Assessing Uncertainty Of Ocean Water Bidirectional Reflectance Model

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Quantifying Ocean BRDF

backscattering coefficient

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

$$\frac{f(\theta_s, W, \mathrm{IOP})}{Q(\theta_s, \theta', \phi, W, \mathrm{IOP})}$$

Why is f/Q important?

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

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

Diffuse reflectance of oceanic waters: its dependence on Sun angle as influenced by the molecular scattering contribution

André Morel and Bernard Gentili
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Applied Optics Vol. 30, Issue 30, pp. 4427-4438 (1991) • doi: 10.1364/AO.30.004427

Diffuse reflectance of oceanic waters. II. Bidirectional aspects

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Diffuse reflectance of oceanic waters. III. Implication of bidirectionality for the remote-sensing problem

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Bidirectional reflectance of oceanic waters: accounting for Raman emission and varying particle scattering phase function

André Morel, David Antoine, and Bernard Gentili
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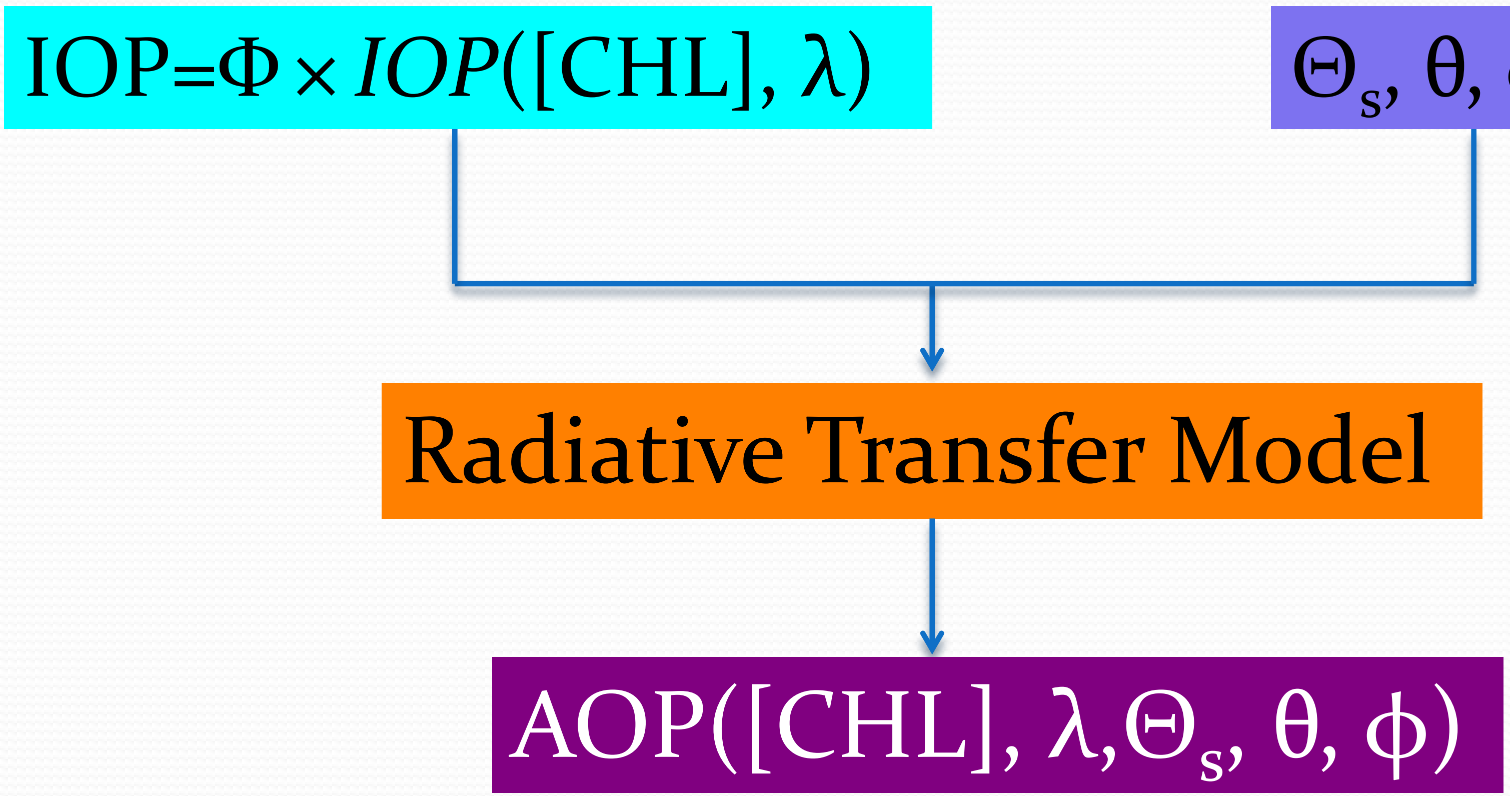
Applied Optics Vol. 41, Issue 30, pp. 6289-6306 (2002) • doi: 10.1364/AO.41.006289

