Assessing Ice-Phase Microphysical Parameterizations for Winter Storms in the United States using In-Situ Observations

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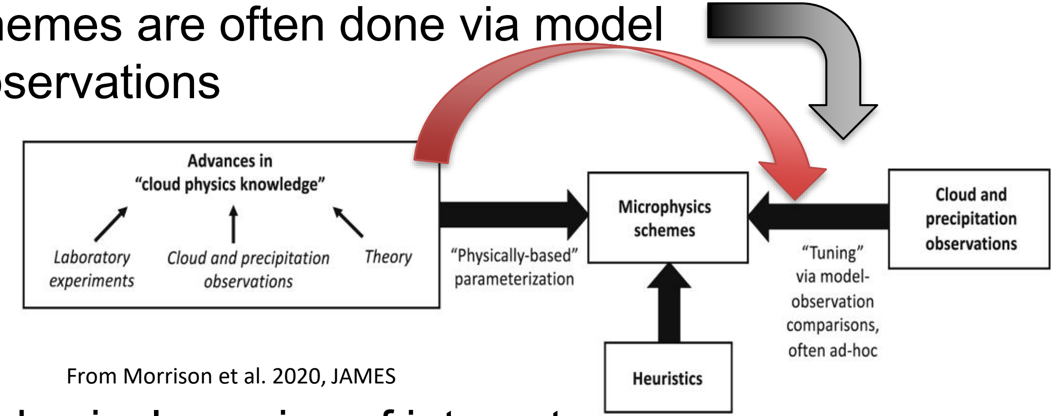
Research Goal

- Motivation:
  - Parameterizations for hydrometeor species can impact microphysical and radiative processes
  - How can in-situ observations be utilized to evaluate and refine parameterizations?
- Objective:
  - Validate key microphysical parameterizations by using a fully observation-based dataset that is representative of global conditions
    - Understand and identify biases or limitations, so tuning can be a more physically-based process
    - Allows for direct, offline evaluations and refinement

Initial Focus on Snow

Incorporating Observations

- Testing and refinements of schemes are often done via model sensitivity experiments with observations



From Morrison et al. 2020, JAMES

<u>Methodology</u>

1. Constrain datasets to fit microphysical species of interest
   – Isolate specific periods where microphysical species is dominant
2. Extract parameterizations from model code, and compute using observed state quantities as input
   – No model data required

Observation Requirements

1-Moment MP Scheme

- State variables
  - T, RH, P, rho_{air}
- Mixing ratios (Q)

Observations

- Weather Station- T, RH, P

$$\rho_{air} = \frac{P - e}{R_d T} + \frac{e}{R_v T}$$

- PSD

$$Q_{snow} = \frac{SWC}{\rho_{air}}$$

Snow Water Content (SWC, g/m^3)

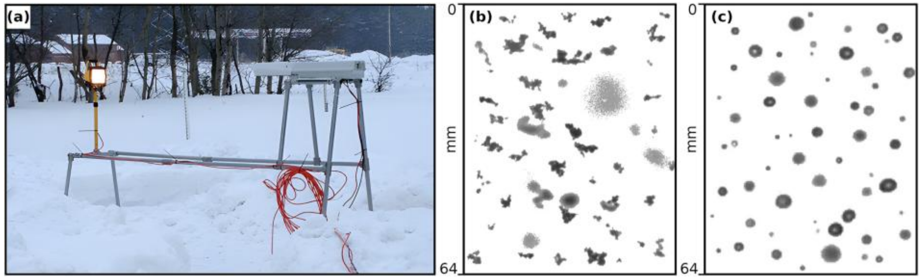
- $SWC = \frac{10^{-3} * \pi}{6} * \int \rho_s(D) * D^3 * N(D) * dD$ (Yu et al. 2020, Hong et al. 2024)
- $SWC = \int m_s(D) * N(D) * dD$ (Heymsfield et al. 2004)

PIP

- Precipitation Imaging Package (PIP)
  - Video Disdrometer w/ open FOV[1,2]
  - Size range: 0.3 to 25.9mm, 0.2mm bin width
  - Observed Quantities (1 minute resolution)
    - Particle size distribution
    - Mean fall velocity distribution
    - Equivalent density distribution
    - Bulk equivalent density
- Co-located Surface Met Station
  - T, RH, WS, WD, and P

