The PACE-MAPP algorithm

Simultaneous aerosol and ocean polarimeter products using **coupled** atmosphere-ocean vector radiative transfer and neural networks

August 10, 2022

PACE-MAPP team

PI

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Co-Investigators

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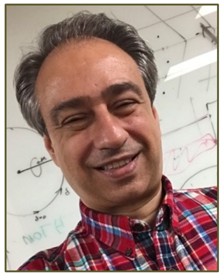

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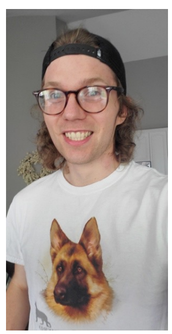

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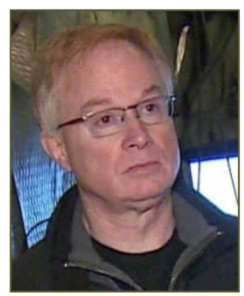
- Chris Hostetler

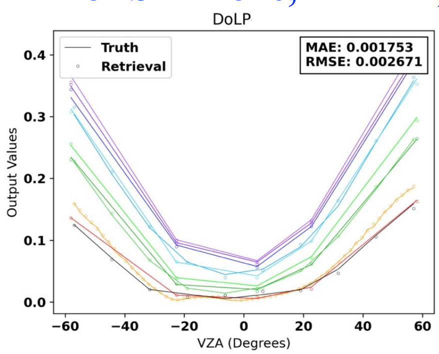


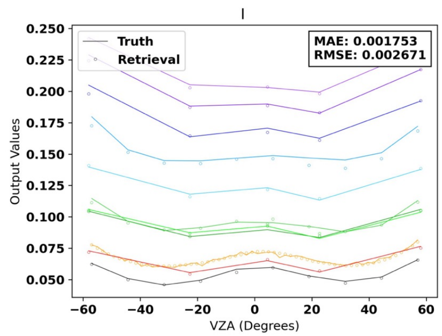
- Yongxiang Hu

PACE-MAPP collaborative algorithm project

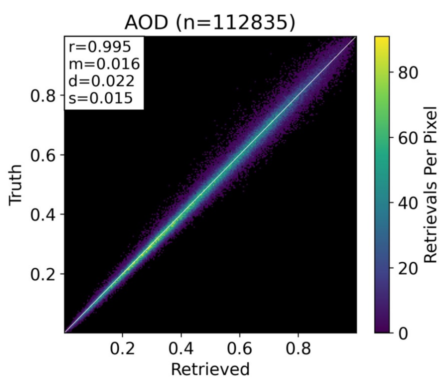
- Produce accurate aerosol optical and microphysical properties and ocean properties
- Use a coupled atmosphere-ocean vector radiative transfer (VRT) model
- Use accurate but fast Mie/SS/T-matrix LUTs
- Use scientific machine learning to speed-up retrievals by 1000x (PACE-MAPP Neural Network)

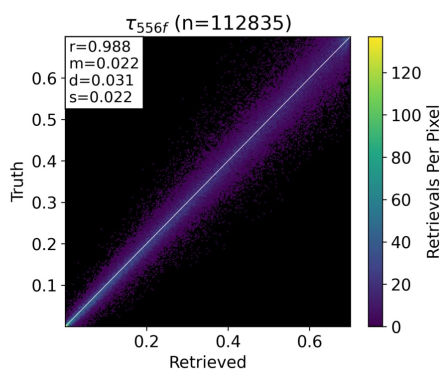
PACE-MAPP is a multi-instrument polarimeter algorithm for SPEXone, HARP2, OCI shortwave infrared channels

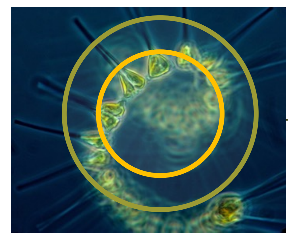




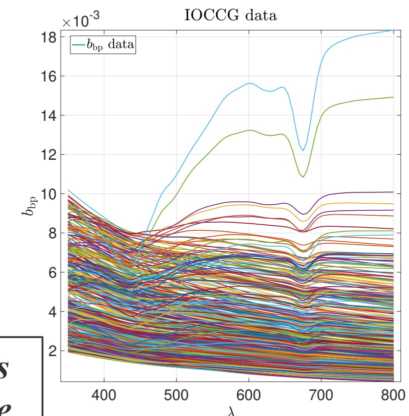
PACE-MAPP uses neural networks to become 1000x faster. 11 channels simulate UV-VIS-NIR at all viewing angles.





