West Texas A&M

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)

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

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

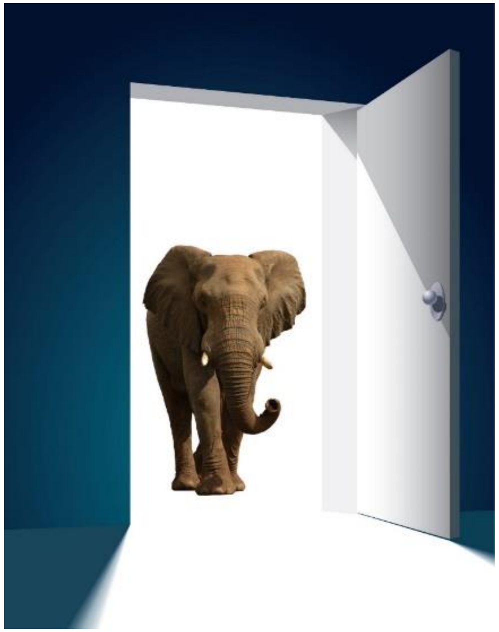
EGU 2020 Sharing Geoscience Online

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.

Refs.: Vali, G. *et al*.: Atmos. Chem. Phys., 15, 10263-10270, 2015; Kanji, Z. A. *et al*.: Meteor. Mon., 58, 1.1-1.33, 2017; Lohmann, U. and Neubauer, D.: Atmos. Chem. Phys., 18, 8807-8828, 2018; Solomon, A., *et al*.: Atmos. Chem. Phys., 18, 17047-17059, 2018.

Climatic Impact of INPs etc.

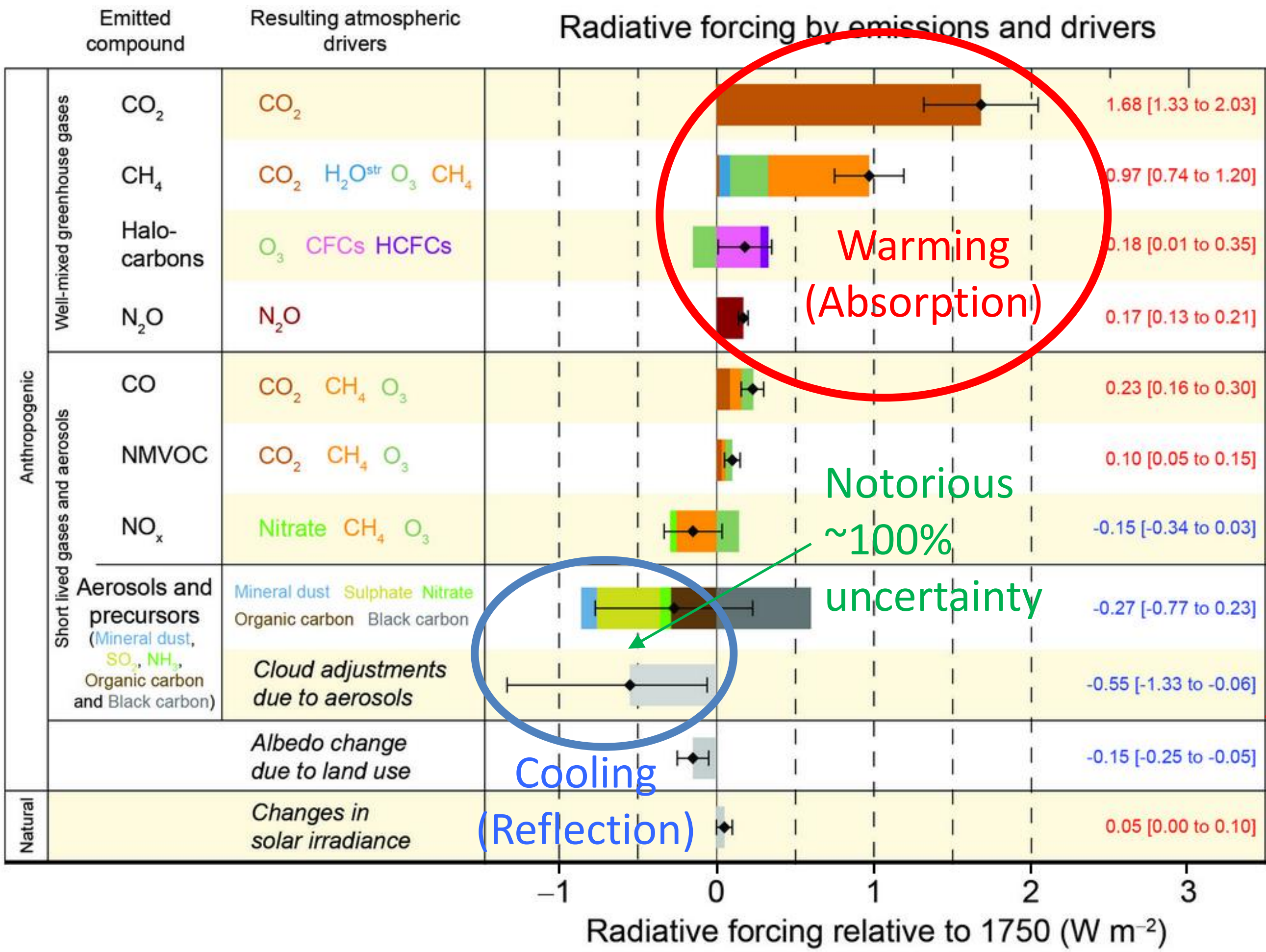


Fig. SPM.5 in 'International Panel for Climate Change' 2013: annual & global mean radiative forcing

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

?

Naruki Hiranuma

Ref.: IPCC, 2013, www.ipcc.ch/report/ar5/wg1/summary-for-policymakers/

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**.

Atmospheric Radiation Measurement (ARM) Southern Great Plains (SGP) Guest Instrument Trailer

Refs.: Hiranuma *et al*.: ESSOAr, 2020 (https://doi.org/10.1002/essoar.10502526.1); Möhler, O. *et al*.: Atmos. Chem. Phys., 3, 211-223, 2003; Hande, L. B. and Hoose, C.: Atmos. Chem. Phys., 17, 14105-14118; Balmes, K. A. *et al*.: J. Geophys. Res. Atmos., 124, 1755-1778, 2019;

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)

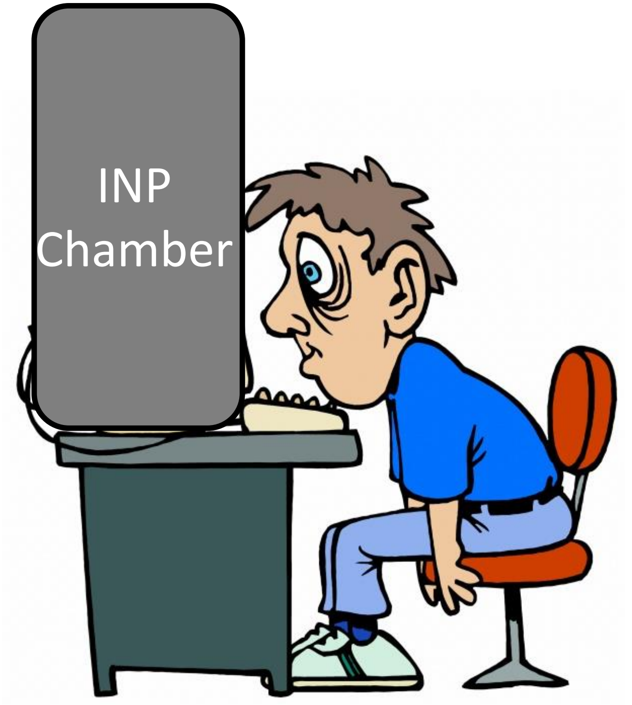
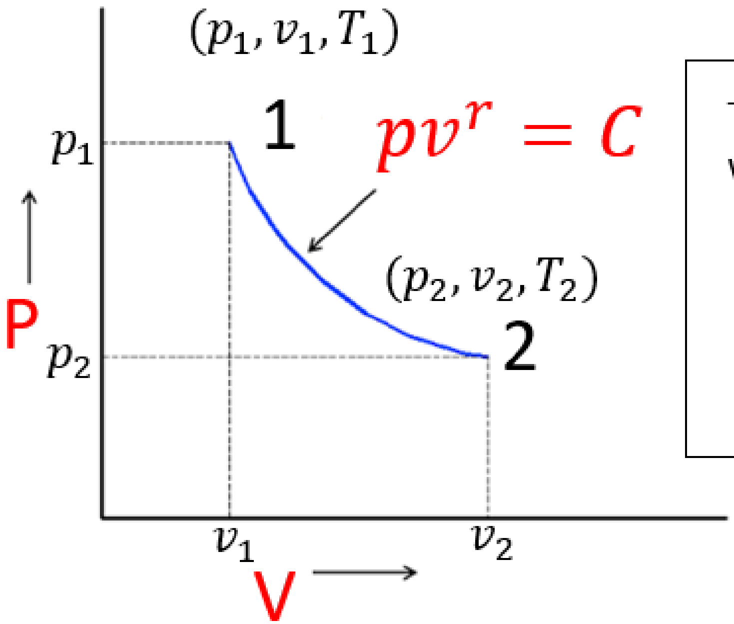
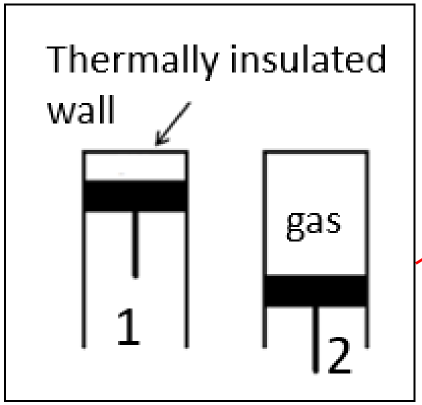


