(2) Improving cloud droplet number concentration estimates

- A short review for ground-based remote sensing approaches can be found in Grosvenor et al. (2018).
- ARM has a VAP (NDROP)
- **Damao Zhang** will review a few of them and present recent results.
- Open discussion
  - Define the instruments needed
  - Instrument calibration
  - Robustness of the methods (assumption, retrieval uncertainty, and **APPLICATION**)

Evaluation of Ground-based Retrievals of Cloud Droplet Number Concentration in Marine Stratocumulus with Aircraft Measurements

Damao Zhang

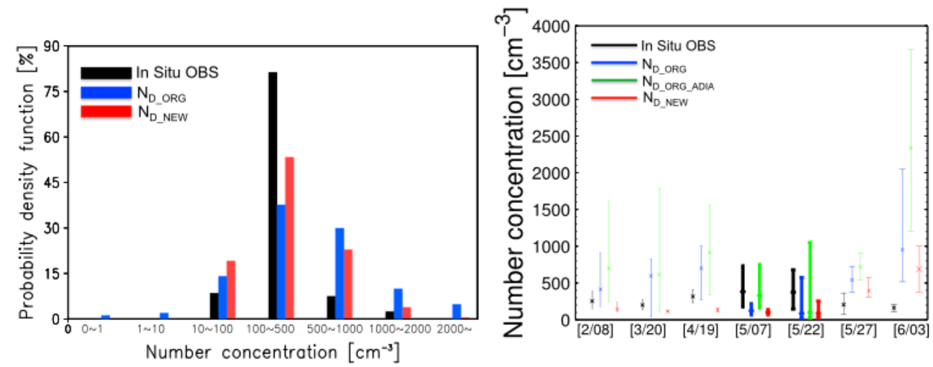
PNNL, ARM Translator

The ARM NDROP Value-added Product (VAP)

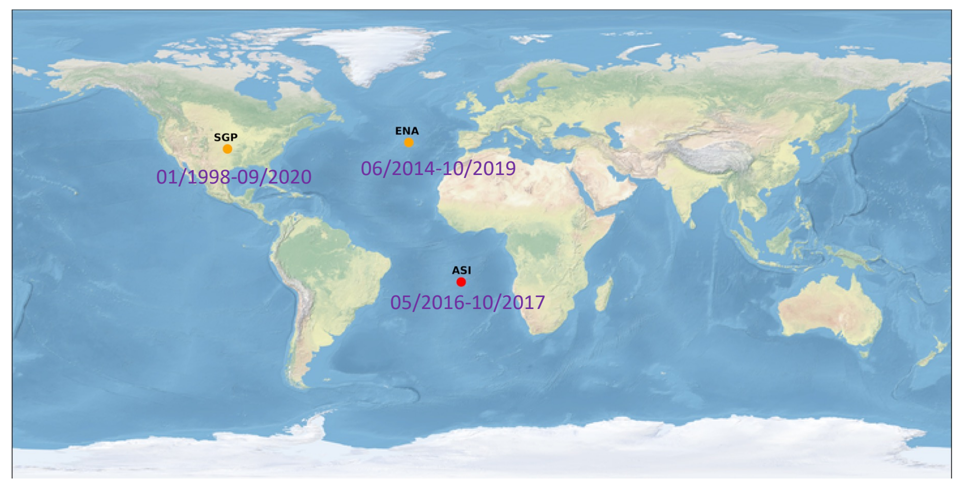
- Retrieval algorithms (Lim et al., 2016)

$$N_d = \left[\frac{2^{-5/2}}{k}\right]\left[\frac{3\pi}{5}Q_{ext}\right]^{-3}\left[\frac{3}{4\pi\rho_w}\right]^{-2}\tau^3 LWP^{-5/2}(f_{ad}c_w)^{1/2}$$

