Characterization of a new Portable Ice Nucleation Experiment chamber (PINE) and first field deployment in the Southern Great Plains

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Abstract

We present our first laboratory calibration and field results of a newly developed commercial ice nucleation chamber, the so-called PINE. The PINE instrument is developed based on the design of the AIDA cloud chamber (Möhler et al., 2003) to advance online atmospheric ice nucleation research. A unique aspect of the PINE chamber includes its plug-and-play feature (so it runs on a standard power outlet), autonomous cryo-cooler-based temperature-ramping operation, capability of quantifying INPs in different IN modes (e.g., immersion freezing and deposition mode at >-60 °C), small particle loss through the system (˜5% for <5 ?m diameter particles), and sensitive optical particle detection of INP concentration ([?]0.1 L-1 at T > -15 degC), promising stand-alone operation at remote locations. To date, the PINE chamber has been calibrated using test aerosol particles with known properties (e.g., illite NX). Briefly, test particles were exposed to ice supersaturation conditions, where a mixture of droplets and ice crystals were formed during the 'expansion' experiment. A comparison of our calibration test results to other techniques will be presented. Further, the PINE instrument has been tested in field campaigns in the Southern Great Plains. With a turnover time of ˜6 minutes, PINE ran continuously and scanned at different temperature intervals to assess different INP episodes. We made sure to assess at least a few degrees of common temperature interval in a series of scan. Our first field results will be shown. Our results suggest that using this autonomous instrument may be critical to minimize error sources in high-temperature and supermicron INP research. Acknowledgement: This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Biological and Environmental Research (DE-SC0018979) – 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. References: * DeMott, P. J. et al. Resurgence in ice nuclei measurement research. Bull. Amer. Meteorol. Soc. 92, 1623, doi:10.1175/bams-d-10-3119.1 (2011). * Mohler, O. et al. Experimental investigation of homogeneous freezing of sulphuric acid particles in the aerosol chamber AIDA. Atmos. Chem. Phys. 3, 211-223 (2003).

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West Texas A&M

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Atmospheric Ice-Nucleating Particles (INPs)

- *NEEDLE IN HAYSTACK*: A small quantity of INPs (a few in a million aerosol particles below -20 °C) can cause substantial impacts on the formation of cloud, precipitation, and the Earth's energy budget [1-2].
- *ELEPHANT IN THE CLOSET*: Contributions from forcing and feedback mechanisms associated with clouds and INPs obviously exist, but they remain quantitatively uncertain [3-5].

Objectives & Motivation

LAB:

- Validating a good heterogeneous INP detection sensitivity of PINE [6] compared to an offline INP measurement technique.
- Verifying the PINE's capability on INP detection at high temperatures (*T*s) nominally above -15 °C, where "clear and significant research issues remain" [7].

FIELD (**Fig. 1**):

- Performing a ground-based INP measurement using PINE at the ARM-SGP atmospheric observatory, where we repeatedly observe ice crystals & clouds below 20 km AGL [8], connecting the aerosols at ground level to higher altitudes (closure study).
- Remotely controlling PINE via network for a semi-autonomous INP measurement on a 24/7 basis, filling a current deficiency in ambient online INP measurements [2].

