Validation of a “Universal” Particulate Scattering Phase Function with Measurements and Simulation of Upwelling Hemispherical Radiance Distributions

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Abstract

Predicting the angular variation of the water leaving radiance (BRDF) for ocean color remote sensing requires knowledge of the inherent optical properties of the water, in particular the absorption coefficient ($a$) and volume scattering function ($VSF$). Remote sensing can be used to estimate both $a$ and the total backscattering coefficient, $b$. Variability in particulate constituents leads to large variability in space and time of the VSF, especially in coastal (case 2) waters. Sullivan and Twaddle (2009), however, found remarkable consistency in the shape of the backward portion of VSFs measured in situ around the world. This is a promising development, because a “universal” particulate scattering phase function would simplify radiative transfer modeling in coastal waters. In particular combining this phase function with $a$ and $b$ from the remote sensing signal would enable the BRDF to be determined. The purpose of this work was to test the applicability of the Sullivan and Twaddle phase function over a range of inherent optical properties. We parameterized a Monte Carlo radiative transfer model with measured inherent optical properties ($a_0$ and $b_0$) and the Sullivan-Twaddle phase function then compared the model output with measured hemispherical upwelling radiance distributions.

Initial tests used data collected in 2004 during the BIOSCOPE cruise, which included both clear, oligotrophic water in the central South Pacific Gyre and moderately eutrophic conditions associated with upwelling off the Chilean coast. The BIOSCOPE dataset spanned a range of $a_0$ from 0.01 to 0.16 m$^{-1}$, $b_0$ from 0.07 to 0.38 m$^{-1}$, and solar zenith angles from 8 to 58 degrees. The average daily difference of upwelling radiance (normalized to the nadir value in each case) between model predictions and measured data was larger than observed in the BIOSCOPE dataset. In general, the Morel-LUT performed best at low Chi levels, but the model using the Sullivan-Twaddle phase function matched the data as well or better than the Morel LUT at higher Chi levels. All of the models matched the data better in the blue (412, 436, 488 nm) than in the green (526 nm).

Method

The approach was to compare measured hemispherical upwelling radiance distributions with model simulations using three different volume scattering functions and two different radiative transfer codes (summarized as A-D in box to the right). Calculations using the Sullivan and Twaddle (2009) VSF and Petzold’s turbid water VSF were conducted using inherent water optical properties measured by ac-9 and ecod-3 instruments. Measured values of total Chlorophyll (Chl) and solar zenith angle were used to interpolate the Morel et al. (2002) look up tables. The NuRADS instrument (Voss and Chapin, 2005) was used to acquire the measured hemispherical upwelling radiance distributions.

The IOPs and Chl were measured using vertical profiling casts and depth-weighted by $a_{wacc}$ with in order to compute average values over the water column to input to the RTE. The NuRADS images were averaged both in time, by grouping 10 minute blocks (4 or 5 individual images), and in space, by exploiting the symmetry of the images about the principal plane.

Planar slices at different azimuths provide qualitative assessment of the agreement among the four datasets (see model-data slices, below). Quantitative comparison between the modeled and measured radiance distributions (see model-data summary, below) was performed by computing the model-data difference at every 5 degrees in nadir from 5 to 45 degrees and every 15 degrees in azimuth from 0 to 180 degrees. After omitting points within the instrument shadow, the average and standard deviation of the model-data difference for all NuRADS images at a given Chi value was computed.

Results

Model - Data Slices, Single Images from One Day

Principal Plane (Azimuth 0-180 degrees)

Azimuth 30-150 degrees

Azimuth 60-120 degrees

Perpendicular to Principal Plane (Azimuth = 90 degrees)

Model - Data Summary

Model with Sullivan - Twaddle VSF

IDP

(a and $b_0$) + (Sullivan and Twaddle, 2009) + RTE

Model with Petzold VSF

IDP

(a and $b_0$) + (Petzold) + RTE

Model with Morel VSF

Chl + VSF (measured) + RTE (Morel)

Measured NuRADS Instrument (Voss and Chapin, 2005)

Reference:
