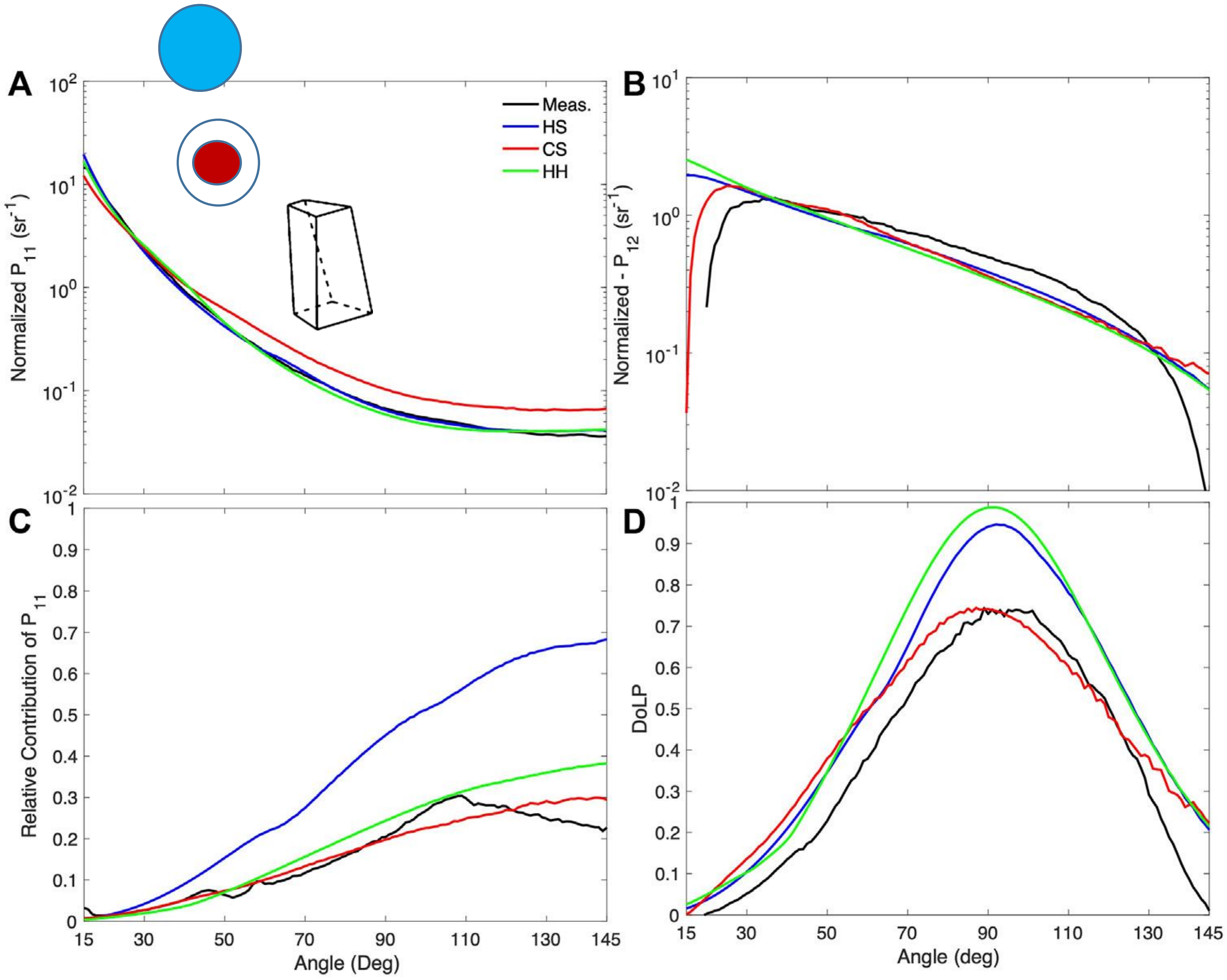
Using Multi-angle Polarimetry to Derive χ factor and Improve BRDF Correction for PACE's OCI (Xiaodong Zhang and Deric Gray)

- A key element in our proposed study was to develop multiple- and hyper-spectral Mueller Matrix database
- The LISST-VSF instrument measures S11 and S12,and a noisy S22
- The MVSM instrument measures S11 at eight wavelengths
- Few instruments are available to measure spectral Mueller matrix of oceanic waters and no database exist
- We developed an inverse-forward modelling approach to develop a spectral Muellller matrix database using the measured VSFs (i.e., S11).

The concept of inverse-forward modeling

- A particle model representing diverse particle species, including both living and nonliving matter
- Use S11 measurements at one wavelength to constrain the particle model to find the optimal combination of different particle species that best reproduce the measured S11 (Inverse)
- Use the constrained particle model to compute the entire Mueller Matrix spectrally (Forward)

Particle model

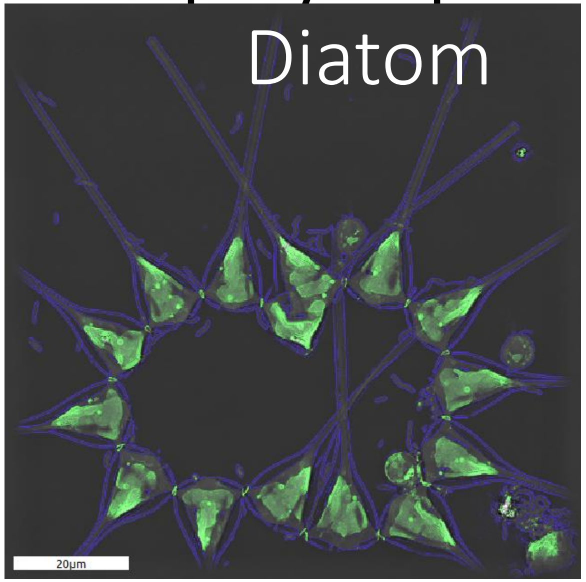


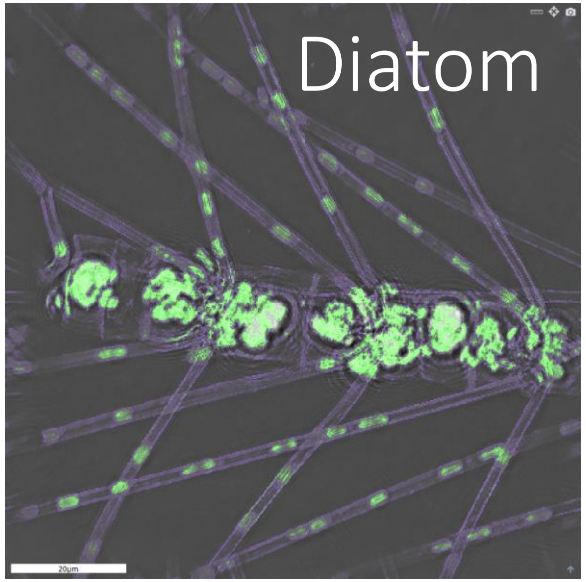
Hu et al. (2022) doi: 10.3389/frsen.2022.925654

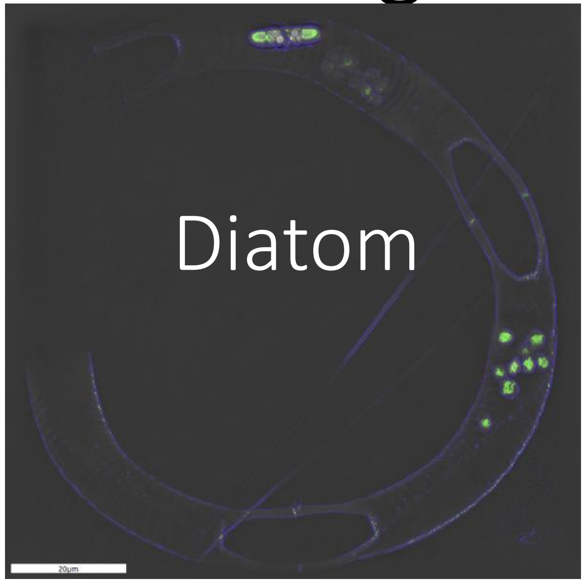
Using the concurrently measured particle size distributions, we simulated light scattering using three particle shapes: spherical, coated spheres, and hexahedra to account for shapes and internal structure of particles.

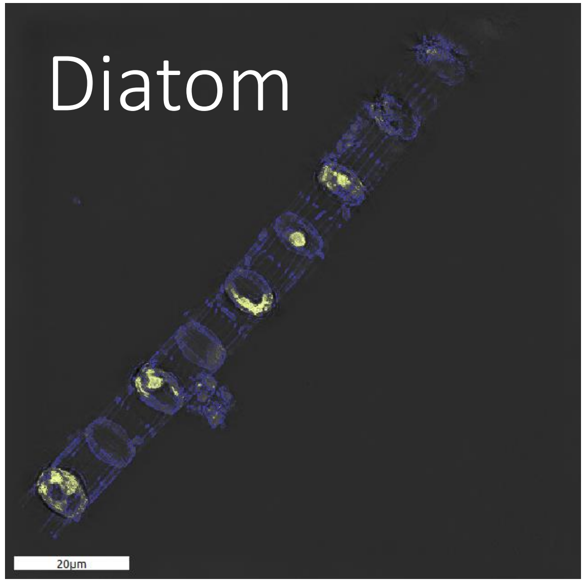
- Each of the particle shape can reproduce some of the scattering features
- But none can reproduce all
- Choose a mixture of particle shapes
  - Coated spheres to represent phytoplankton particles to account for cellular structure
  - Hexahedra to represent other type of particles to account for non-spherical nature of oceanic particles

