The PACE-MAPP algorithm

Simultaneous aerosol and ocean products from **combined polarimeter** and *shortwave infrared* measurements

12/13/2021

PACE-MAPP team

PI

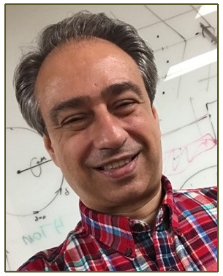
- Snorre Stamnes

- James Allen

- Adam Bell

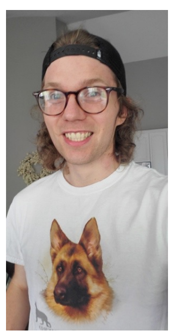
Co-Investigators

- Jacek Chowdhary



- Ed Chemyakin

- Michael Jones



- Sharon Burton

- Xu Liu

- Bastiaan van Diedenhoven

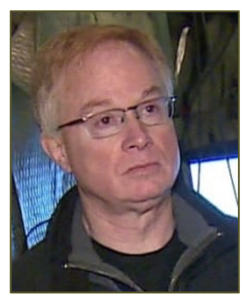
- Otto Hasekamp

- Johnathan Hair

- Richard Ferrare

Collaborators

- Chris Hostetler

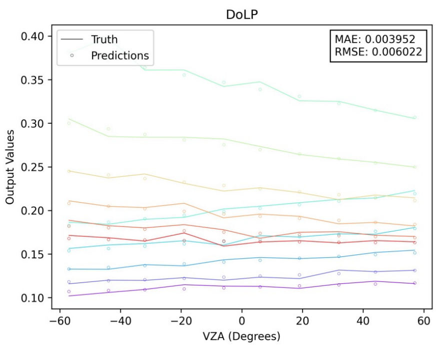


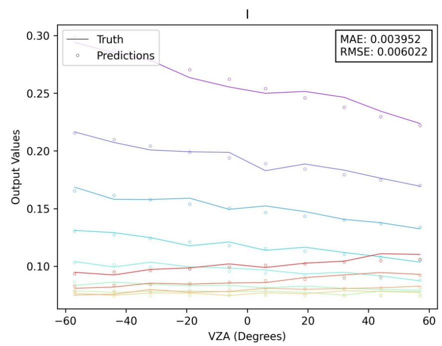
- Yongxiang Hu

PACE-MAPP collaborative algorithm project

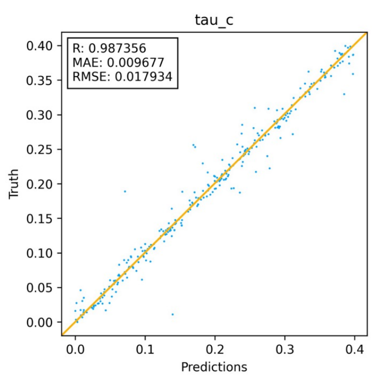
- Produce accurate aerosol optical and microphysical properties and ocean properties
- Use a coupled atmosphere-ocean vector radiative transfer (VRT) model
- Use accurate but fast Mie/SS/T-matrix LUTs
- Use scientific machine learning to speed-up retrievals by 1000x (PACE-MAPP Neural Network)

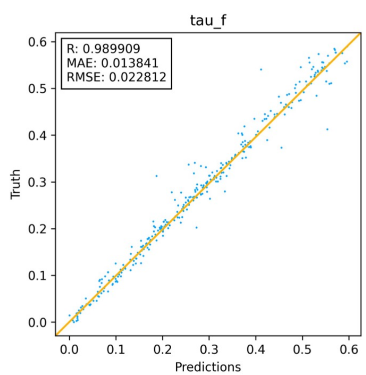
PACE-MAPP is a multi-instrument polarimeter algorithm for SPEXone, HARP2, OCI shortwave infrared channels

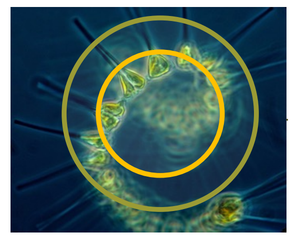




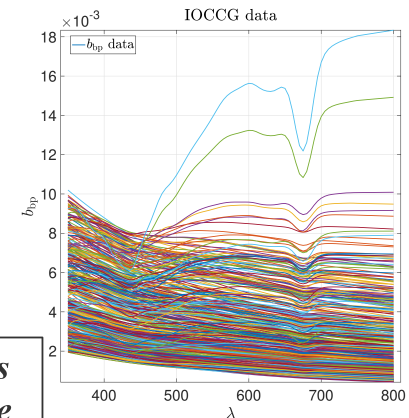
PACE-MAPP uses neural networks to become 1000x faster. 11 channels simulate UV-VIS-NIR at all viewing angles.





