A Review of Satellite Cloud Condensation Nuclei Retrieval Methods for Evaluation with In-situ Measurements from Aircraft-Based Observations in the Marine Boundary Layer

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Abstract

Aerosol-cloud interactions are the most uncertain component of the Earth system, due to their major influence on cloud properties, and as a result, Earth's energy budget. We need to better characterize these interactions, which requires constraining the cloud condensation nuclei (CCN) budget and disentangling the influences of aerosol microphysics from meteorology. Observational data are essential for evaluating and improving climate models, but airborne field campaigns have, until recently, been limited to a few (mostly continental) regions worldwide. CCN measurements over the remote ocean are scarce and only occur during extensive field missions involving airborne or ship-based measurements of limited spatial and temporal extent. Polar-orbiting satellite observations hold great promise for expanding the spatial coverage of observations to remote regions, however, it is currently not well understood to what extent these active and passive remote sensing observations can be considered adequate proxies for CCN. Recent literature make use of column integrated retrievals, such as aerosol optical depth or aerosol index, to characterize aerosol concentration and CCN, and the utility of vertically resolved optical properties from active sensors is only now becoming more fully understood. The NASA ACTIVATE, NAAMES, CAMP^{2}EX and ORACLES field campaigns are particularly well suited for evaluating the skill of advanced satellite aerosol and cloud microphysical retrievals, given the comprehensive suite of airborne aerosol, cloud, and trace gas measurements, combined with airborne High Spectral Resolution Lidar (HSRL) and polarimetric imaging instruments that will be the basis for the next generation of space-based remote sensors. Here, we characterize the properties of aerosol and CCN from these NASA field campaigns and critically assess methods for deriving CCN and CCN proxies using visible and infrared satellite remote sensing retrievals.

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PRESENTER:
Kevin Sanchez

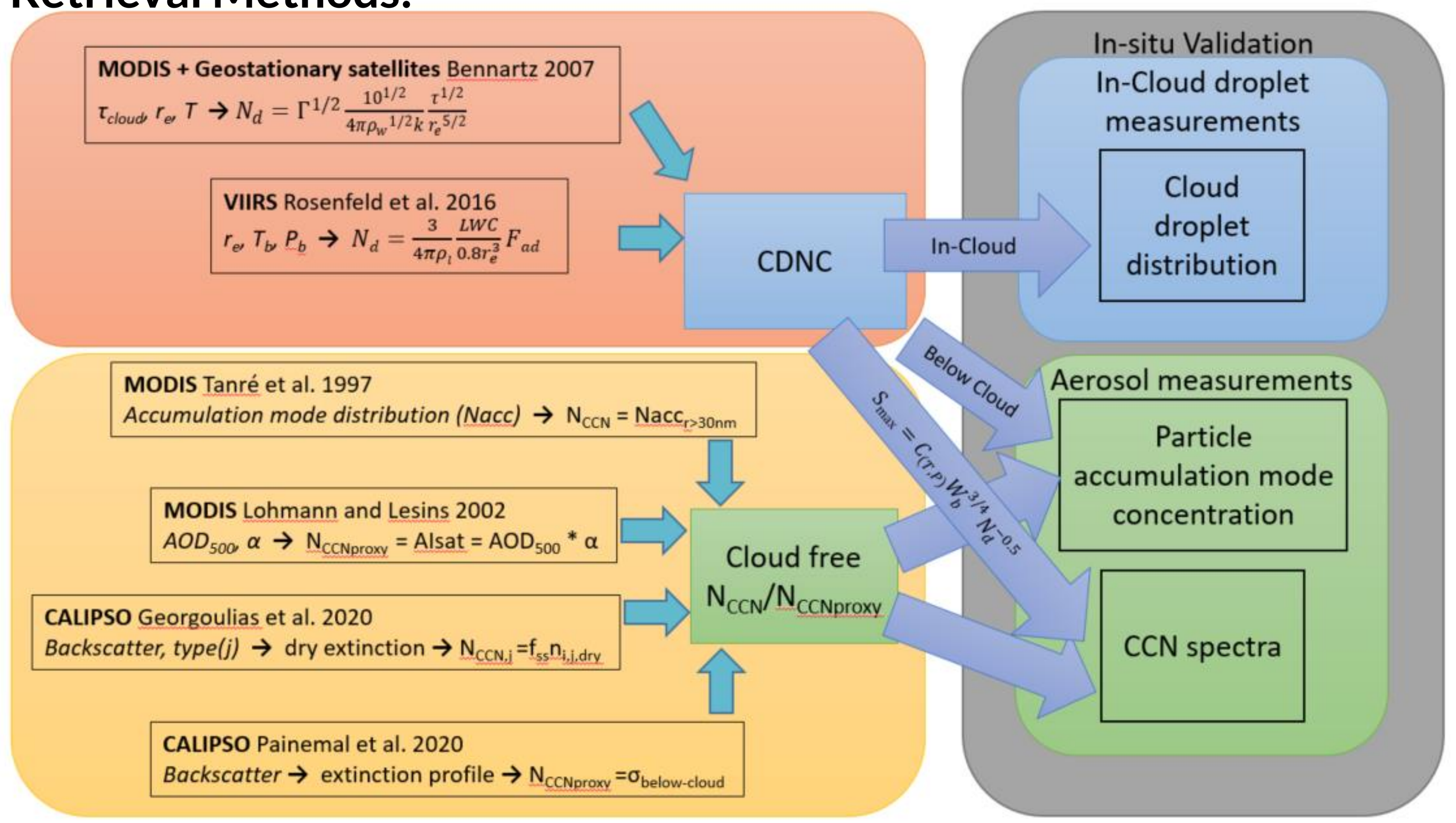
Motivation:

- Several methods exist for acquiring remote estimates of a subset of atmospheric aerosol particles known as cloud condensation nuclei (CCN) or related proxies, but few are thoroughly evaluated and intercompared using real-world observations.
- Such measurements are necessary to fill in substantial gaps in observations, particularly over the ocean, where collecting in-situ measurements are costly.

Goals:

- Test the skill of several published methods using in-situ measurements from several marine boundary layer targeted campaigns.
- Identify key sources of error for each method (possible sources: pollution, low signal, cloud type, local climate, remote sensing resolution, method assumptions, etc.)

Retrieval Methods:



Satellite Proxies (Aircraft Remote Measurements):

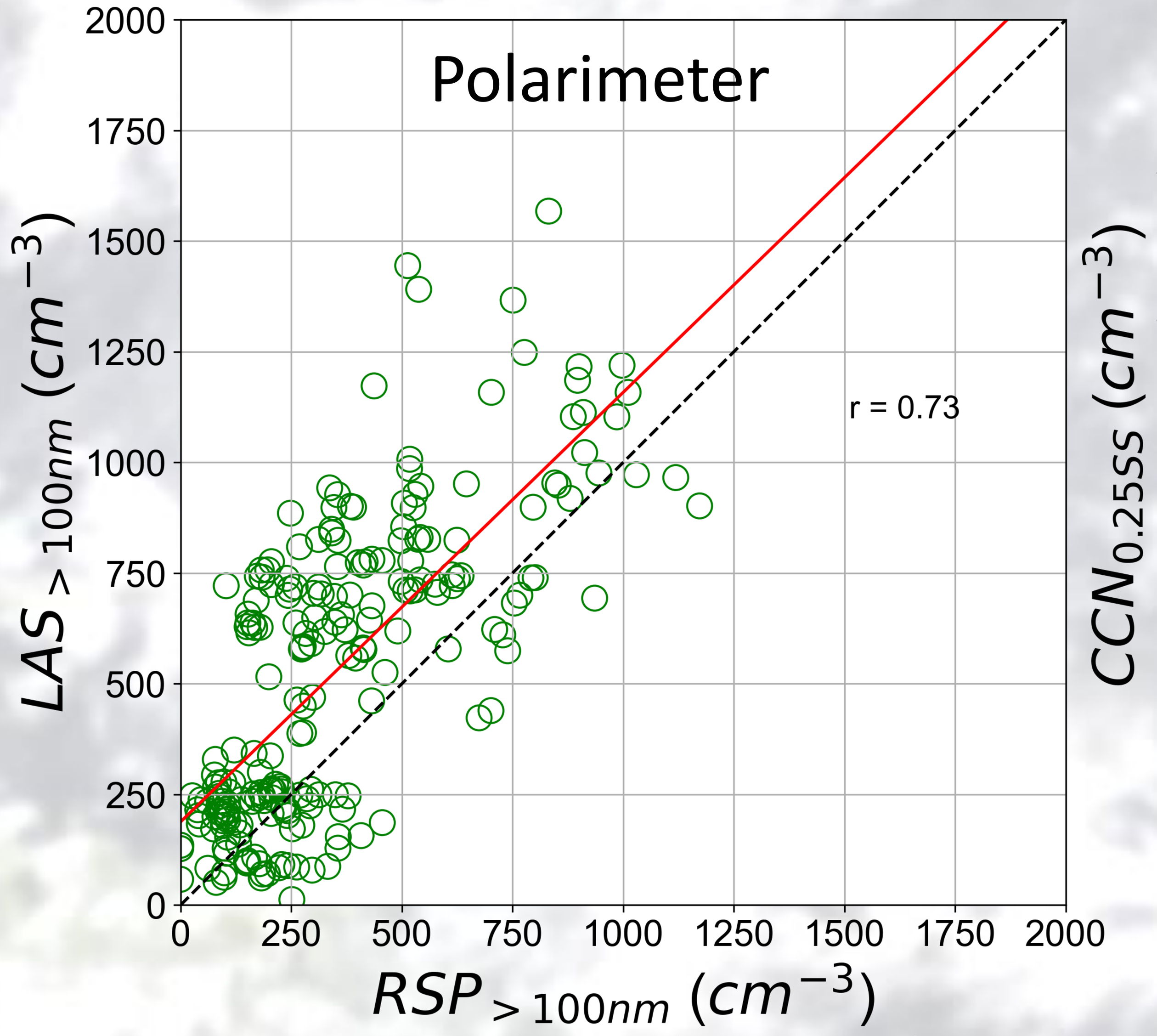
Almost all campaigns used include airborne High Spectral Resolution Lidar (HSRL) and Research Scanning Polarimeter (RSP) imaging instruments that are expected to be the basis for the next generation of space-based remote sensors and can be used as a proxy for potential future satellite.