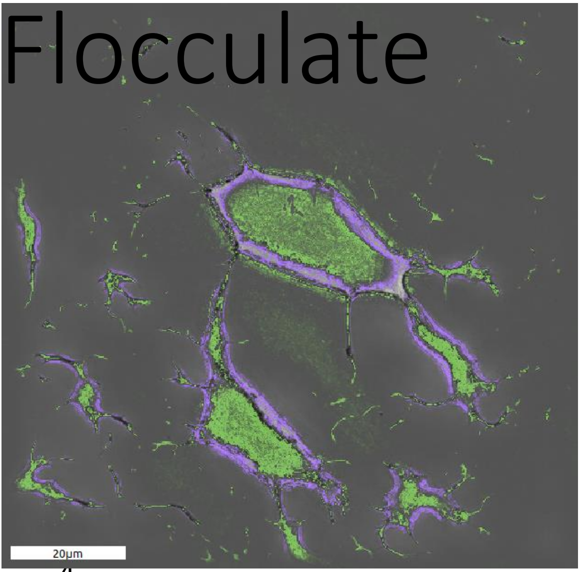
Mapping 3D refractive index distribution in phytoplankton cells using a rotating interferometer

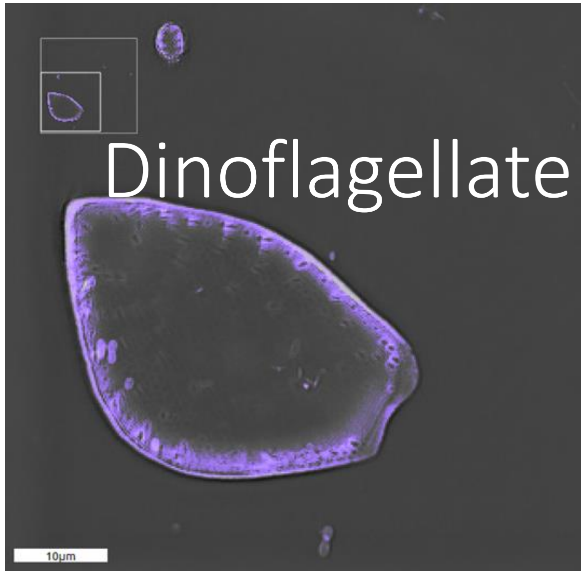


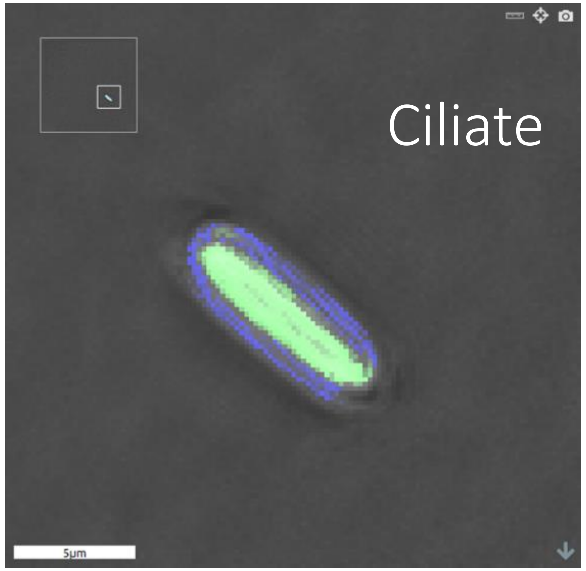




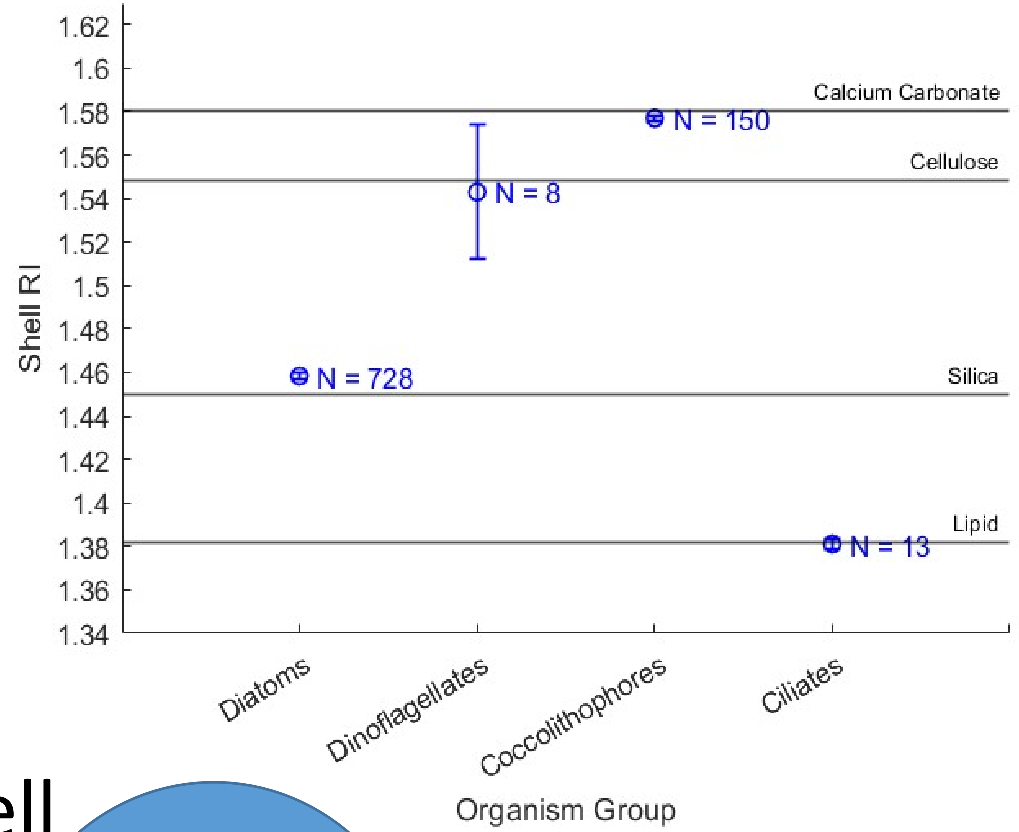


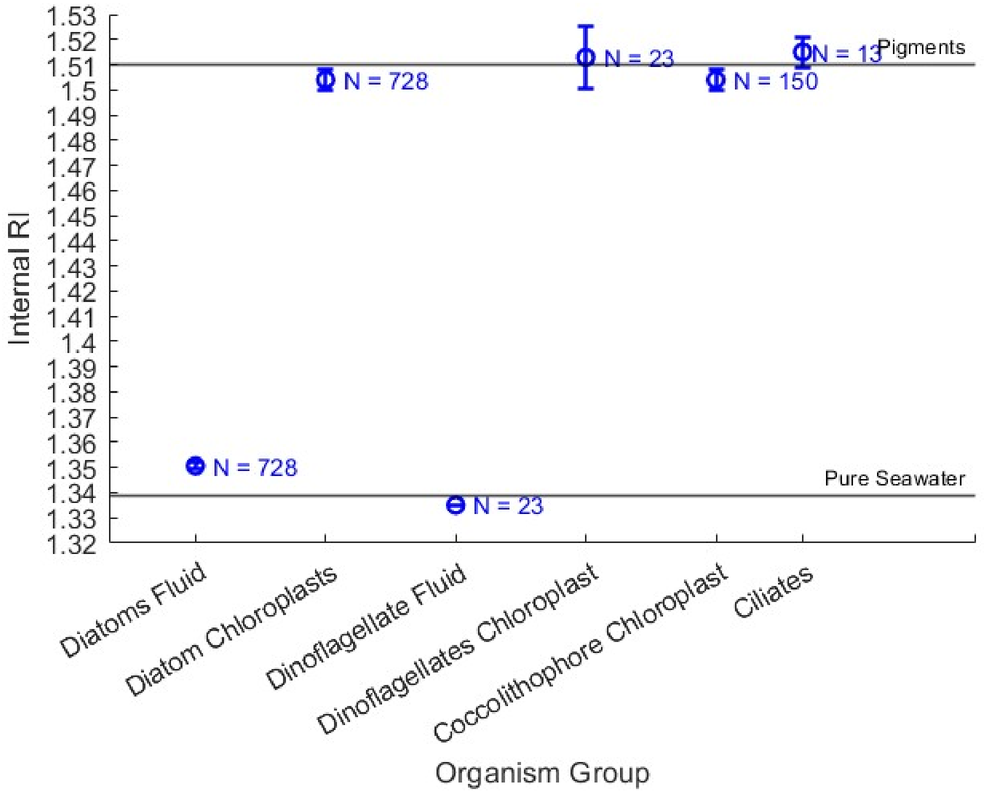


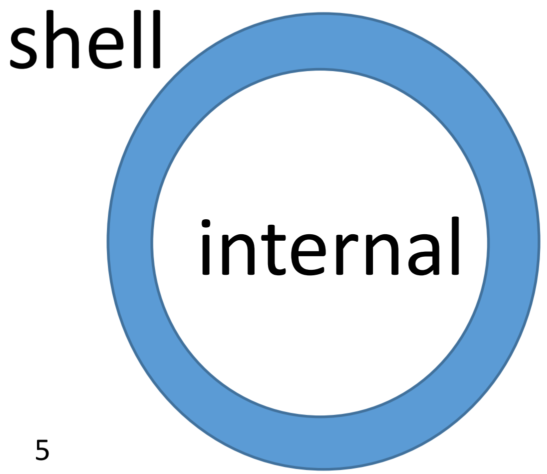




Refractive Indices of phytoplankton cells at 515 nm

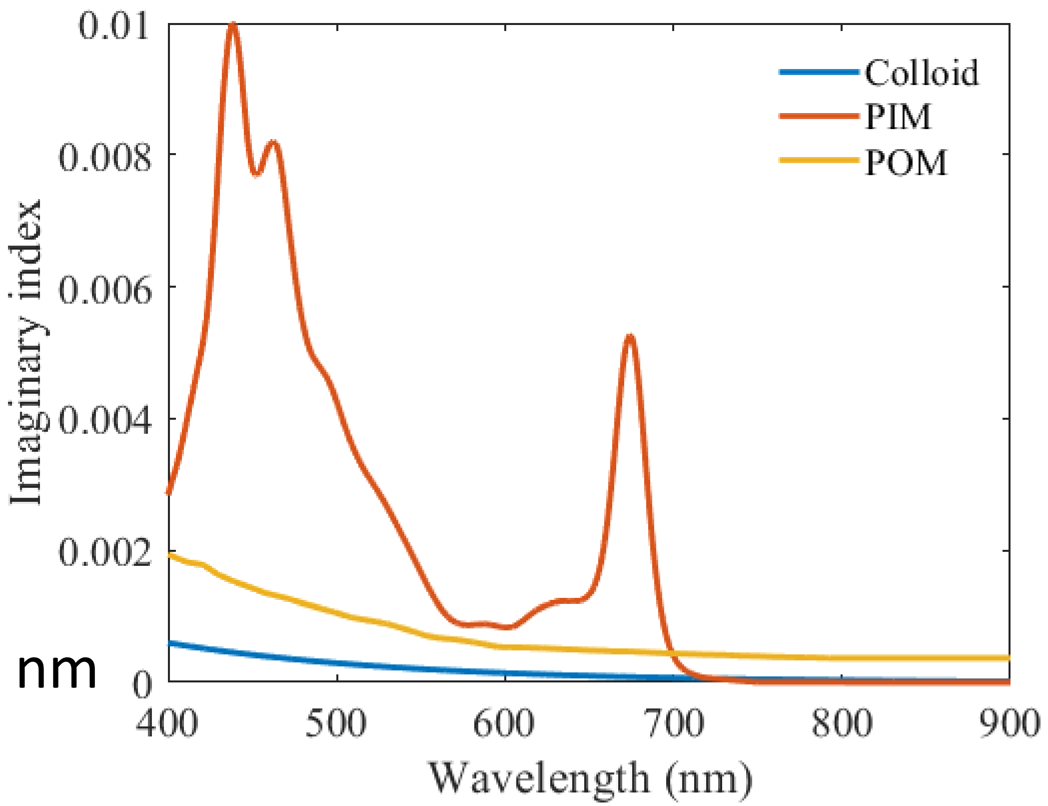






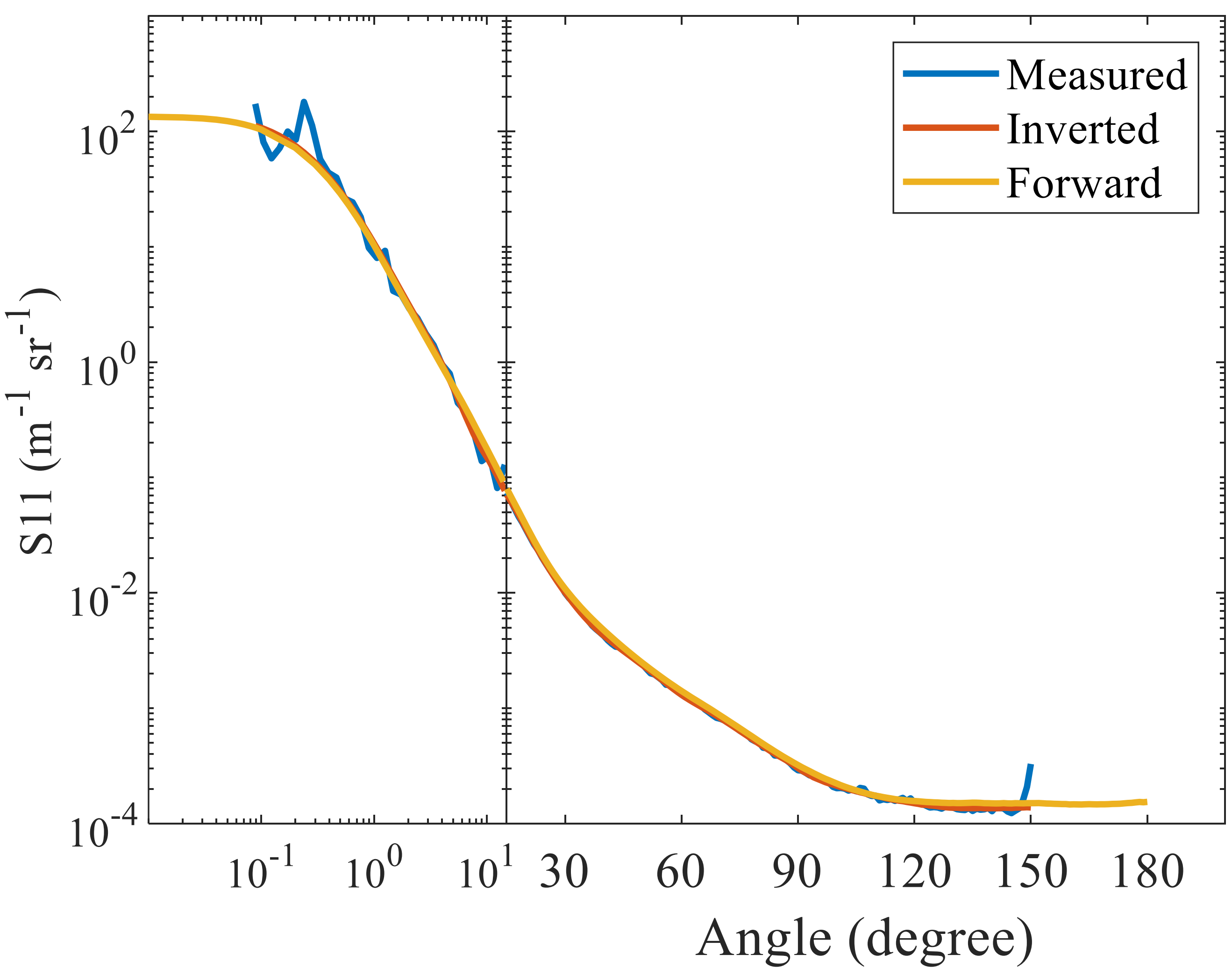
Structure	Refractive Index	Relative Index
Silica Membrane	1.458	1.10
Calcium Carbonate Scales	1.577	1.19
Cellulose	1.545	1.16
Phospholipid Membrane	1.381	1.04
Chloroplast	1.504	1.13

