Portable Ice Nucleation Experiment (PINE) chamber: laboratory characterization & field test for its semi-automated ice-nucleating particle (INP) measurements in the Southern Great Plains (SGP)

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What are ice-nucleating particles (INPs)?

① NEEDLE IN HAYSTACK

- A few in a million aerosol particles producing ice crystals below 0 °C.

② ELEPHANT IN THE CLOSET

- Causing substantial impacts on the formation of cloud, precipitation, and the Earth’s energy budget.

BUT the impact remains quantitatively uncertain.

**Climatic Impact of INPs etc.**

Radiative forcing = the difference between sunlight absorbed by the Earth and energy reflected back to space

Notorious ~100% uncertainty

<table>
<thead>
<tr>
<th>Emitted compound</th>
<th>Resulting atmospheric drivers</th>
<th>Radiative forcing by emissions and drivers</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>CO₂</td>
<td>1.68 [1.33 to 2.03]</td>
</tr>
<tr>
<td>CH₄</td>
<td>CO₂, H₂O, O₃, CH₄</td>
<td>0.97 [0.74 to 1.20]</td>
</tr>
<tr>
<td>Halocarbons</td>
<td>O₃, CFCs, HCFCs</td>
<td>0.18 [0.01 to 0.35]</td>
</tr>
<tr>
<td>N₂O</td>
<td>N₂O</td>
<td>0.17 [0.13 to 0.21]</td>
</tr>
<tr>
<td>CO</td>
<td>CO₂, CH₄, O₃</td>
<td>0.23 [0.16 to 0.30]</td>
</tr>
<tr>
<td>NMVOC</td>
<td>CO₂, CH₄, O₃</td>
<td>0.10 [0.05 to 0.15]</td>
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<tr>
<td>NOₓ</td>
<td>Nitrate, CH₄, O₃</td>
<td>-0.15 [-0.34 to 0.03]</td>
</tr>
<tr>
<td>Aerosols and precursors (Mineral dust, SO₂, NH₃, Organic carbon and Black carbon)</td>
<td></td>
<td></td>
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<tr>
<td>Cloud adjustments due to aerosols</td>
<td></td>
<td>-0.55 [-1.33 to -0.06]</td>
</tr>
<tr>
<td>Albedo change due to land use</td>
<td></td>
<td>-0.15 [-0.25 to -0.05]</td>
</tr>
<tr>
<td>Natural</td>
<td>Changes in solar irradiance</td>
<td>0.05 [0.00 to 0.10]</td>
</tr>
</tbody>
</table>

Fig. SPM.5 in ‘International Panel for Climate Change’ 2013: annual & global mean radiative forcing

Objectives

**LAB:**
- Validating PINE results compared to the **homogeneous** freezing data of AIDA (Aerosol Interaction & Dynamics in the Atmosphere).
- Verifying the PINE chamber’s capability on INP detection across a wide range of **heterogeneous** freezing (i.e., **immersion**) temperatures.

**FIELD:**
- Performing a **45 days straight** ground-based INP measurement using PINE at the ARM-SGP atmospheric observatory, where we repeatedly observe ice crystals & clouds below 20 km AGL.
- Remotely controlling PINE via network for INP measurements on a **24/7 basis**.

Motivation

- Enabling remote, autonomous & continuous INP measurement, filling a current deficiency in ambient online INP measurements.
- Reducing labor intensity of INP monitoring & analyses (increasing consistency)
Portable Ice Nucleation Experiment (PINE) Chamber: Theory

Adiabatic expansion process

\[ p v^r = C \]

Ref: mechanicalbooster.com
Portable Ice Nucleation Experiment (PINE) Chamber: Specs

- Parallel twin Perma Pure Nafion® Dryers run @ >100 mb
- A cryo-cooler (Thales) controls T between 0 °C and -60 °C
- A 10 L aluminum vessel (air leak <0.4 mb/min) is thermally insulated, enabling an ‘expansion’ experiment every 8 min
- The PALAS Fidas® detector optically measures INP concentrations and sizes for ~0.7 - 220 μm (optical diameter based on a spherical assumption) with 256 bin sizes
- The measured particle loss in a current setup is 35% for 5 μm particles & <5% at <3 μm particles.
- PINE is computer-controlled with 2 pumps, 3 mass flow controllers & 6 valves.
- Multiple sensors (3 Ti thermocouple, 3 Tw pt-100, P & Dew Point) are equipped (± 0.4 °C accuracy).

**PINE Operation**

- **RAMPING-T MODE**: $T$ cycles of $-5 \, ^\circ C \leftrightarrow -35 \, ^\circ C$ every 90 min with automated sequence of **Flush** $\rightarrow$ **Expand** $\rightarrow$ **Refill**.

- **SINGLE-T MODE**: Measurements at a fixed $T$.

- **BACKGROUND MODE**: Expansions without aerosol injection are carried out daily for ~1 hour to ensure a zero-INP background.