Image: Courtesy of bernews.com

Portable Ice Nucleation Experiment (PINE) Chamber: Theory

Adiabatic expansion process

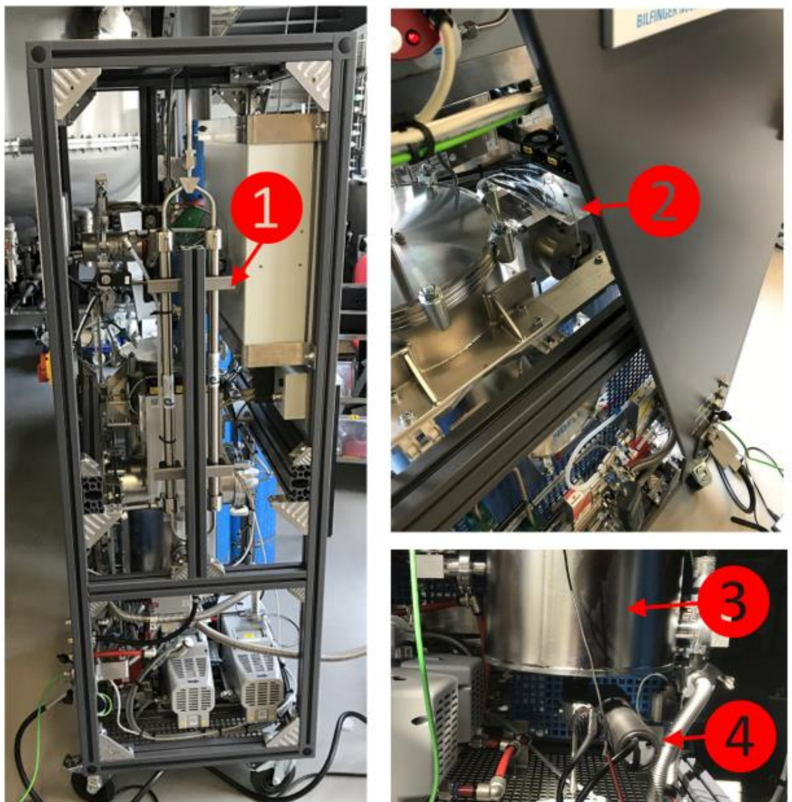




10 L Volume

Ref: mechanicalbooster.com

Portable Ice Nucleation Experiment (PINE) Chamber: Specs



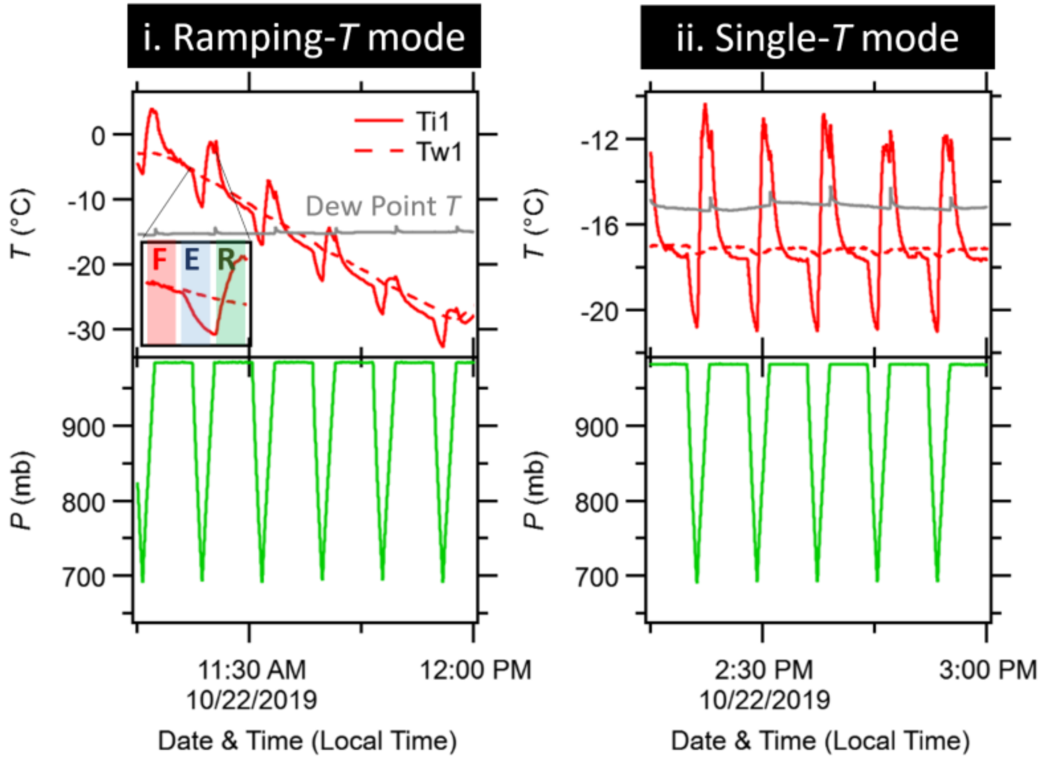
- Parallel twin Perma Pure Nafion® Dryers run @ >100 mb ①
- A **cryo-cooler** (Thales) controls *T* between 0 °C and -60 °C ②
- A 10 L aluminum vessel (air leak <0.4 mb/min) is thermally insulated, enabling an 'expansion' experiment **every 8 min** ③
- The PALAS Fidas® detector **optically measures INP**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

 Naruki Hiranuma

Ref.: Hiranuma *et al.*: ESSOAr, 2020 (https://doi.org/10.1002/essoar.10502526.1).