Details of particle model



- Particle shape
  - Coated spheres for phytoplankton cells
  - Hexahedra for other particles
- Refractive indices
  - Measured indices for phytoplankton cells at 515 nm
  - 1.02 – 1.20 for other particles at 517 nm
  - Imaginary part of index (i.e., absorption) was obtained from Stramski & Wozniak (2005) for colloidal particles, Bernard et al. (2009) for particulate organic matter, and Patterson et al. (1977) for particulate inorganic matter
  - Account for anomalous dispersion for real part of the index
- Size distribution
  - Log-normal size distribution for each particle species

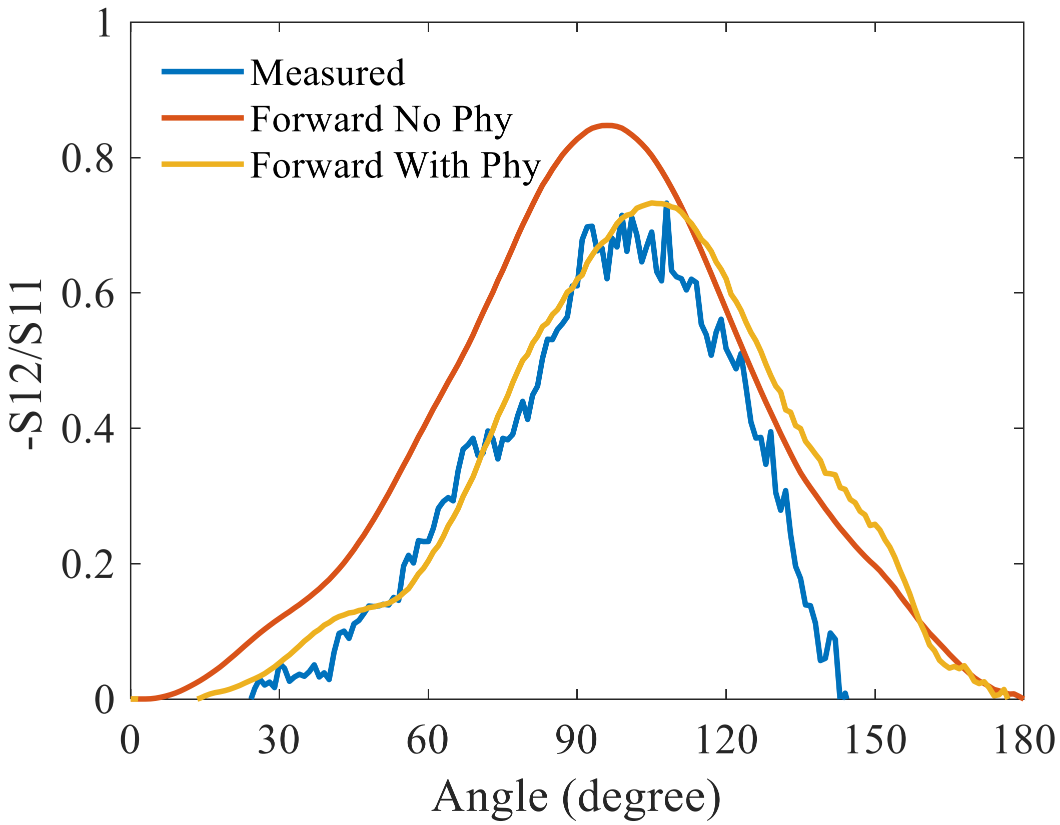
Validation of inverse-forward modeling result