- Inputs
  - LWP from the MWRRET VAP
  - τ from the MFRSRCLDOD VAP
  - Cloud boundary from the ARSCL VAP
  - Temperature from the INTERPSONDE VAP
- Available at several ARM observatories
- Limitations
  - Single-layered overcast clouds
  - Daytime
  - Can't extend to high-latitude regions



Lim et al., 2016



N_d Retrievals with Active Remote Sensing Measurements

Lidar-based N_d retrievals (Snider et al., 2017; Zhang et al., 2023):

$$N_{d,z} = \frac{2\rho_w^2}{9\pi k} \frac{\beta_{e,z}^3}{LWC_z^2}$$

- $\beta_{e,z}$ from MPL or RL
- Using k to eliminate the need for assuming a specific DSD shape
- LWC_z is assumed to be a constant fraction (f_{ad}) of its adiabatic value ($LWC_{z,ad}$)

Radar-based N_d retrieval (Wu et al., 2019):

$$N_d = \frac{1}{Z_c}\left(\frac{6\, LWC_c}{\pi \exp(-4.5\sigma_x^2)}\right)^2$$

- A new method to separate drizzle and cloud droplet contributions to the measured radar reflectivity
- Simultaneously retrieving cloud and drizzle microphysical properties, including N_d

The ACE-ENA Field Campaign

Aircraft measurements:

- Gulfstream-159 (G-1) research aircraft
- Two IOPs Jun-Jul 2017 and Jan-Feb 2018
- N_d and r_e measured by **FCDP** and **CAS**

Ground-based remote sensing :

Micropulse Lidar (MPL), Raman Lidar (RL), Ka-band ARM Zenith Radar (KAZR), Microwave Radiometer 3-Channel (MWR3C), Balloon-Borne Sounding System (SONDE)

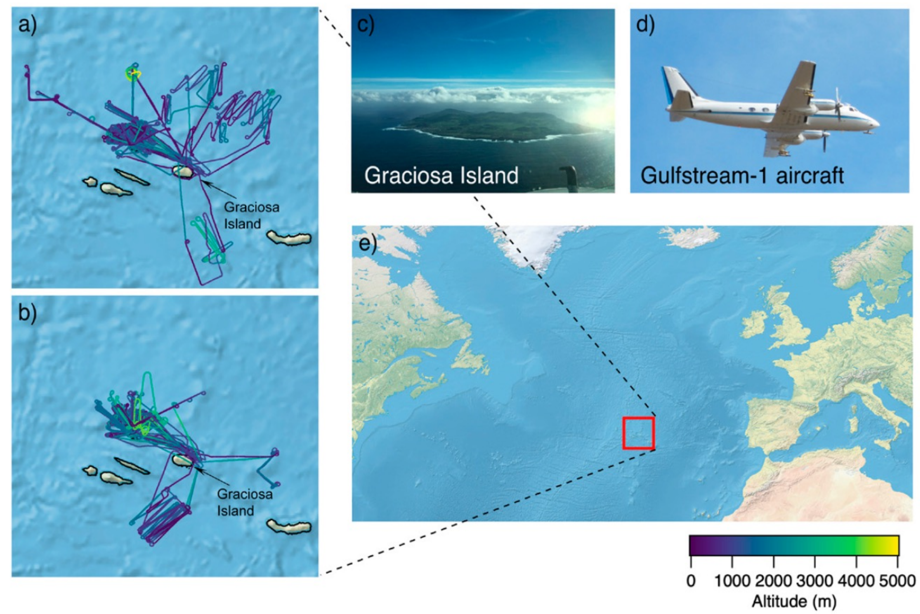


Fig. 1. The fight paths of the G-1 research aircraft colored by altitude during (a) the summer IOP and (b) the winter IOP. (c) Most of the flight paths are in the vicinity of the ENA site on Graciosa Island. (d) A photo of the G-1 aircraft. (e) The general geographic location of the sampling area.

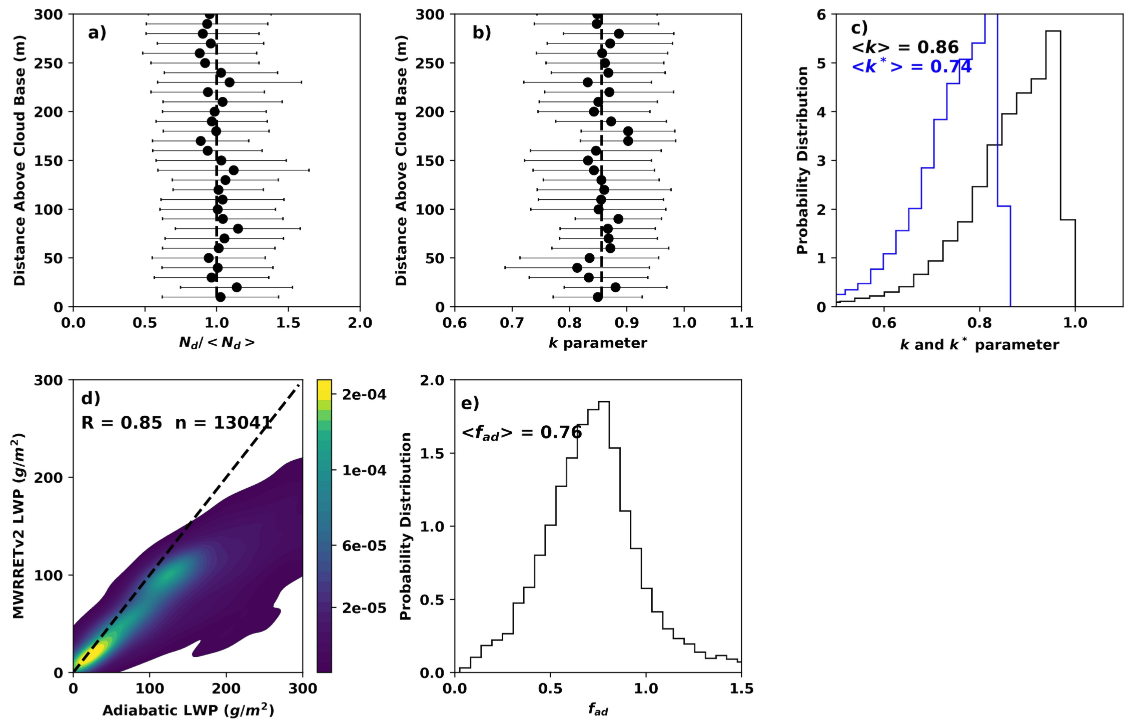
Wang et al., 2022, BAMS

Evaluations of Retrieval Algorithm Assumptions

ARM

Assumptions:

- N_d can be treated as constant within the cloud layer
- The *k* parameter is assumed to be vertically constant with a value of 0.86
- LWC or LWP is assumed to be a constant fraction its adiabatic value



a) Normalized N_d; b) k parameter profile within clouds; c) The PDFs of the k and k parameters; d) LWPs from MWRRETv2 vs. adiabatic calculations; and e) PDF of f_{ad}.*

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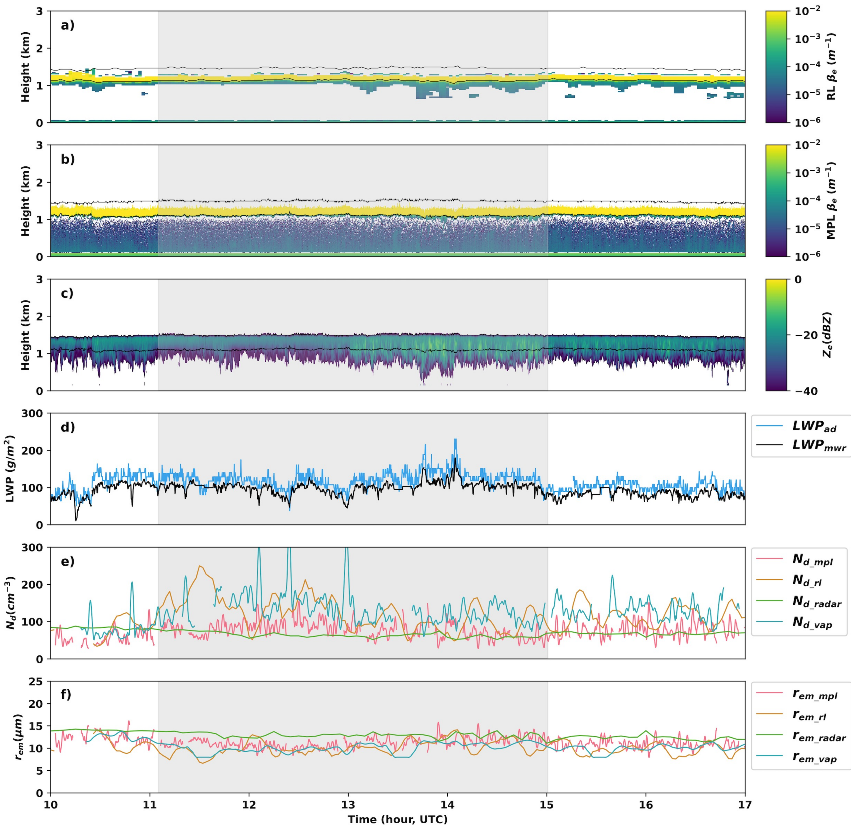
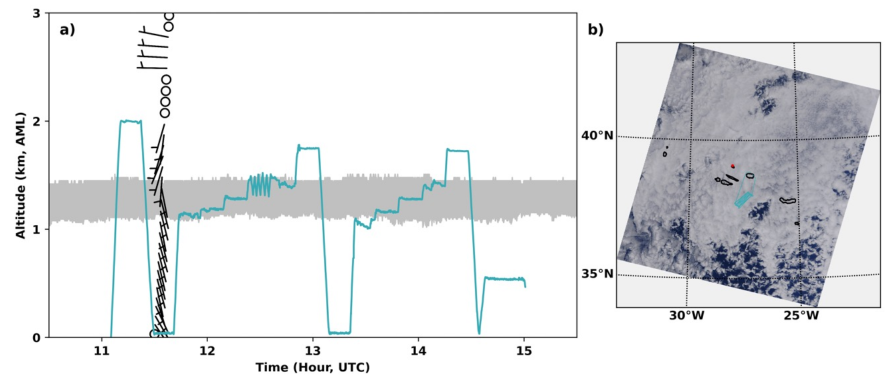
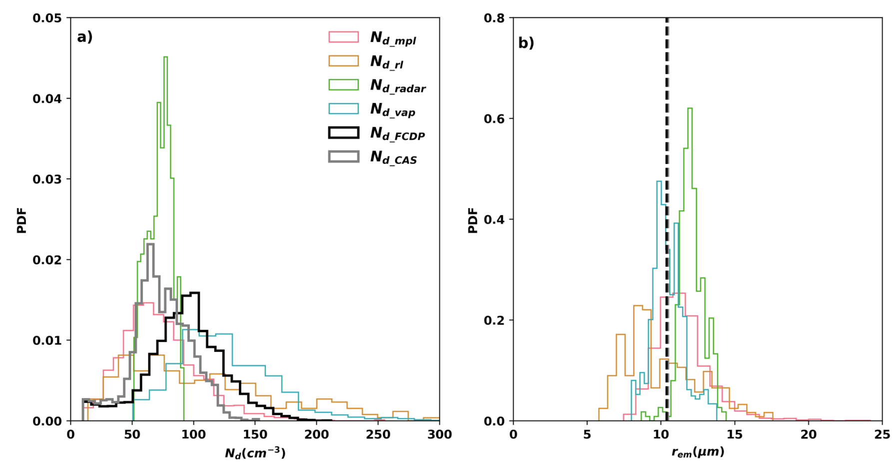
Evaluation of N_d Retrievals on Jan 26, 2018