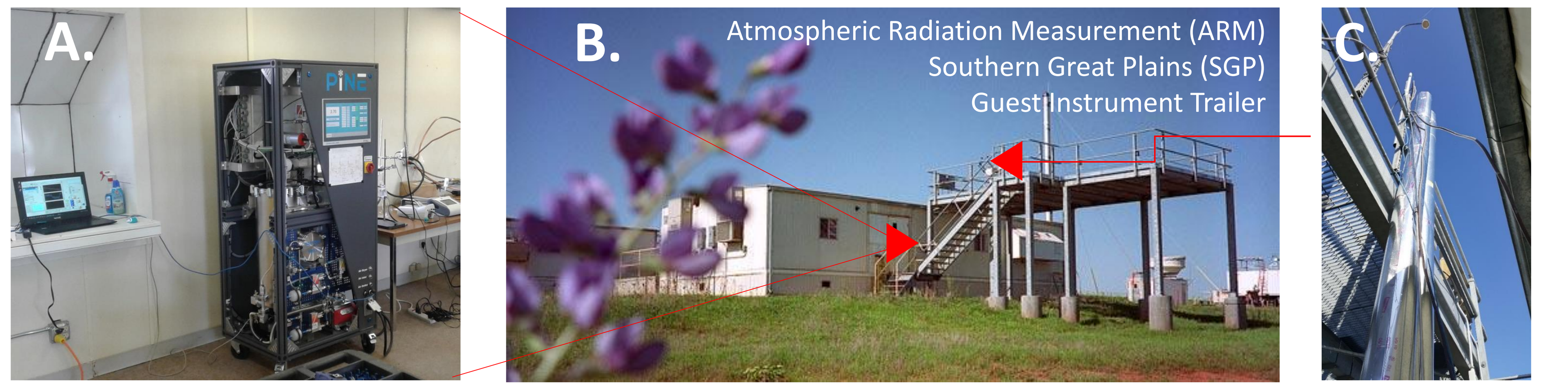
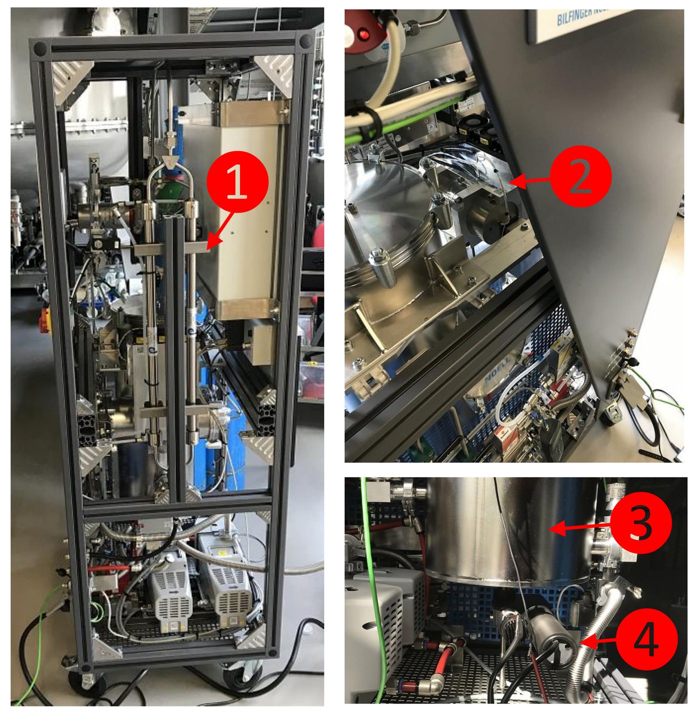


Figure 1. PINE (A) deployed at the SGP site (B). A semi-laminar flow stack inlet (17.5' AGL), built by Daniel Knopf, was used to intake aerosols to PINE. *Photo B* – courtesy of Michael Ritsche.

PINE Specs

- Parallel twin Perma Pure Nafion® Dryers run @ >100 mb ①
- A cryo-cooler (Thales) controls *T* between 0 °C and -60 °C ②
- A 10 L aluminum vessel (air leak <0.4 mb/min) is thermally insulated, enabling an 'expansion' expansion (**Fig. 2**) every 8 min ③
- The Fidas® detector optically measures INP concentrations and sizes for ~0.7 - 220 µm (optical diameter based on a spherical assumption) with 256 bin sizes ④
- 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.