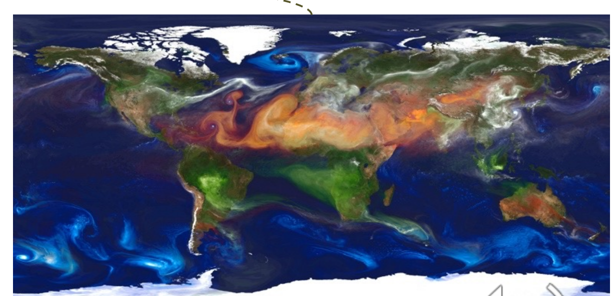


Bio-optical model includes coated particles



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)

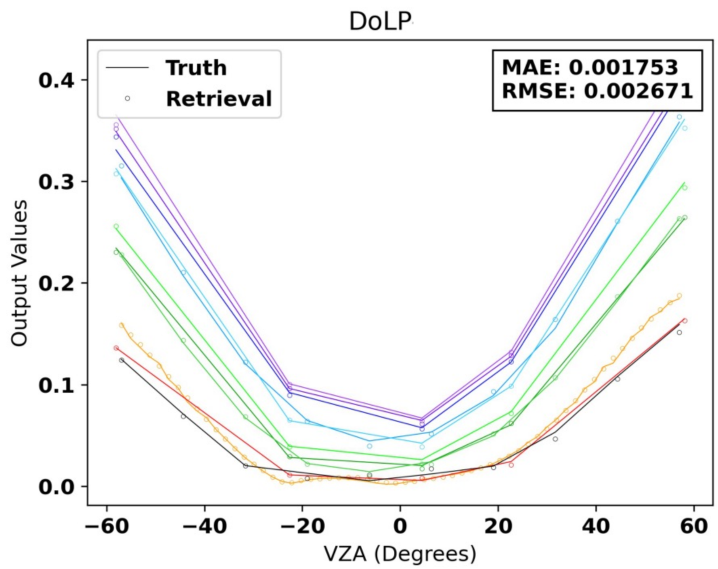
❑ Thin cirrus optical and microphysical properties

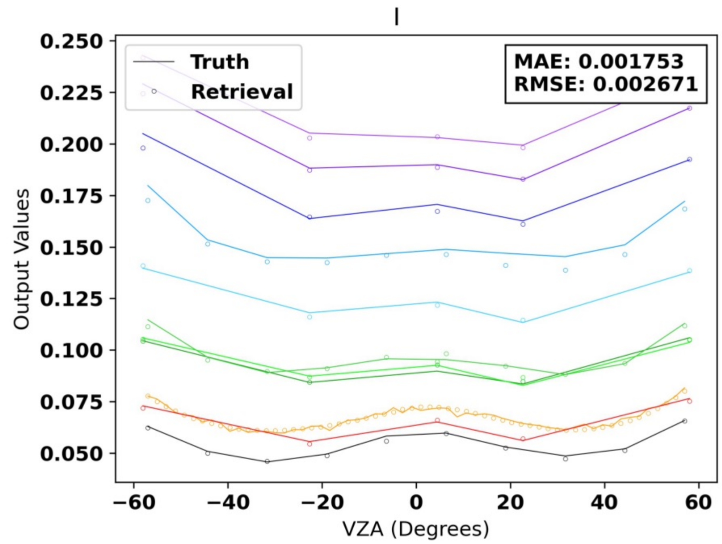
- Thin cirrus optical depth (< 1.0) and effective radius
- Sensitivity to shape and height will be assessed