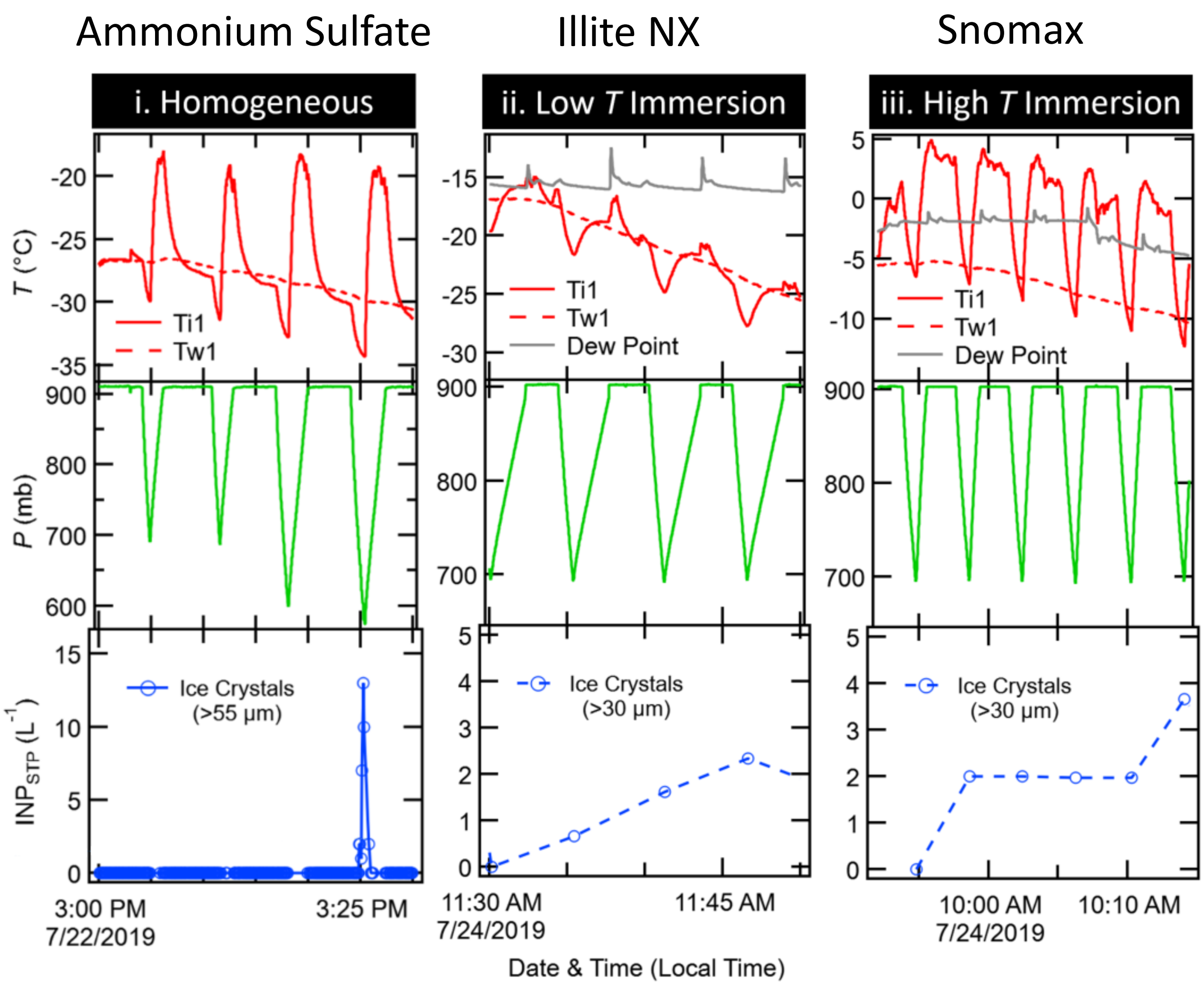
PINE Operation

- ***RAMPING-T MODE***: *T* cycles of -5 °C ←→ -35 °C every 90 min with automated sequence of **Flush → Expand → 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 (0.2-50K INP L^{-1} STP).



Ti1 = inside-vessel gas temperature
Tw1 = wall temperature

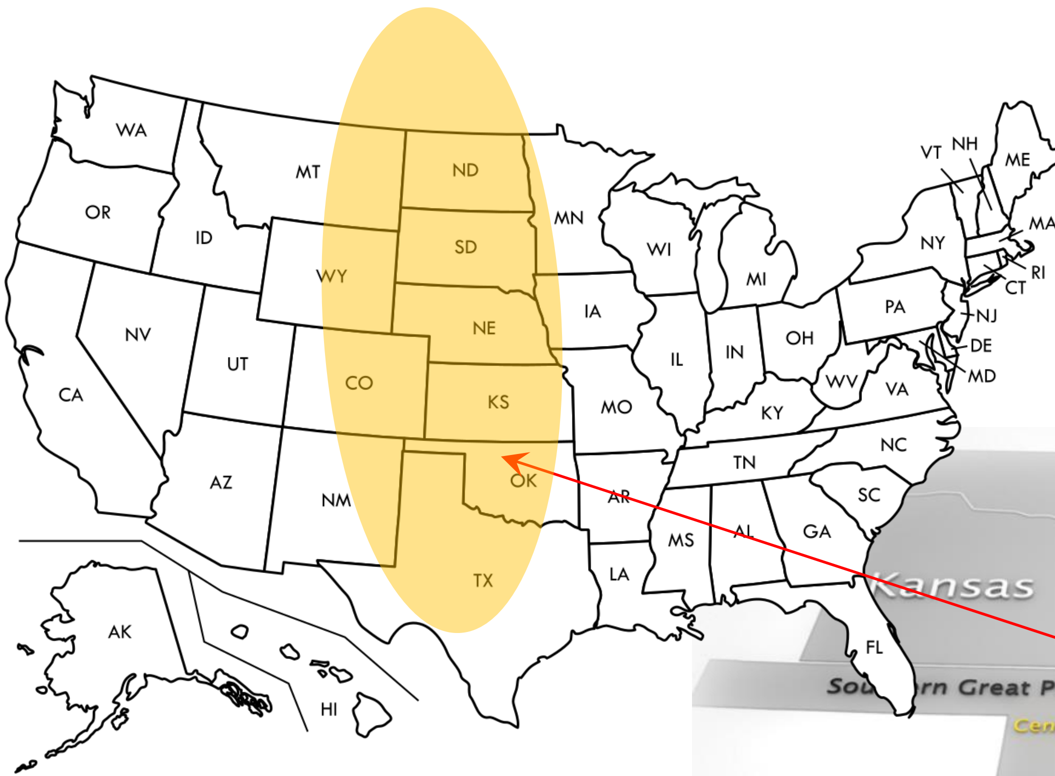
Lab homo- & hetero-geneous freezing test

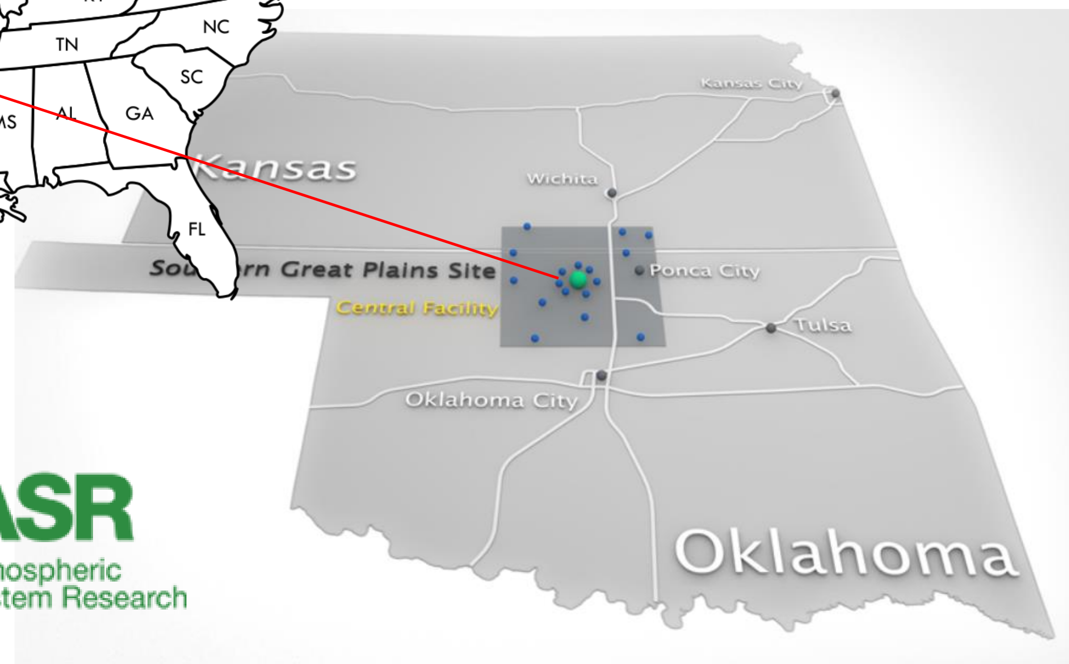


Naruki Hiranuma

Hiranuma, N. *et al.*: Atmos. Meas. Tech., 9, 3817-3836, 2016; Hiranuma, N. *et al.*: Atmos. Chem. Phys., 15, 2489-2518, 2015; Wex, H. *et al.*: Atmos. Chem. Phys., 15, 1463-1485, 2015; Polen et al., J. Geophys. Res. Atmos., 121, 11666-11678, 2016.