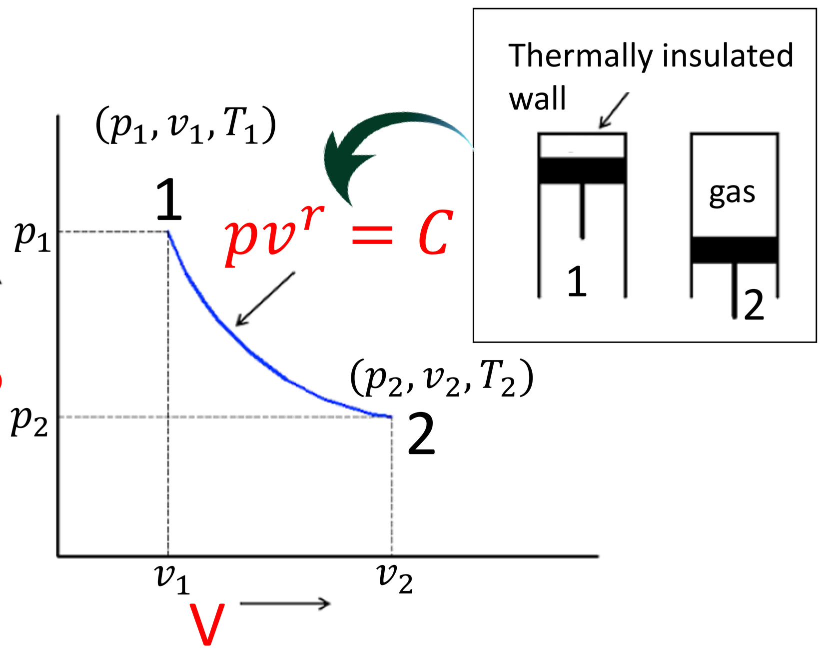


Figure 2. PINE system and adiabatic expansion process and curve; ©2017mechanicalbooster.com.

PINE Operation

- *RAMPING-T MODE*: *T* cycles of -5 °C ←→ -35 °C every 45 min and automated sequence of **Flush** → **Expand** → **Refill** at (**Fig. 3i**). Note Ti1 = inside-vessel temperature & Tw1 = wall temperature.
- *SINGLE-T MODE*: Measurements at a fixed *T* (**Fig. 3ii**).
- *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 (0.2-50K INP L^{-1} STP).

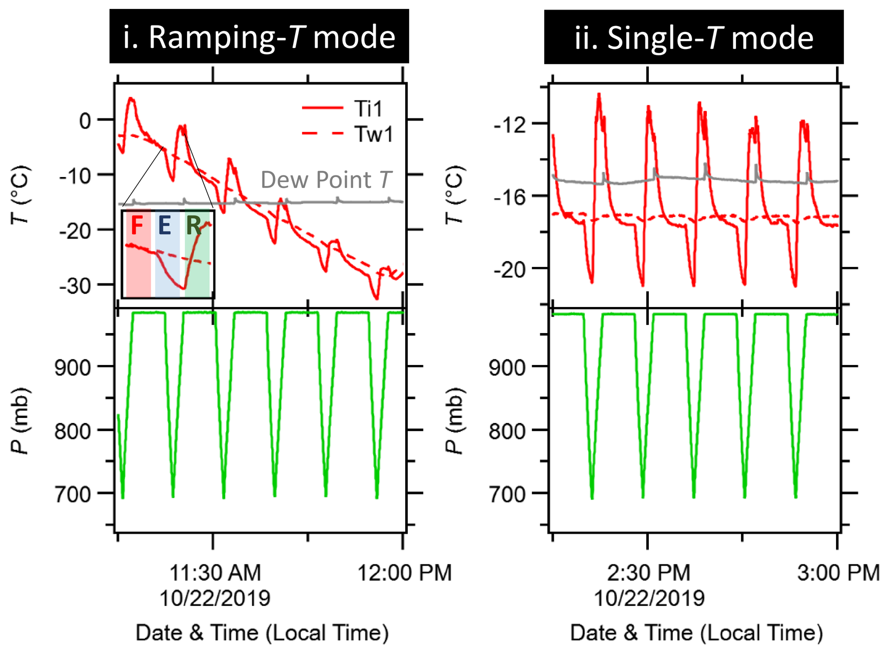
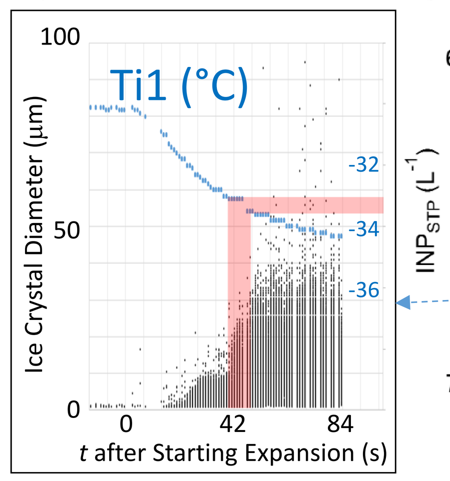