Name	Lat (°N), Lon (°E)	Elevation (m)	Coverage	Met Resolution
Finland (FIN)	61.845, 24.287	170	2017/09/01 - 2022/05/19	Res= 3-11s, resampled to 1min
Marquette, MI (MQT)	46.532, -87.548	426	2015/01/01 - 2023/08/31	Res= 5min
North Slope, AK (NSA)	71.323, -156.612	8	2018/10/24 - 2023/07/18	Res=1min
ICE-POP, South Korea (ICP)	37.665, 128.7	789	2018/01/07 - 2018/04/24	Res= 10s, resampled to 1min
UConn, CT (UCN)	41.807, -72.294	78	2021/09/15 - 2024/05/01	Res=1min

From King et al. 2024, ESS

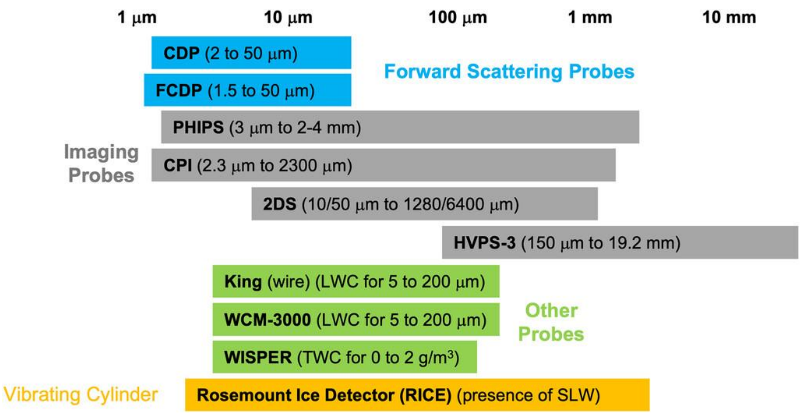


1 Pettersen et al. 2020, Atmosphere
2 King et al. 2024, ESS

Aircraft Probes

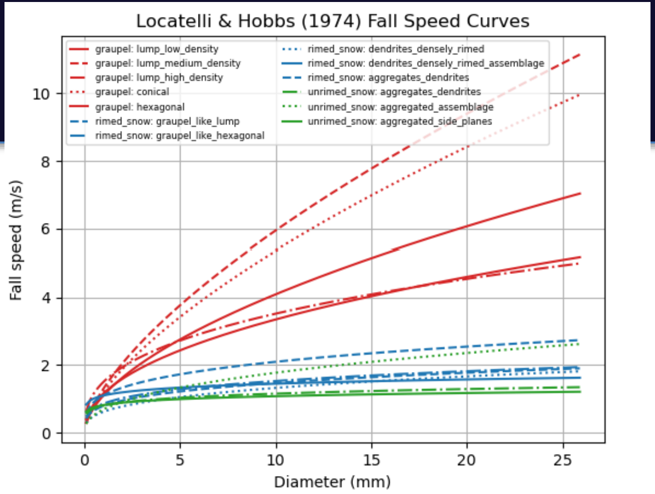
Fig 1 From Yorks et al. 2025, BAMS

- IMPACTS- NASA P-3 Aircraft
  - 22 flights over 3 winter deployments (2020, 2022, 2023) over Midwest/Eastern US
  - PSD from 2D-S and HVPS-3
- Co-located Meteorological observations
  - Standard measurements: T, RH, P
  - Other useful instruments/probes for identifying SCLW, Cloud LWC, and particle habit/shape



From Yorks et al. 2025, BAMS

Identifying Snow



- PIP
  - Bulk equivalent density <0.4 g/cm^3– remove non-ice species
  - Observed size (0.3-25.9mm)- assume no cloud ice remains
  - Snow and Graupel separated using fall speed distribution
    - Curves from Locatelli and Hobbs 1974
    - Match to curve via least squares
- Aircraft
  - Removed periods with large amounts of liquid water
    - CDP N_t >10, CDP LWC>= 0.1, King LWC >0.1, RICE frequency change > 2 Hz (only at temperatures <-4)[1]
  - Minimum size of 0.1 mm from 2D-S and HVPS-3 (assume no significant cloud ice … for now)
- Additional Thresholds
  - Use only Good QA/QC Flags
  - N_t >100 m^{-3} – ensure a minimum number of species exist

[1]Lance et al. 2010, Finlon et al. 2019, Wanget al. 2020, Varcie et al. 2023, Nicholls et al. 2025

Example Snow Application

- Thompson Scheme (1 moment for snow)
  - Based on Field et al. 2005, used aircraft data to parameterized PSD through moments and temperature
  - Moment 2 is the basis for most of the snow parameterizations

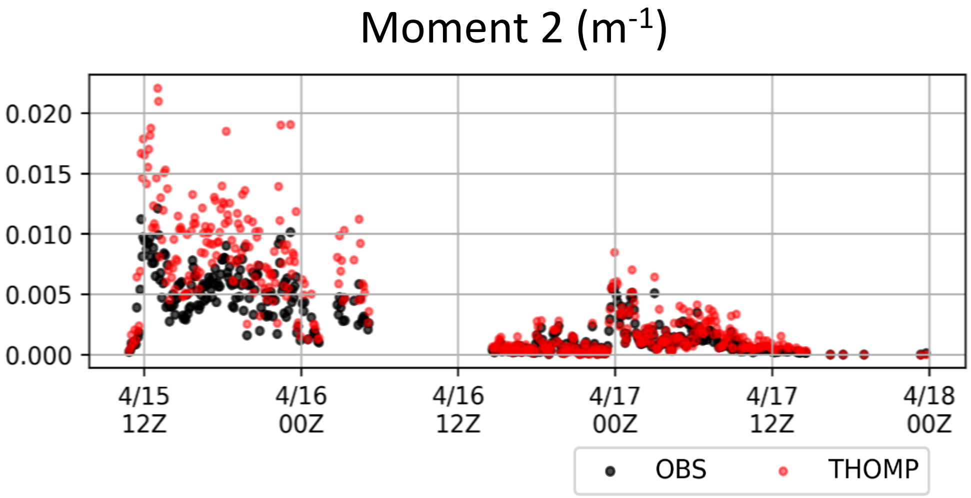
Moment 2: $M_2 = \frac{q_s}{0.069}\left[\frac{0.622P}{287.04 * T(q_v + 0.622)}\right]$

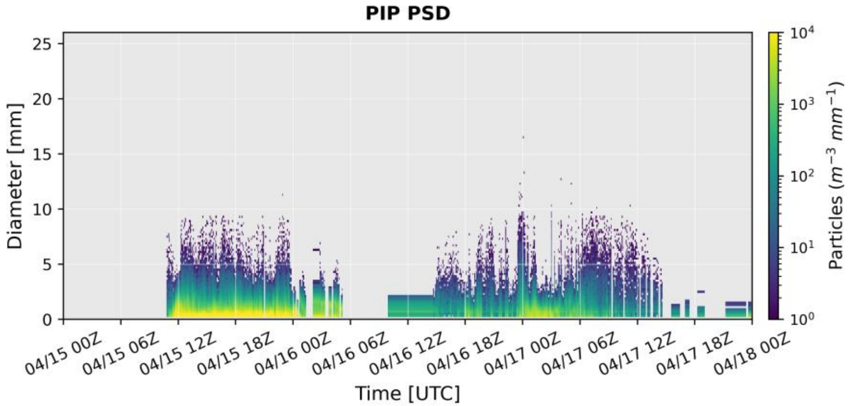
PSD: $N(D) = \frac{{M_2}^4}{{M_3}^3}\left[490.6 * e^{-\frac{M_2}{M_3}20.78D} + 17.46 * \left(\frac{M_2}{M_3}D\right)^{0.6357} * e^{-\frac{M_2}{M_3}3.29D}\right]$

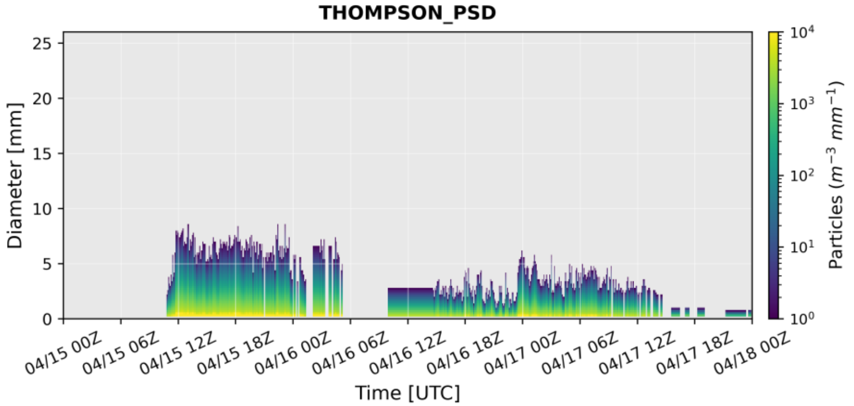
- Observations (PIP and P-3 Probe data)
  - PSD is observed
  - $M_2 = \int (D)^2 * N(D) * dD$