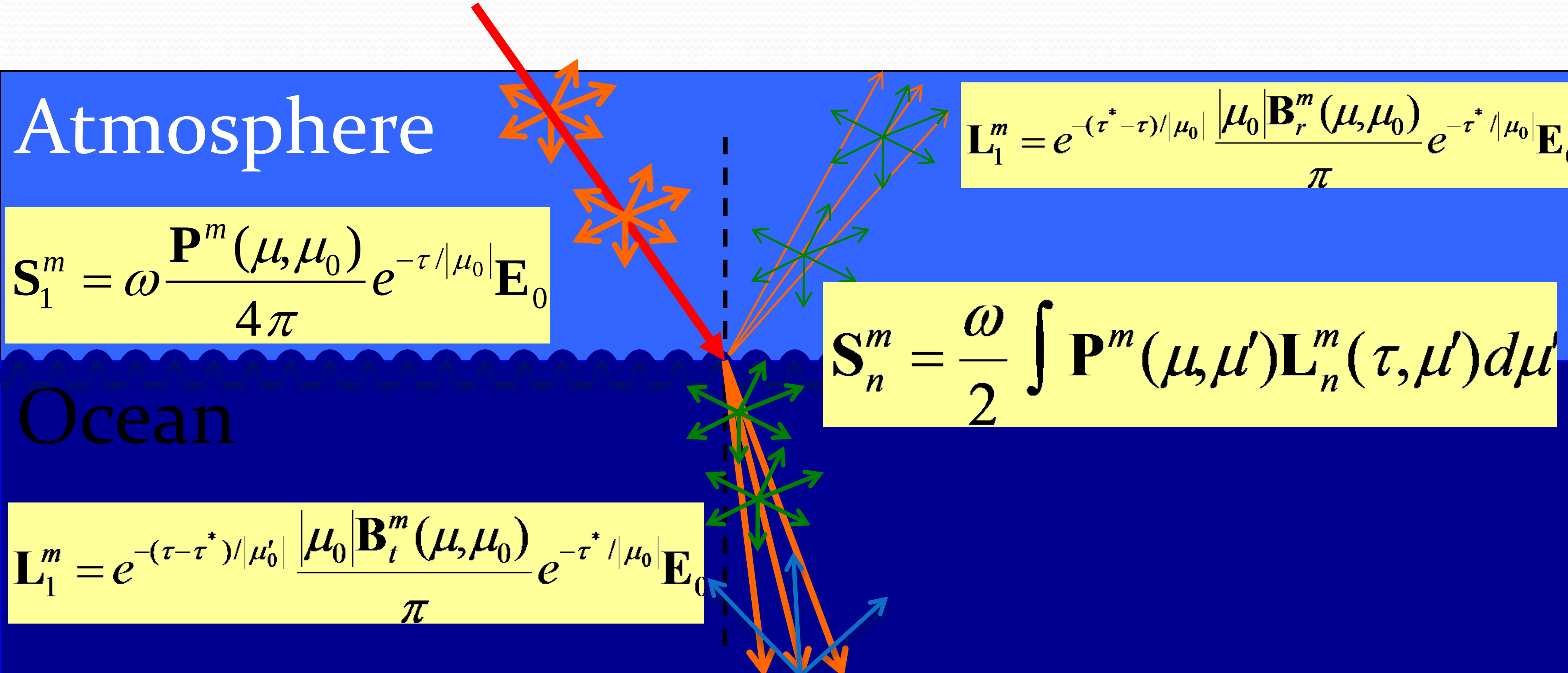
Unresolved BRDF Issue

- 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?