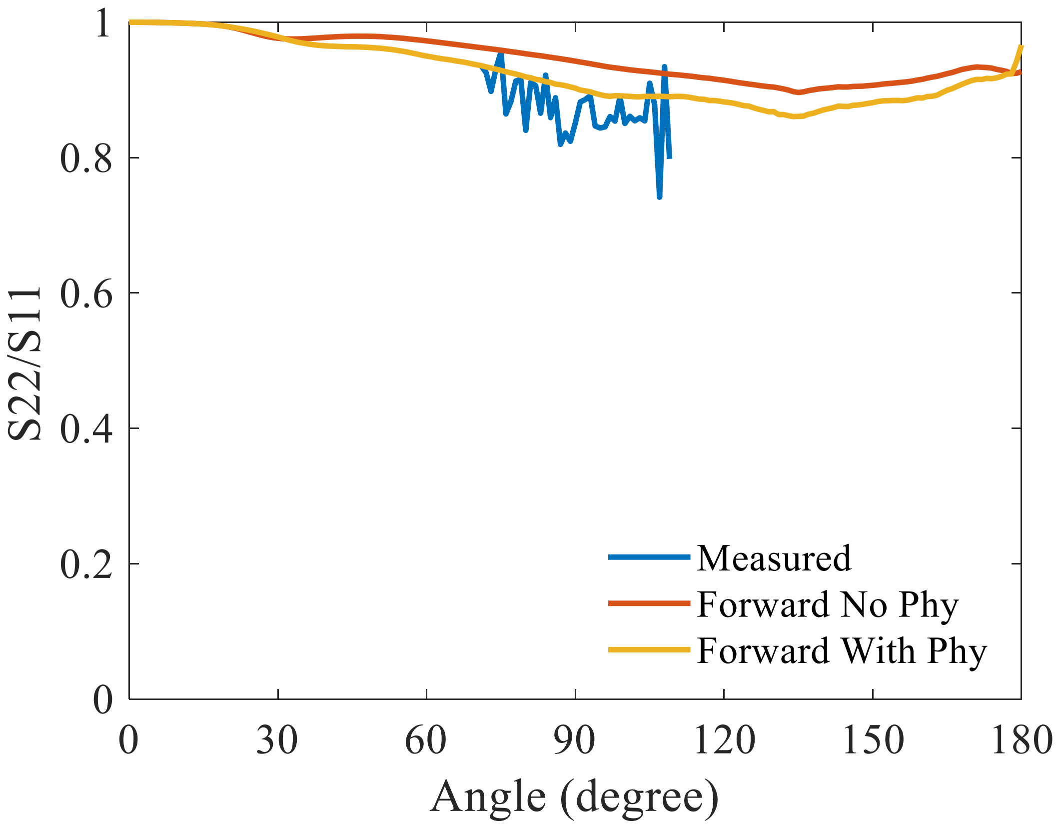


Conclusion:

1. Both inverse and forward modeling can reproduce the observed VSF or S11 component.
2. This is not surprising because S11 was used to constrain the particle models. However, it does demonstrate the inverse-forward model is performing as expected.

Validation of inverse-forward modeling result using LISST-VSF's S12 and S22 data

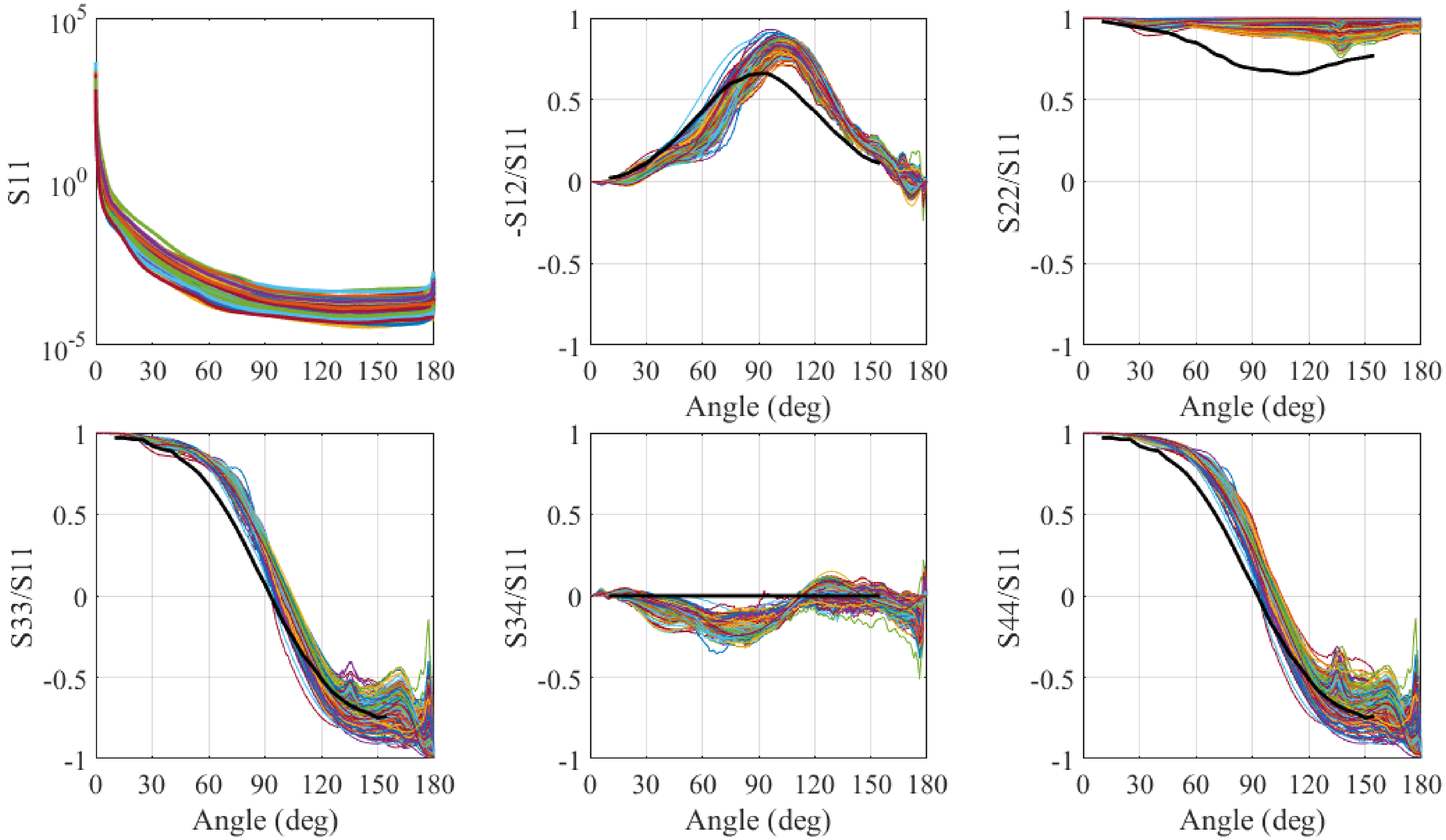




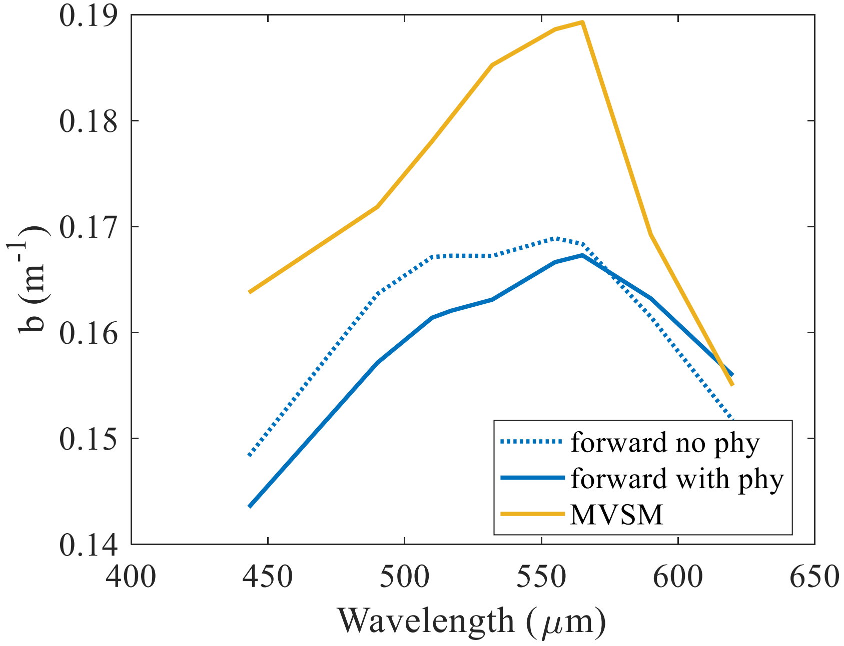
Conclusion:

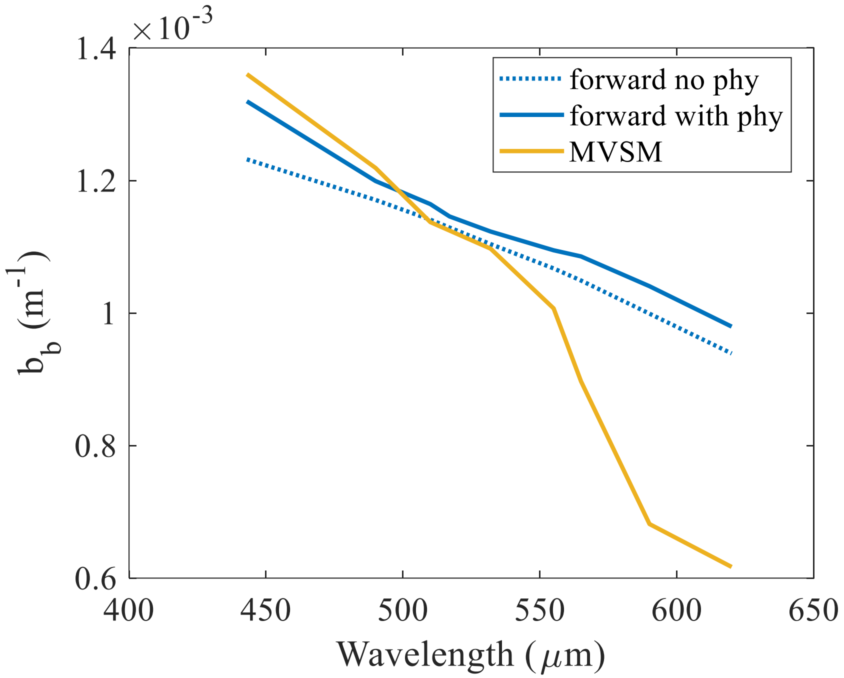
1. Our forward model can simulate P12 and P22 reasonably well.
2. Better agreement with the measured values of S12 and S22 was found when including phytoplankton particles in the model, indicating the importance of cellular structure in regulating polarized light scattering in the ocean.