Future Work Outline

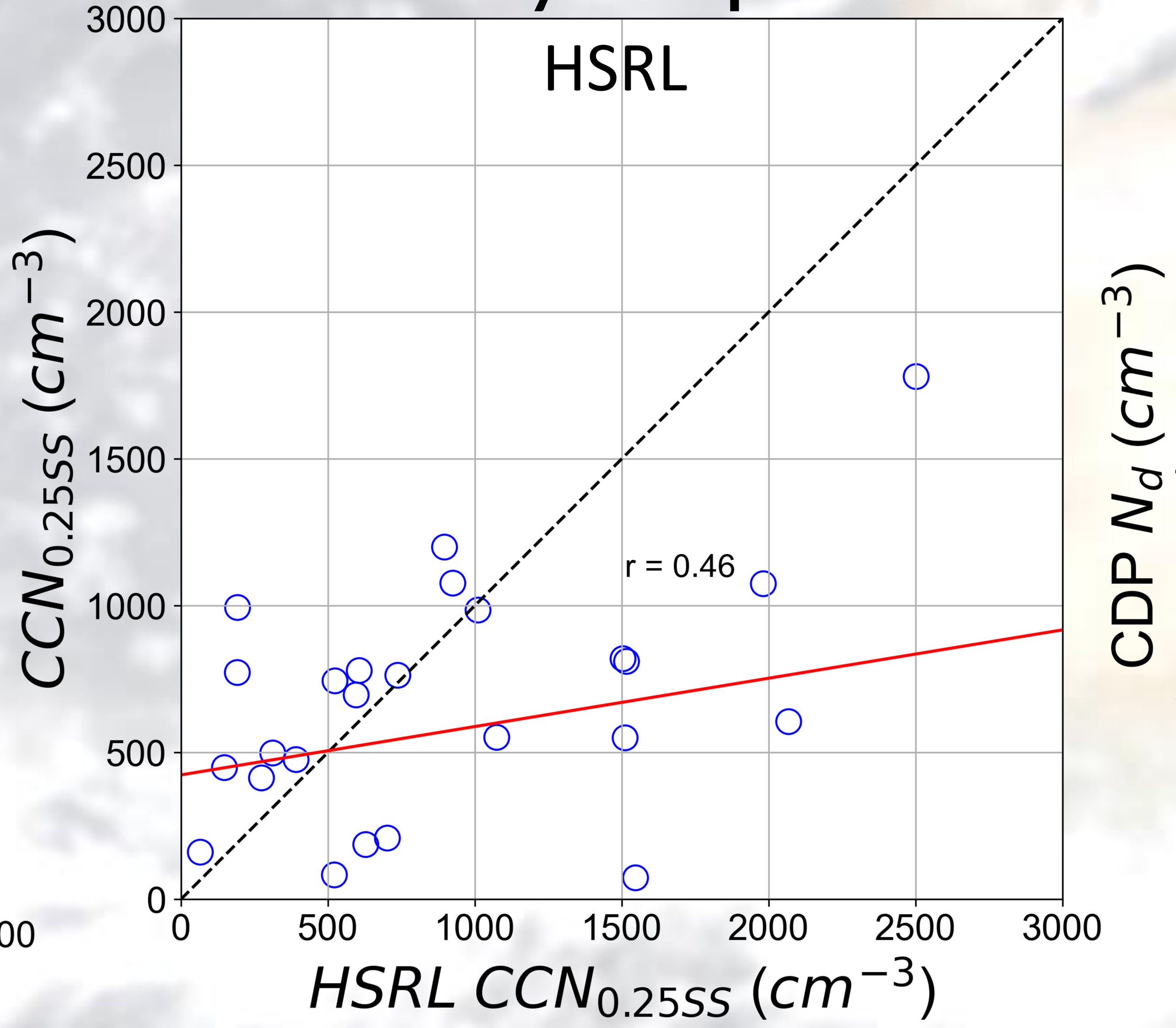
1. Complete synthesis of spatially collocated measurements.
2. Characterization relevant in-situ, CCN, aerosol and cloud microphysical observations, and describe the data, instruments, quality control details and interconnectedness of data in a **published data descriptor**.
3. Complete **implementation of** all remote CCN and CCN proxy **retrieval methods**.
4. **Assess the skill of retrievals** by region, season and overall.
5. **Evaluate sources of error** through validation of retrieval inputs and assumptions.
6. **Publish results and make synthesized dataset publicly available for future use!**

Remote cloud droplet and cloud condensation nuclei measurement methods need more in-situ validation.