Case Study

Example Event: Marquette, MI
synoptic snowfall followed by LES

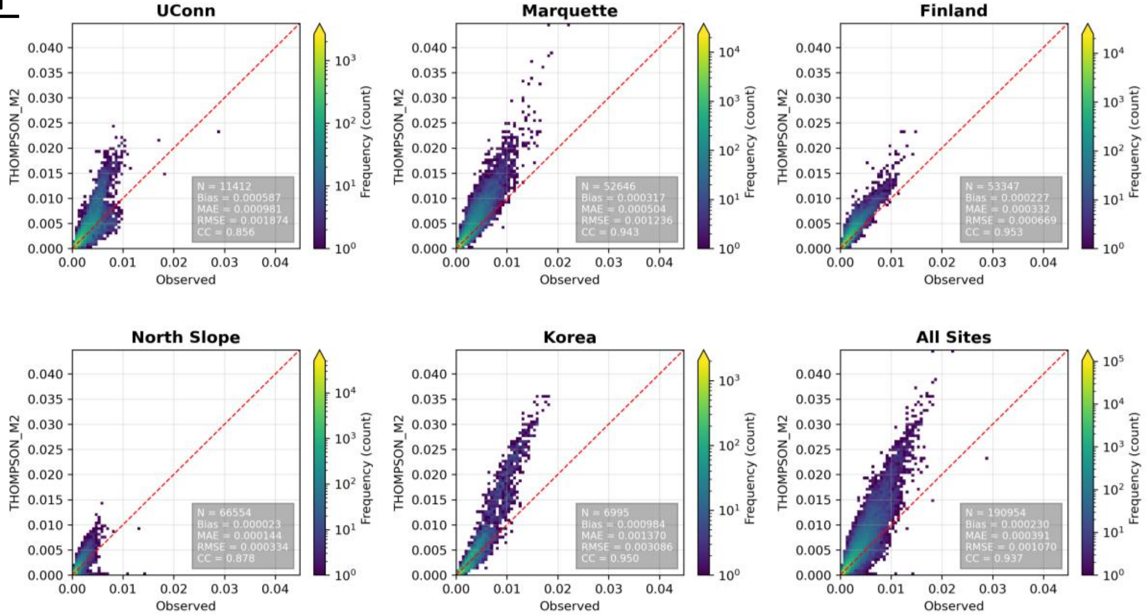




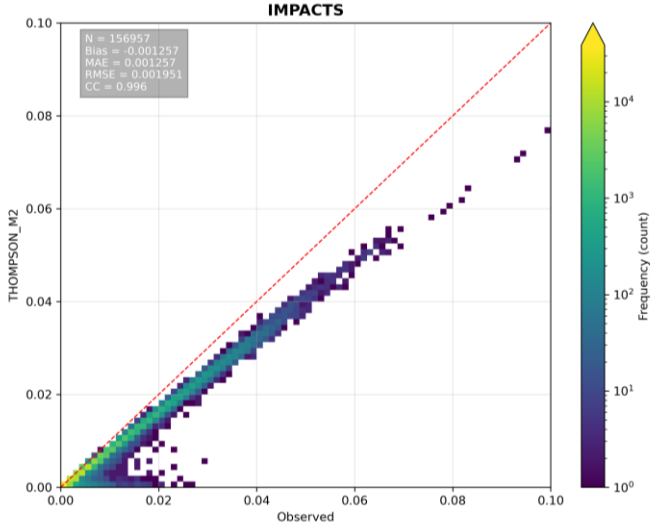


Global Evaluation

PIP



P-3

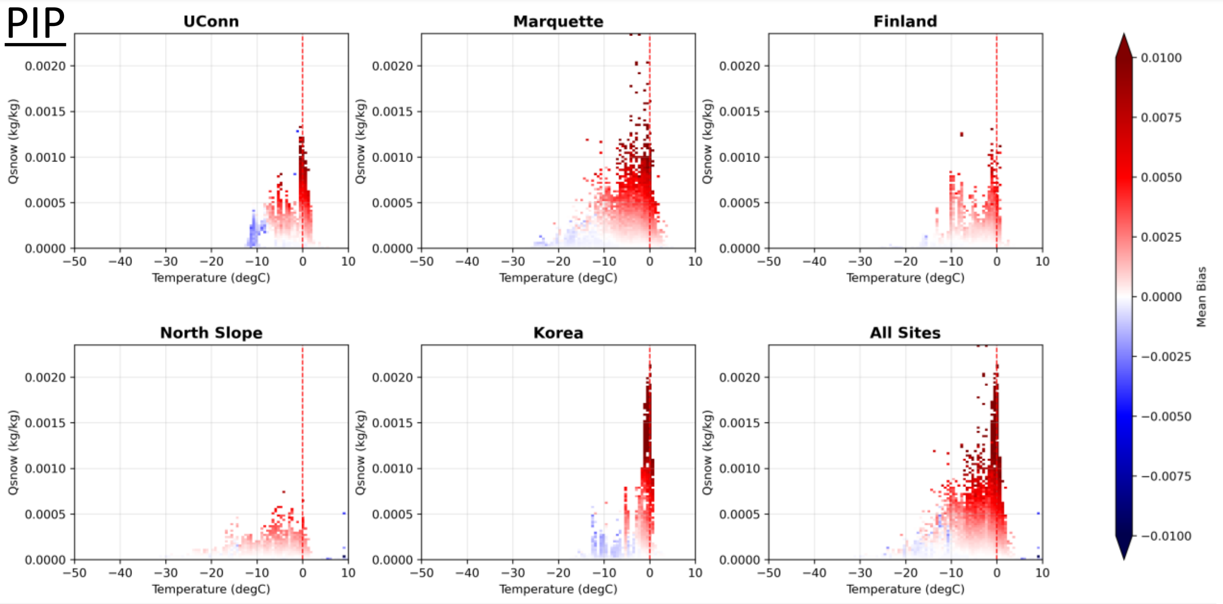


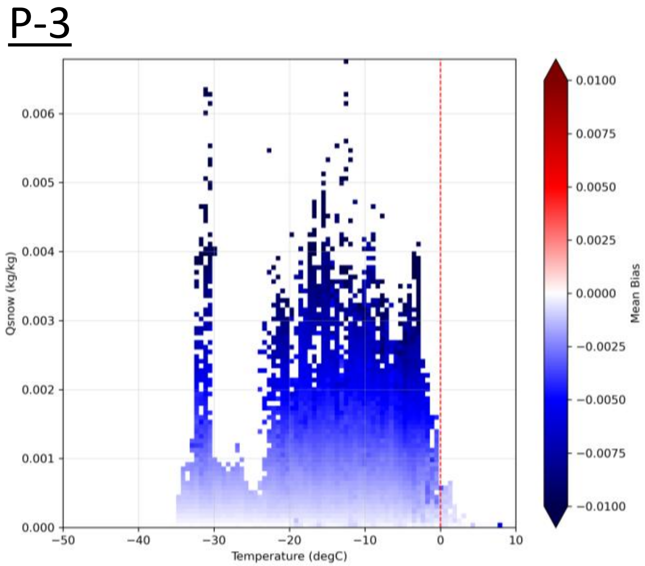
✓**PIP comparison shows broad overestimation**

✓**P-3 comparison shows slight underestimation**

✓**Instruments used impacts evaluation (but also the derived relationship!)**

Understanding Biases





✓**PIP biases occur as function of both increasing Temperature and Qsnow**

✓**P-3 biases are mostly dependent on Qsnow magnitude**

Generalizability

- The methodology presented can be applied to most microphysics schemes and parameterizations and use different observational datasets
- Can be tuned to scheme-specific assumptions (min/max hydrometeor size)
- Identification of hydrometeor species
  - Can be separated by size, fall speed, or image classification
- Limitations
  - Not applicable to all parameterizations (e.g., process rates)
  - Hard to evaluate periods with combinations of hydrometeors
  - Instrumentation can limit the types of hydrometeors to be evaluated

Future Work

- Focus on ensuring generalizability and understanding evaluation limitations
- Improving separation of ice phase species in aircraft probes
- NASA Goddard Microphysics
  - Currently evaluating all snow parameterizations
    - N_0, lambda, PSD, N_t, rho_{snow}, effective radius, fall speed
- Starting point for data-driven applications

Summary

- Developed an offline methodology for improving refinements of microphysical parameterizations through only observational datasets
- Highlighted the requirements of observational datasets and provided examples of processing for PIP and P-3 probe data
- Evaluated the Thompson Moment 2 and PSD parameterizations
  – Found that Moment 2 biases occurred in both PIP and P-3 but in different ways
- The method presented is flexible and generalizable to both other observational datasets and microphysical parameterizations

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