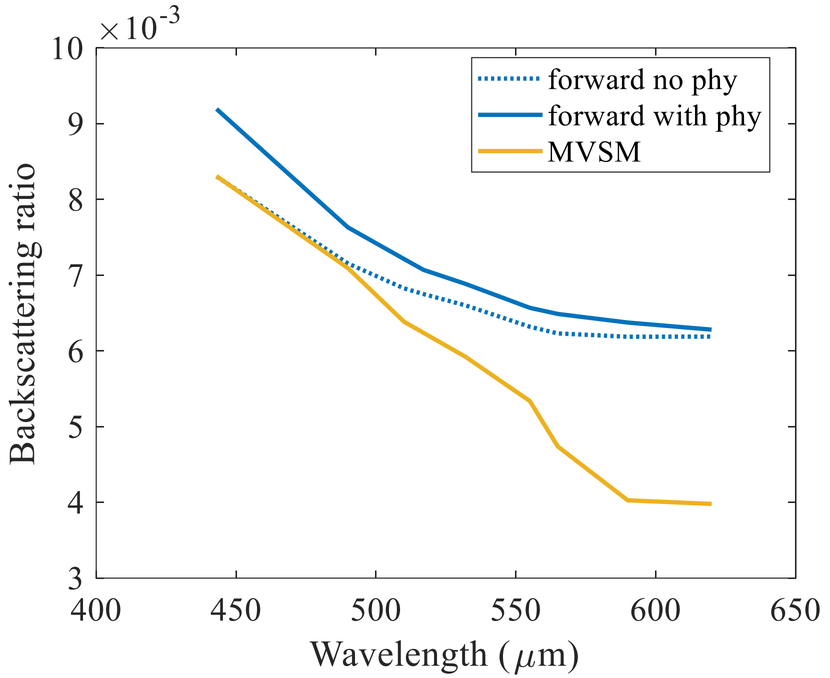
Comparison with Voss data in North Pacific Ocean



Comparison with MVSM measuring VSFs at 8 wavelength



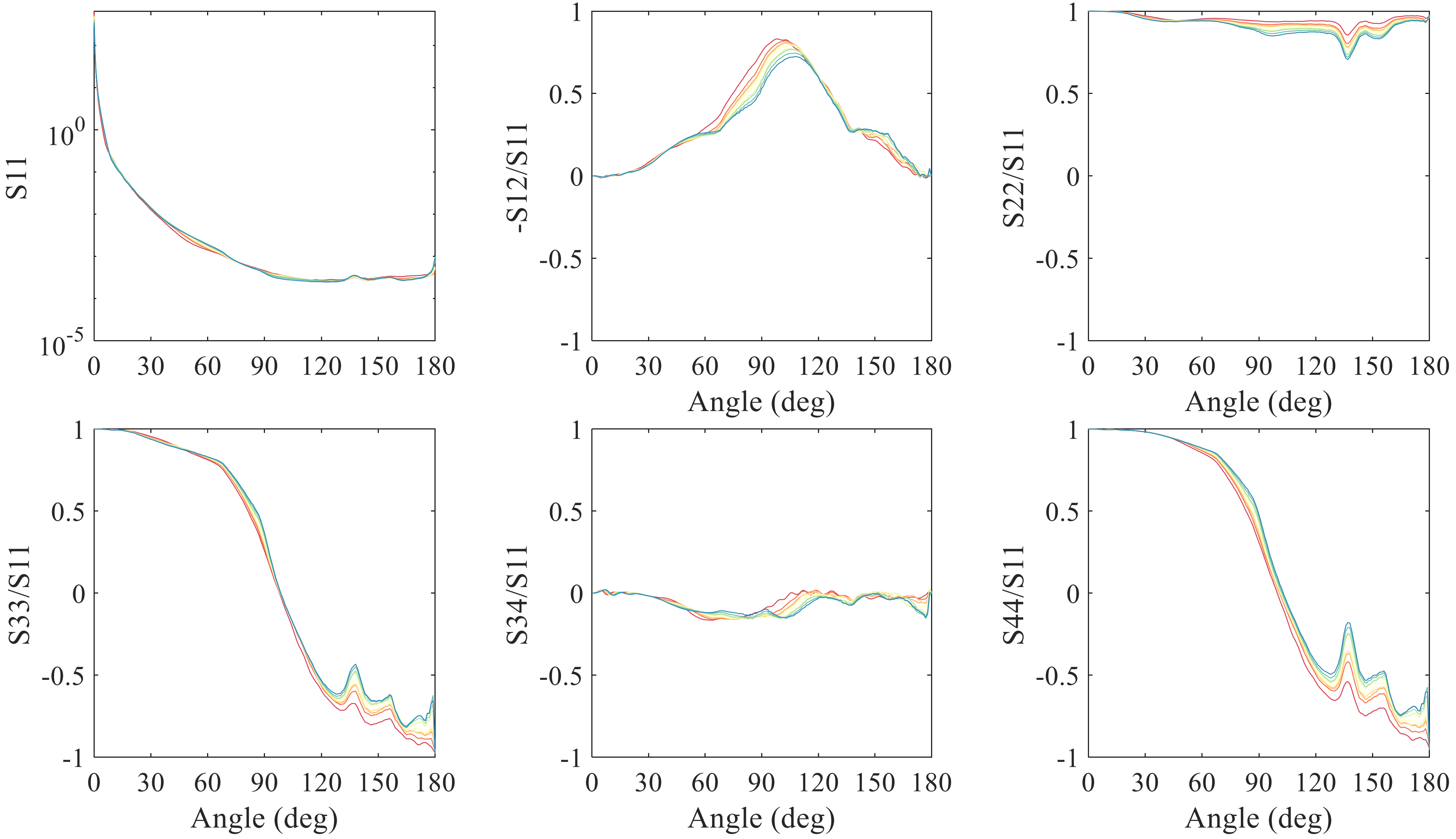




Conclusion:

1. Our forward model can reproduce the spectral variation of both forward and backward scattering reasonably well.
2. Interestingly, where or not including phytoplankton cells did not affect the spectra of scattering very much. This would make sense if we accept that it is mainly those small particles that regulate the spectral variation of scattering.

Spectral variation of Mueller matrix

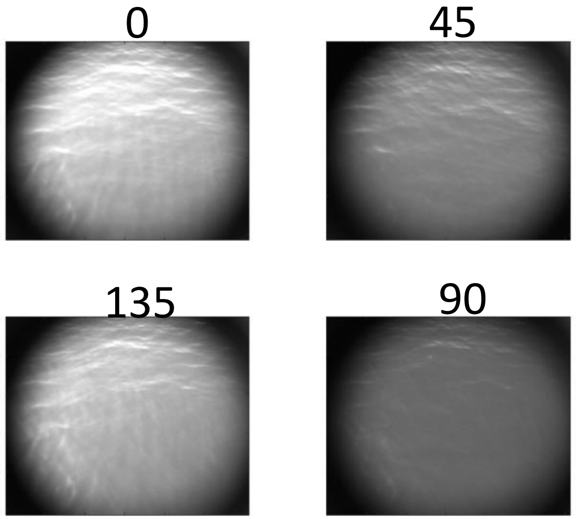


Mississippi Sound Cruise (February 2022)