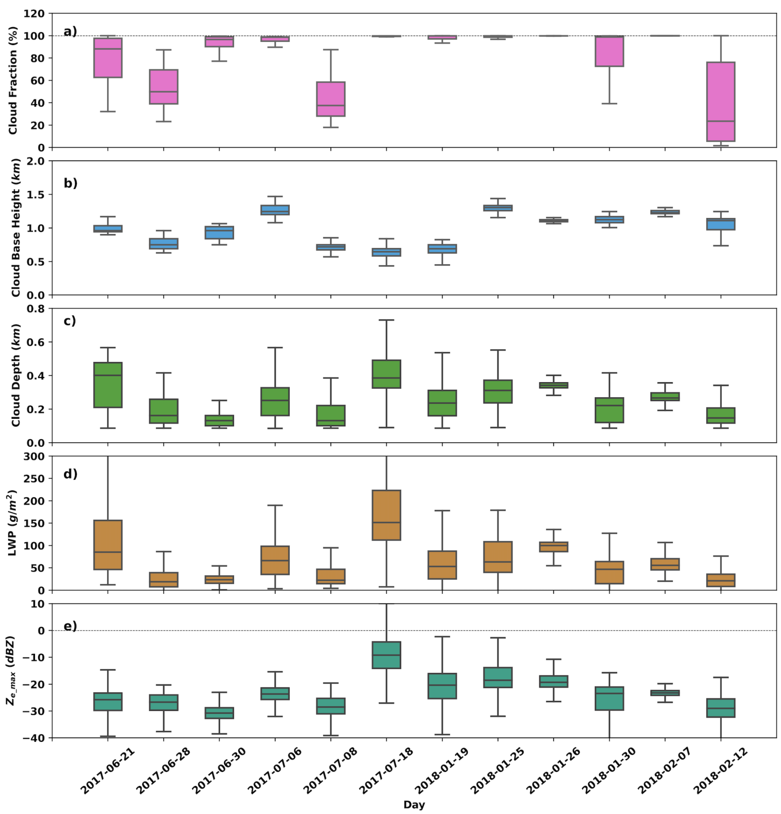


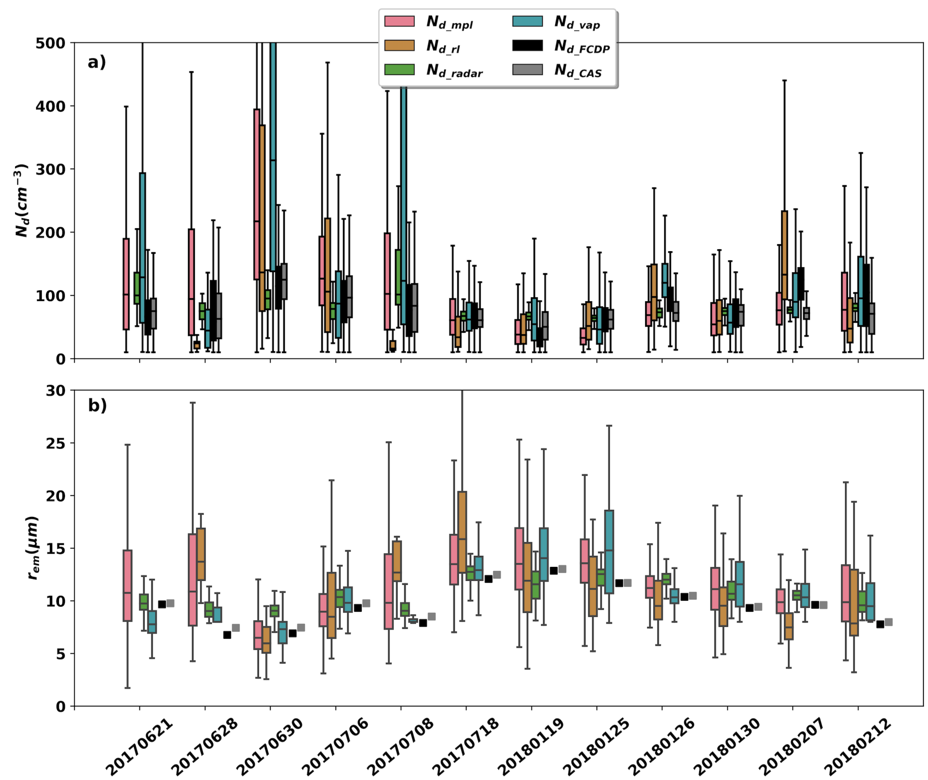




Evaluation of N_d with 12 Flight days

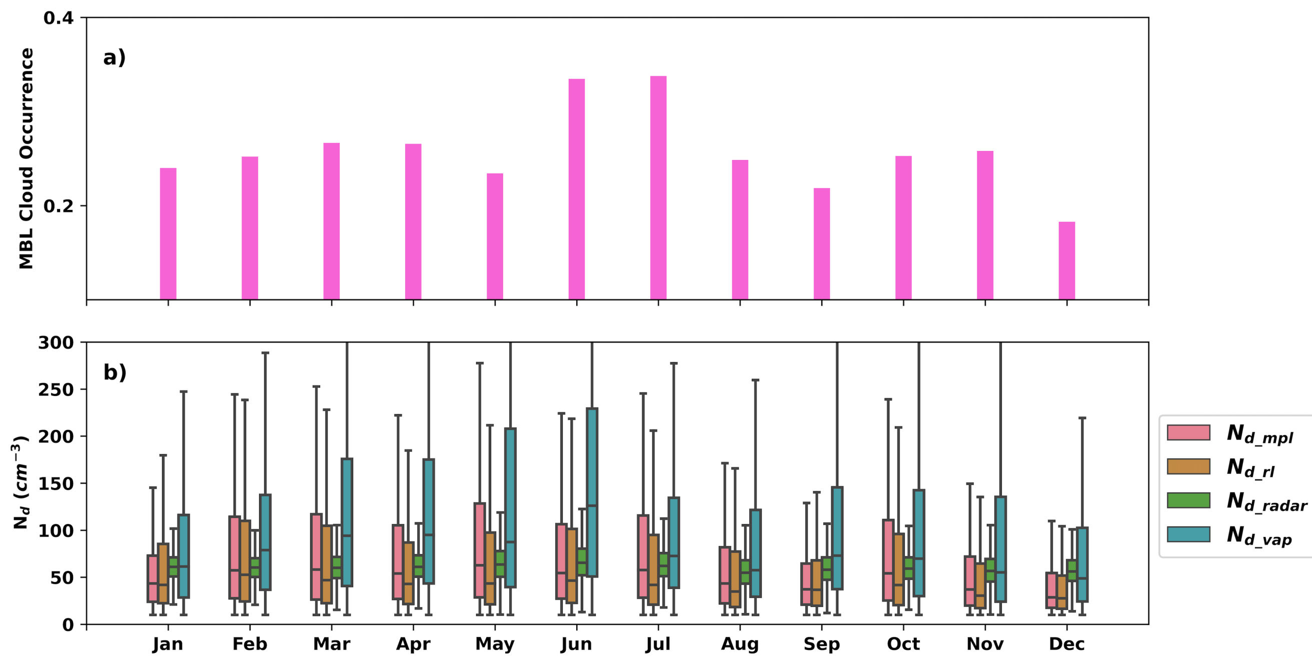
ARM





N_d Retrievals from Multiple Years of ENA Data

- Retrievals show slightly seasonal N_d variations with higher N_d during the summer season and lower N_d during the winter season
- N_{d_vap} is systematically larger compared to other retrievals



Summary

- Assumptions used in the retrieval algorithms were assessed or characterized
- Ground-based N_d and cloud r_e retrievals generally follow the same day-to-day variation of the *in situ* measurements.
- We recommend using the MPL lidar-based method given its good agreement with *in situ* measurements and it has less sensitivity to issues arising from precipitation and low cloud LWP/optical depth
- The ensemble of retrievals using different measurements and retrieval algorithms can help to quantify N_d retrieval uncertainties and identify reliable N_d retrieval scenarios.