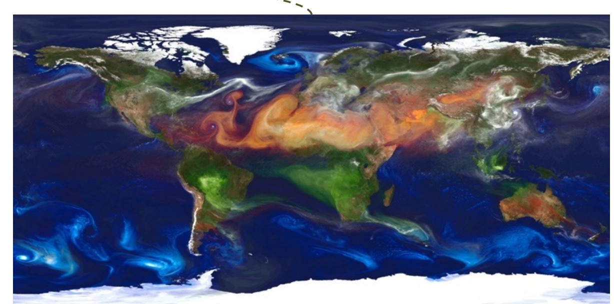


Bio-optical model includes coated particles



Collaborations needed to solve challenges in coastal zones

Thin cirrus correction



Aerosol VIS-NIR-SWIR properties: fine mode (absorbing), sea salt, and dust

PACE-MAPP aerosol/thin cloud products

❑ Aerosol optical and microphysical properties

- Fine mode AOD (aerosol optical depth), SSA (single-scattering albedo, quantifies absorption), real refractive index, effective radius (size), and effective variance (size distribution width)
- Seasalt AOD, effective radius and effective variance (CRI assumed)
- Dust AOD, effective radius and effective variance (CRI modeled according to Hasekamp/SRON model, with updates from Chowdhary, Schuster and Moosmüller)

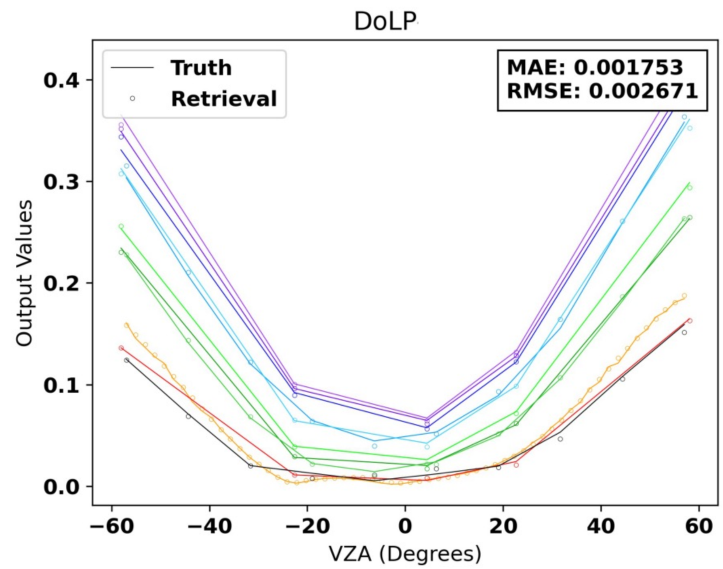
❑ Thin cirrus optical and microphysical properties

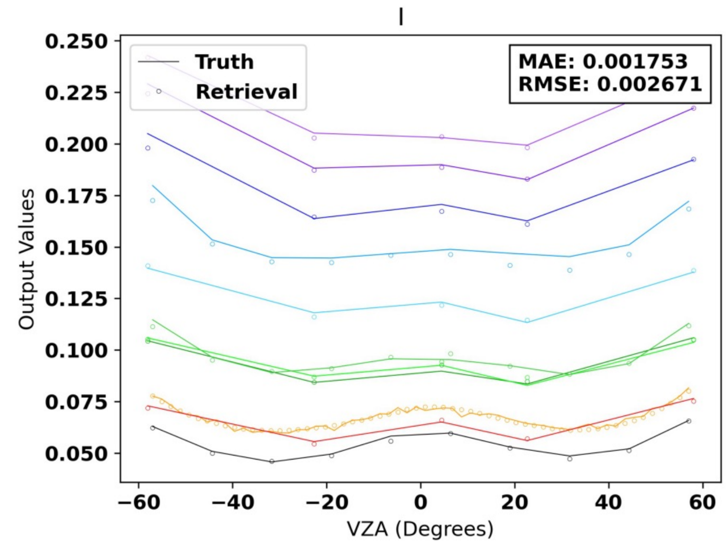
- Thin cirrus optical depth (< 1.0) and effective radius
- Sensitivity to shape and height will be assessed