Vector Radiative Transfer (VRT) Model



$$\mathbf{S}_1^m = \omega \frac{\mathbf{P}^m(\mu,\mu_0)}{4\pi} e^{-\tau/|\mu_0|}\mathbf{E}_0$$

$$\mathbf{L}_1^m = e^{-(\tau^*-\tau)/|\mu_0|} \frac{|\mu_0|\mathbf{B}_r^m(\mu,\mu_0)}{\pi} e^{-\tau^*/|\mu_0|}\mathbf{E}_0$$

$$\mathbf{S}_n^m = \frac{\omega}{2}\int \mathbf{P}^m(\mu,\mu')\mathbf{L}_n^m(\tau,\mu')d\mu'$$

$$\mathbf{L}_1^m = e^{-(\tau-\tau^*)/|\mu_0'|} \frac{|\mu_0|\mathbf{B}_t^m(\mu,\mu_0)}{\pi} e^{-\tau^*/|\mu_0|}\mathbf{E}_0$$

$$\mathbf{L}_n^m(\tau,\mu>0) = \int_{\tau}^{\tau^*} \exp\{-(\tau'-\tau)/\mu\}\mathbf{S}_n^m(\tau',\mu)d\tau/\mu$$

$$\mathbf{L}_n^m(\tau,\mu<0) = \int_{0}^{\tau} \exp\{-(\tau'-\tau)/\mu\}\mathbf{S}_n^m(\tau',\mu)d\tau/|\mu|$$

Zhai, P, Y. Hu, J. Chowdhary, C. R. Trepte, P. L. Lucker, D. B. Josset, "A vector radiative transfer model for coupled atmosphere and ocean systems with a rough interface," J Quant Spectrosc Radiat Transf, **111**, 1025-1040 (2010).
Zhai, P, Y. Hu, C. R. Trepte, and P. L. Lucker, "A vector radiative transfer model for coupled atmosphere and ocean systems based on successive order of scattering method," Opt. Express **17**, 2057-2079 (2009).

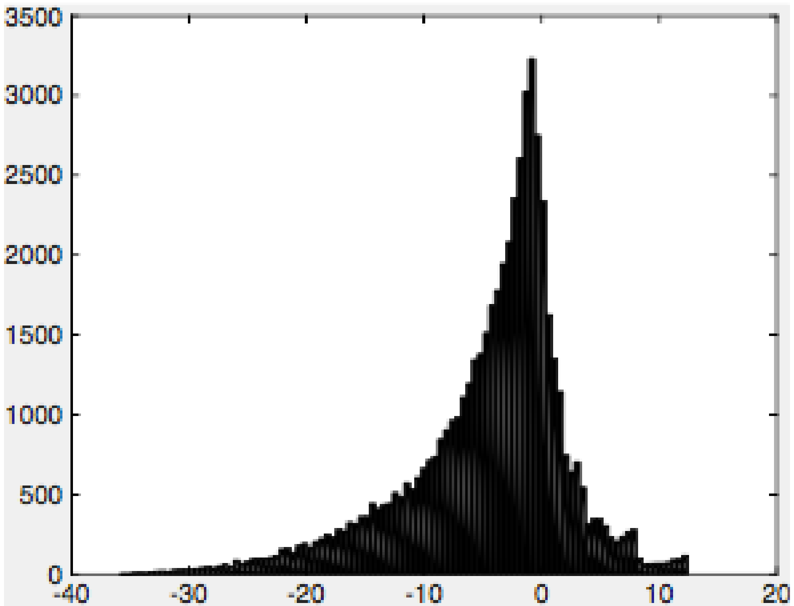
Key Features of the SOS VRT model

- 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.

