Ocean-color remote sensing using non-polarized component of top-of-atmosphere reflectance

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Reference. Frouin R. J., B. A. Franz, A. Ibrahim, K. Knobelspiesse, Z. Ahmad, B. Cairns, J. Chowdhary, H. M. Dierssen, J. Tan, O. Dubovik, X. Huang, A. B. Davis, O. Kalashnikova, D. R. Thompson, L. A. Remer, E. Boss, O. Coddington, P.-Y. Deschamps, B.-C. Gao, L. Gross, O. Hasekamp, A. Omar, B. Pelletier, D. Ramon, F. Steinmetz, and P.-W. Zhai, 2019: Atmospheric Correction of Satellite Ocean-Color Imagery During the PACE Era. *Frontiers in Earth Science*, 7:145, doi: 10.3389/feart.2019.00145, 70 pp.

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INTRODUCTION

-A major problem in ocean-color remote sensing using TOA total reflectance measurements (the usual approach) is that atmospheric and surface effects dominate the signal measured at the wavelengths of interest. They typically contribute 90% (or more) of the TOA signal.

-To reduce these effects, one may exploit the polarization properties of reflected sunlight.

-Because molecules, aerosols, and the surface polarize incident sunlight, the contribution of the water body to unpolarized TOA reflectance may be enhanced, at least for some geometries.

-If the enhancement is substantial, then correction of the perturbing effects may become easier, leading to a more accurate retrieval of the diffuse water reflectance (the signal to retrieve).