Parameter Values
All values randomly selected from a uniform distribution. For VZA 160 angles are generated between 65° and -65° for every observation. Altitude is fixed at top of atmosphere (TOA).

Parameter [Units]	Min	Max
SZA [degrees]	0	60
RAA [degrees]	0	180
n_{rf}	1.39	1.65
n_{if}	1e-5	0.045
r_{nf}	0.075	0.22
r_{nc}	0.5	1.5
τ_{556f}	1e-5	0.7
τ_{556c}	1e-5	0.3
σ_{gf}	log(1.4)	log(2.01)
σ_{gc}	log(1.35)	log(2.01)
FTL Base Height [km]	1.01	7.0
v [m/s]	0.5	10
Chla [mg/m^3]	0.01	9.9

PACE-MAPP Neural Network





1000x faster than online VRT

11 channels simulating SPEXone and HARP2 from UV-VIS-NIR

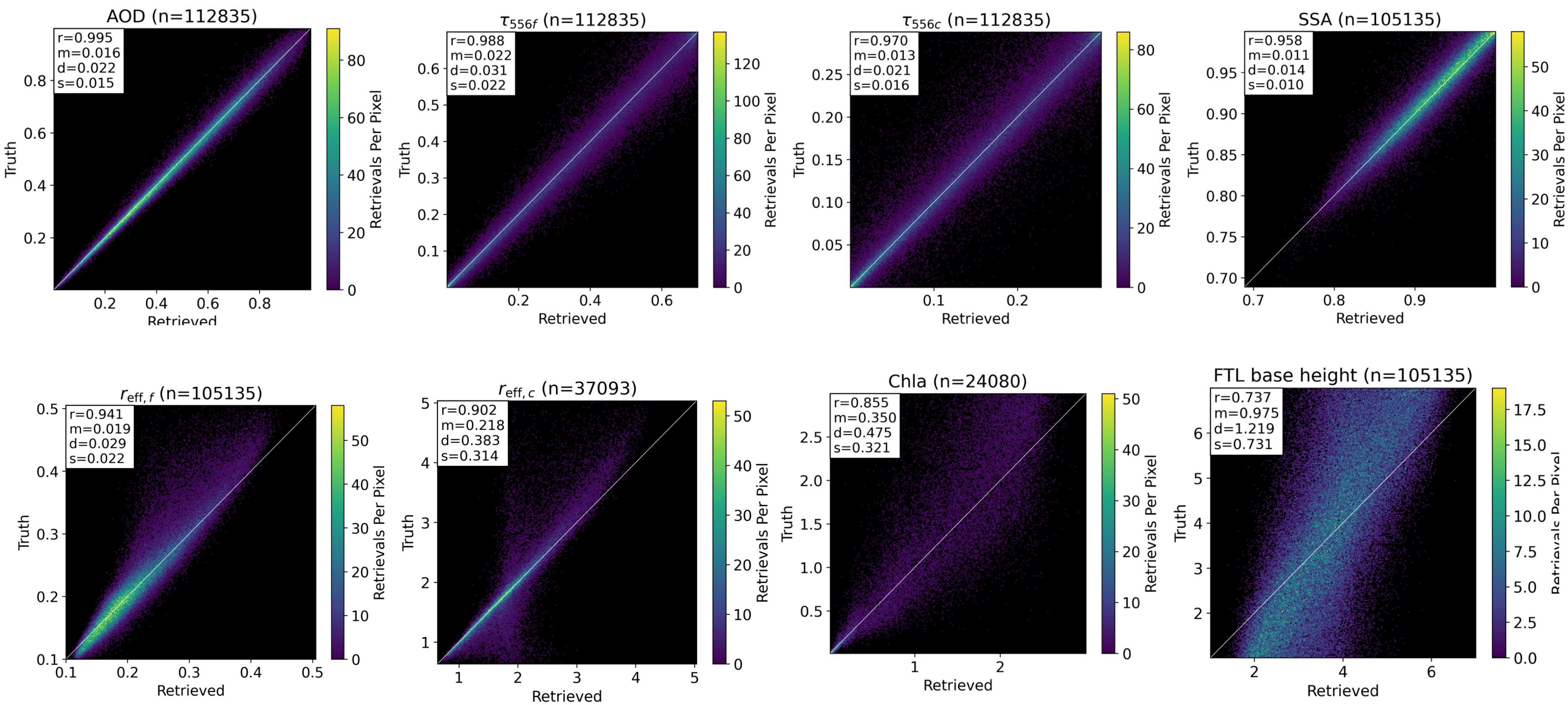
(556, 385, 396, 413, 441, 470, 533, 549, 669, 759, and 873 nm)