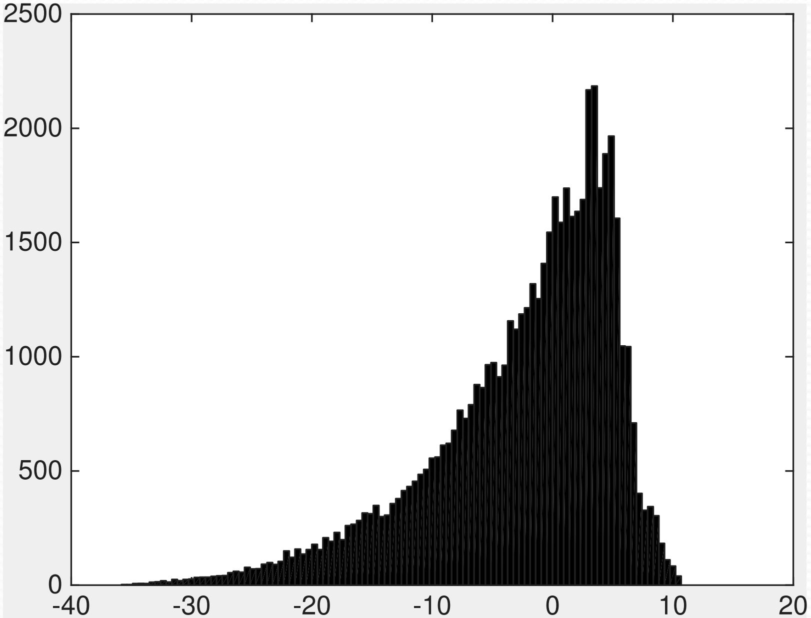
Simulation Parameters

- Wavelength, λ (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, Φ (five values): 0.1, 0.5, 1.0, 2.0, and 10.;
- Scattering coefficient factor, Φ_s (three values): 0.5, 1.0, and 2.0;
- Ocean water polarization at 90°, $p(90°)$ (five values): 0.5, 0.6, 0.66, 0.7, and 0.8;
- Solar zenith angle, θ_s (six values): 0°, 15°, 30°, 45°, 60°, and 75°;
- Viewing azimuth angle, ϕ (13 values): 0°–180° with increment of 15°;
- Viewing zenith angle, θ (17 values): 1.078°, 3.411°, 6.289°, 9.278°, 12.300°, 15.330°, 18.370°, 21.410°, 24.450°, 27.500°, 30.540°, 33.590°, 36.640°, 39.690°, 42.730°, 45.780°, and 48.830°.

Ocean Water BRDF Uncertainty



Histogram of ζ Without Raman



Histogram of ζ With Raman

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

$$\zeta = 100\% \cdot \frac{f/Q_{\Phi=\Phi_s=1} - f/Q_{\mathrm{MAG2002}}}{f/Q_{\mathrm{MAG2002}}},$$

Why the differences?

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

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

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

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

$$\neq$$

$$b_p(550, [Chl]) = 0.416[Chl]^{0.766}$$ 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

