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

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].

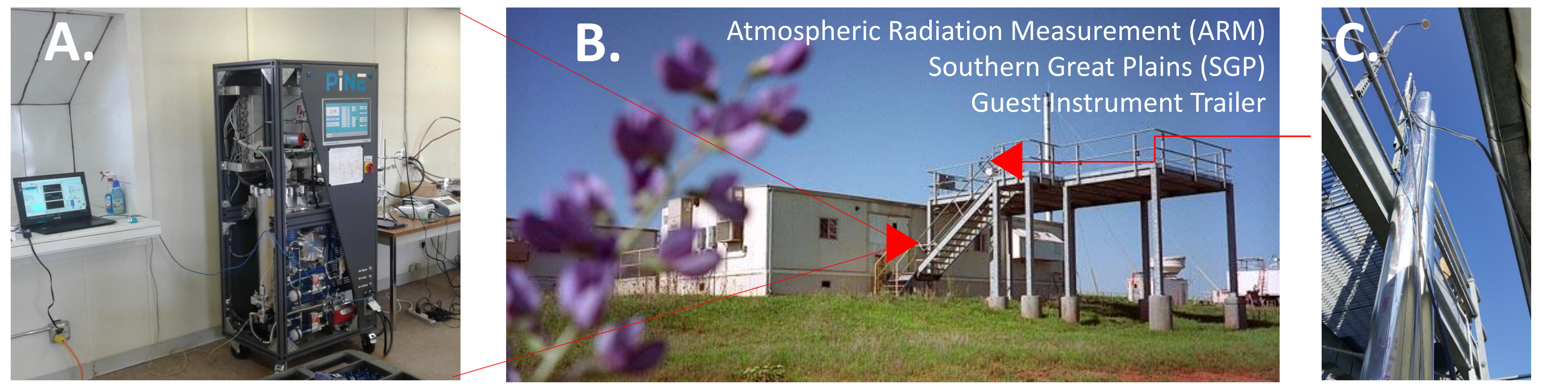
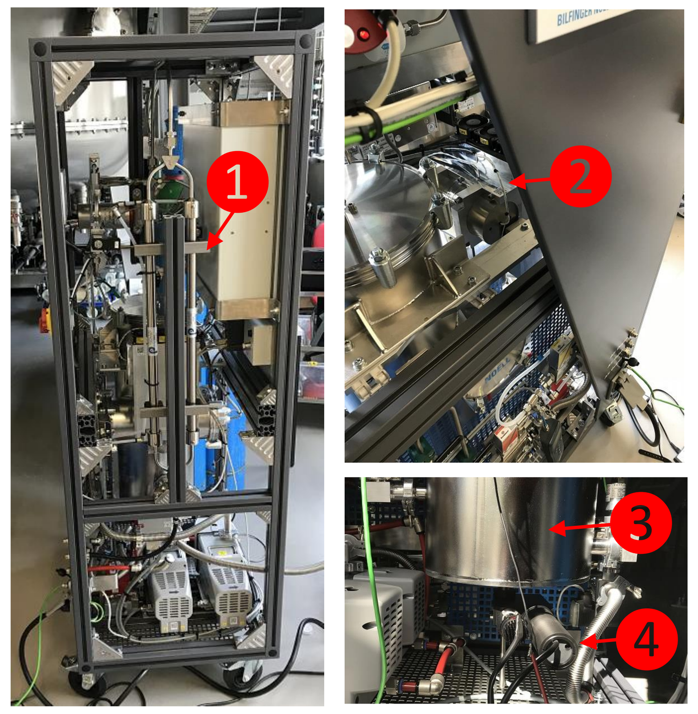


Figure 1. PINE (A) deployed at the SGP site (B). A semi-laminar flow stack inlet (17.5' AGL), built by Daniel Knopf, was used to intake aerosols to PINE. *Photo B* – courtesy of Michael Ritsche.

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.