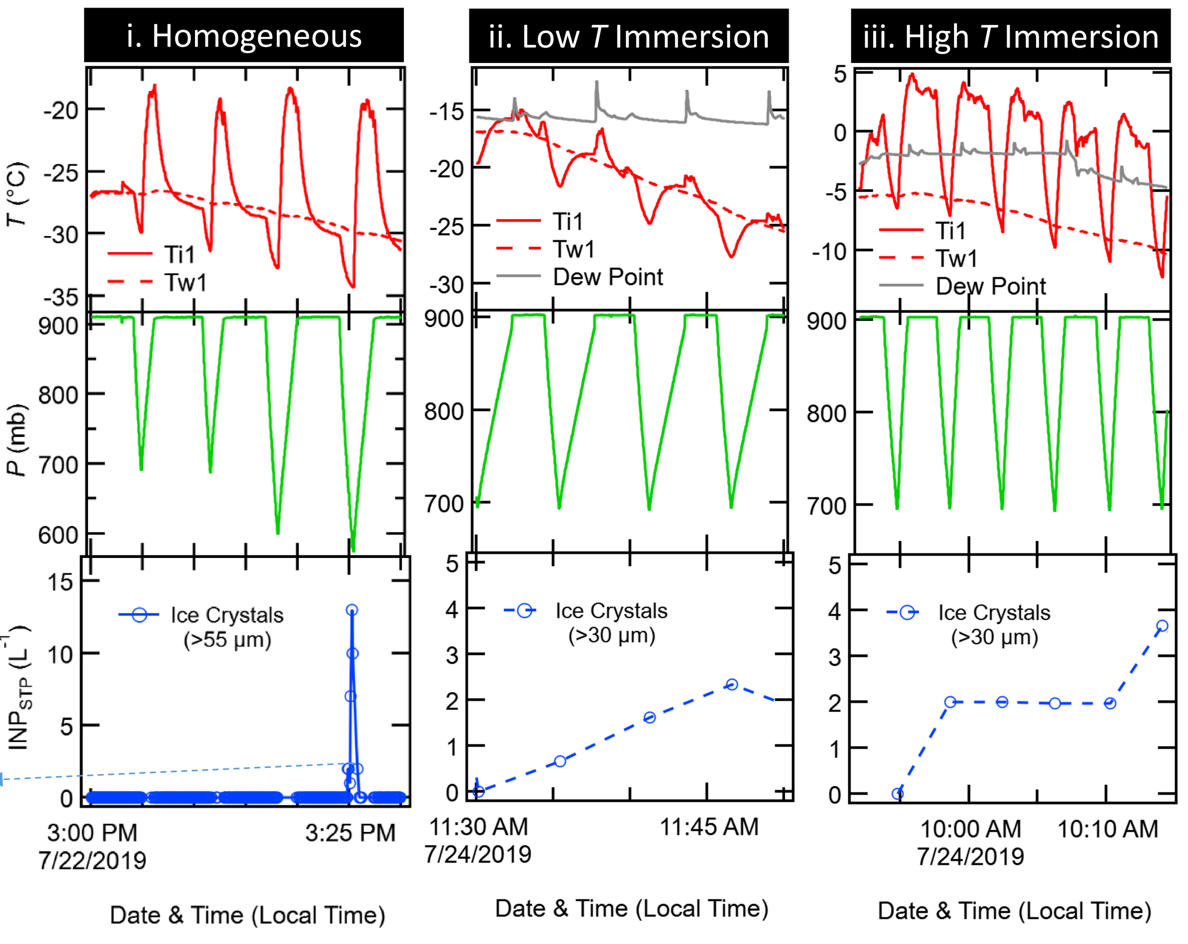
Figure 3. Two different operation modes of PINE. Time series of *T*s and *P* in PINE are shown for each mode. A sub panel in (i) represents a single expansion cycle.

