Coupled Ocean-Atmosphere Radiative Transfer (COART) Model Simulations

The COART model (Du & Lee, 2014) was used to produce a synthetic dataset as described in detail in the following pages. Output from these runs included above surface remote sensing reflectance (R_{rs}; sr^{-1}), and top of atmosphere (TOA) reflectance (sr^{-1}). Note that this parameter is given by:

$$TOA(\lambda) = \frac{L_{TOA}(\lambda)}{E_{dTOA}(\lambda)}$$

where L_{TOA} is top of atmosphere radiance (W m^{-2} nm^{-2} sr^{-1}) and E_{dTOA} is top of atmosphere downwelling irradiance (W m^{-2} nm^{-1}) at wavelength λ (nm).

Additional model configuration information is as follows:

- Inelastic processes (Raman, chlorophyll, coloured dissolved organic matter (CDOM) fluorescence) were NOT included.
- The effect of absorbing gases was simulated in the 'absgas' files. These gases were H_2O, O_3, NO_2, O_2, N_2, CO_2, CH_4, N_2O, and CO.
- Sea surface conditions were simulated by setting windspeed to 5 ms^{-1}.

Hydrolight Model Simulations

These runs were performed using only Hydrolight (Mobley & Sundman, 2013), which generated above surface remote sensing reflectance (R_{rs}; sr^{-1}).

- Inelastic processes (Raman, chlorophyll, coloured dissolved organic matter (CDOM) fluorescence) were NOT included.
- Sea surface conditions were simulated by setting windspeed to 5 ms^{-1}.
- Absorbing gases included in Hydrolight's built in sky model were H_2O, O_2, and O_3.

Both COART and Hydrolight model runs were constrained with a set of modelled inherent optical properties based on *in situ* data mined from NASA's SeaBASS repository (https://seabass.gsfc.nasa.gov/), using a similar approach to that employed in IOCCG Report No. 5 (IOCCG, 2006).

Parameters and Symbols

Name	Description	Units
a_{tot}	Total absorption coefficient	m^{-1}
a_{ph}	Phytoplankton absorption coefficient	m^{-1}
a_g	CDOM absorption coefficient	m^{-1}
a_d	Detrital absorption coefficient	m^{-1}
b_{btot}	Total backscattering coefficient	m^{-1}
b_{bp}	Particulate backscattering coefficient	m^{-1}
b_{bdm}	Detrital matter backscattering coefficient	m^{-1}

References

Du, K.P., & Lee, Z.P. (2014). Remote-sensing reflectance from above-surface measurements: a revisit based on a coupled ocean-atmosphere model. In, *Ocean Optics XXII*. Portland, Maine, USA.

IOCCG (2006). Remote Sensing of Inherent Optical Properties: Fundamentals, Tests of Algorithms, and Applications. Lee, Z.-P. (ed.), Reports of the International Ocean-Colour Coordinating Group, No. 5, IOCCG, Dartmouth, Canada.

Mobley, C. D. and L. K. Sundman (2013). Hydrolight 5.2 Ecolight 5.2 Technical Documentation. Bellevue, Sequoia Scientific, Inc.

Synthetic hyperspectral TOA dataset for PACE

Objectives:

Using coupled ocean-atmosphere model to create a free-of-measurement-error hyperspectral (350-800 nm, 5 nm resolution) top-of-atmosphere radiance for algorithm test and evaluation

General rules for water properties:

1. Representative to commonly encountered waters
2. Consistent with up-to-date knowledge

Coupled ocean-atmosphere radiative transfer model (COART)

Implement a more realistic skylight model (e.g., wavelength dependent) to simulate sky radiance; Hydrolight for radiance simulation in water.

General rules:

1. **Highly reliable physical models for atmosphere**
2. **Thoroughly validated atmospheric radiative transfer solver, e.g., DISORT**
3. **Fortran source code available**

Approach:

Integrate SBDART (Ricchizzi 1998) with Hydrolight through iterative approach. Replace RADTRAN for irradiance, and replace the model of Harrison and Coombes (1988) for distribution of sky radiance.

A. W. Harrison and C. A. Coombes, "An opaque cloud cover model of sky short wavelength radiance," Sol. Energy **41**(4), 387–392 (1988).

Santa Barbara DISORT Atmospheric Radiative Transfer (SBDART)

Computes plane-parallel radiative transfer in clear and cloudy conditions within the earth's atmosphere.

All important processes that affect the ultraviolet, visible, and infrared radiation fields are included.