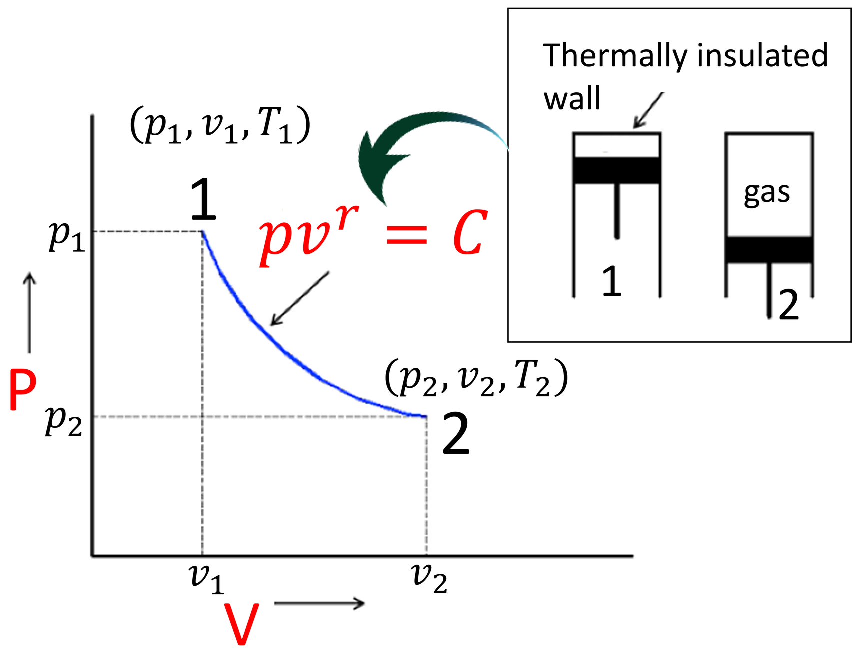


Figure 2. PINE system and adiabatic expansion process and curve; *©2017mechanicalbooster.com*.

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).

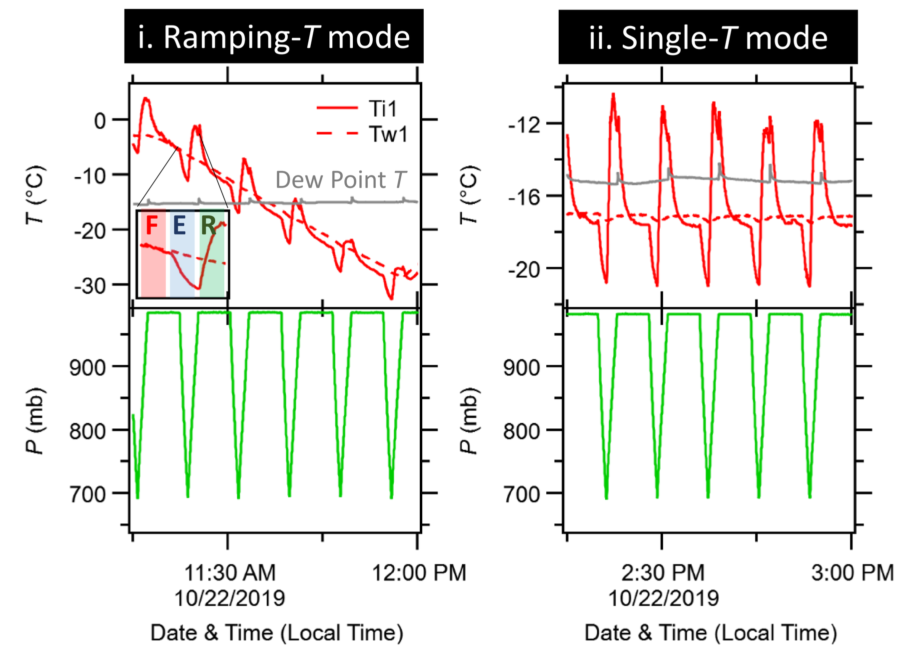
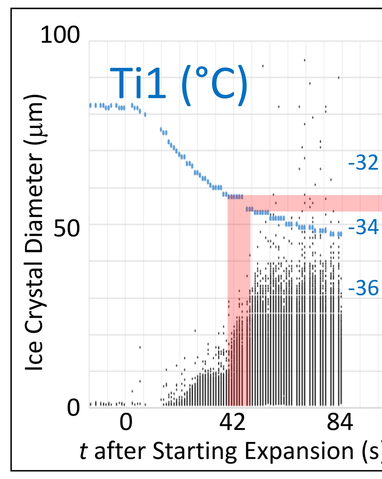