Southern Great Plains (SGP)





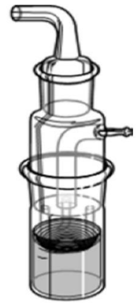
ARM

ASR
Atmospheric System Research

U.S. DEPARTMENT OF ENERGY | Office of Science

www.arm.gov/tour/sgp-overview.html

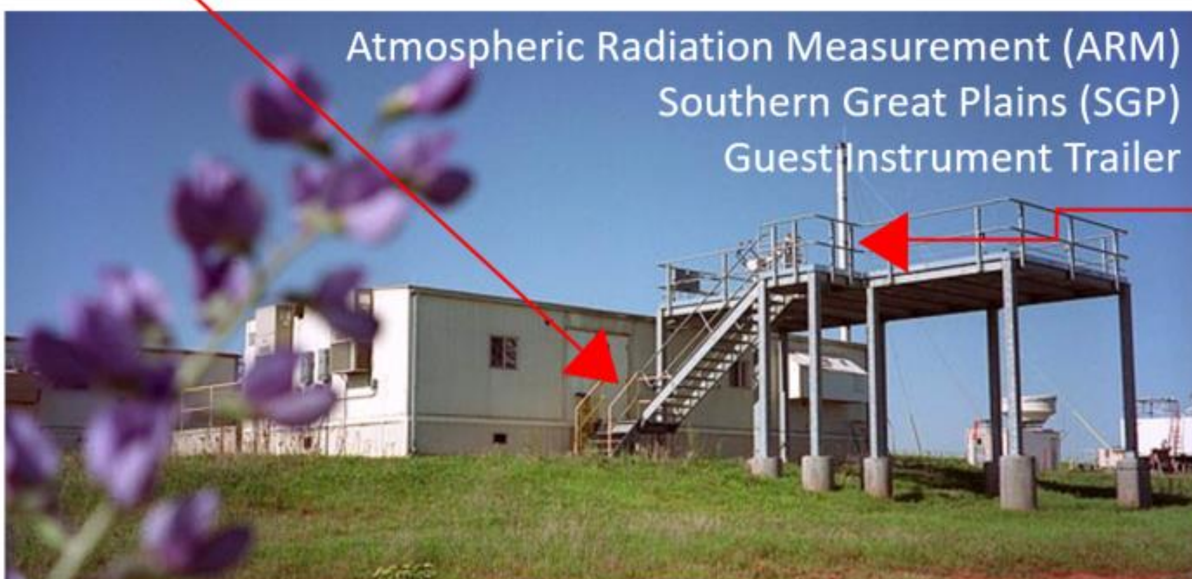
Southern Great Plains (SGP)



Impinger

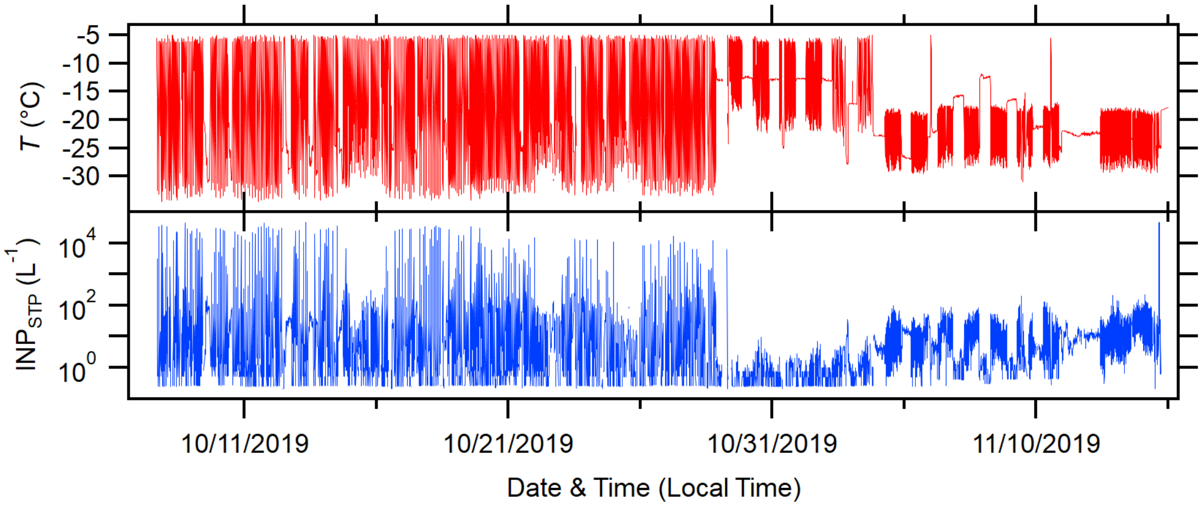
◀PINE deployed in the side-by-side position of offline samplers.

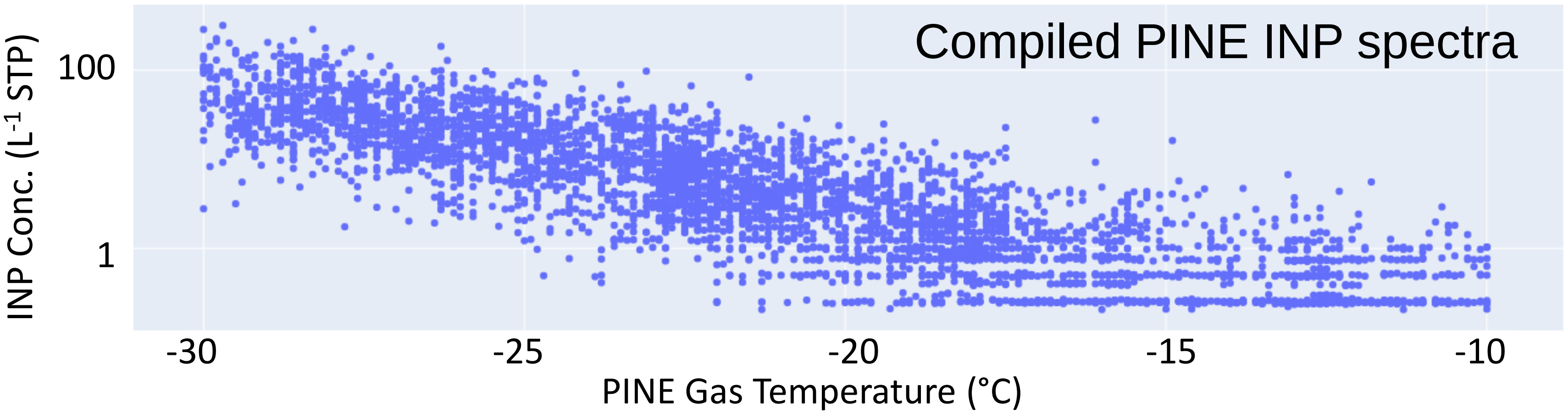
▼A semi-laminar flow stack inlet (17.5’ AGL), built by Daniel Knopf, was used to intake aerosols to PINE.



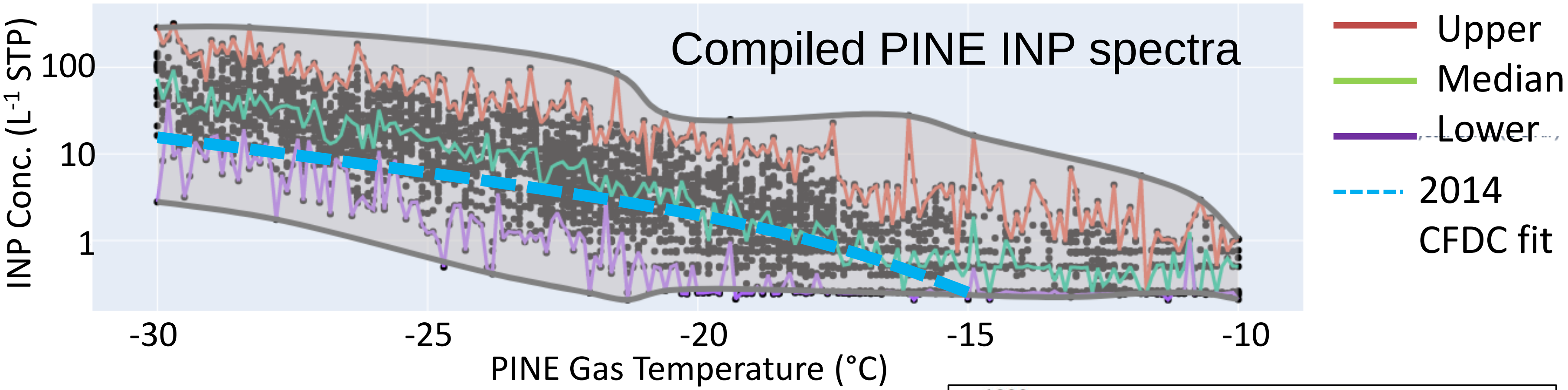
Overview: 45 days PINE data from SGP

Oct. 1st – Nov. 14th in 2019.