Homogeneous & Heterogeneous Freezing Tests

- **Ammonium sulfate** (**Fig. 4i**) homogeneously freezes at -33 °C in PINE, which is comparable to the previous homogeneous freezing AIDA result [9].
- We observe immersion freezing of **illite NX** (**Fig. 4ii**) at -20 °C in PINE [10].
- **Snomax** (**Fig. 4iii**) heterogeneously freezes at -7 °C as seen by other online INP instruments [11], verifying the PINE's capability for high *T* INP research.

▶ **Figure 4**. Lab test results of homogeneous (i) and heterogeneous (ii & iii) freezing runs with PINE. Note that the dew point during the (i) experiment was maintained at ~-14 °C to ensure water saturation in each expansion. Aerosol conc. in PINE were kept around 20 L^{-1} for all experiments.





PINE vs. Filter-based WT-CRAFT Method

- We conducted the online PINE INP measurements and filter sampling of ambient aerosols in West Texas, followed by an offline analysis of INP using a cold stage.
- Reasonable agreement between two techniques was found around -24 °C, but a substantial deviation was found at higher *T*s (**Fig. 5**).
- A possible explanation for the observed deviation is discussed elsewhere e.g., [10,12].

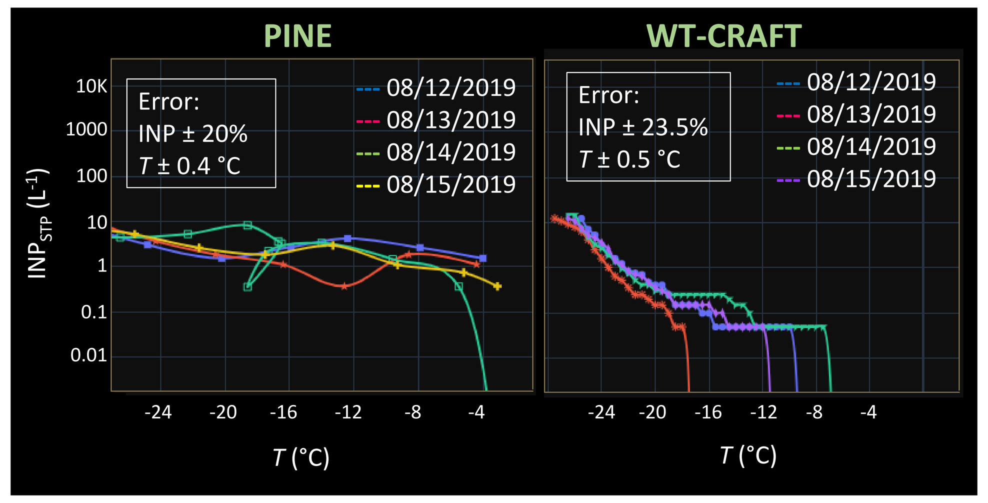


Figure 5. Comparison of INP spectra from PINE to those from West Texas Cryogenic Refrigerator Applied to Freezing Test (WT-CRAFT)[10] for ambient particles collected at WTAMU through ~10' (3/8" OD) SS tubes.