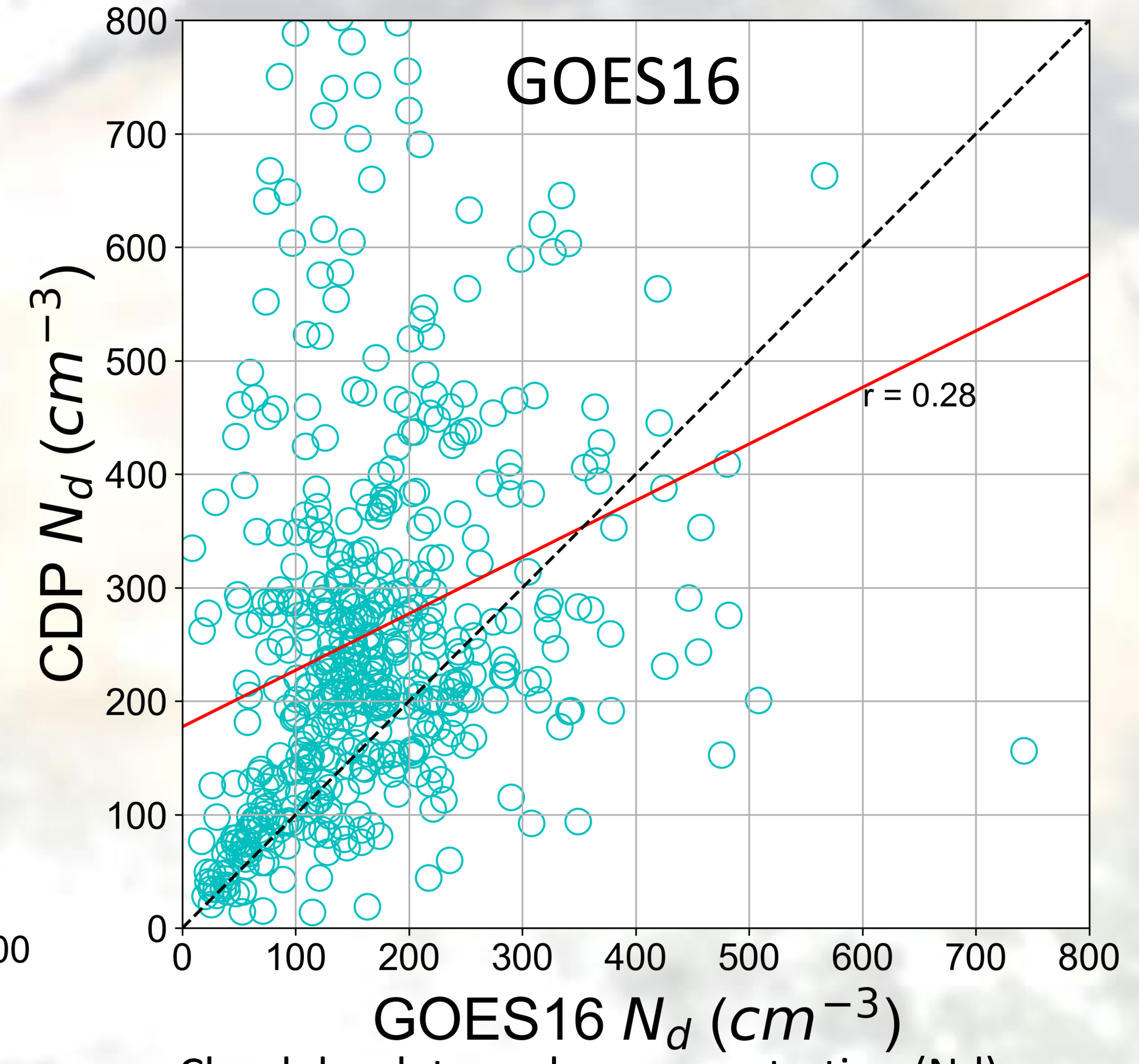
Preliminary Comparisons



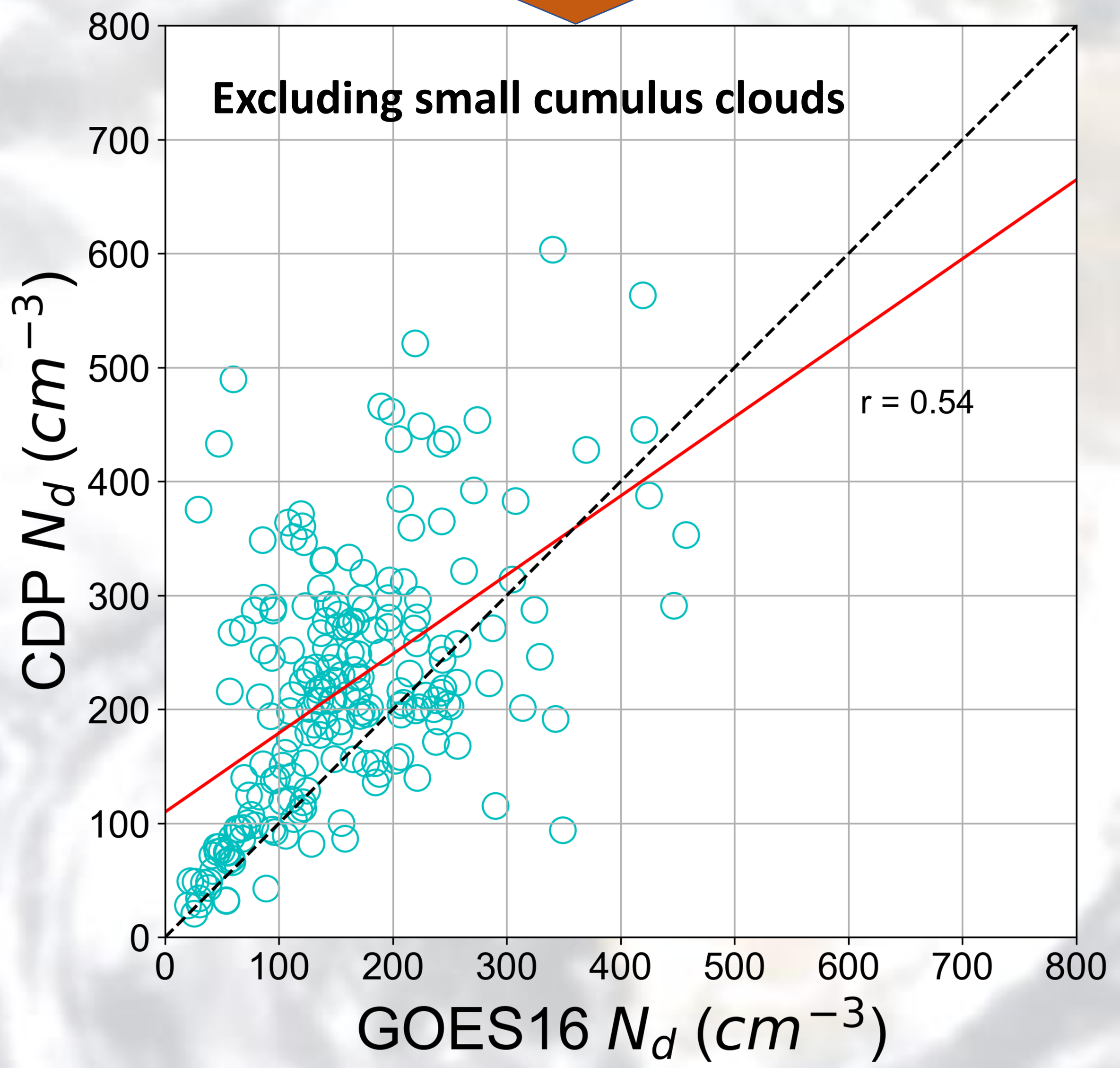
Microphysical Aerosol Properties from Polarimetry (MAPP) Stamnes et al 2018



CCN concentrations derived from lidar Georgoulias et al. 2020



Cloud droplet number concentration (Nd) derived from satellite Bennartz et al 2007



Further filtering and error source evaluation could improve some retrieval method results under certain conditions.