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-NN





1000x faster than online VRT

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

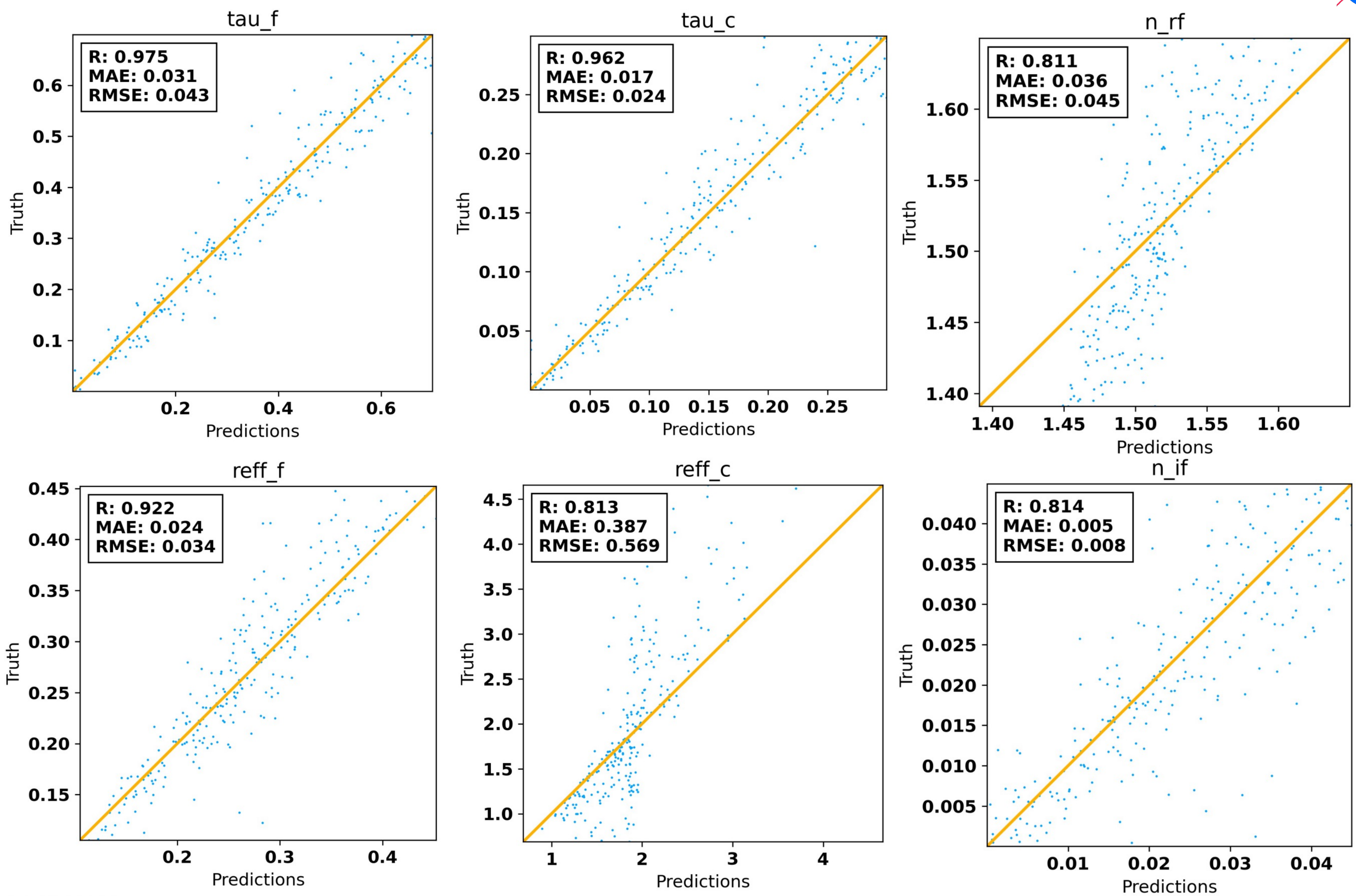
(556, 385, 396, 413, 441, 470, 533, 549, 669, 759, and 873 nm)

All viewing angles

Performance goal for retrievals:

1 second per L1C pixel

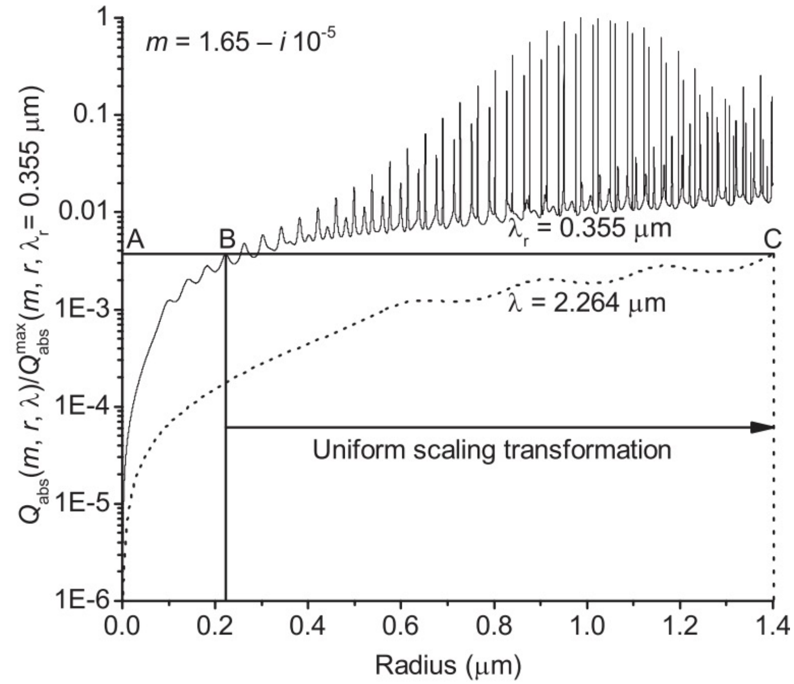
PACE-MAPP-NN


tau_f
R: 0.975
MAE: 0.031
RMSE: 0.043
Truth
Predictions
tau_c
R: 0.962
MAE: 0.017
RMSE: 0.024
Truth
Predictions
n_rf
R: 0.811
MAE: 0.036
RMSE: 0.045
Truth
Predictions
reff_f
R: 0.922
MAE: 0.024
RMSE: 0.034
Truth
Predictions
reff_c
R: 0.813
MAE: 0.387
RMSE: 0.569
Truth
Predictions
n_if
R: 0.814
MAE: 0.005
RMSE: 0.008
Truth
Predictions

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

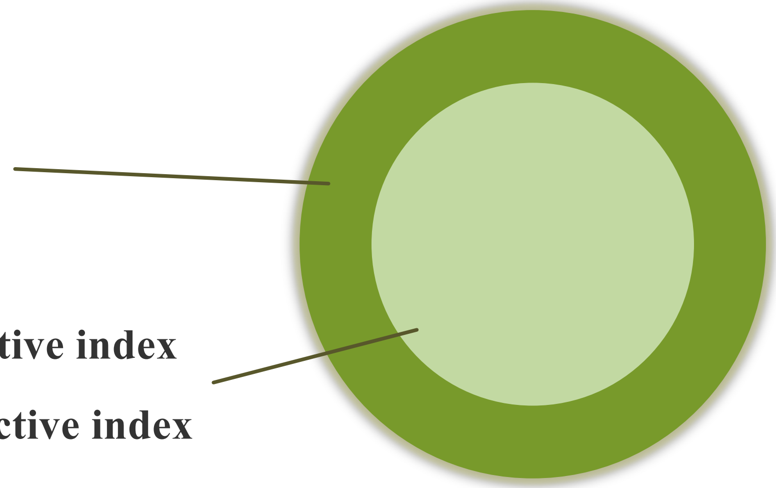


Normalized absorption efficiencies at wavelengths 0.355 and 2.264 μm are related by a uniform scaling transformation which is a type of Euclidean affinity transformation.