Preliminary SGP Field Results

- We have successfully completed our INP measurements for 45 consecutive days with a turnover time of ~8 min (**Fig. 6**).
- PINE was remotely operated for >2 weeks (with every 4 hours check-ups).
- The highest daily averaged INP conc. @ -25 °C during *T*-ramping was observed on **10/15** (**35.7 ± 14.0 L^{-1}**) right after the frontal passage event.
- Relatively high INP conc. (**23.7 ± 2.8 L^{-1}**) coincided with the supermicron particle laden condition observed on **10/22**.
- The low INP conc. on **10/25** (**4.9 ± 1.2 L^{-1}**) may be due to suppression in supermicron particles.

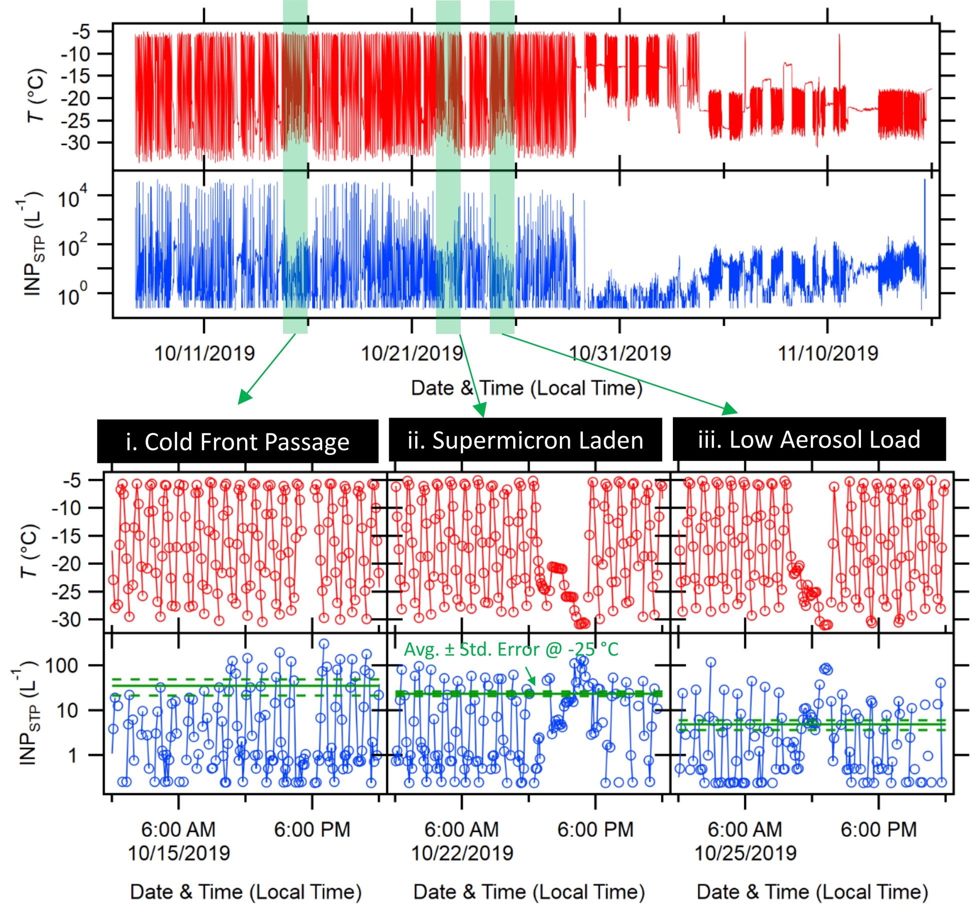
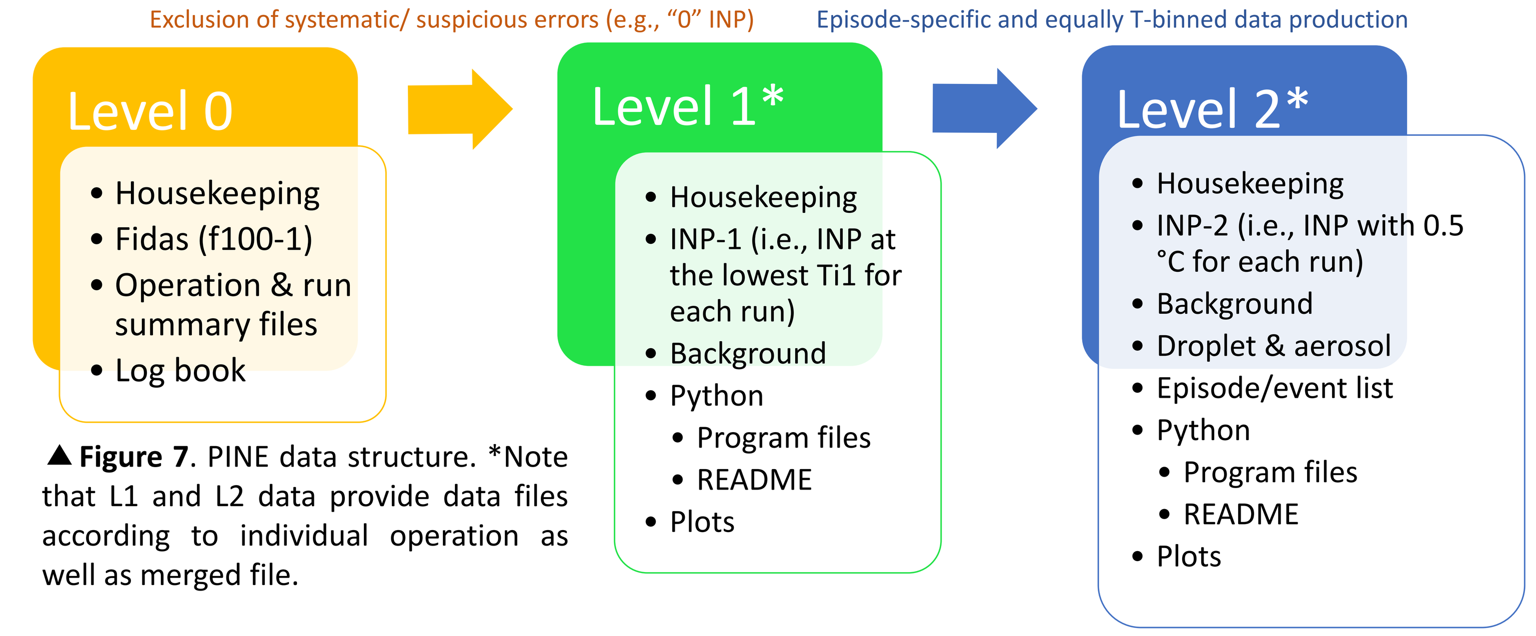