TOA reflectance (total, polarized, unpolarized), DoLP

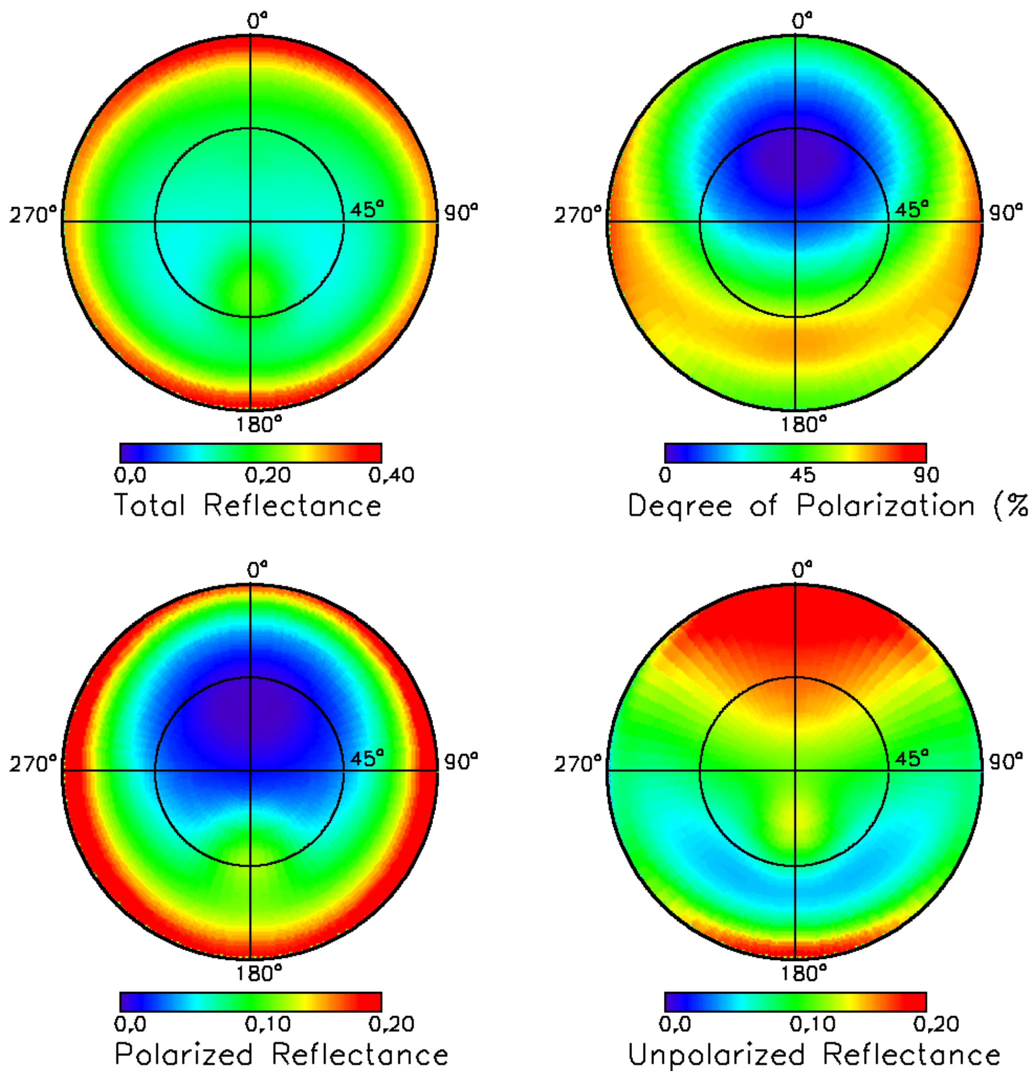

Figure 1: *TOA total reflectance, DoLP, polarized and unpolarized reflectance for ocean-atmosphere system with WMO maritime aerosols, AOT of 0.1 at 550 nm, [Chl] = 0.1 mg/m^3, and wind speed of 5 m/s. Wavelength is 443 nm and SZA 30 deg.*