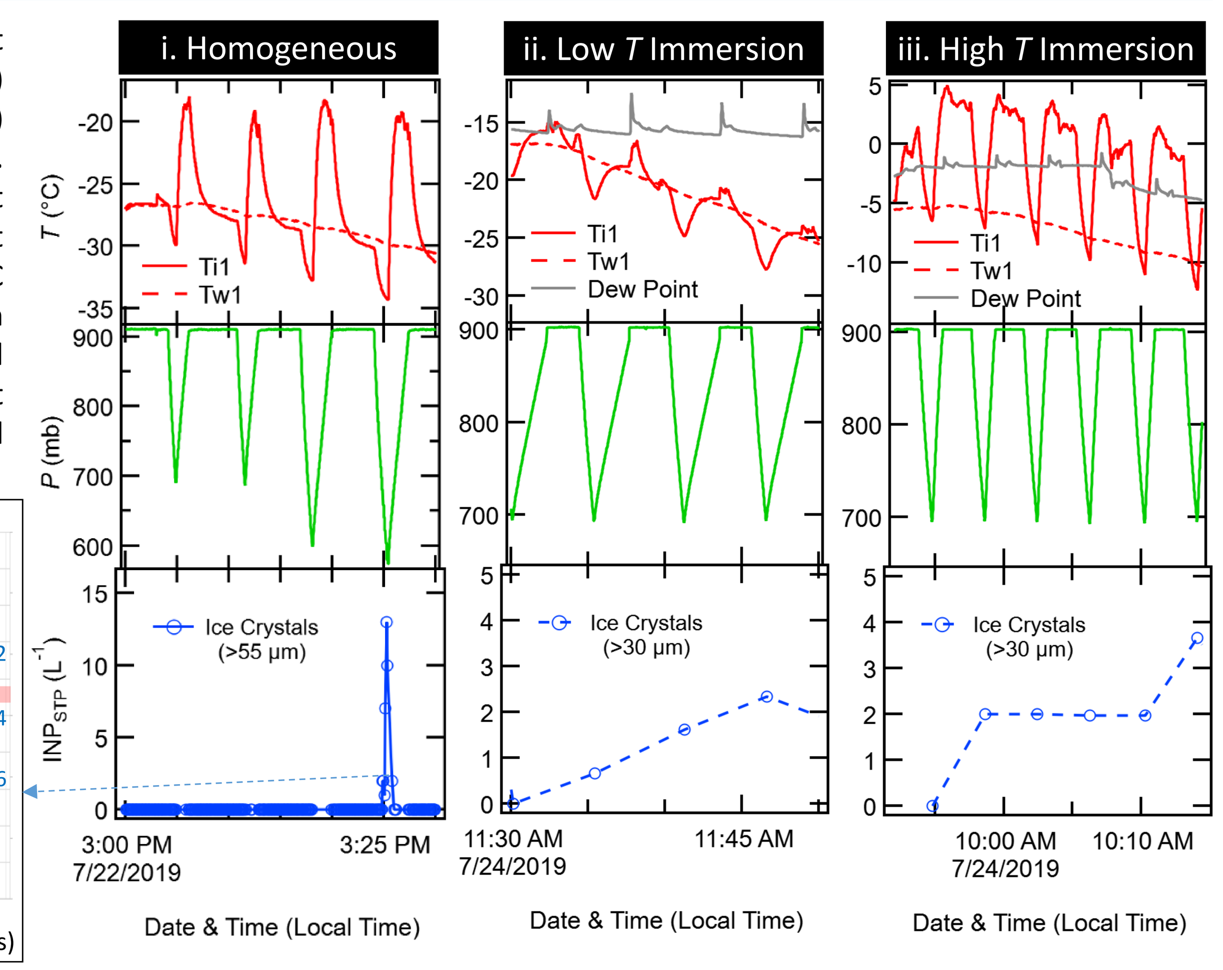
Figure 3. Two different operation modes of PINE. Time series of *T*s and *P* in PINE are shown for each mode. A sub panel in (i) represents a single expansion cycle.

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].