The code is a marriage of a sophisticated discrete ordinate radiative transfer module, low-resolution atmospheric transmission models, and Mie scattering results for light scattering by water droplets and ice crystals.

Ricchiazzi, P., S. Yang, C. Gautier, and D. Sowle (1998), SBDART: A research and teaching software tool for plane-parallel radiative transfer in the Earth's atmosphere, *Bulletin of the American Meteorological Society, 79, 2101-2114.*

Code considerations of COART:

- ✓ Revise the Hydrolight (HL) code as little as possible.
- ✓ No change for the HL input file format to protect the existing running cases.
- ✓ User configurable. A user can still use the original RANTRAN-X and H&C models.
- ✓ Fit into the current framework (e.g., batch mode capability, makefile compile mode, high performance fortran compiler)
- ✓ Compatible with the Hydrolight code style, and use common blocks to communicate

Approach for synthesizing water IOPs for COART:

$$b_b(\lambda) = b_{bw}(\lambda) + b_{b-ph}(\lambda) + b_{b-dm}(\lambda)$$

$$a(\lambda) = a_w(\lambda) + a_{ph}(\lambda) + a_y(\lambda) + a_d(\lambda)$$

synthesized

constants

From measurements

and,

$$a_y(\lambda) = a_y(440)e^{-S_y(\lambda-440)}; \quad a_y(440) = p_1 \times a_{ph}(440)$$

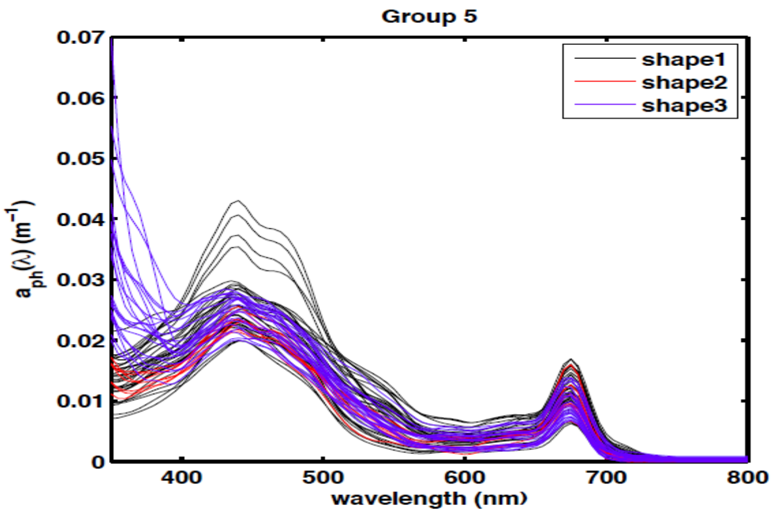
$$a_d(\lambda) = a_d(440)e^{-S_d(\lambda-440)}; \quad a_d(440) = p_2 \times a_{ph}(440)$$

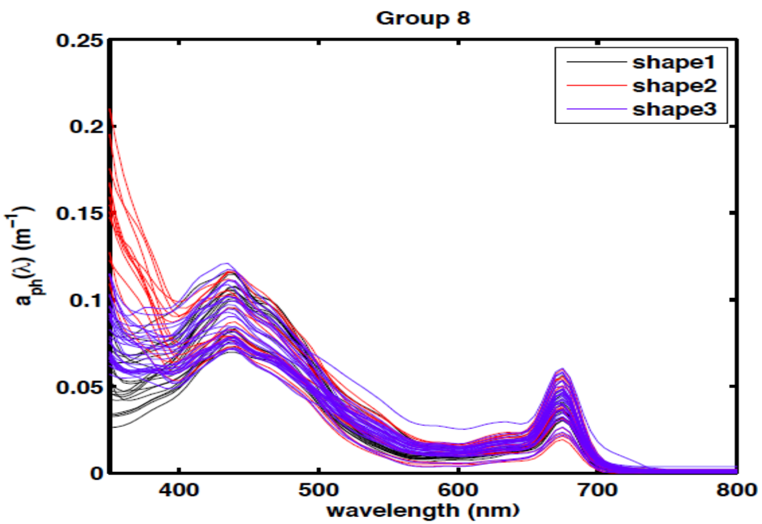
$$b_{b-ph}(\lambda) = 0.01 \times \left(c_{ph}(\lambda) - a_{ph}(\lambda)\right) \qquad c_{ph}(\lambda) = p_3 \times \left(\frac{440}{\lambda}\right)^{p_4}$$