Cruise stations

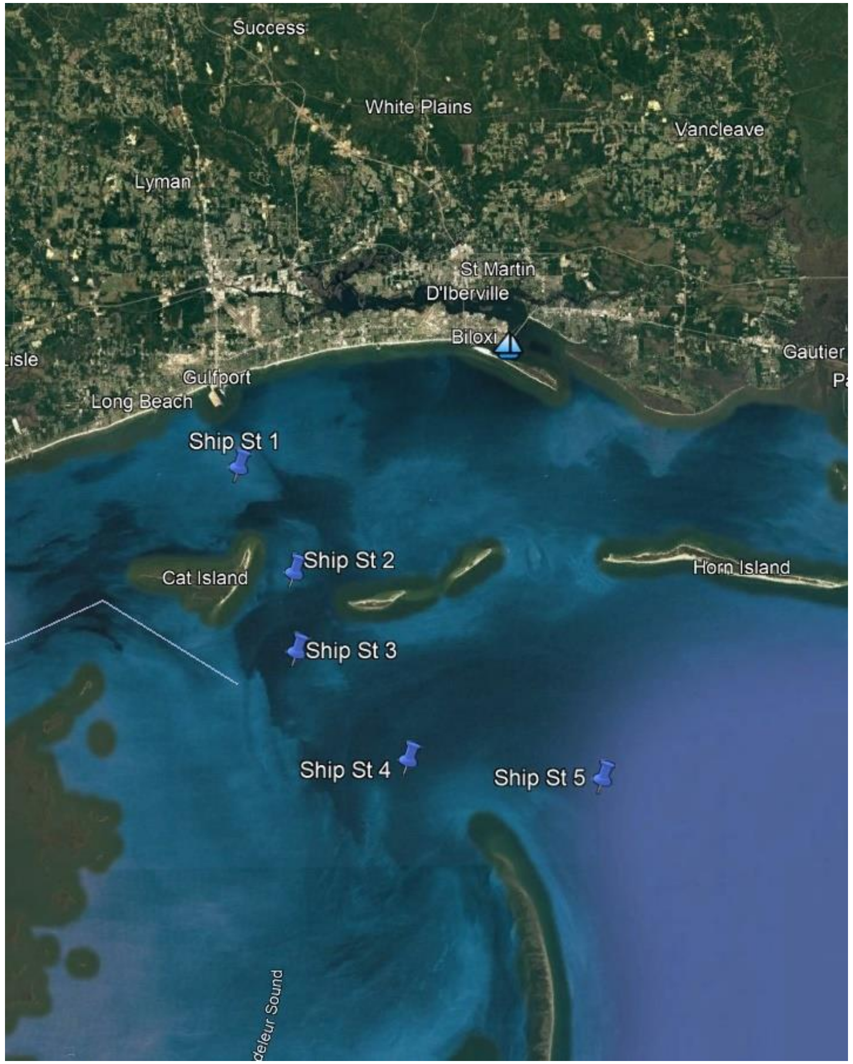
University of Southern Mississippi and NRL

- Linear and Stokes polarimeters
- 3-color sky-viewing fish-eye polarization camera
- Mantis all-sky hyperspectral polarimeter (on land)
- In-water optical properties
- Collected water samples for filtration and fractionation analysis
- Absolutely unique data set



Mississippi Sound Cruise

Cruise stations

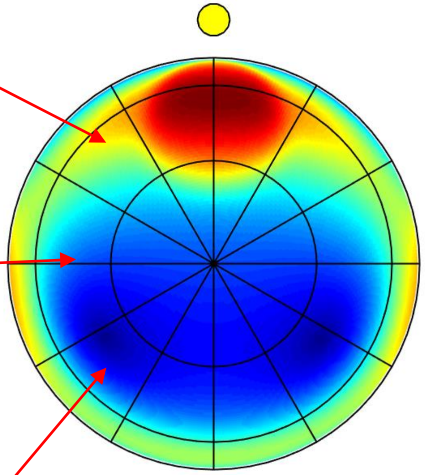


View Angle = 50° from nadir, 0.3 nm sampling interval, 3 nm FWHM

View Azimuth Angle = 45° from sun

View Azimuth Angle = 90°

View Azimuth Angle = 135°



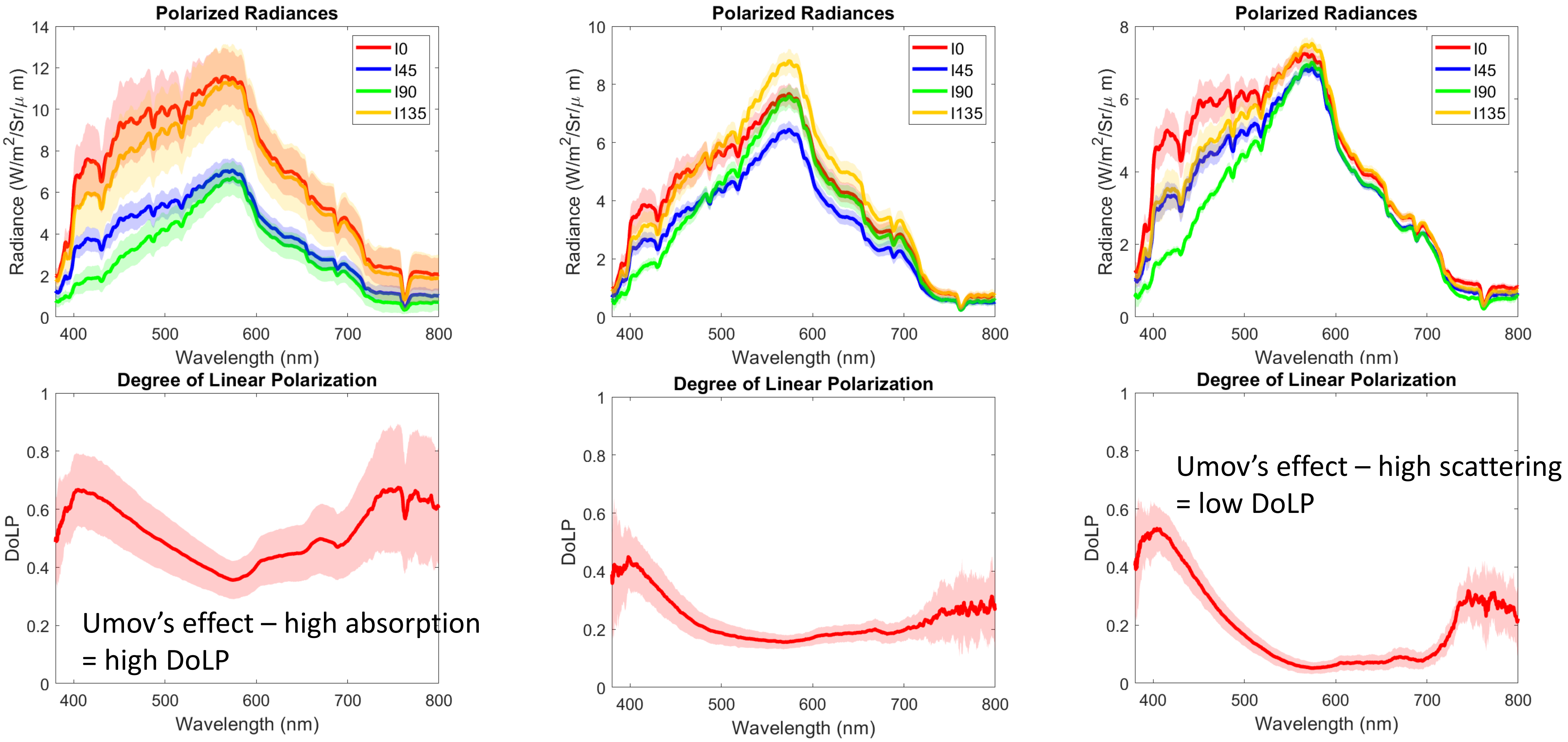
Simulated DoLP with Sun at 47°

Ship 1 – ocean (very turbid water)