All viewing angles

Performance goal for retrievals:

1 second per L1C pixel

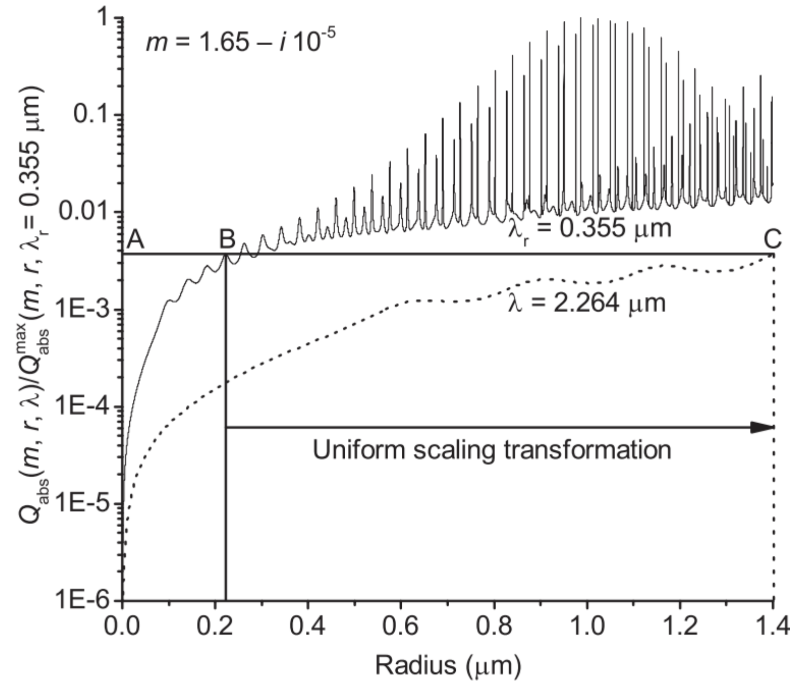
PACE-MAPP simulated retrieval performance



Coated hydrosol LUT scale invariance rule

Size parameter $$x = 2\pi \frac{1.4}{2.264} = 2\pi \frac{r}{\lambda} = 2\pi \frac{\frac{0.355}{2.264} \cdot 1.4}{0.355}$$

Efficiencies $$Q_p(., r, \lambda) = Q_p\left(., \frac{\lambda_r}{\lambda} r, \lambda_r\right)$$



Normalized absorption efficiencies at wavelengths 0.355 and 2.264 μm are related by a uniform scaling transformation which is a type of Euclidean affinity transformation.

In terms of integrals $$\int_{r_{min}}^{r_{max}} Q_p(., r, \lambda) \mathrm{d} \ln r = \int_{\frac{\lambda_r}{\lambda} r_{min}}^{\frac{\lambda_r}{\lambda} r_{max}} Q_p(., r, \lambda_r) \, \mathrm{d} \ln r.$$

Coated hydrosol LUT

- We have created a coated hydrosol LUT for PACE
- Coated particles can realistically simulate bbp without resorting to tiny sizes as required by solid spheres
- LUT structure based on Chemyakin et al., 2021

Core-to-shell ratio: 0.85

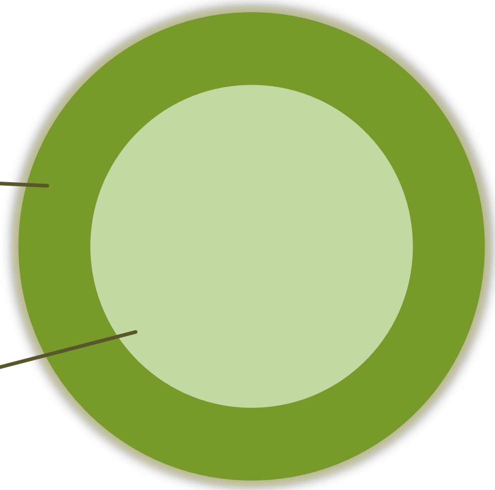
Shell real refractive index

Shell imag. refractive index

Size distribution:
Effective radius
Effective variance

Core real refractive index

Core imag. refractive index

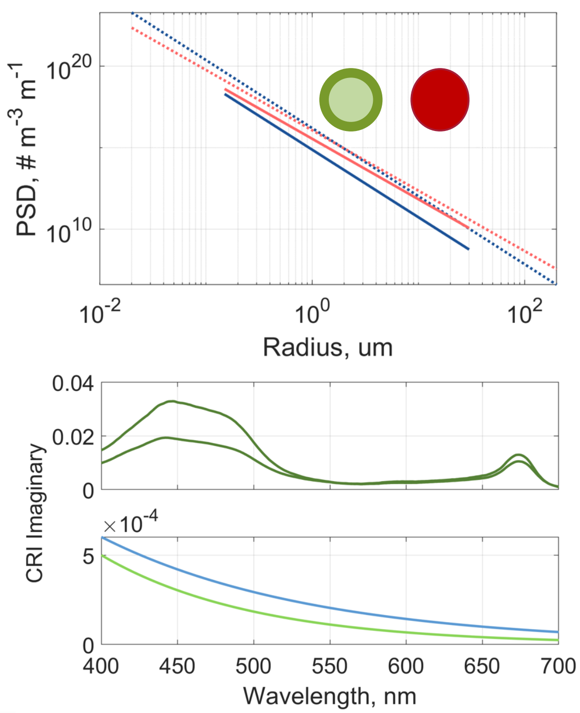


PACE-MAPP has 2 Bio-Optical Models

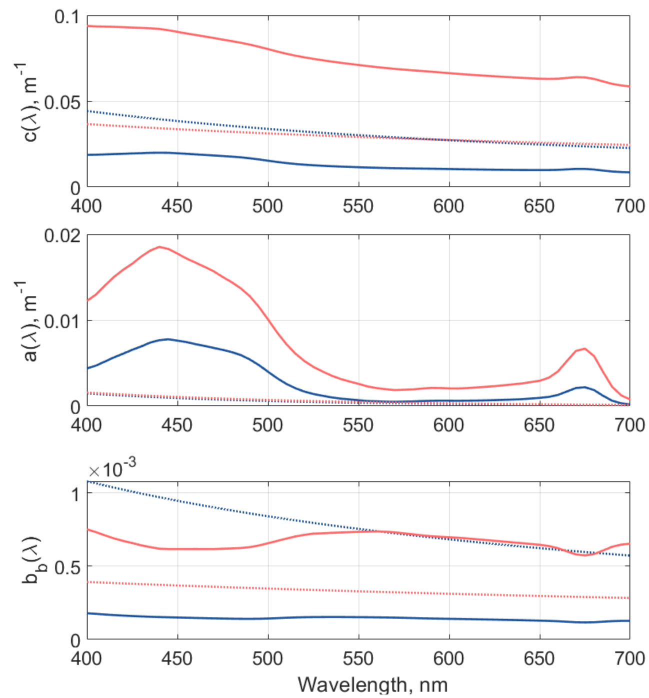
- **For simple waters that can be parameterized by chlorophyll-a concentration**
  - Bio-optical model from Chowdhary et al., 2006, 2012
- **For complex waters found in coastal zones or very clear waters**
  - We are developing a new bio-optical model with phytoplankton (coated spheres) and non-algal particles (solid spheres)
  - Coated spheres can produce realistic spectral variations in bbp without resorting to empirical formulas