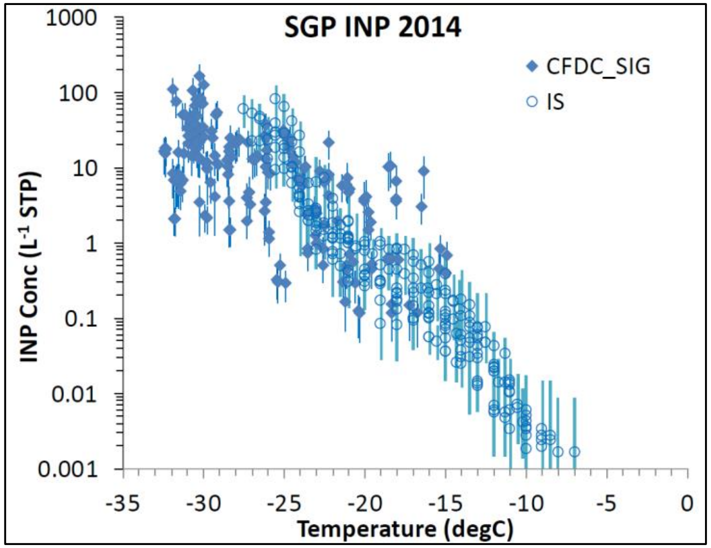
Qualitative comparison to 2014 SGP-INP data



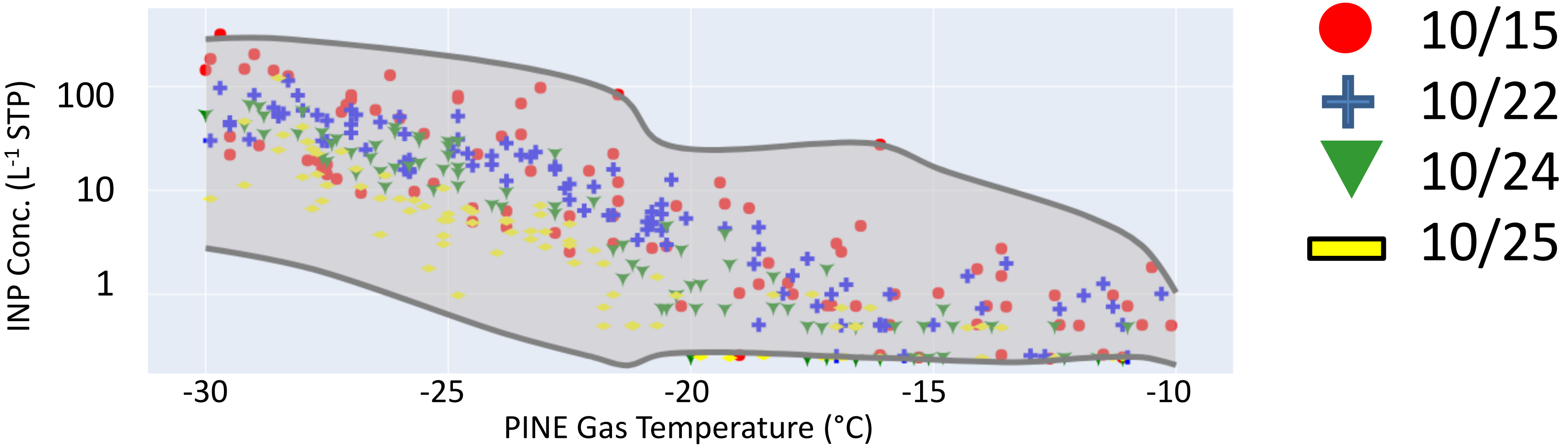
▲ PINE-measured upper & lower INP boundaries and median line added.

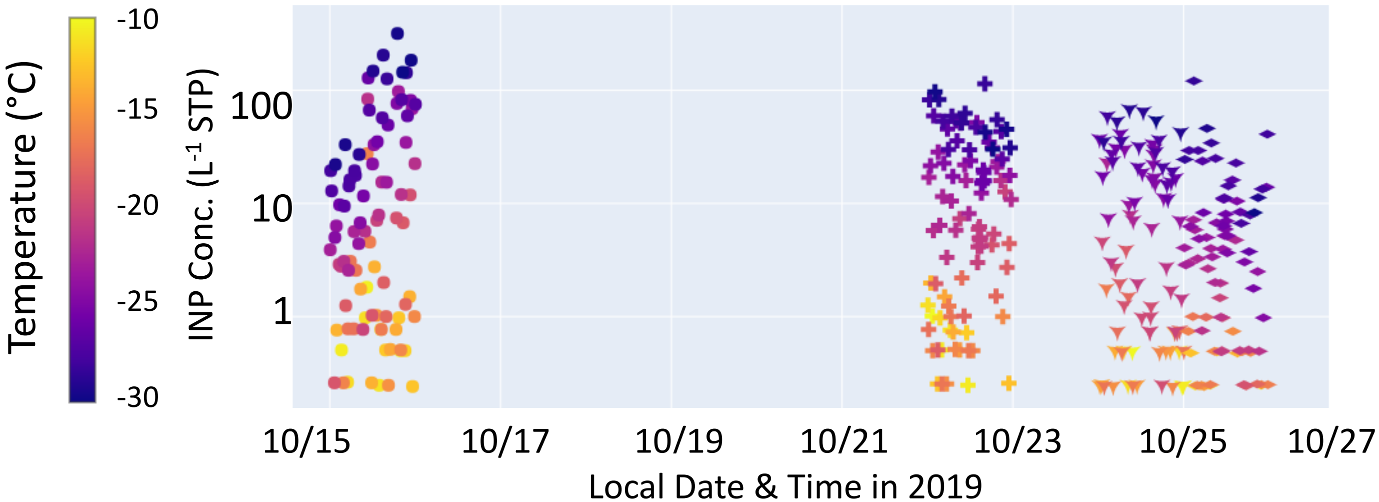
▶ CSU-CFDC & IS measured INP spectra from the May-June 2014 measurements

- data adapted from DeMott *et al.*, 2015 (DOE/SC-ARM-15-012).