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



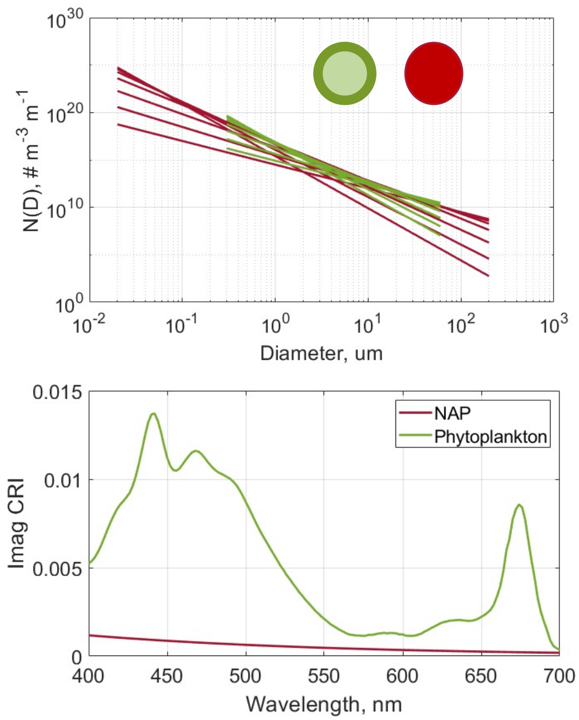
Core-to-shell ratio: 0.85

The Bio-Optical Model

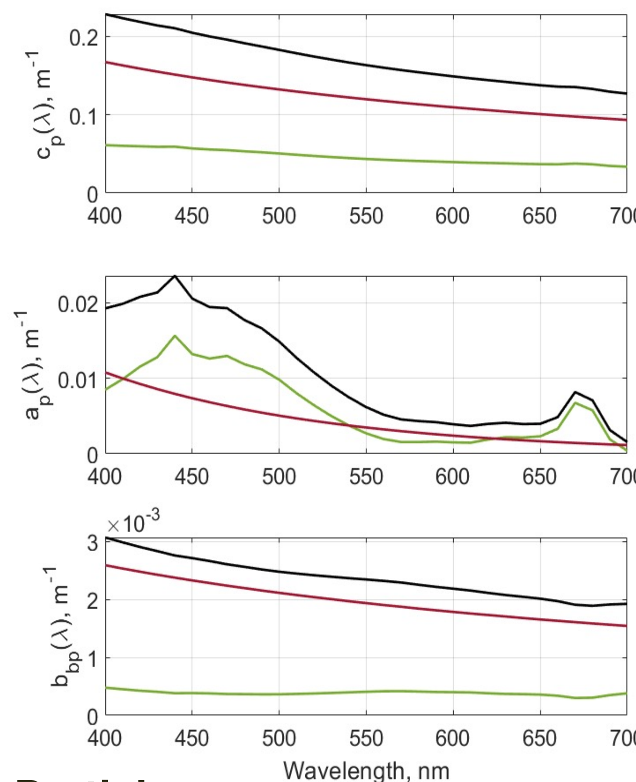
Single Particle Optical Efficiencies

Model Inputs	
Chlorophyll	0.01-10mg m^3
Chl Density	1-10kg m^3
Phyto Shell n	1.05-1.2
NAP n	1.02-1.2
NAP n' slope	0.005-0.02
NAP n' intercept	0.004-0.009
Junge PSD	2.5-6
% Phyto Volume	0.05-0.95

