Assessing Uncertainty Of Ocean Water Bidirectional Reflectance Model

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Quantifying Ocean BRDF

\[ L_w(0^+, \theta_s, \theta, \phi, \lambda, W, \text{IOP}) = E_d(0^+, \theta_s, \lambda) \cdot \mathcal{R}(\theta', W) \frac{f(\theta_s, W, \text{IOP})}{Q(\theta_s, \theta', \phi, W, \text{IOP})} \left( \frac{b_b}{a} \right) \]
Why is $f/Q$ important?

$AOP(IOP, \theta_s, \theta, \phi)$

C. D. Mobley, Ocean Optics Web Book, Atmospheric Correction for satellite Ocean Color Radiometry,
“It would be desirable to have an AOP that completely removes the effects of solar zenith angle, viewing direction, atmospheric conditions, and sea state, while retaining a strong dependence on the water IOPs. It would then be possible to compare this AOP for measurements made at different times and/or locations, and thereby extract information about the differences in the water columns for the different measurements.”
Previous work on ocean BRDF
Unresolved BRDF Issue

- The dependence of $f/Q$ on the IOPs, and viewing geometry was studied in terms of a bio-optical model.
- However, the IOP–[Chl] parameterizations are not unique due to the inherent variability of the correlations.
- Mobley et al. (2004) have pointed out that “within Case 1 waters, there is a factor-of-two (and sometimes much greater) variability in the values of optical properties for a given chlorophyll value.”
- It is then necessary and important to understand how the $f/Q$ factors respond to different choices of bio-optical models and the natural variability of the IOPs.
How do we address this?

\[ \text{IOP} = \Phi \times IOP([\text{CHL}], \lambda) \]

Radiative Transfer Model

\[ \text{AOP}([\text{CHL}], \lambda, \Theta_s, \theta, \phi) \]
Vector Radiative Transfer (VRT) Model

\[ S_{1}^{m} = \frac{\omega}{4\pi} \frac{P_{m}(\mu, \mu_{0})}{e^{-\tau/|\mu_{0}|}} E_{0} \]

\[ L_{1}^{m} = e^{-(\tau - \tau^{*})/|\mu_{0}|} \left| \frac{\mu_{0}}{\mu_{0}} B_{m}^{n}(\mu, \mu_{0}) \right| e^{-\tau^{*}/|\mu_{0}|} E_{0} \]

\[ S_{n}^{m} = \frac{\omega}{2} \int P_{m}(\mu, \mu') L_{n}^{m}(\tau, \mu') d\mu' \]


Key Features of the SOS VRT model

- Full four Stokes parameters solution.
- Full physics coupling of atmosphere and ocean.
- Elastic and Inelastic scattering.
- Handle both coastal and open oceans.
- Analytical single scattering correction (Nakajima and Tanaka 1988) for both atmosphere and ocean.
- Advanced angular interpolation scheme using (Schulz and Stamnes, 2000)
- Flexible detector position.
Simulation Parameters

- Wavelength, $\lambda$ (seven values): $412.5$, $442.5$, $490$, $510$, $560$, $620$, and $660$ nm;
- Chlorophyll a concentration (six values): $0.03$, $0.1$, $0.3$, $1.0$, $3.0$, and $10.0$ mg m$^{-3}$;
- CDOM absorption factor, $\Phi$ (five values): $0.1$, $0.5$, $1.0$, $2.0$, and $10.$;
- Scattering coefficient factor, $\Phi_s$ (three values): $0.5$, $1.0$, and $2.0$;
- Ocean water polarization at $90^\circ$, $p(90^\circ)$ (five values): $0.5$, $0.6$, $0.66$, $0.7$, and $0.8$;
- Solar zenith angle, $\theta_s$ (six values): $0^\circ$, $15^\circ$, $30^\circ$, $45^\circ$, $60^\circ$, and $75^\circ$;
- Viewing azimuth angle, $\phi$ (13 values): $0^\circ$–$180^\circ$ with increment of $15^\circ$;
- Viewing zenith angle, $\theta$ (17 values): $1.078^\circ$, $3.411^\circ$, $6.289^\circ$, $9.278^\circ$, $12.300^\circ$, $15.330^\circ$, $18.370^\circ$, $21.410^\circ$, $24.450^\circ$, $27.500^\circ$, $30.540^\circ$, $33.590^\circ$, $36.640^\circ$, $39.690^\circ$, $42.730^\circ$, $45.780^\circ$, and $48.830^\circ$. 
Ocean Water BRDF Uncertainty

Histogram of $\zeta$ Without Raman

Histogram of $\zeta$ With Raman

$L_w(0^+ , \theta, \theta, \phi , \lambda , W, IOP) = E_d(0^+ , \theta, \lambda) R(\theta' , W) \frac{f(\theta , W, IOP)}{Q(\theta , \theta', \phi , W, IOP)} \left( \frac{b_b}{a} \right)$.

$\zeta = 100\% \cdot \frac{f/Q_{\Phi=\phi=1} - f/Q_{MAG2002}}{f/Q_{MAG2002}}$.
Why the differences?

\[ b_p(\lambda, [\text{Chl}]) = b_p(660, [\text{Chl}]) \left( \frac{\lambda}{660} \right)^\nu \]

\[ \Phi_s 0.347[\text{Chl}]^{0.766} \]

\[ \nu = 0.5(\log_{10}[\text{Chl}] - 0.3) \]

\[ b_p(550, [\text{Chl}]) = 0.3566[\text{Chl}]^{0.766} \quad \text{If } [\text{Chl}] = 1.0 \text{ mg/m}^3 \]

\[ b_p(550, [\text{Chl}]) = 0.416[\text{Chl}]^{0.766} \quad \text{In Morel 2002.} \]
Where is 0.416 from?

be taken into consideration. Indeed, (9) can be replaced by a new empirical relationship, derived from a recent and much larger data set, and specifically valid for the oceanic upper layer [Loisel and Morel, 1998]; this revised expression, established for $\lambda = 660$ nm, is

$$b_{p660}([\text{Chl}]) = 0.347[\text{Chl}]^{0.766}$$

transformed into

$$b_{p550}([\text{Chl}]) = 0.416[\text{Chl}]^{0.766} \quad (12)$$

at 550 nm if a $\lambda^{-1}$ spectral dependency is adopted for this scattering coefficient.

From Morel and Maritorena, JGR, 2002
Ocean Water BRDF Uncertainty II

Histogram of $\xi'$.  

$\xi' = 100\% \cdot \frac{f/Q_{\Phi \neq 1, \Phi_z = 1} - f/Q_{\Phi = 1, \Phi_z = 1}}{f/Q_{\Phi = 1, \Phi_z = 1}}$

Histogram of $\xi''$.  

$\xi'' = 100\% \cdot \frac{f/Q_{\Phi = 1, \Phi_z \neq 1} - f/Q_{\Phi = 1, \Phi_z = 1}}{f/Q_{\Phi = 1, \Phi_z = 1}}$
Angular distribution of Solar Zenith Angle 30 Deg.
Take Home Messages

- A systematic evaluation of the MAG2002 BRDF LUT is performed.
- General consistency is observed.
- Difference remains due to the different radiative transfer modeling details, singles scattering phase functions, IOPs.
- Uncertainty of BRDF simulation are assessed by comparing new simulations and those of MAG2002.
- The BRDF study needs to be continued considering the newest bio-optical model for Case 1 and coastal waters.