$$b_{b-dm}(\lambda) = p_5 \times \left(\frac{440}{\lambda}\right)^{p_6}$$

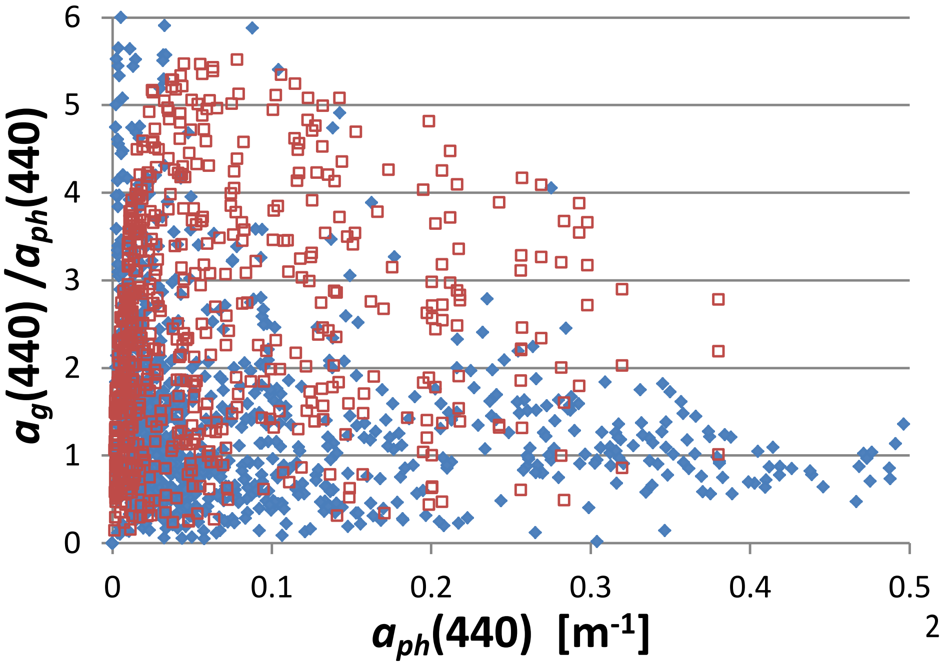
- a_{ph} spectrum is treated as a free variable, to maintain the spectral variations of this important IOP
- Values of p_1, S_y, p_2, S_d, p_3, p_4, p_5, and p_6 are determined randomly, with constraints, for each $a_{ph}(440)$, as in IOCCG Report #5.

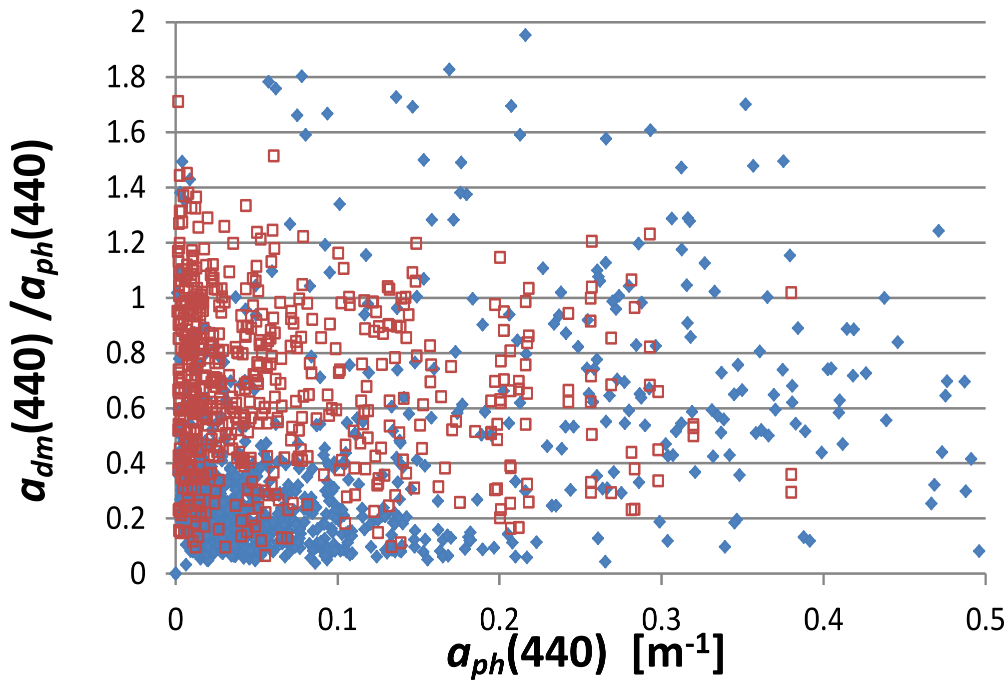
- *720* a_{ph} spectra were selected from >4000 SeaBASS spectra
- Divided into 12 "classes" (separated by $a_{ph}(440)$ value), and ~3 groups within each "class", with examples showing below