Model Inputs	
Chlorophyll	0.01-50mg m^3
Chl Density	1-10kg m^3
Phyto Shell n	1.05-1.2
NAP n	1.02-1.2
NAP n' slope	0.007186
NAP n' intercept	0.010658
Junge PSD	2.5-6
% Phyto Volume	0.05-0.95

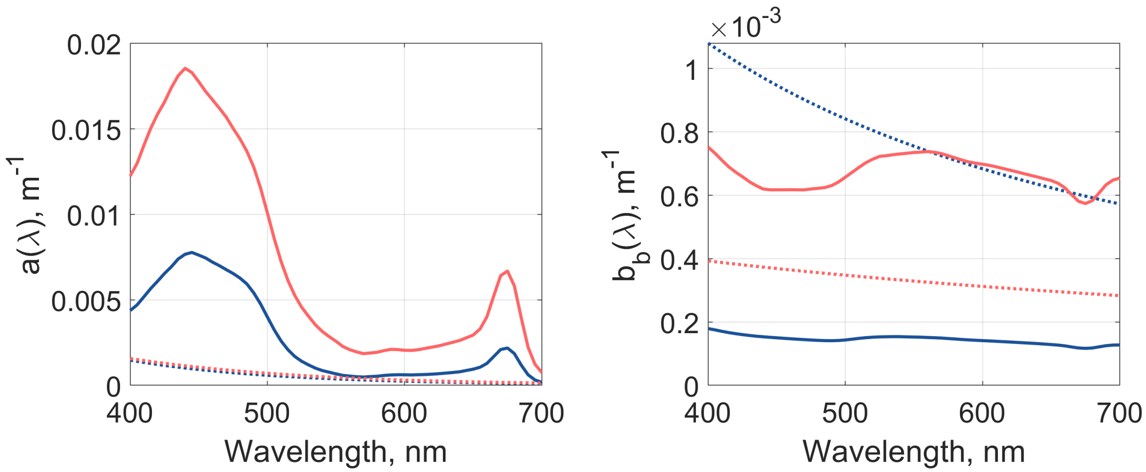
Bulk Particle Optics



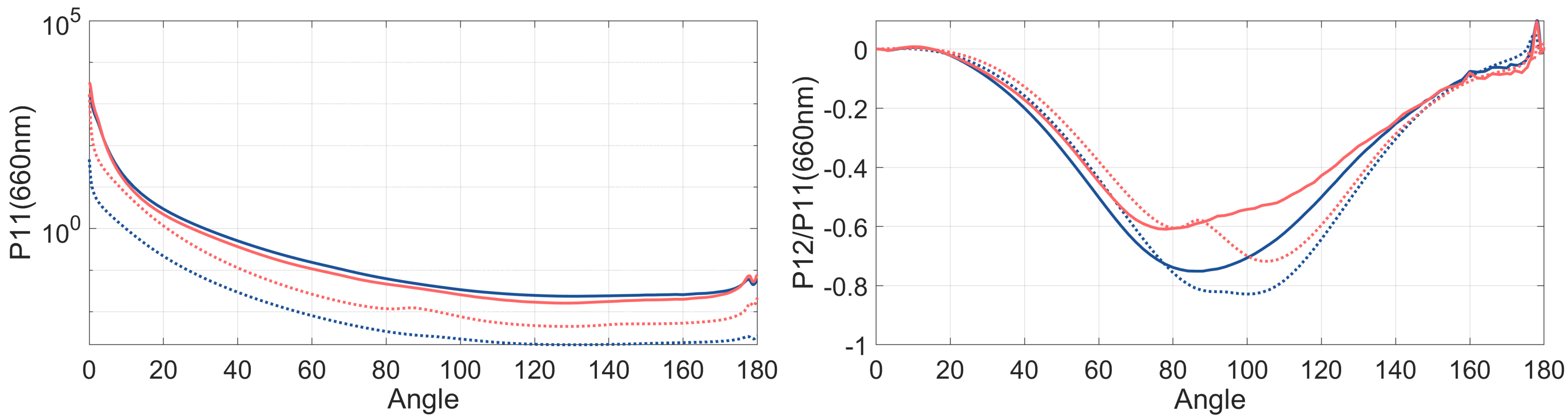
Model Outputs



BOM Test Inversion



Model Inputs:
Chl
Rrs(lambda)



Retrievals show realistic results from satellite remote sensing reflectance

Scattering processes switch between phytoplankton and non-algal particles

Future work will improve the Imaginary Refractive Index (IRI) for the phytoplankton shell

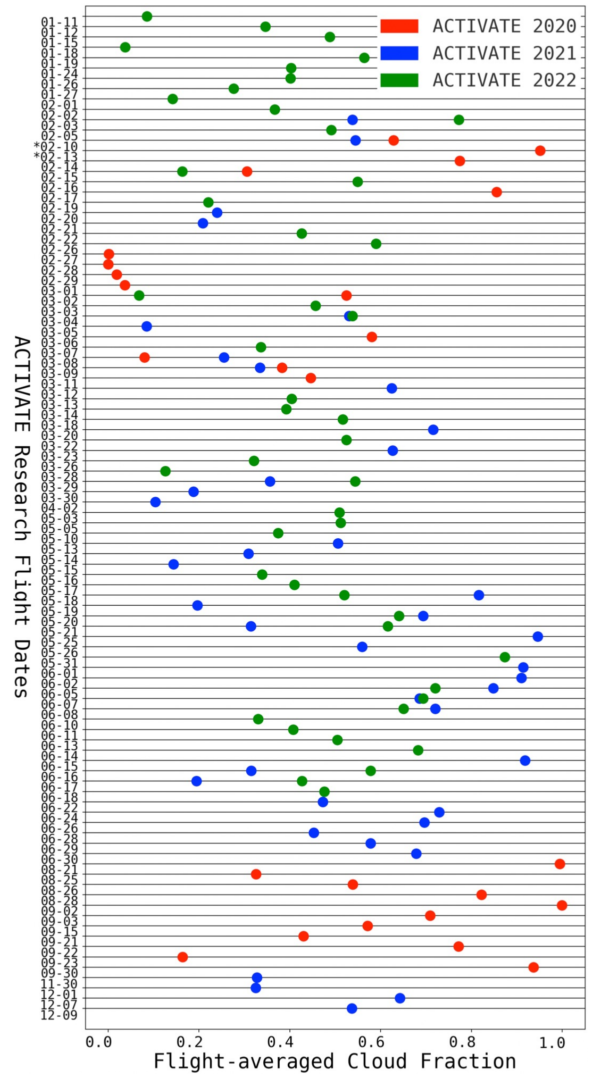
Vector Radiative Transfer Code (VRT) Updates in PACE-MAPP

Integrate Atmosphere-Ocean System model: *eGAP* (*Chowdhary et al.*, 2020)

- eGAP is one of a small number of coupled atmosphere-ocean VRT models
- Calculates total and polarized (*I, Q,* and *U*) reflectance of radiation emerging from top of an atmosphere-ocean system
- Extended to include underwater light computations of:
  - Upwelling radiance (L_u) at four user-specified ocean depths
  - Upwelling irradiance (E_d) at four user-specified ocean depths
  - Diffuse irradiance attenuation coefficient (K_d) at three user-specified ocean depths
  - Remote sensing reflectance values just above the ocean surface (R_{rs})
- Incorporate new coated hydrosol LUT bio-optical model
  - Compute water leaving contributions to total and polarized reflectance measurements
- Modeling of optically thin cirrus cloud properties (alone or coincident with aerosols) to aid in:
  - Cirrus cloud detection
  - Quantify bias in retrieved aerosol properties due to thin cirrus

Why worry about high-level clouds/cirrus?