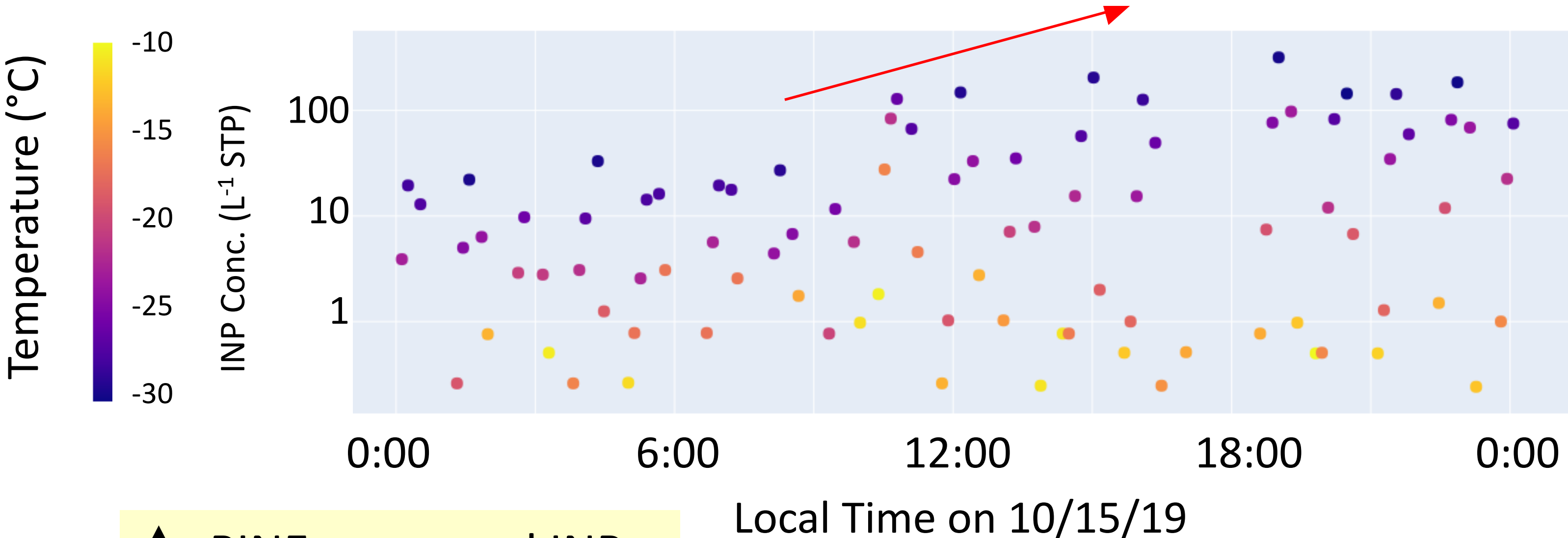


PINE time-series data
Oct. 15th, 22nd, 24th & 25th



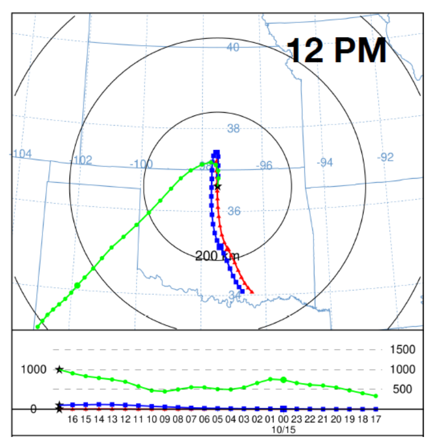


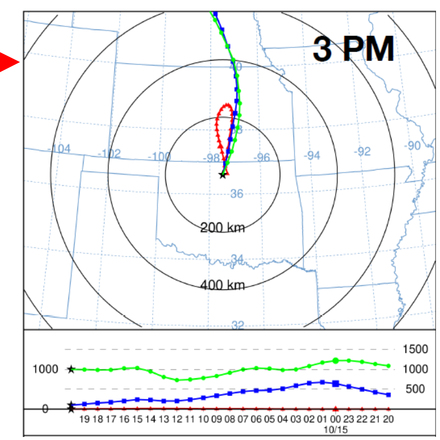
Oct. 15th, 2019



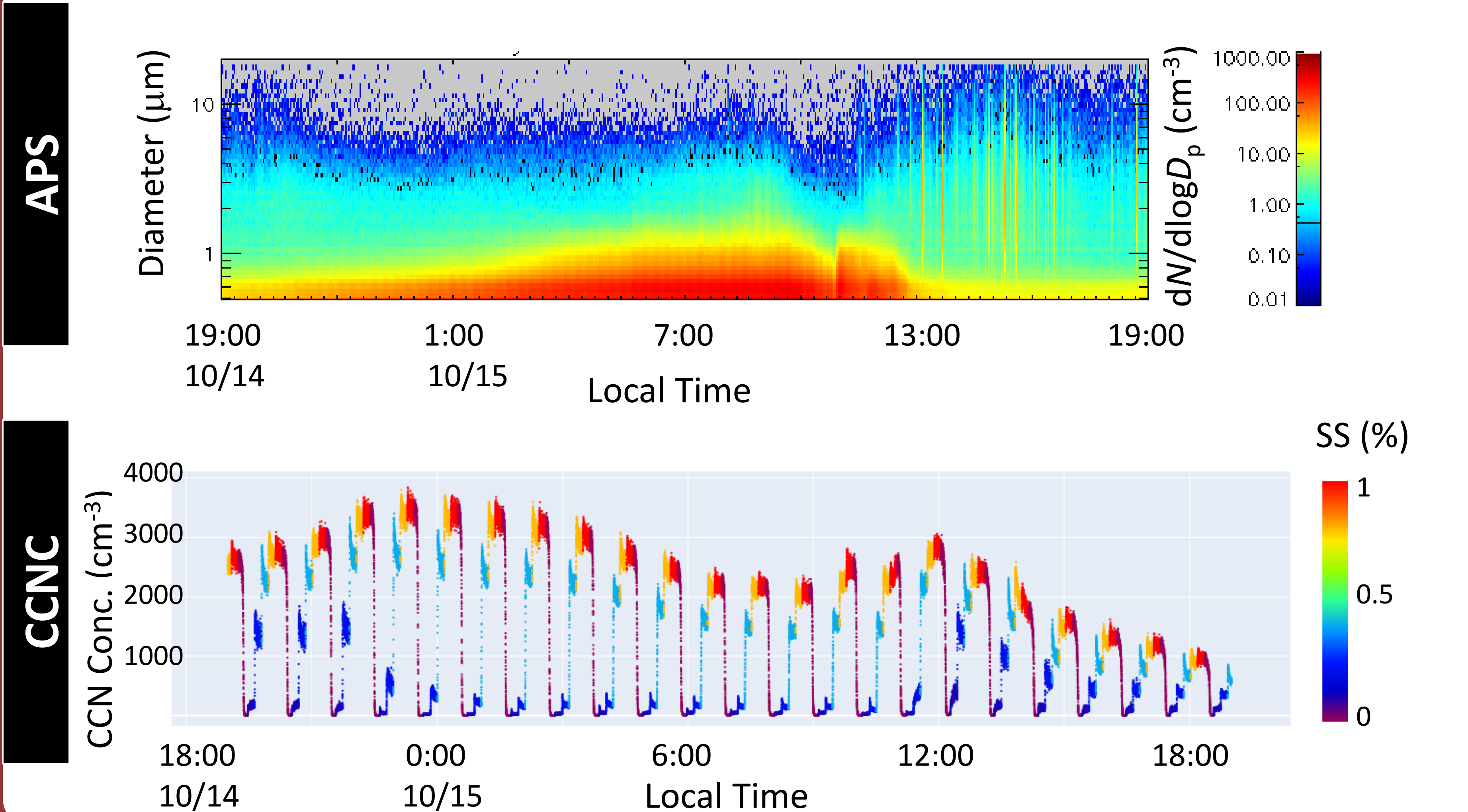
▲ PINE-measured INP increase during the cold-frontal passage.

▶ Back Trajectories at the Surface level @ SGP.





Supermicron size dominant INPs & CCN suppression?