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

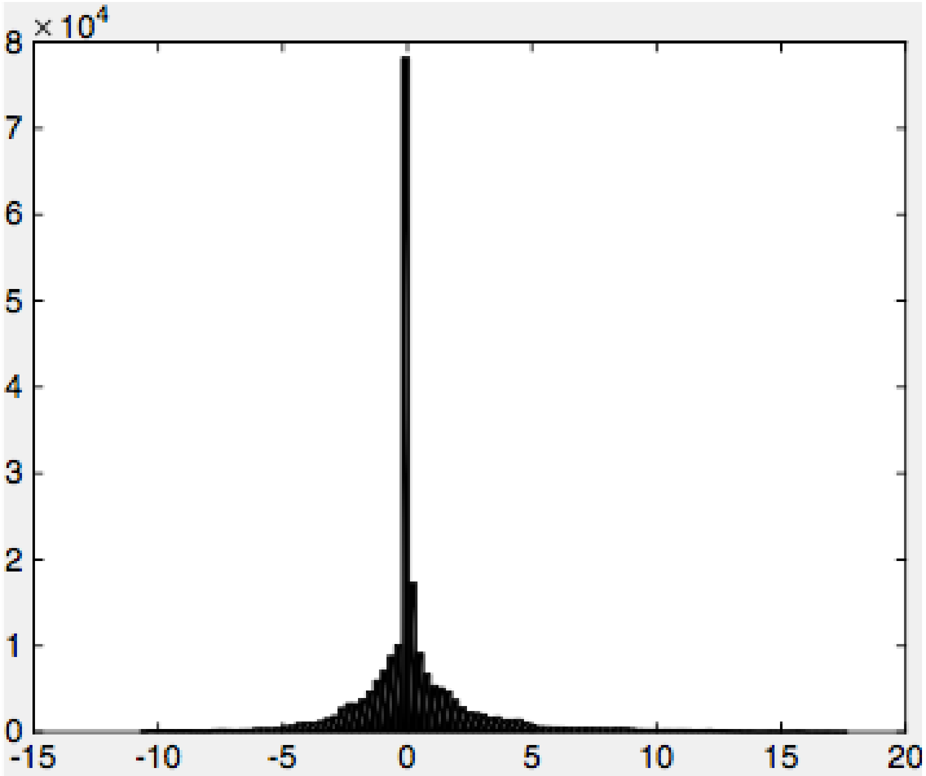
transformed into

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

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

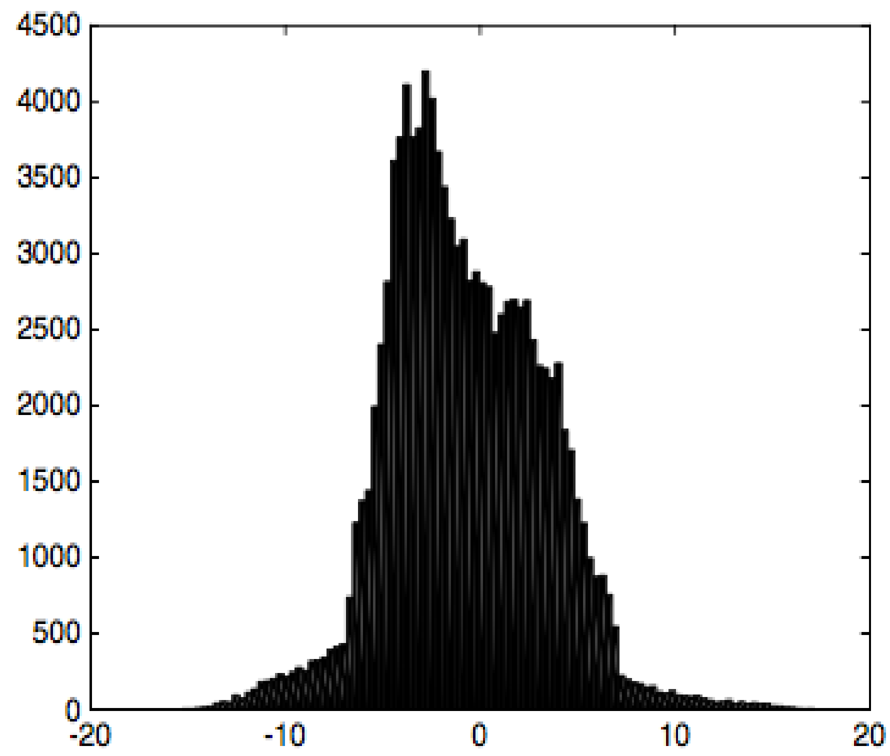
From Morel and Maritorena, JGR, 2002

Ocean Water BRDF Uncertainty II



Histogram of ζ'.

