline INP measurements highlighted the important factors to be considered, like collection efficiency & transmission losses of supermicron INPs in PINE & other sampling techniques.
- We need to look into the relationship between INP propensity and **ambient conditions**, **atmospheric dynamics,** & **thermodynamics**, connecting the aerosols at ground level to higher altitudes.
- Contributions of deposition nucleation (INP measured at *T* above Dew Point and/or at <-30°C at SGP) will be further investigated along with the estimation of mole fraction of water in aerosol particles to finalize our immersion INP data.
- A water activity based ice nucleation kinetics parameterization[5] will be developed using SGP PINE data.
- The Poisson mean based 95% confidence intervals[6] for PINE measured INP data will be developed as Level-3 PINE data.

References

[1] Balmes, K. A. et al.: J. Geophys. Res. Atmos., 124, 1755–1778, 2019.
[2] DeMott, P. J. et al.: SINCE *Campaign Summary* (No. DOE/SC-ARM-15-012)., 2015.
[3] Hiranuma, N. et al.: Atmos. Chem. Phys., 19, 4823–4849, 2019.
[4] Kanji, Z. A. et al.: Meteor. Mon., 58, 1.1–1.33, 2017.
[5] Knopf, D. A. and Alpert, P. A.: Faraday Discuss., 165, 513–534, 2013.
[6] Krishnamoorthy, K. and Lee, M.: Journal of Stat. Comp. Simul., 83:12, 2232–2243, 2013.
[7] Möhler, O. et al.: Atmos. Meas. Tech., in review, 2020.
[8] Niemand, M. et al.: J. Atmos. Sci., 69(10), 3077–3092, 2012.
[9] Schiebel, T.: Ph.D. thesis., IMK-AAF, KIT, Germany, 2017
[10] Schneider, J. et al.: Atmos. Chem. Phys., in review, 2020.

Acknowledgement: This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Biological and Environmental Research program (DESC0018979, Atmospheric Processes) under Early Career Research Program Award (DE-FOA-0001761) – work packages 1-2 of Implications of Aerosol Physicochemical Properties Including Ice Nucleation at ARM Mega Sites for Improved Understanding of Microphysical Atmospheric Cloud Processes.

We acknowledge the ARM-SGP technicians and admin team for maintaining and operating the guest facility as well as for data sharing.

U.S. DEPARTMENT OF ENERGY | Office of Science

ARM SGP

Paul Engler College of Agriculture and Natural Sciences
Dept. of Life, Earth and Environmental Sciences
Discover Real-World Experience

www.wtamu.edu