NASA Led Campaigns

NAAMES – North Atlantic Aerosol and Marine Ecosystem Study

ACTIVATE – Aerosol Cloud meTeorological Interactions oVer the western ATlantic Experiment

CAMP²EX- Clouds, Aerosol, Monsoon Processes-Philippines EXperiment

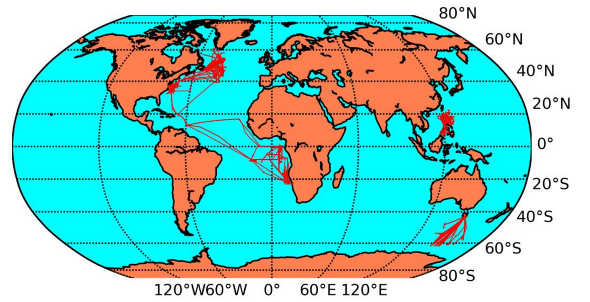
ORACLES – ObseRvations of Aerosols above CLouds and their intEractionS

Others

SOCRATES – Southern Ocean Clouds, Radiation, Aerosol Transport Experimental Study

CAPRICORN2 (ship only) – Clouds, Aerosol, Precipitation, Radiation, and Atmospheric Composition over the Sothern Ocean

All campaign ship and flight tracks



HSRL Retrievals:

- Vertically resolved extinction (1-2 wavelengths)
- Vertically resolved aerosol backscatter (2-3 wavelengths)

RSP Retrievals:

- Aerosol and ocean upwelling total and polarized reflectance at multiple wavelengths and multiple viewing lengths
- Microphysical aerosol properties from polarimetry (MAPP) algorithm using radiative transfer and mie calculations

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Bennartz, R.: Global assessment of marine boundary layer cloud droplet number concentration from satellite, J. Geophys. Res. Atmos., 112(2), 1–16, doi:10.1029/2006JD007547, 2007.

Georgoulias, A. K., Marinou, E., Tsekeri, A., Proestakis, E., Akritidis, D., Alexandri, G., Zanis, P., Balis, D., Marenco, F., Tesche, M. and Amiridis, V.: A first case study of CCN concentrations from spaceborne lidar observations, Remote Sens., 12(10), doi:10.3390/rs12101557, 2020.

Painemal, D., Painemal, D., Chang, F. L., Chang, F. L., Ferrare, R., Burton, S., Li, Z., Li, Z., Smith, W. L., Minnis, P., Minnis, P., Feng, Y., Clayton, M. and Clayton, M.: Reducing uncertainties in satellite estimates of aerosol-cloud interactions over the subtropical ocean by integrating vertically resolved aerosol observations, Atmos. Chem. Phys., 20(12), 7167–7177, doi:10.5194/acp-20-7167-2020, 2020.

Lohmann, U. and Lesins, G.: Stronger constraints on the anthropogenic indirect aerosol effect, Science (80)., 298(5595), 1012–1015, doi:10.1126/science.1075405, 2002.

Rosenfeld, D., Zheng, Y., Hashimshoni, E., Pöhlker, M. L., Jefferson, A., Pöhlker, C., Yu, X., Zhu, Y., Liu, G., Yue, Z., Fischman, B., Li, Z., Giguzin, D., Goren, T., Artaxo, P., Barbosa, H. M. J., Pöschl, U. and Andreae, M. O.: Satellite retrieval of cloud condensation nuclei concentrations by using clouds as CCN chambers, Proc. Natl. Acad. Sci., 113(21), 5828–5834, doi:10.1073/pnas.1514044113, 2016.

S. Stamnes, C. Hostetler, R. Ferrare, S. Burton, X. Liu, J. Hair, Y. Hu, A. Wasilewski, W. Martin, B. van Diedenhoven, J. Chowdhary, I. Cetinić, L. K. Berg, K. Stamnes, and B. Cairns, "Simultaneous polarimeter retrievals of microphysical aerosol and ocean color parameters from the "MAPP" algorithm with comparison to high-spectral-resolution lidar aerosol and ocean products," Appl. Opt. 57, 2394-2413 (2018)