PINE Data Archiving & Structure

Exclusion of systematic/suspicious errors

Episode-specific and equally T-binned data production

Level 0

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

QA/QC

Level 1*

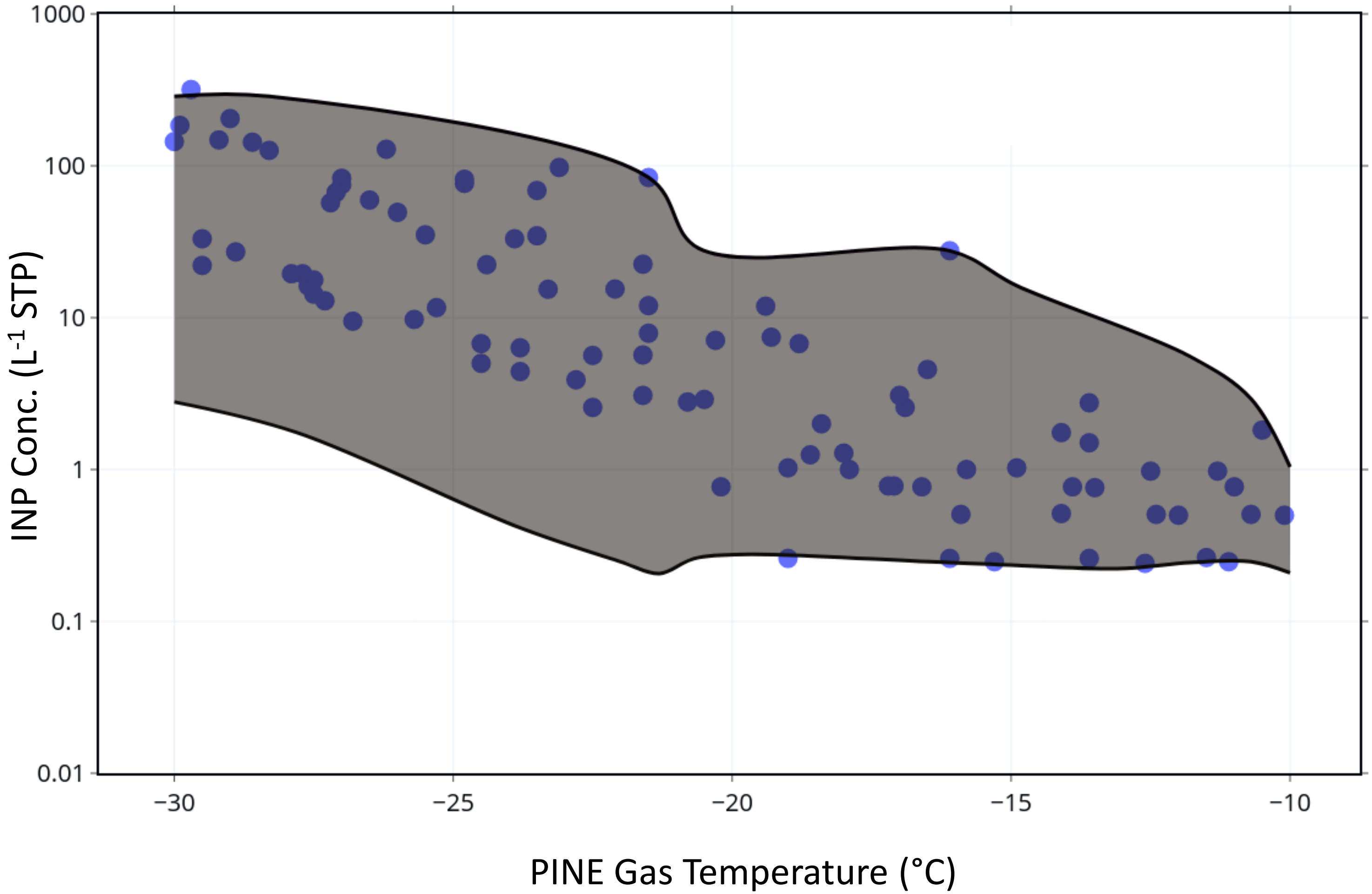
- Housekeeping
- INP-1 (i.e., INP at the lowest Ti1 for each run)
- Background
- Python
  - Program files
  - README
- Plots