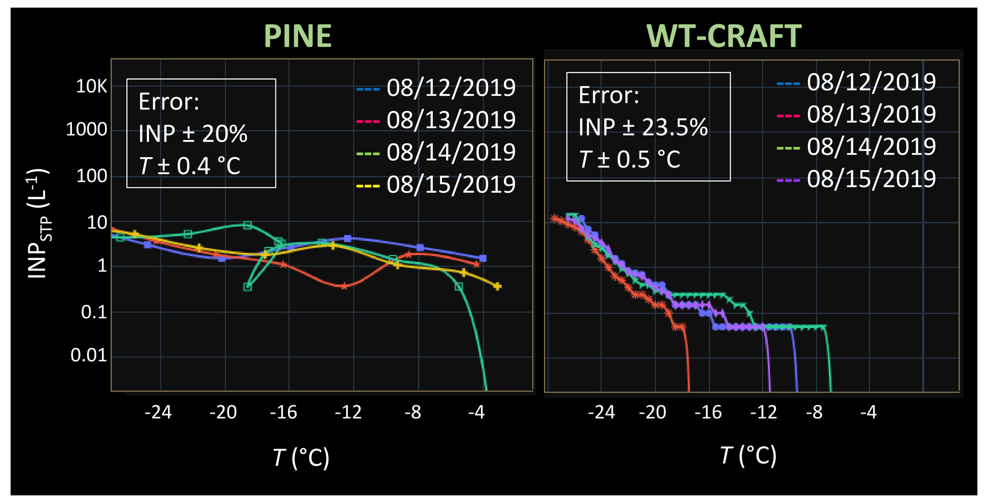


Figure 5. Comparison of INP spectra from PINE to those from West Texas Cryogenic Refrigerator Applied to Freezing Test (WT-CRAFT)[10] for ambient particles collected at WTAMU through ~10' (3/8" OD) SS tubes.

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.