- **The ubiquity of high-level clouds**
  - CAMP2Ex NASA field campaign conducted near the Philippines
  - For all CAMP2Ex flights, 53% of flights had above-aircraft cloud fraction above 50% (clouds above ~7 km)
  - For ACTIVATE in the North Atlantic off the coast of Virginia: 52% in 2020 and 54% in 2021
- **Impacts on aerosol radiative forcing**
  - Thorsen et al. (2020) demonstrate sensitivity of shortwave aerosol direct radiative effect (DRE) to thin cirrus clouds
  - Aerosols ***below*** thin clouds occur with greater frequency and are more impactful on overall aerosol DRE than aerosols ***above*** clouds
- **Thin cirrus aliasing of aerosol property retrievals**
  - Impact retrievals of aerosol optical depth (AOD) and aerosol physical properties like shape, size, and single-scattering albedo (SSA)
  - How does the presence of thin high-level cloud/cirrus impact our goal to retrieve AOD and SSA to ~0.02?



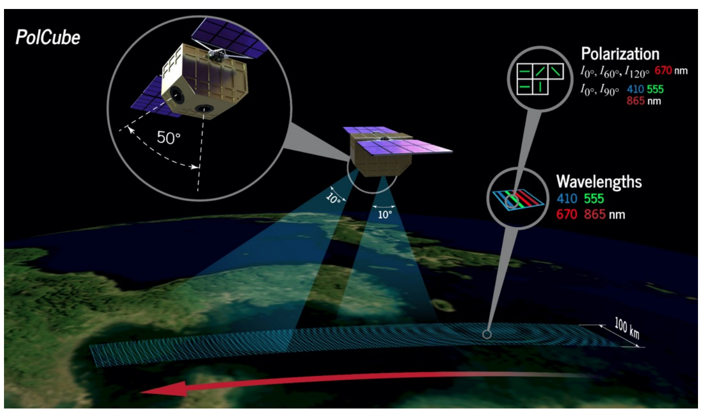
CAMP2Ex above-aircraft cloud fraction

Flight	Cirrus	No cirrus	Incloud
	P3	P3	P3
20190824	0.75	0	0.25
20190827	0.61	0.24	0.15
20190829	0.64	0.07	0.29
20190830	0.71	0.18	0.11
20190904	0.87	0.03	0.10
20190906	0.83	0.03	0.14
20190908	0.56	0.22	0.22
20190913	0.81	0.13	0.05
20190915	0.77	0.10	0.13
20190916	0.59	0.24	0.17
20190919	0.79	0.12	0.09
20190921	0.70	0.26	0.04
20190923	0.34	0.61	0.05
20190925	0.24	0.74	0.02
20190927	0.32	0.66	0.01
20190929	0.92	0.04	0.05
20191001	0.57	0.35	0.08
20191003	0.42	0.57	0.01
20191005	0.23	0.87	0.05
All Flights	**0.61**	**0.28**	**0.11**

Conclusion

- PACE-MAPP-related papers/presentations:
  - PACE-MAPP paper: submitted to Frontiers in Remote Sensing
  - MAPP paper: https://doi.org/10.1364/AO.57.002394
  - VDISORT paper: https://doi.org/10.3389/frsen.2022.880768
  - Aerosol LUT paper: https://doi.org/10.3389/frsen.2021.711106
  - Cloud LUT: See Ed Chemyakin's APOLO poster
  - Bio-optical model: James Allen's APOLO poster
  - Hydrosol LUT: https://science.larc.nasa.gov/polarimetry
  - Thin cirrus: https://agu.confex.com/agu/fm21/meetingapp.cgi/Paper/928558
  - Polarimeter + lidar-derived Na paper: https://doi.org/10.3389/frsen.2022.885332
- Welcome to all questions, suggestions, collaborators!

Polarimeter Aerosol, Hydrosol, Cloud, Coated Hydrosol LUTs are available to the research community: https://science.larc.nasa.gov/polarimetry



PolCube CubeSat polarimeter: https://doi.org/10.3389/frsen.2021.709040

Polarimeter engineer opportunity

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