Surface reflectance (total, polarized, unpolarized), DoLP

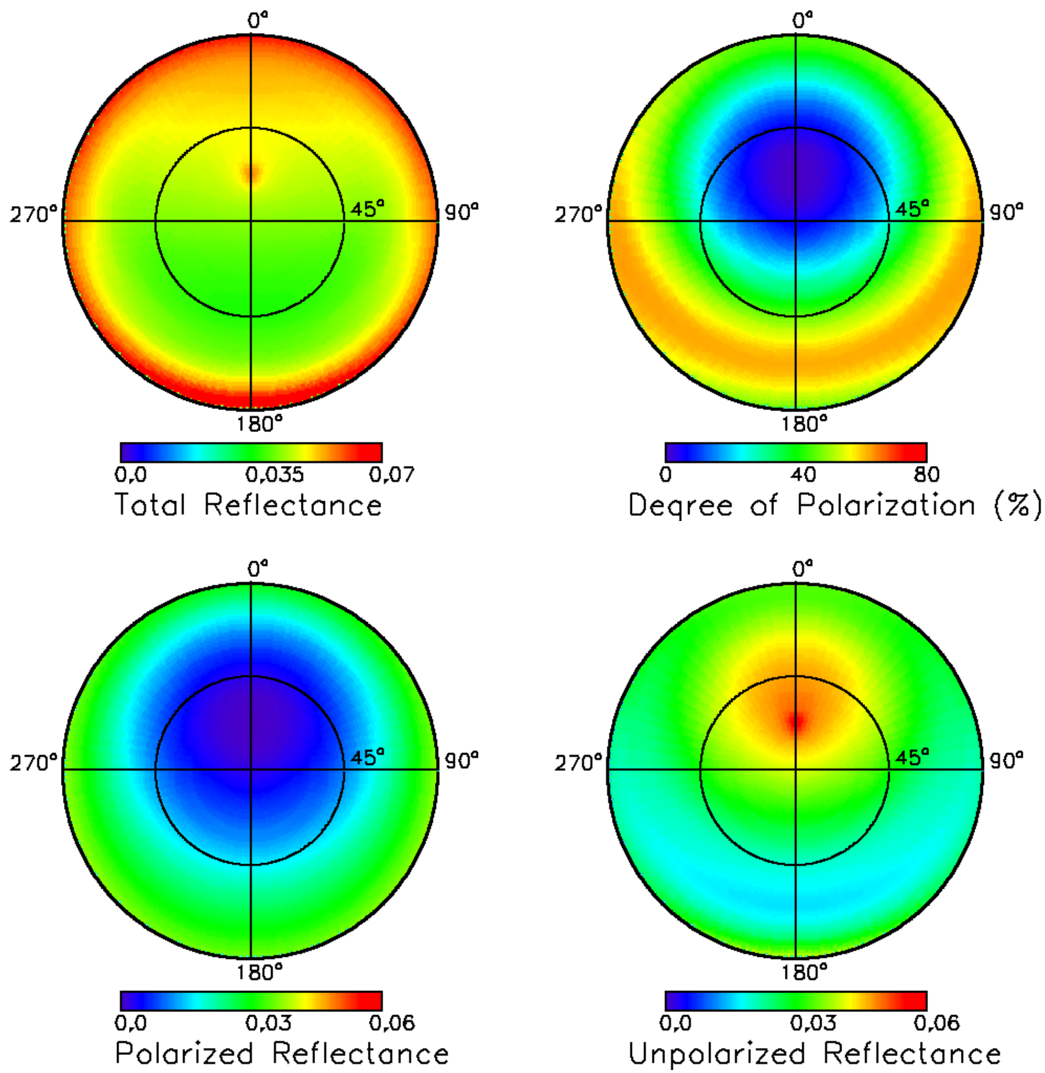

Figure 2: *Same as Figure 1, but just below the surface (0-). Compared with TOA signal, no sun glint pattern, DoLP shifted due to refraction, and backward scattering peak in total and unpolarized reflectance due to hydrosol phase function.*

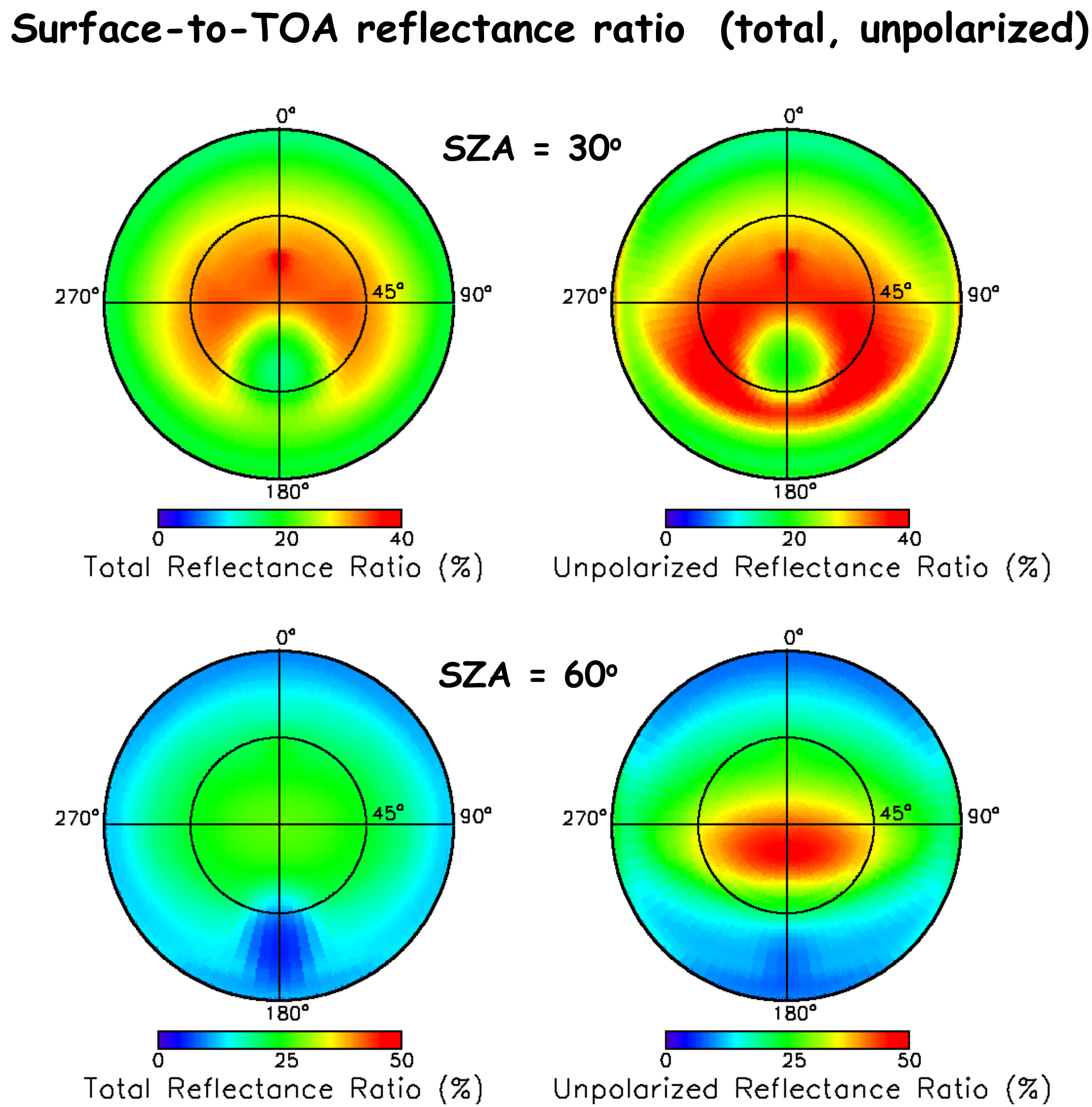

***Figure 3**: Ratios of surface (0-) and TOA reflectance, total (left) and unpolarized (right). Top: SZA = 30°; Bottom: SZA = 60°. Geophysical conditions are those of Figure 1. Ratio is generally higher for unpolarized reflectance, especially when SZA = 60°.*

Surface-to-TOA reflectance ratio (total, unpolarized)

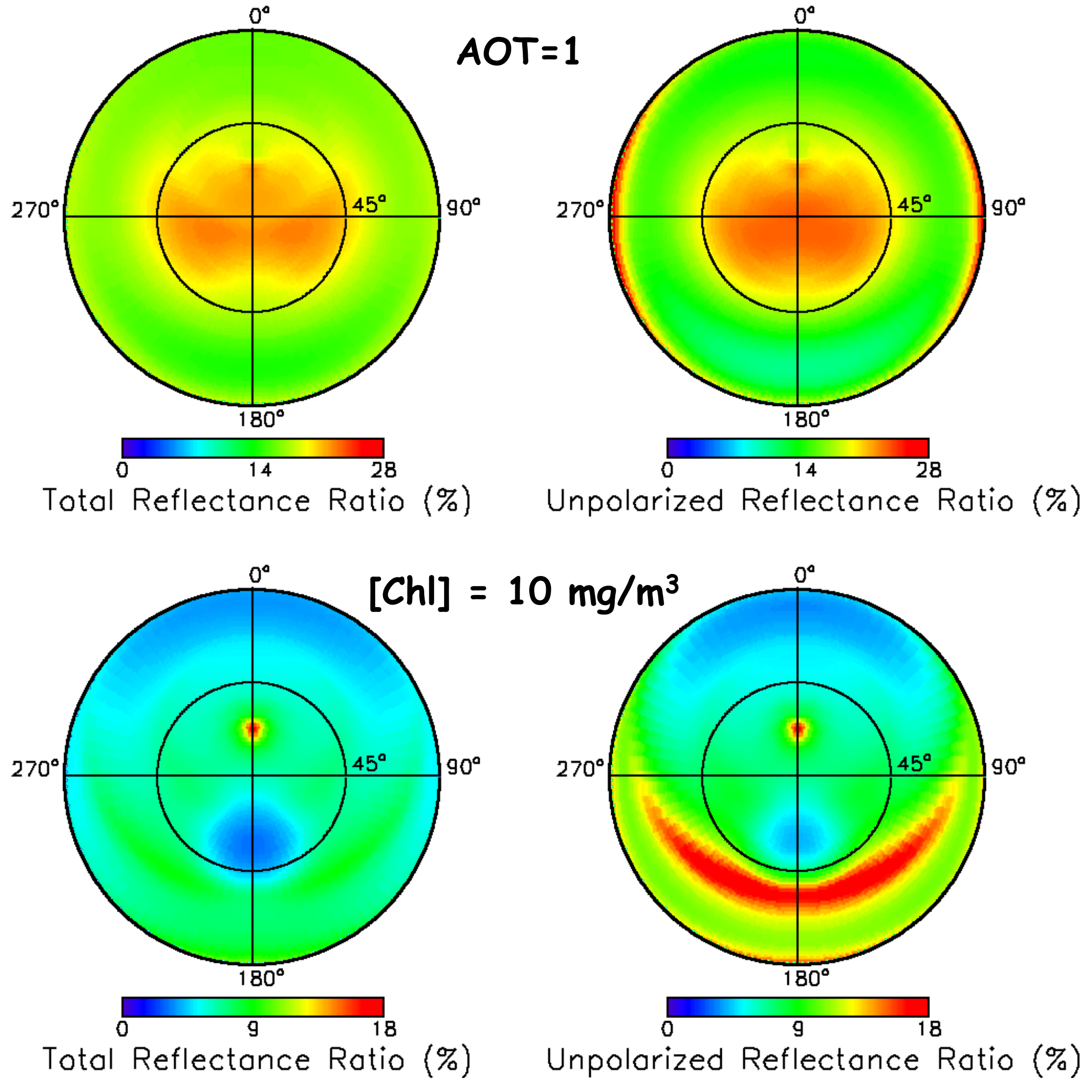

***Figure 4**: Same as Figure 3, but AOT = 1 at 550 nm (top) and [Chl} = 10 mg/m³ (bottom). No or small enhancement of the surface signal when AOT is 1, due to multiple scattering, but large enhancement when [Chl] is 10 mg/m³ at scattering angles ~90 deg.*

Unpolarized versus total reflectance ratio (0-/TOA)