View angle =50°

SZA=47°

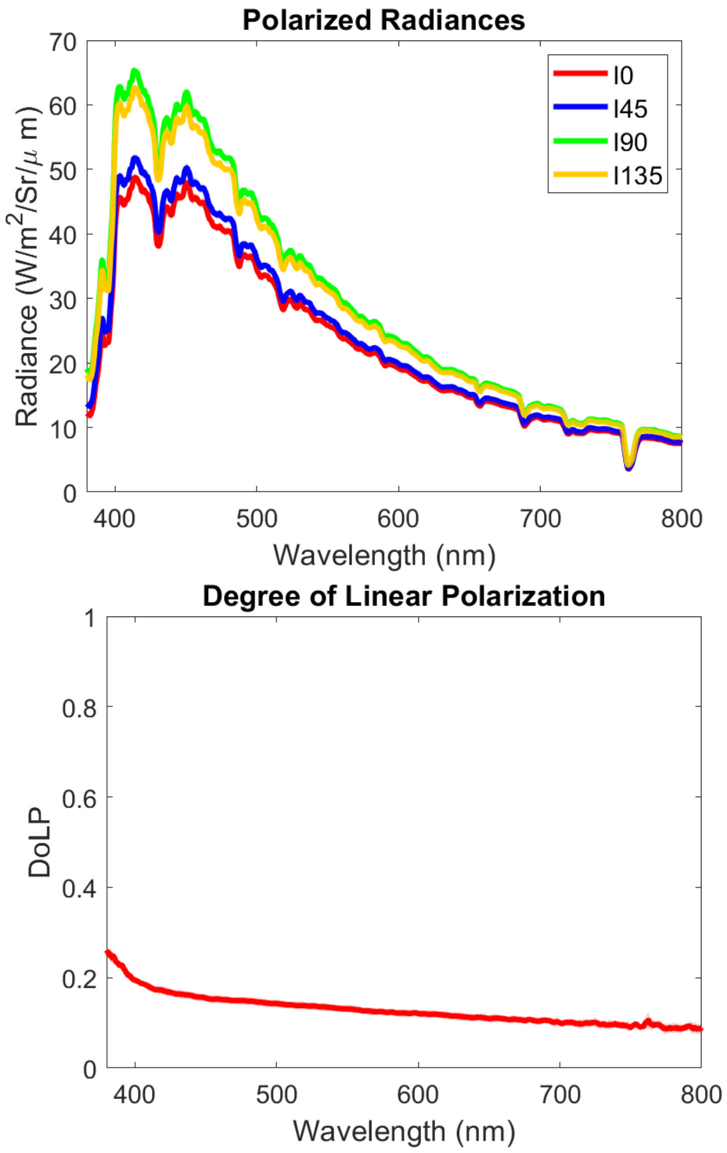
Delta 45 | Delta 90 | Delta 135



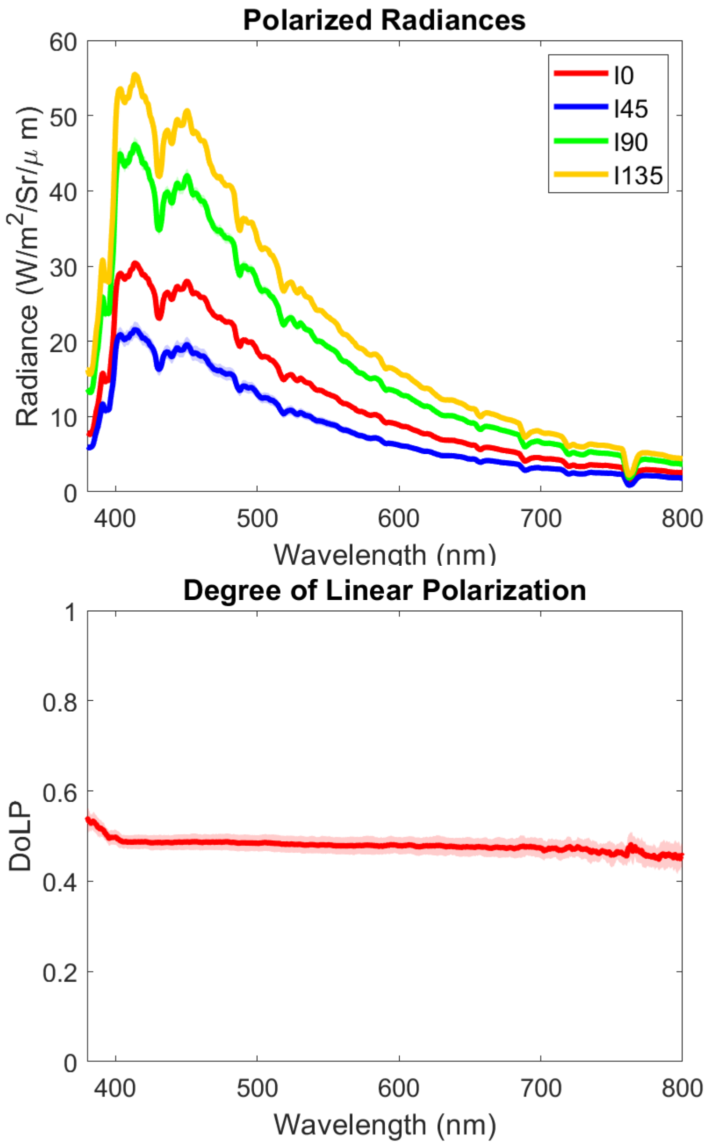
Ship 1 - sky

SZA=47°

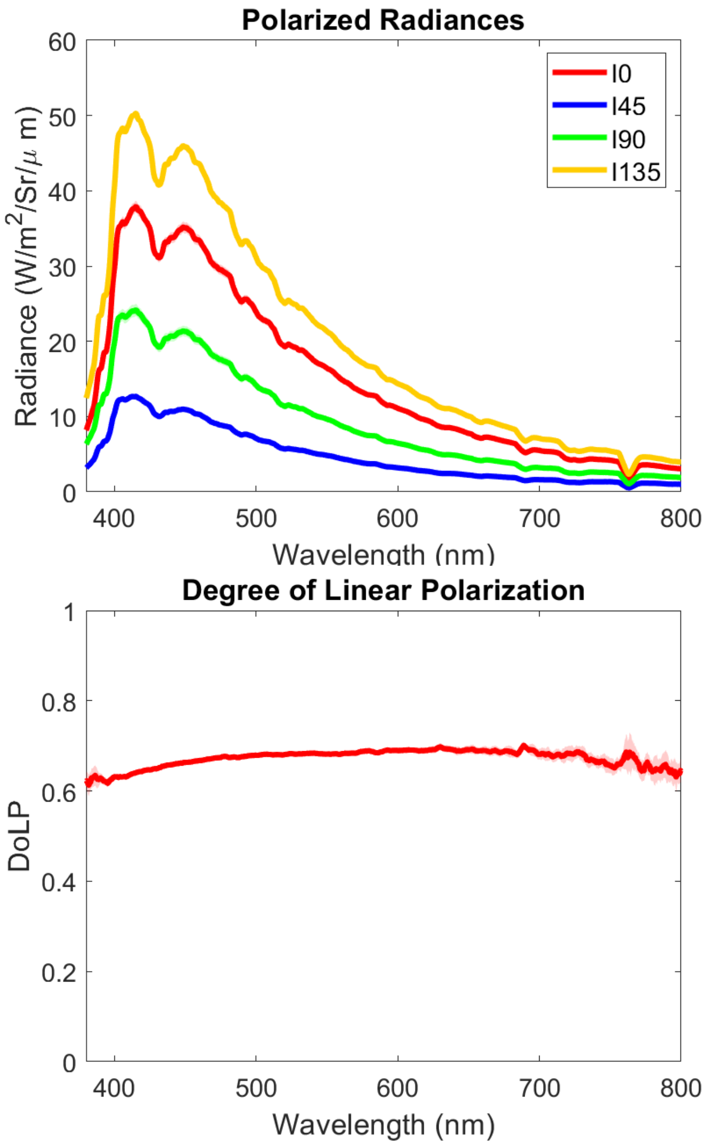
Delta 45



Delta 90



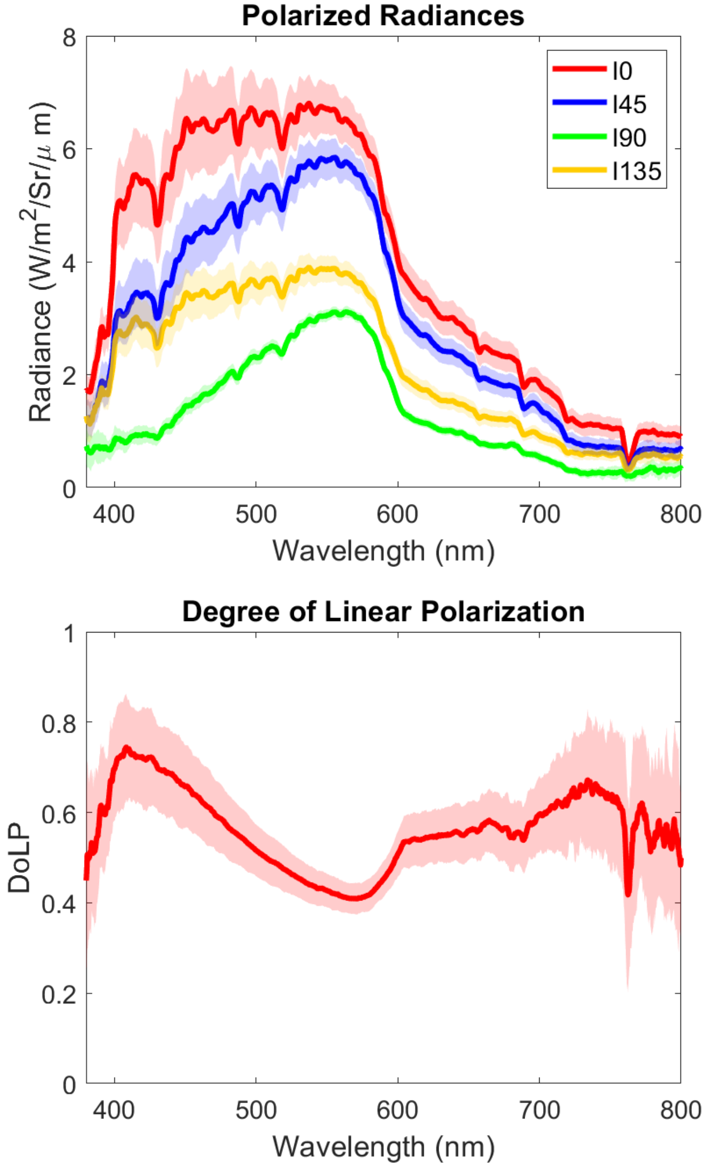
Delta 135



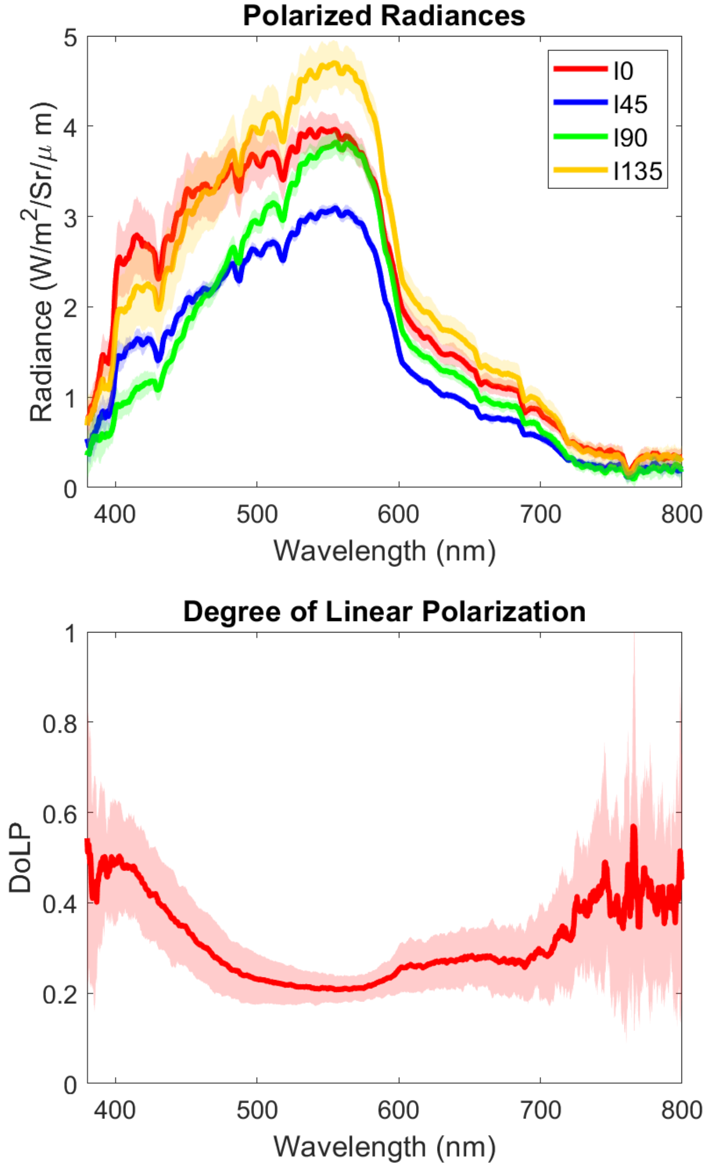
Ship 5 – ocean (slightly less turbid water)

SZA=58º

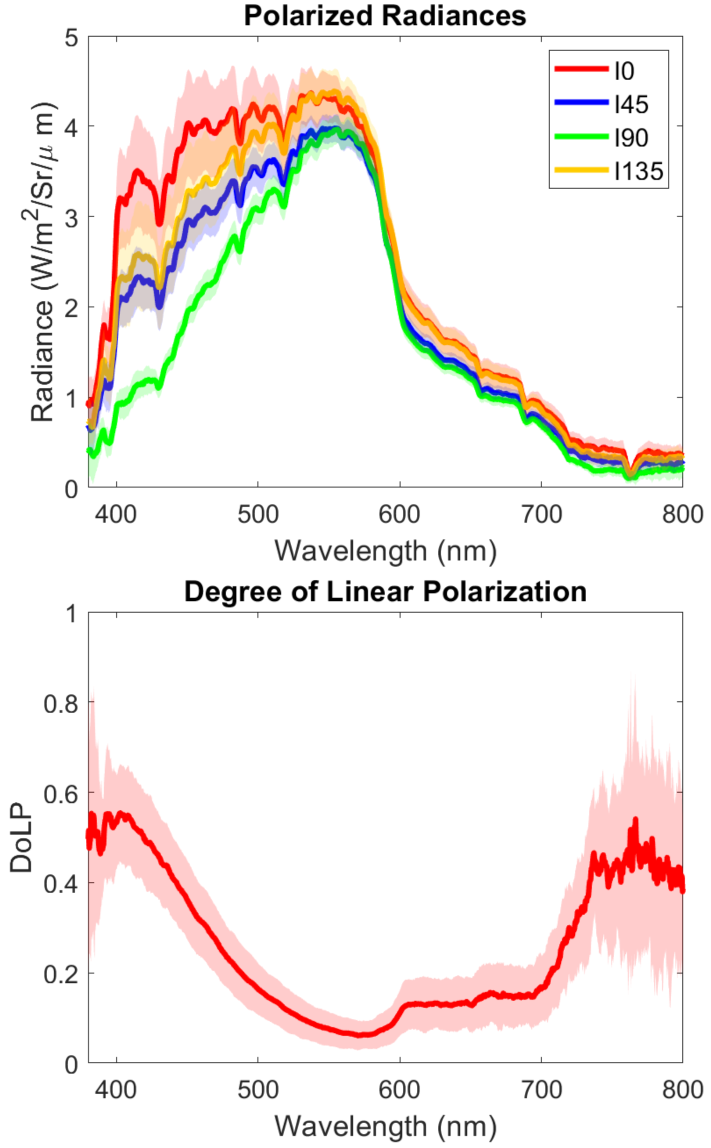
Delta 45



Delta 90

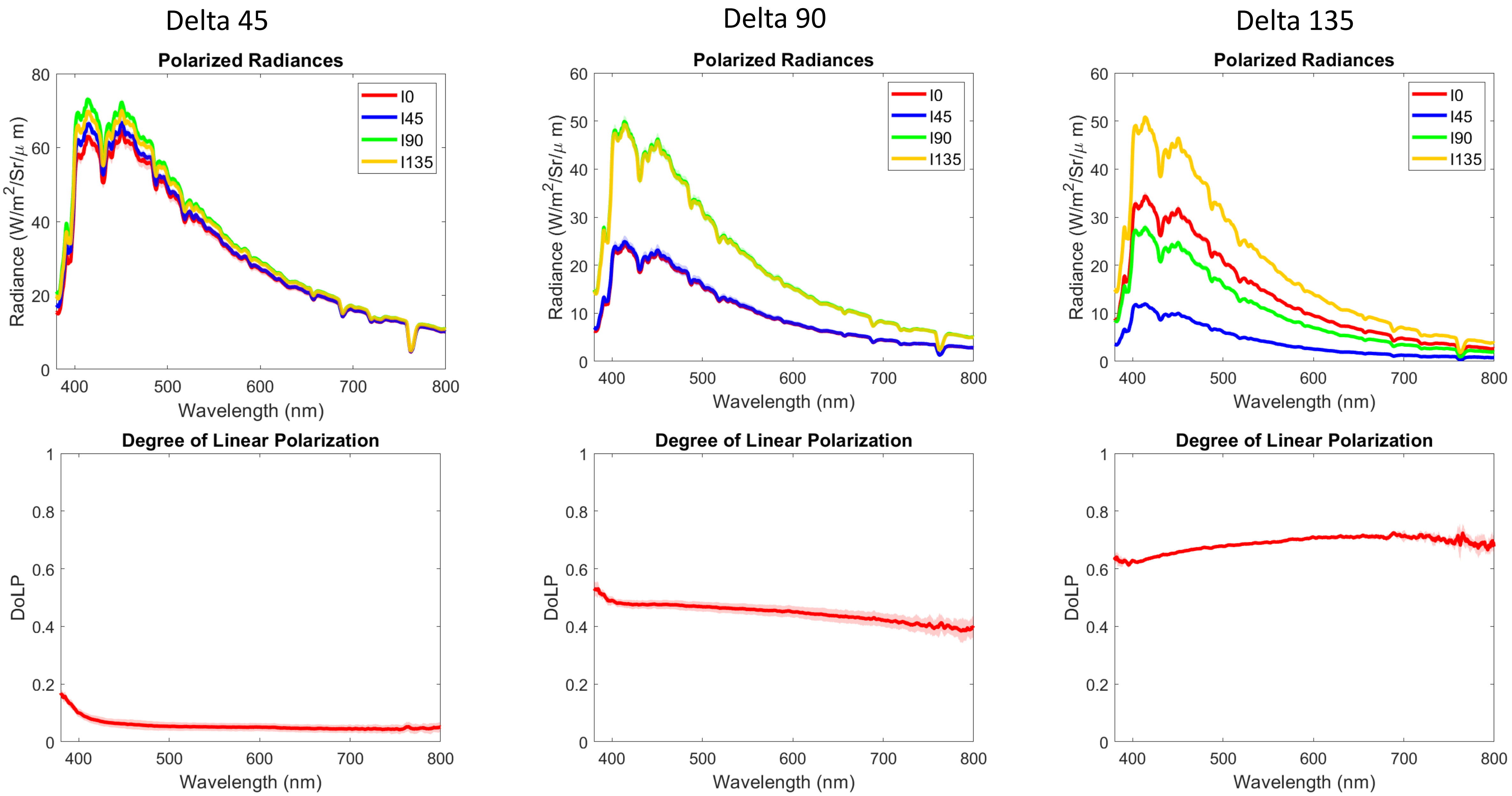


Delta 135

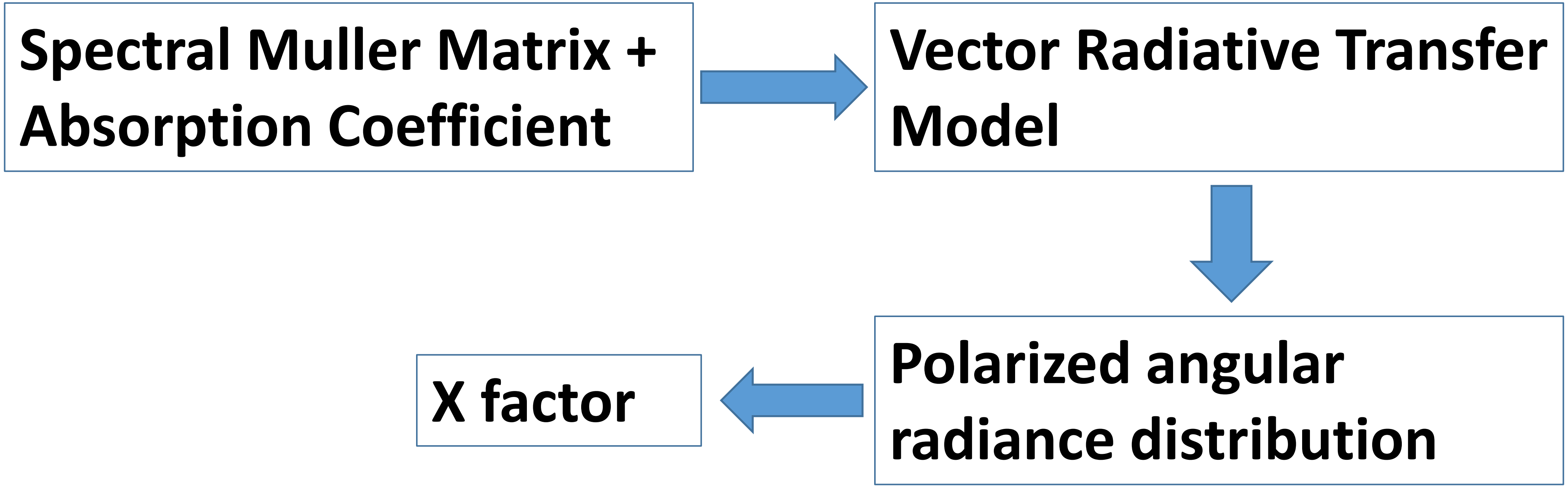


Ship 5 - sky

SZA=58º



Future Work


Spectral Muller Matrix + Absorption Coefficient
Vector Radiative Transfer Model
Polarized angular radiance distribution
X factor