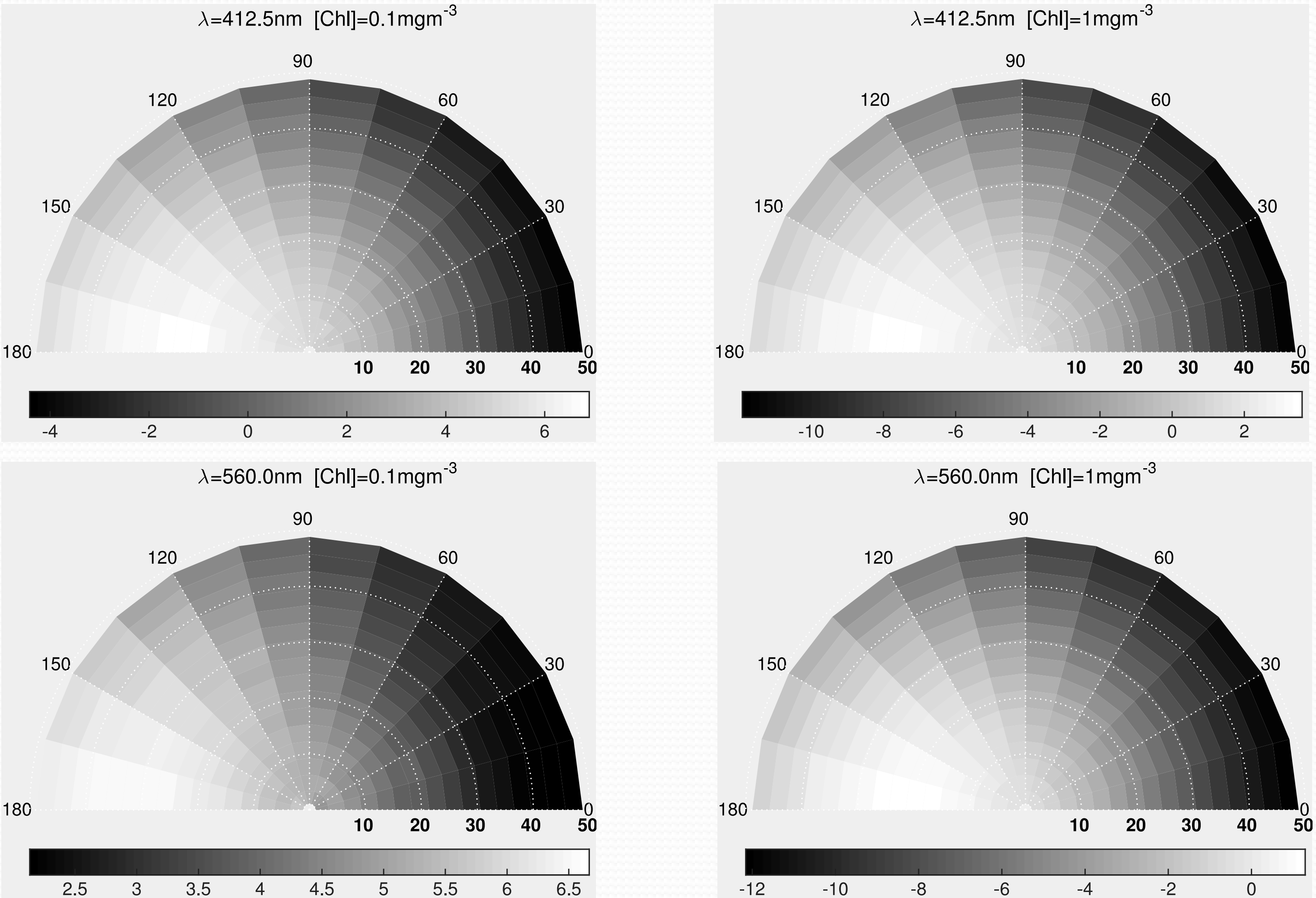
$$\zeta' = 100\% \cdot \frac{f/Q_{\Phi\neq1,\Phi_s=1} - f/Q_{\Phi=1,\Phi_s=1}}{f/Q_{\Phi=1,\Phi_s=1}}$$



Histogram of ζ''.

$$\zeta'' = 100\% \cdot \frac{f/Q_{\Phi=1,\Phi_s\neq1} - f/Q_{\Phi=1,\Phi_s=1}}{f/Q_{\Phi=1,\Phi_s=1}}.$$

Angular distribution of $\zeta = 100\% \cdot \dfrac{f/Q_{\Phi=\Phi_s=1} - f/Q_{MAG2002}}{f/Q_{MAG2002}}$,



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.