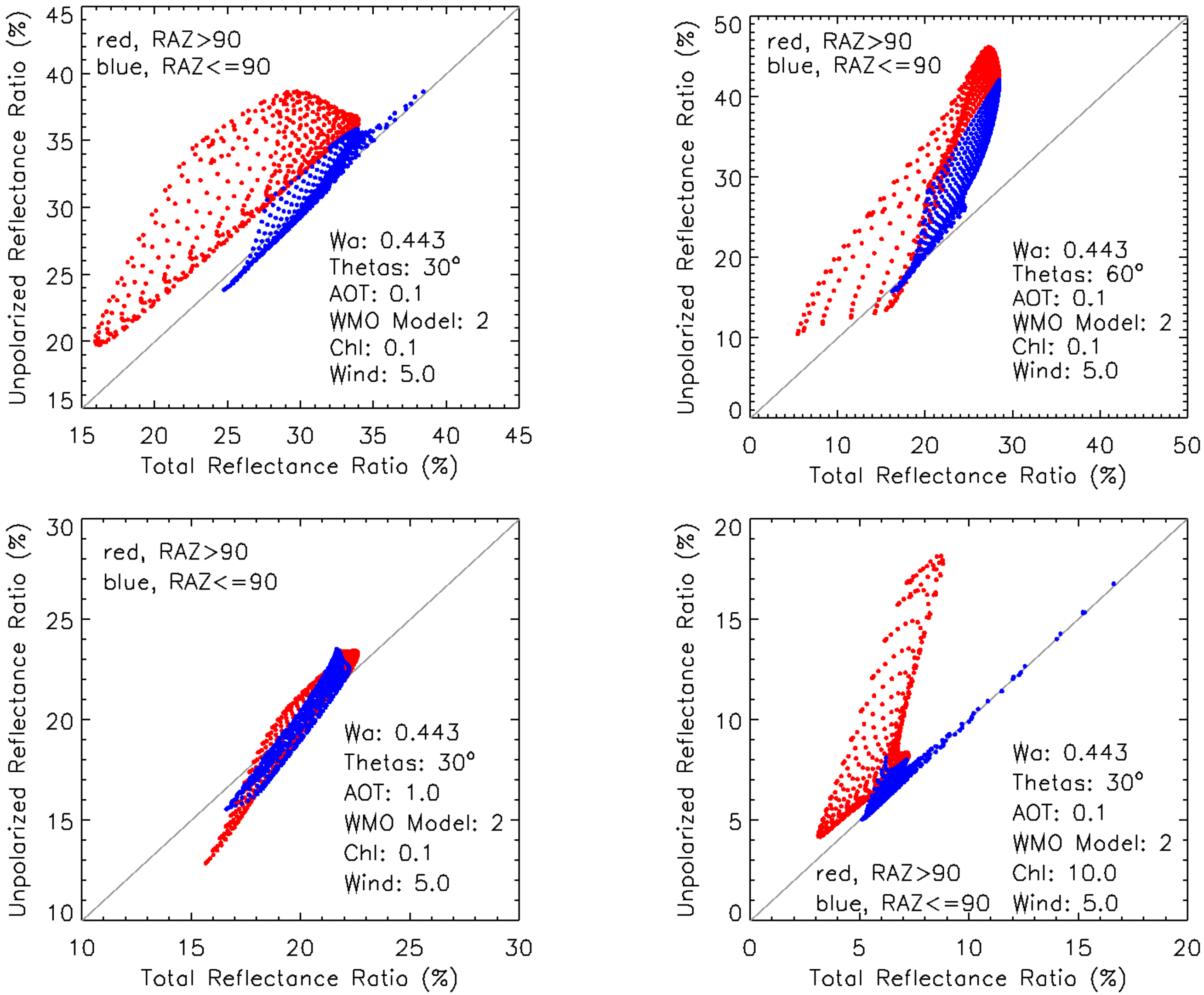

***Figure 5**: Unpolarized versus total reflectance ratio (0-/TOA) for the situations of Figures 3 and 4 and VZA <60 deg. Red: Forward scattering; Blue: Backward scattering. Unpolarized ratio is generally higher than total ratio, except when AOT is large.*