QA/QC

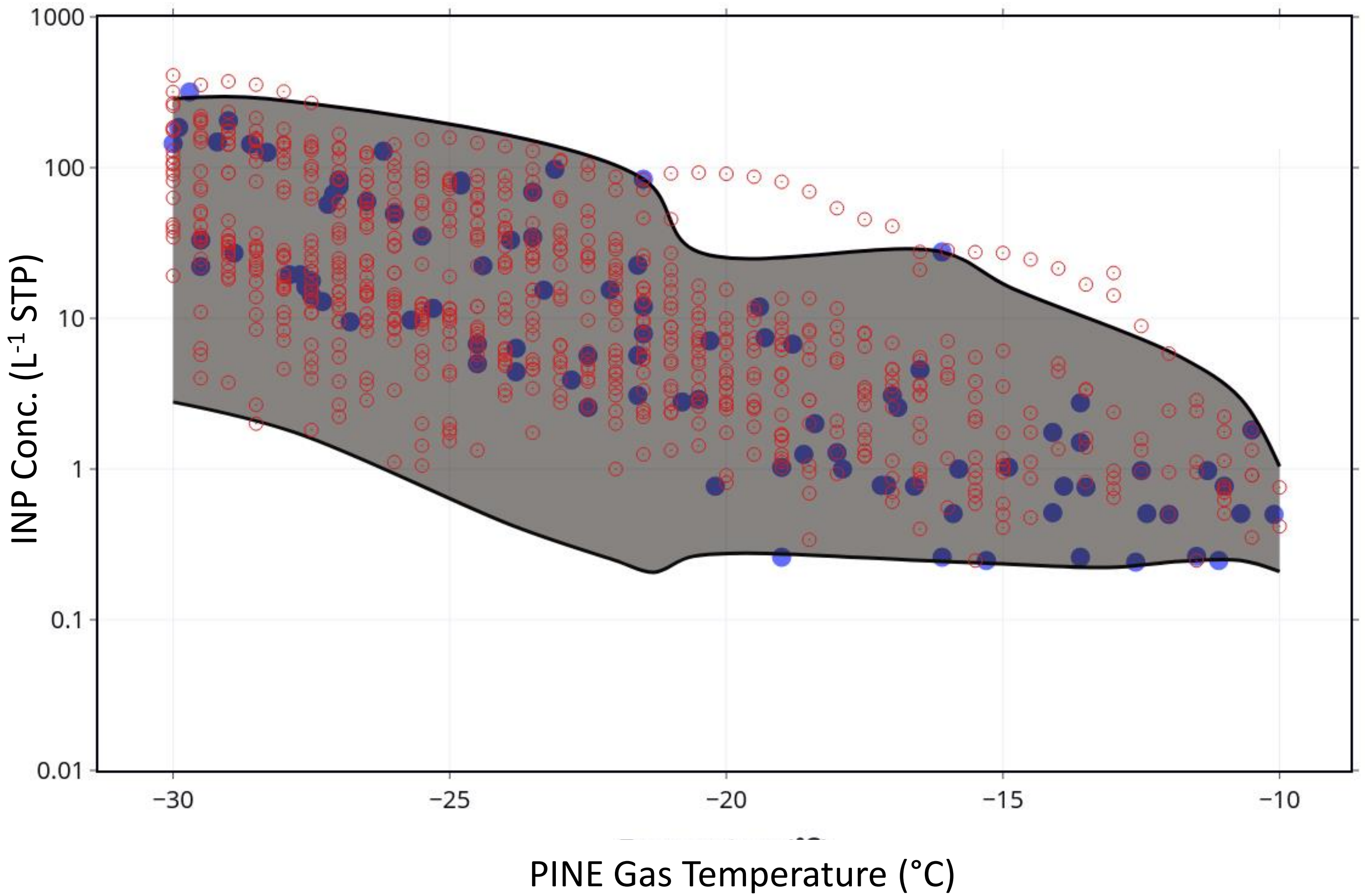
Level 2*

- 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

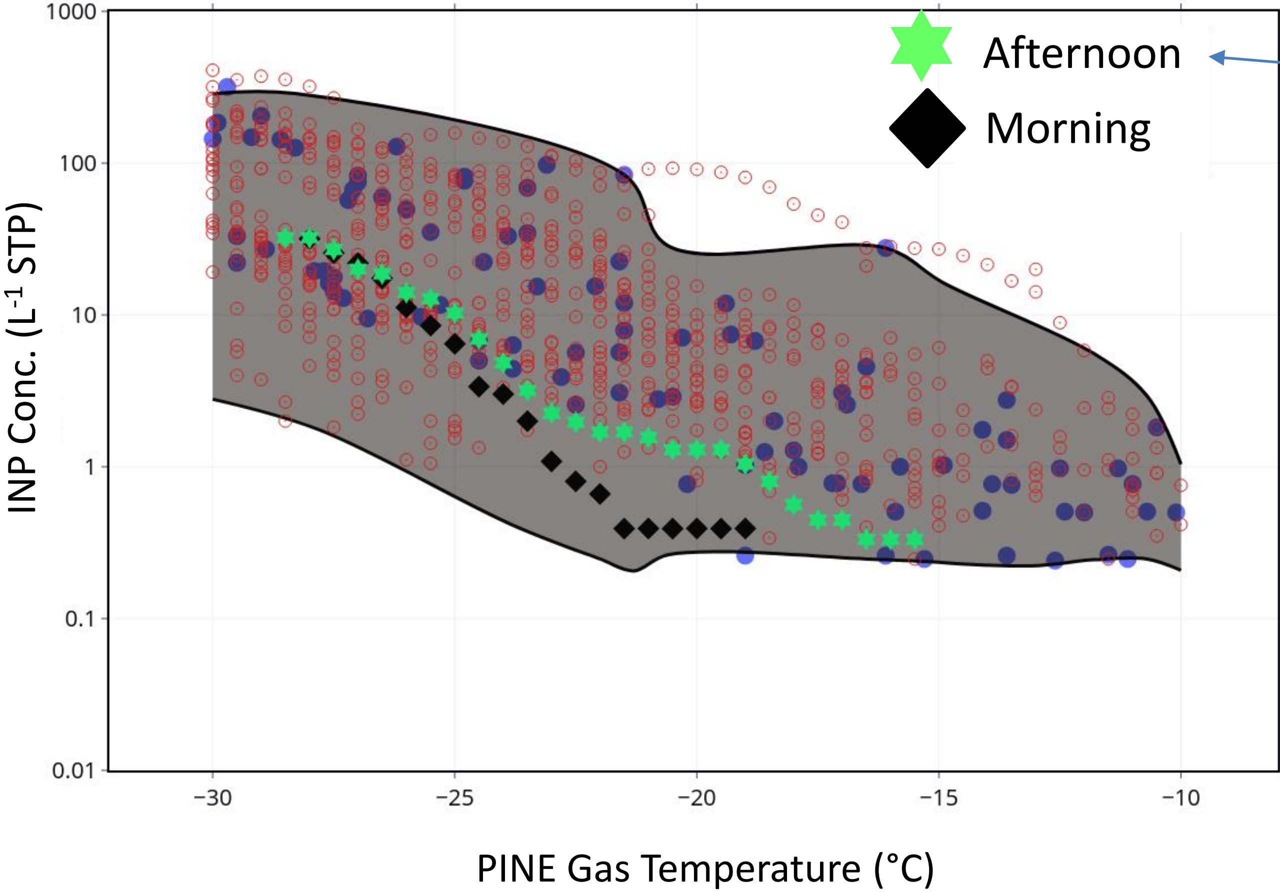
Level 1 data example from Oct. 15th, 2019 (One data point from each run)

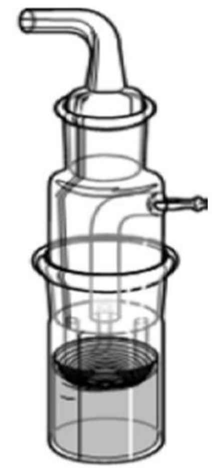


Level 2 data example from Oct. 15th, 2019 (Multi-*T*-binned data points from each run)



Final product example from Oct. 15th, 2019 (Offline INP data superposed on PINE data)





Impinger sampling → Cold stage

Cold Stage Refs.: Hiranuma, N. *et al*.: Atmos. Chem. Phys., 4823-4849, 2019; Cory, K. et al.: ESSOAr, 2019 (https://doi.org/10.1002/essoar.10500739.1); Whiteside, C. et al.: ESSOAr, 2019 (https://doi.org/10.1002/essoar.10500578.1).

Summary & Outlook

1. PINE is susceptive to the high *T* INP detection for INP > 0.2 L^{-1} with ~8 min time resolution.
2. Unattended remote operation of PINE at SGP was successful, and we have processed 45 days of PINE data for L0 → L1 → L2.
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 °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 → E3SM model & comparison to CNT etc.

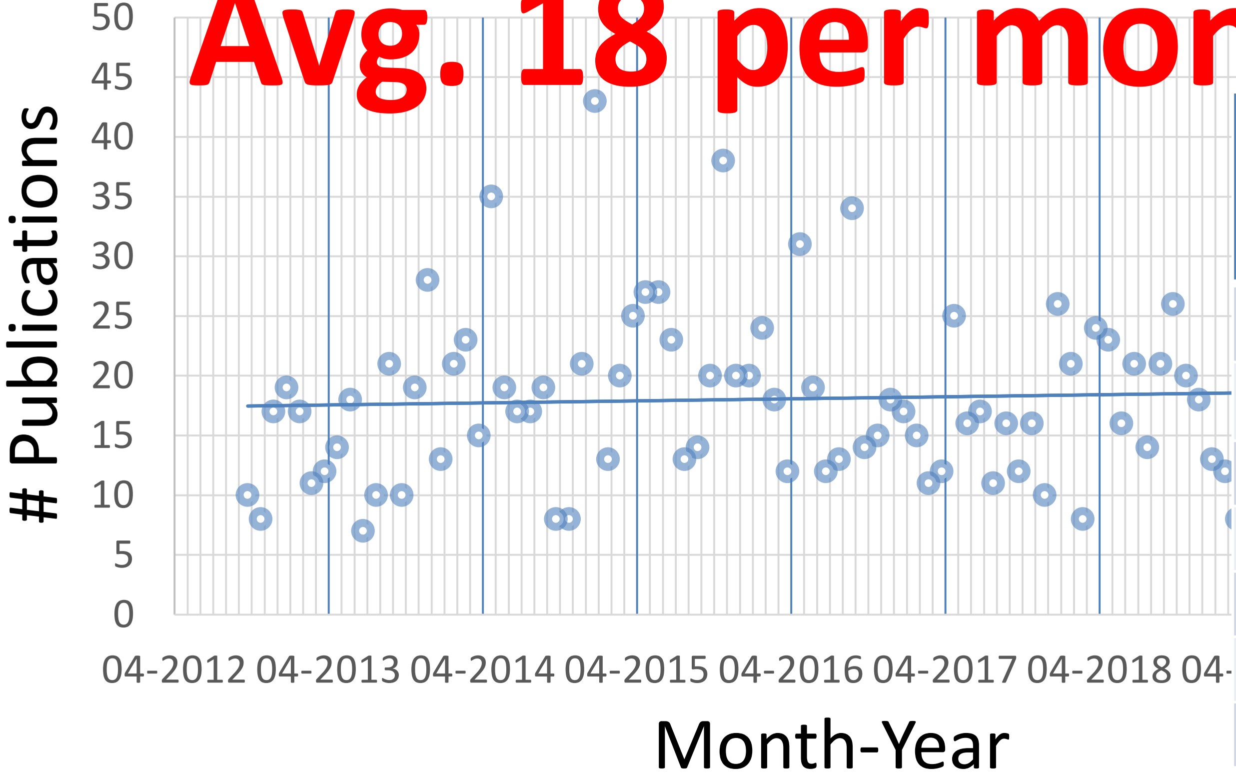
E3SM Ref.: Zhang, K. *et al*.: Geosci. Model Dev., 11, 1971-1988, 2018.

Atmospheric Ice Research

# of publications per month

(JGR, GRL, ACP, AMT, AS&T, Atmos. Environ., PCCP, ACS, JAS, Nature, Science, PNAS, Atmosphere)

Avg. 18 per month



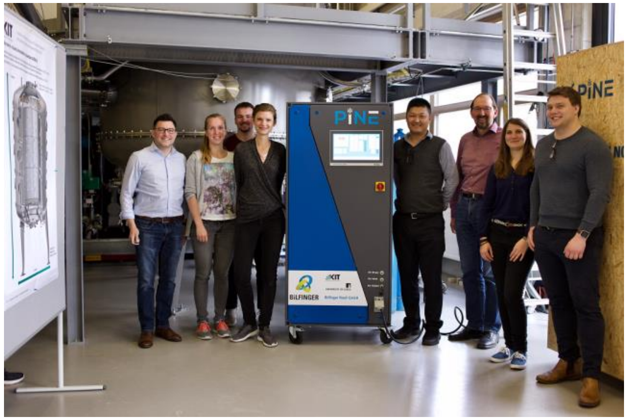
Year	# of publications
2019	204
2018	238
2017	178
2016	230
2015	283
2014	216
2013	186

Naruki Hiranuma
nhiranuma@wtamu.edu

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.



West Texas A&M

KIT Karlsruher Institut für Technologie

AIDA

UNIVERSITY OF LEEDS

BILFINGER

ASR Atmospheric System Research

ARM

PALAS®

U.S. DEPARTMENT OF ENERGY | Office of Science