Bulk Particle Optics



Model Outputs

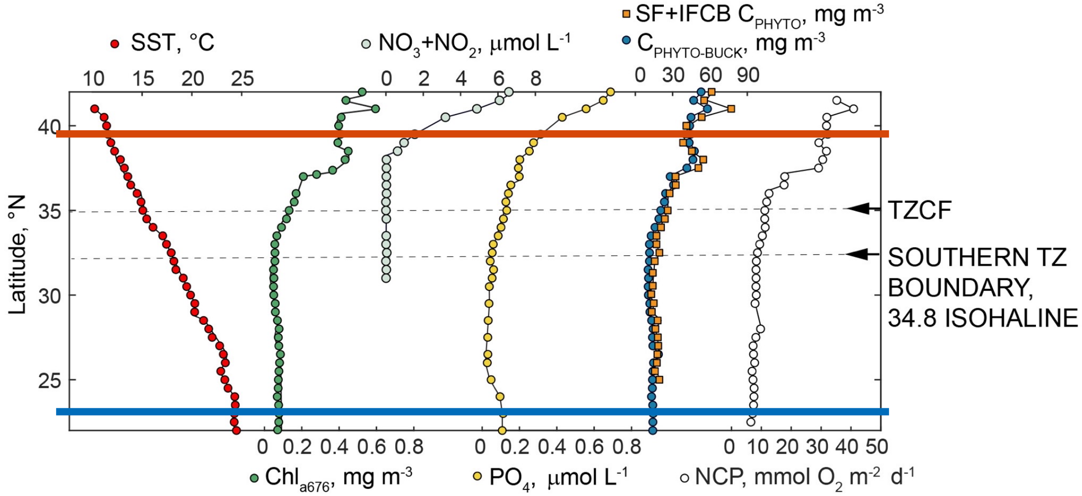


Model Coated Phytoplankton and Homogenous Non-Algal Particles

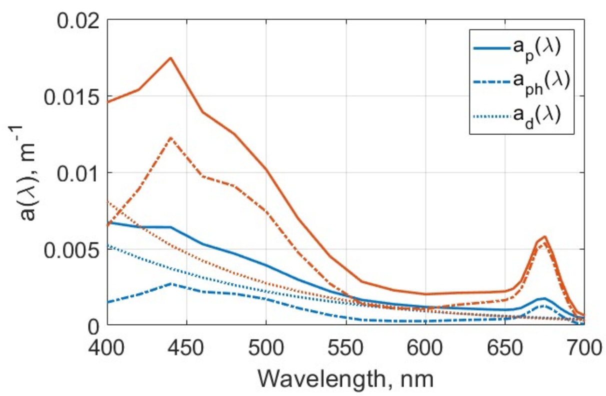
Chl and relative volume concentration scale to bulk particle population

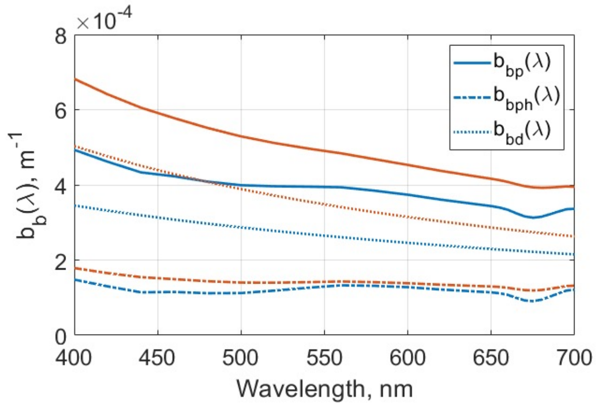
Forward model realistic biological ranges for Phyto coated spheres and NAP spheres

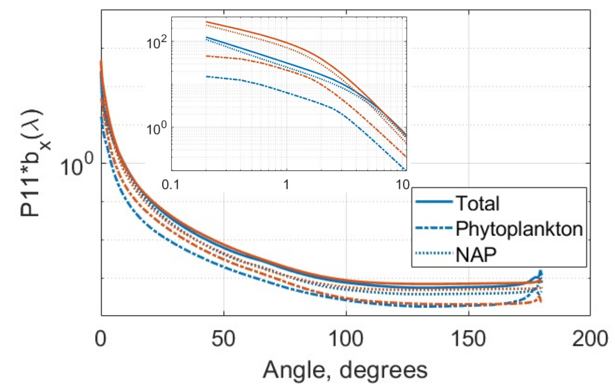
In situ BOM Test



Model Inputs:
Chl
ap(lambda)
cp(lambda)
bbp(700)







Retrievals show expected results just from total particle optics

Scattering processes still dominated by NAP

Future work will improve the Imaginary CRI for the phytoplankton shell

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

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

- 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 we care about thin cirrus

- **The ubiquity of cirrus clouds**
  - CAMP2Ex NASA field campaign conducted near the Philippines
  - For all CAMP2Ex flights, 61% of the time cirrus is present above the aircraft (NOTE: this is a particularly cirrus prone region)
- **Impacts on aerosol radiative forcing**
  - Thorsen et al., (2020) demonstrated 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 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 cirrus impact our goal to retrieve AOD and SSA to ~0.02?

CAMP2Ex above-aircraft cirrus 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

- **Submitting paperwork to include PACE-MAPP in the PACE data processing system**
  - Aerosol, Hydrosol, Coated Hydrosol LUTs can be made available to community
- **Also preparing papers for PACE-MAPP, Coated Hydrosol LUT, Bio-Optical Model using Coated and Uncoated Hydrosols with in-situ data, and thin cirrus detection**
  - PACE-MAPP paper
  - Three additional PACE-MAPP-related AGU Fall 2021 presentations
    - LUT structure: https://agu.confex.com/agu/fm21/meetingapp.cgi/Paper/914286
    - Thin cirrus: https://agu.confex.com/agu/fm21/meetingapp.cgi/Paper/928558
    - VDISORT: https://agu.confex.com/agu/fm21/meetingapp.cgi/Paper/851920
- **Questions, suggestions, collaborators welcome!**