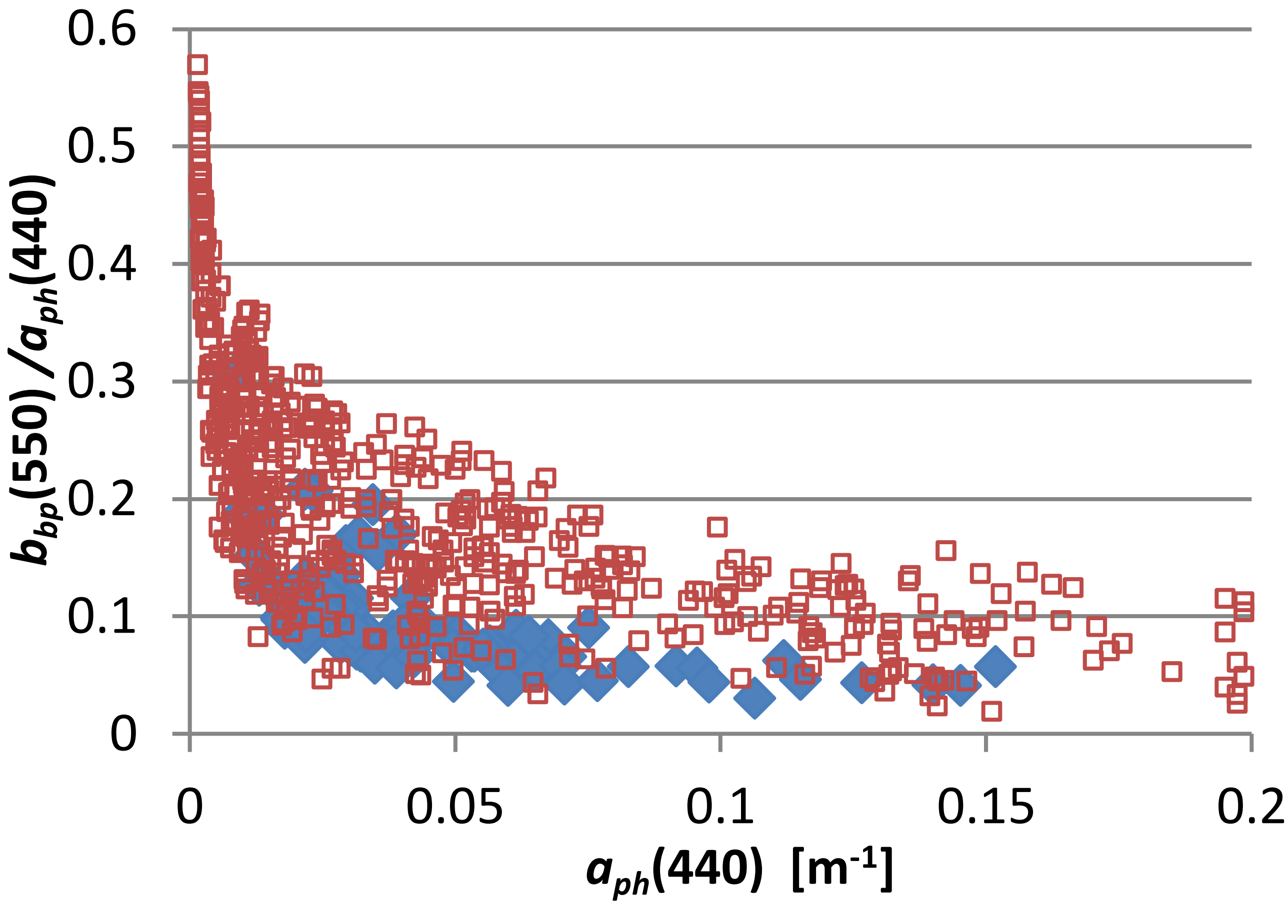




Comparison between synthetic (red square) and measured (blue dots) data.






0.6
0.5
0.4
0.3
0.2
0.1
0
$b_{bp}(550)/a_{ph}(440)$
0
0.05
0.1
0.15
0.2
$a_{ph}(440)$ [m^{-1}]