- The Fidas® PM-voltage (only free parameter in PINE) is calibrated periodically to optimize its detection sensitivity ($0.2-50$ K INP L$^{-1}$ STP).

![Graphs showing temperature fluctuations](image)

- **Ti1** = inside-vessel gas temperature
- **Tw1** = wall temperature
Lab homo- & hetero-geneous freezing test

Ammonium Sulfate

i. Homogeneous

Illite NX

ii. Low T Immersion

Snomax

iii. High T Immersion

Date & Time (Local Time)

Temperature (°C)

Pressure (mb)

INP_{STP} (L^{-1})

Ice Crystals (>55 μm)

Ice Crystals (>30 μm)

Southern Great Plains (SGP)

www.arm.gov/tour/sgp-overview.html
Southern Great Plains (SGP)

PINE deployed in the side-by-side position of offline samplers.

A semi-laminar flow stack inlet (17.5’ AGL), built by Daniel Knopf, was used to intake aerosols to PINE.
Overview: 45 days PINE data from SGP

Oct. 1\textsuperscript{st} – Nov. 14\textsuperscript{th} in 2019.

Compiled PINE INP spectra
Qualitative comparison to 2014 SGP-INP data

Compiled PINE INP spectra

- PINE-measured upper & lower INP boundaries and median line added.
- CSU-CFDC & IS measured INP spectra from the May-June 2014 measurements - data adapted from DeMott et al., 2015 (DOE/SC-ARM-15-012).

INP Conc. (L⁻¹ STP)
PINE Gas Temperature (°C)
PINE time-series data
Oct. 15th, 22nd, 24th & 25th

Temperature (°C)

INP Conc. (L⁻¹ STP)

PINE Gas Temperature (°C)

10/15 10/17 10/19 10/21 10/23 10/25 10/27
Local Date & Time in 2019
PINE-measured INP increase during the cold-frontal passage.

Back Trajectories at the Surface level @ SGP.
Supermicron size dominant INPs & CCN suppression?

**APS**

- Diameter (μm)
- Local Time: 19:00, 1:00, 7:00, 13:00, 19:00
- 10/14, 10/15

**CCNC**

- CCN Conc. (cm⁻³)
- Local Time: 18:00, 0:00, 6:00, 12:00, 18:00
- 10/14, 10/15
PINE Data Archiving & Structure

Exclusion of systematic/suspicious errors

Level 0
- Housekeeping
- Fidas (f100-1)
- Operation & run summary files
- Digital log book

Level 1*
- Housekeeping
- INP-1 (i.e., INP at the lowest Ti1 for each run)
- Background
- Python
  - Program files
  - README
  - Plots

Level 2*
- Housekeeping
- INP-2 (i.e., T-binned INP with 0.5 °C for each run)
- Droplet & aerosol data
- Episode/event-resolved data
- Python
  - Program files
  - README
  - Plots

Episode-specific and equally T-binned data production
Level 1 data example from Oct. 15th, 2019 (One data point from each run)
Level 2 data example from Oct. 15\textsuperscript{th}, 2019

(Multi-$T$-binned data points from each run)
Final product example from Oct. 15th, 2019
(Offline INP data superposed on PINE data)

PINE Gas Temperature (°C)

INP Conc. (L⁻¹ STP)

- Afternoon
- Morning

Impinger sampling → Cold stage

Summary & Outlook

1. PINE is susceptible to the high $T$ INP detection for $\text{INP} > 0.2 \text{ L}^{-1}$ with $\sim 8$ min time resolution.

2. Unattended remote operation of PINE at SGP was successful, and we have processed 45 days of PINE data for $L_0 \to L_1 \to L_2$.

3. We need to look into the relationship between INP propensity and other cloud micro-/macro-physical properties, aerosol emission, dynamics & thermodynamics observed at SGP, connecting the aerosols at ground level to higher altitudes (closure study).

4. The correlation between INP concentration at high $T$ and supermicron aerosol abundance (e.g., particle mass concentration) should also be looked into to examine the importance of supermicron INP.

5. Contributions of deposition nucleation (INP measured at $T$ above Dew Point and/or at $<-30 \ ^\circ\text{C}$ at SGP) will be quantified to finalize our immersion INP data. Diffusional growth of droplets and ice crystals as well as impacts of evaporation in PINE should also be looked into.

6. PINE INP parameterization $\to$ E3SM model & comparison to CNT etc.
Atmospheric Ice Research

# of publications per month

Avg. 18 per month

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<th>Year</th>
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<td>2019</td>
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Acknowledgement

$ DOE ECRP (DE-SC0018979) 2018-2023
$ DOE Continuation of Solicitation for the Office of Science FAP (DE-SC0020006) 2019-2020
$ EUROCHAMP-2020 (AcCloud-001-2019) 2019

We thank our DOE collaborators & many individuals at the SGP-ARM station (including but not limited to) Chris Martin, Mark Smith, Ken Teske, John Schatz, Michael Ritsche, Jody Martin, James Martin, George Sawyer, David Swank, Tim Grove, Rod Soper and all SGP & ARM admin people.