Figure 6. Time series of the measured chamber *T* and associated INP concentration at the end of each expansion. Three specific events (i, ii, & iii) were looked into.

Data Archiving & Structure

- Proprietary data are archived on the password-protected secure drive at WTAMU which is backed up daily.
- Each project is assigned its own subdirectory for storage of data files. Further subdirectories contain the raw (L0) and processed data files (L1-L2).
- All raw and processed-data files are stored based on the structure shown in **Fig. 7**.



▲ **Figure 7**. PINE data structure. *Note that L1 and L2 data provide data files according to individual operation as well as merged file.

Summary & Outlook

- PINE is susceptive to the high *T* INP detection for INP > 0.2 L^{-1} with ~8 min time resolution.
- Unattended remote operation of PINE at SGP was successful, and we have processed 45 days of PINE data for L0 → L1.
- *T* distribution in the vessel (avg. deviation between Ti1 and Ti2 = ±0.4 °C) should be carefully assessed, and suspicious data should be kicked out while producing the L2 data.
- We need to look into the relationship between INP propensity and ambient conditions observed at SGP. 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.
- The comparison between PINE and the offline INP measurements (with samples of filter impactor and impinger collected through a same stack inlet @ SGP) will be carried out to assess the loss of supermicron INPs in PINE.
- Contributions of deposition nucleation (INP measured at *T* above Dew Point and/or at <-30 °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.

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