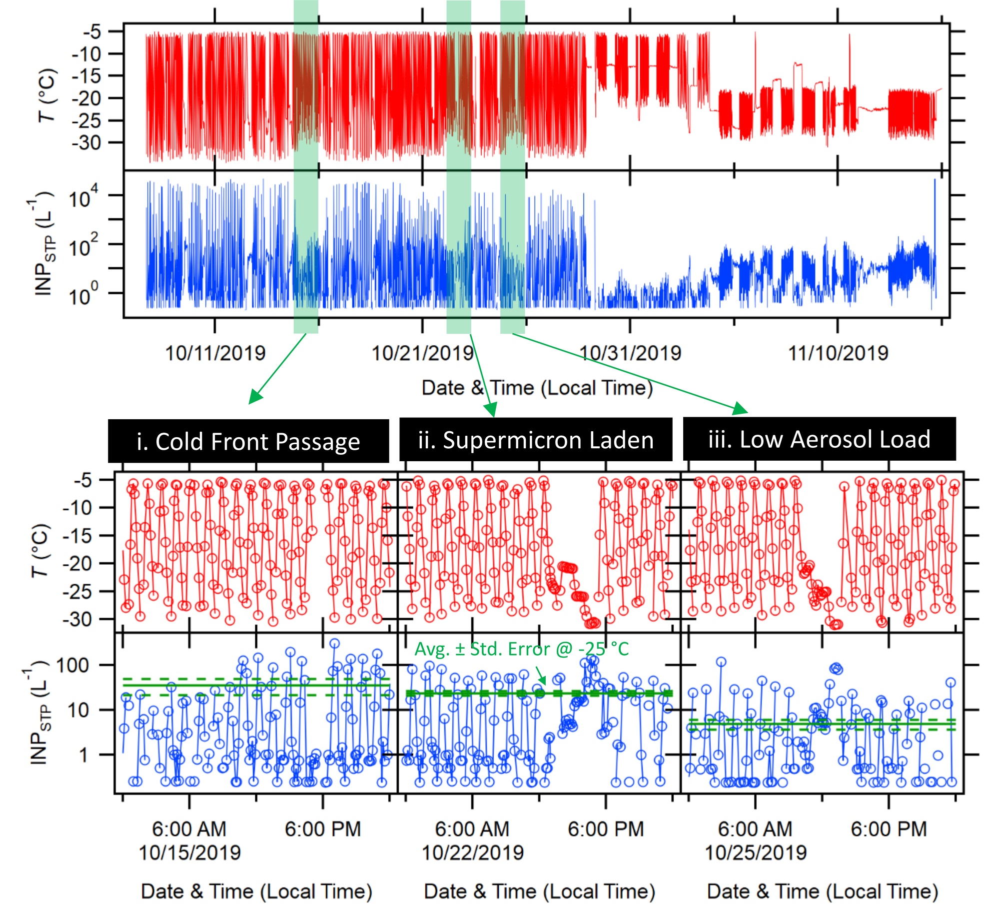
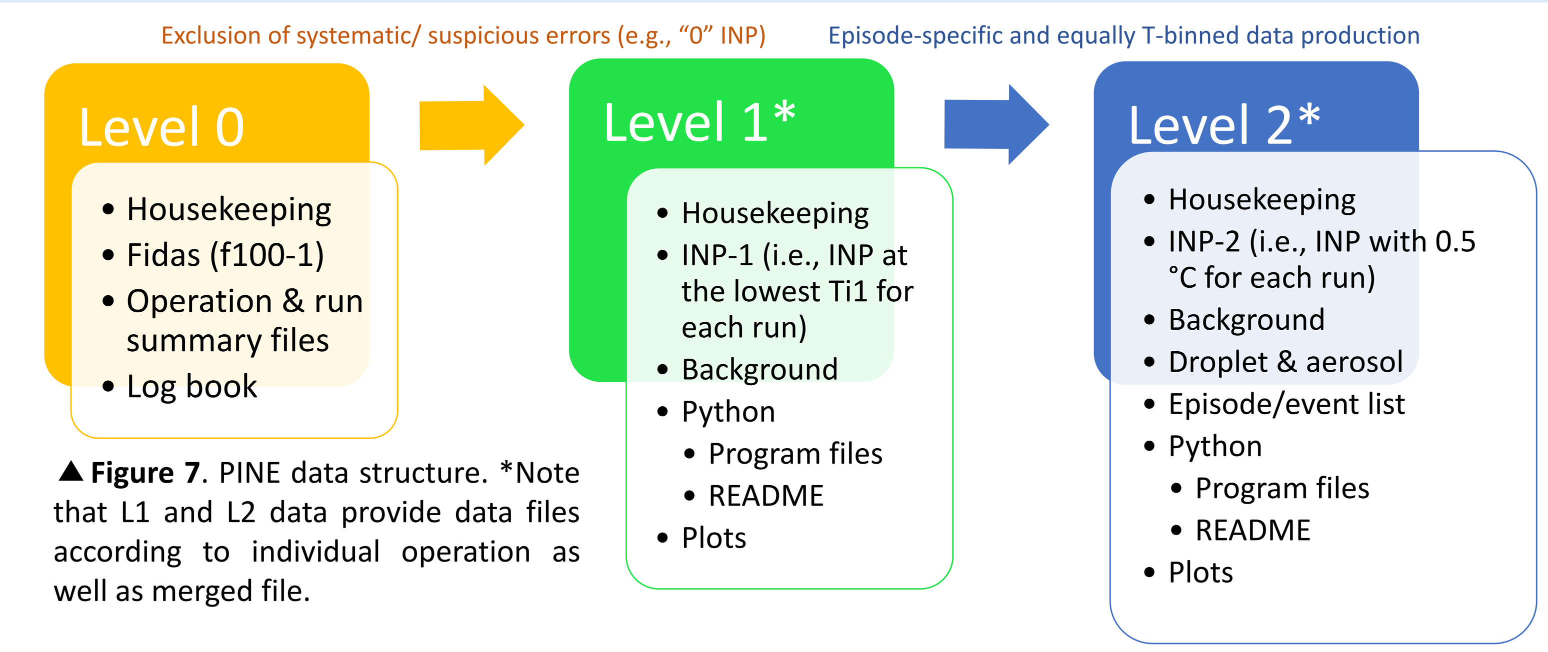


Figure 6. Time series of the measured chamber *T* and associated INP concentration at the end of each expansion. Three specific events (i, ii, & iii) were looked into.

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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