The PolCube CubeSat polarimeter for Earth Science

Snorre Stamnes[1], Vianni Ricano Cadenas[1], Brian Cairns[2], Yongxiang Hu[1], Nathan Dostart[1], Adam Bell[1], Eduard Chemyakin[1,3], Joseph Schlosser[1], Michael Jones[1], Jacek Chowdhary[2], Wenbo Sun[1,3], Gorden Videen[4], Marilee Roell[1], Ali Omar[1], Rosemary Baize[1], Sungsoo S. Kim[5], Chae Kyung Sim[6], Bongkon Moon[6], Young-Jun Choi[6]

[1]NASA Langley Research Center; [2]NASA Goddard Institute for Space Studies; [3]Science Systems and Applications, Inc.; [4]US Army Research Laboratory; [5]Kyung Hee University; [6]Korea Astronomy and Space Institute

Why PolCube?

- Aerosol absorption is a key climate geophysical variable (GV) that polarimeters can quantify
- Polarimetry is vital to understanding the impacts of aerosols and clouds on climate and weather
- Incredible advances in aerosol and cloud remote sensing using polarimetry are possible using machine learning (Stamnes et al., 2017; Gao et al., 2021; Stamnes et al., 2023, in prep.)

PolCube-like airborne data

- Aerosol Cloud Meteorology Interactions Over the Western Atlantic Experiment (ACTIVATE)
  - Research scanning polarimeter (RSP)
  - Multiwavelength high spectral resolution lidar (HSRL-2)

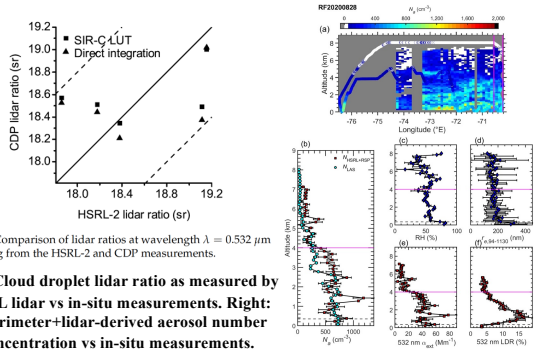
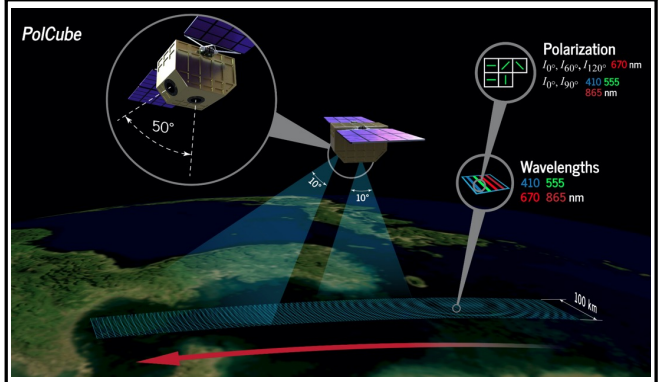


Fig. 3. Comparison of lidar ratios at wavelength $\lambda = 0.532\ \mu m$ resulting from the HSRL-2 and CDP measurements.

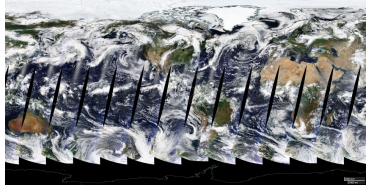
Top: Cloud droplet lidar ratio as measured by HSRL lidar vs in-situ measurements. Right: Polarimeter+lidar-derived aerosol number concentration vs in-situ measurements.

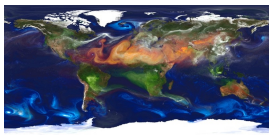
What is PolCube?



Polarimeters like PolCube measure light not only at multiple wavelengths, but also measure both the intensity *and polarization* <u>at multiple angles</u>

- PolCube is a contributed, flight-ready instrument & spacecraft
  - PolCube polarimeter instrument
  - 12U CubeSat bus
- Collaboration between NASA Langley with the Korea Astronomy and Space Science Institute (KASI) for Earth Science
- PolCube is based on the PolCam polarimeter onboard the Korean Pathfinder Lunar Observatory (KPLO)





PolCube performance

	Symbol	Range	PolCube forward-looking mode (1σ)
PolCube aerosol products			
Total AOD_{555}	τ	0–0.9	0.068
Fine-mode AOD_{555}	τ_f	0–0.5	0.078
Sea-salt AOD_{555}	τ_c	0–0.2	0.039
Dust AOD_{555}	τ_d	0–0.2	0.038
Fine-mode effective radius	$r_{eff,f}$	0.1–0.4 μm	0.059 μm
Sea-salt mode effective radius	$r_{eff,c}$	1.0–3.5 μm	1.3 μm
Dust mode effective radius	$r_{eff,d}$	1.0–4.0 μm	1.2 μm
Fine-mode SSA	SSA	0.8–1.0	0.036
Fine-mode real refractive index	n_{rf}	1.36–1.65	0.074
Aerosol top height	h_f	1.1–5 km	1.4 km
PolCube ocean products[a]			
Ocean surface windspeed	v	0.02–11.5 m/s	1.1 m/s
Ocean chlorophyll-a concentration	[Chla]	0.025–9.9 mg/m^3	2.4 mg/m^3

[a]*Ocean product uncertainties for AOD_{555} < 0.3.*

- The PolCube-MAPP retrieval algorithm uses optimal estimation, artificial intelligence, and inherent optical property look-up-tables for the Earth's aerosol, cloud, and hydrosol particles
- PolCube can retrieve total aerosol optical depth at 555 nm (AOD555) within ±0.07, fine-mode AOD555 within ±0.08, and fine-mode single-scattering albedo within ±0.036 (uncertainties expressed as 1σ)

References

Stamnes et al., 2021, Simultaneous aerosol and ocean properties from the PolCube CubeSat polarimeter. Frontiers in Remote Sensing, 2, p.709040.
Stamnes et al., 2018, 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. Applied optics, 57(10), pp.2394-2413.
Stamnes et al., 2018, Advantages of measuring the Q Stokes parameter in addition to the total radiance I in the detection of absorbing aerosols. Frontiers in Earth Science, 6, p.34.
Gao et al., 2021, Efficient multi-angle polarimetric inversion of aerosols and ocean color powered by a deep neural network forward model. Atmospheric Measurement Techniques, 14(6), pp.4083-4110.
Chemyakin et al., 2023, Efficient single-scattering look-up table for lidar and polarimeter water cloud studies. Optics Letters, 48(1), pp.13-16.
Chemyakin et al., 2021, Improved Lorenz-Mie Look-Up Table for Lidar and Polarimeter Retrievals. Frontiers in Remote Sensing, 2, p.711106.
Schlosser et al., 2022, Polarimeter + Lidar–Derived Aerosol Particle Number Concentration. Front. Remote Sens. 3:885332. doi: 10.3389/frsen.2022.885332