References

- Snider, J. R., et al..: Droplet Concentration and Spectral Broadening in Southeast Pacific Stratocumulus Clouds, JAS, 74(3), 719-749. 2017.
- Lim, K.-S., et al.: Evaluation of long-term surface-retrieved cloud droplet number concentration with in situ aircraft observations, JGR-Atmos., 121, 2318–2331, 2016.
- Wu, P., et al., Profiles of MBL cloud and drizzle microphysical properties retrieved from ground-based observations and validated by aircraft in situ measurements over the Azores. JGR. Atmos., 125, 2020
- Zhang, D., et al.,: Evaluation of Four Ground-based Retrievals of Cloud Droplet Number Concentration in Marine Stratocumulus with Aircraft In Situ Measurements, AMT, submitted

Open Discussion (1)

- The instruments that are necessary for retrieving cloud droplet number concentration
  - Lidar
  - Lidar, radar, and shortwave zenith radiance measurements
  - Lidar, radar, and microwave radiometer
  - Lidar, radar, and narrowband flux measurements
  - microwave radiometer, optical depth retrievals from shortwave radiation, temperature, pressure

- Instrument calibration
  - Microwave radiometer
  - Shortwave radiation (narrowband flux or zenith radiance)
  - Lidar: MPL, ceilometer, Raman lidar?
  - Zenith pointing radar: KAZR

Open Discussion (2)

- Robustness of the methods
  - Assumption (size distribution, adiabatic)
  - Uncertainty quantification
  - Application: climatology, model evaluation, process-level understanding, aerosol-cloud interactions

Open Discussion (3)

THIN LIQUID WATER CLOUDS

Their Importance and Our Challenge

BY D. D. TURNER, A. M. VOGELMANN, R. T. AUSTIN, J. C. BARNARD, K. CADY-PEREIRA, J. C. CHIU, S. A. CLOUGH, C. FLYNN, M. M. KHAIYER, J. LILJEGREN, K. JOHNSON, B. LIN, C. LONG, A. MARSHAK, S. Y. MATROSOV, S. A. MCFARLANE, M. MILLER, Q. MIN, P. MINNIS, W. O'HIROK, Z. WANG, AND W. WISCOMBE

AN INTERCOMPARISON OF MICROPHYSICAL RETRIEVAL ALGORITHMS FOR UPPER-TROPOSPHERIC ICE CLOUDS

BY JENNIFER M. COMSTOCK, ROBERT D'ENTREMONT, DANIEL DESLOVER, GERALD G. MACE, SERGEY Y. MATROSOV, SALLY A. MCFARLANE, PATRICK MINNIS, DAVID MITCHELL, KENNETH SASSEN, MATTHEW D. SHUPE, DAVID D. TURNER, AND ZHIEN WANG

- **Our proposal:** A review paper (probably BAMS) for cloud droplet number concentration retrievals using ground-based remote sensing observations
  - Thorough review of existing methods (ARM/ASR, European)
  - Unified cases and assumptions (testing various retrieval methods and summarizing pros and cons)
  - Impact of assumptions on cloud droplet number concentration retrievals
  - Impacts of retrieval uncertainty on various applications, i.e., warm cloud and precipitation processes, aerosol-cloud interaction quantification, model evaluation
  - Instrument and retrieval requirements for the applications above
  - Providing ARM with **clear pathways** to address this need