Sensitivity to chlorophyll concentration

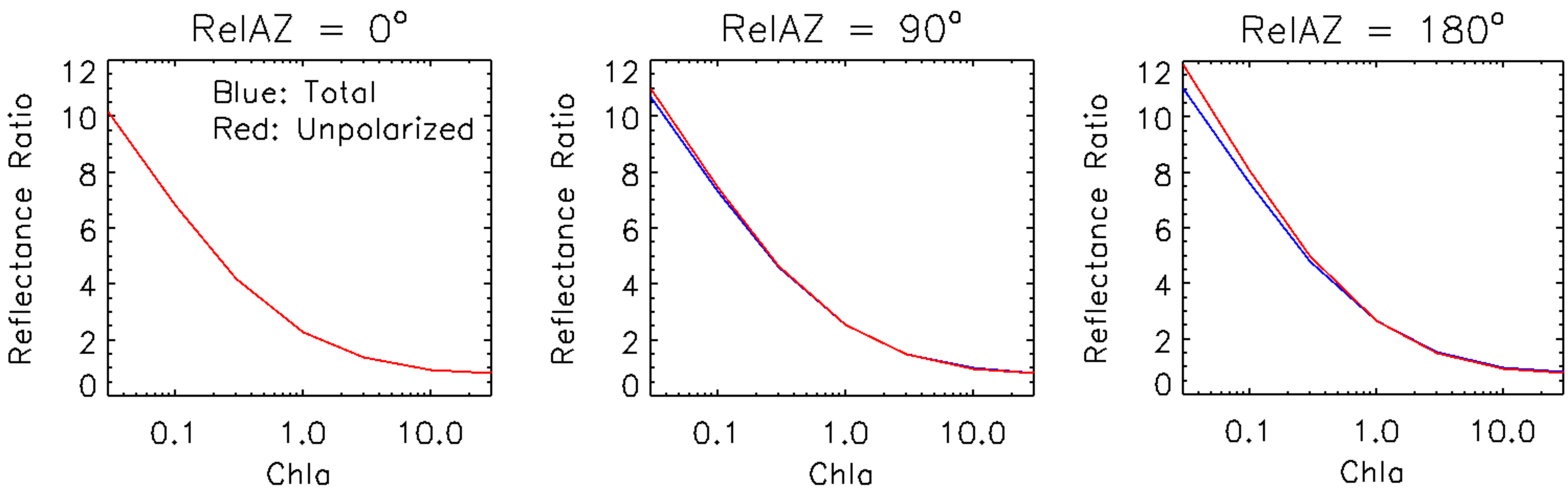

***Figure 6**: Sensitivity of ratio of water reflectance (0-) at 443 nm and 550 nm to chlorophyll concentration Chla (mg/m^3). Total and unpolarized signals are used (blue and red curves). Atmospheric and surface conditions are those of Figure 1. VZA = SZA = 30^o. Variation with Chla is similar using total or unpolarized reflectance.*

---> New paradigm for remote sensing of ocean biogeochemical variables from space, but bio-optical relations need to be established (few polarization measurements are currently available).

PCA-BASED STATISTICAL INVERSION

-Atmospheric correction was performed to retrieve total water reflectance from unpolarized TOA reflectance in the PACE Ocean Color Instrument (OCI) threshold aggregated bands in the UV, VIS, NIR, and SWIR, centered on 350, 380, 412, 443, 490, 510, 555, 665, 748, 865, 1245, 1640, and 2135 nm.

-PCA-based inversion was used, in which the TOA unpolarized reflectance is decomposed into PCs, and the PCs sensitive to the water signal are combined to retrieve the water reflectance PCs, allowing reconstruction of the water reflectance. Neural network methodology was applied to map the selected TOA reflectance PCs to the water reflectance PCs.

$$\rho_{\boldsymbol{u}} = f(\rho_{\boldsymbol{w}})$$

$$\rho_{\boldsymbol{u}} = \sum_i c_{ui} \boldsymbol{e}_{\boldsymbol{u}i}$$

$$\rho_{\boldsymbol{w}} = \sum_j c_{wj} \boldsymbol{e}_{\boldsymbol{w}j}$$

$$c_{wj} = g_j(c_{ui})$$

PCA-BASED STATISTICAL INVERSION (cont.)

-The TOA signal (U, Q, and U) was simulated for a wide range of geophysical conditions and Sun and view angles, i.e., mixtures of WMO aerosol models water-soluble, dust-like, soot, and oceanic), τ_a(550 nm) from 0 to 0.8, H_a from 1 to 8 km, U from 0 to 15 m/s, SZA and VZA from 0 to 75°, RAZ from 0 to 180°, and 720 situations of Case 1 and Case 2 waters.

-It was assumed that polarization information was available in all the spectral bands.

-Atmosphere, surface, and water parameters were selected randomly from uniform distributions within the range of values (atmosphere, surface) and from the distribution of the 720 water types. Better performance is expected for waters with total absorption between 0.01 and 0.3 m^{-1} (more numerous data). About 2M cases for training and 1M for validation.

-Results were compared with those obtained using TOA total reflectance, to evaluate the eventual gain in retrieval accuracy when using TOA unpolarized reflectance.

Correlation between PCs of TOA, atmosphere/surface, and water signals

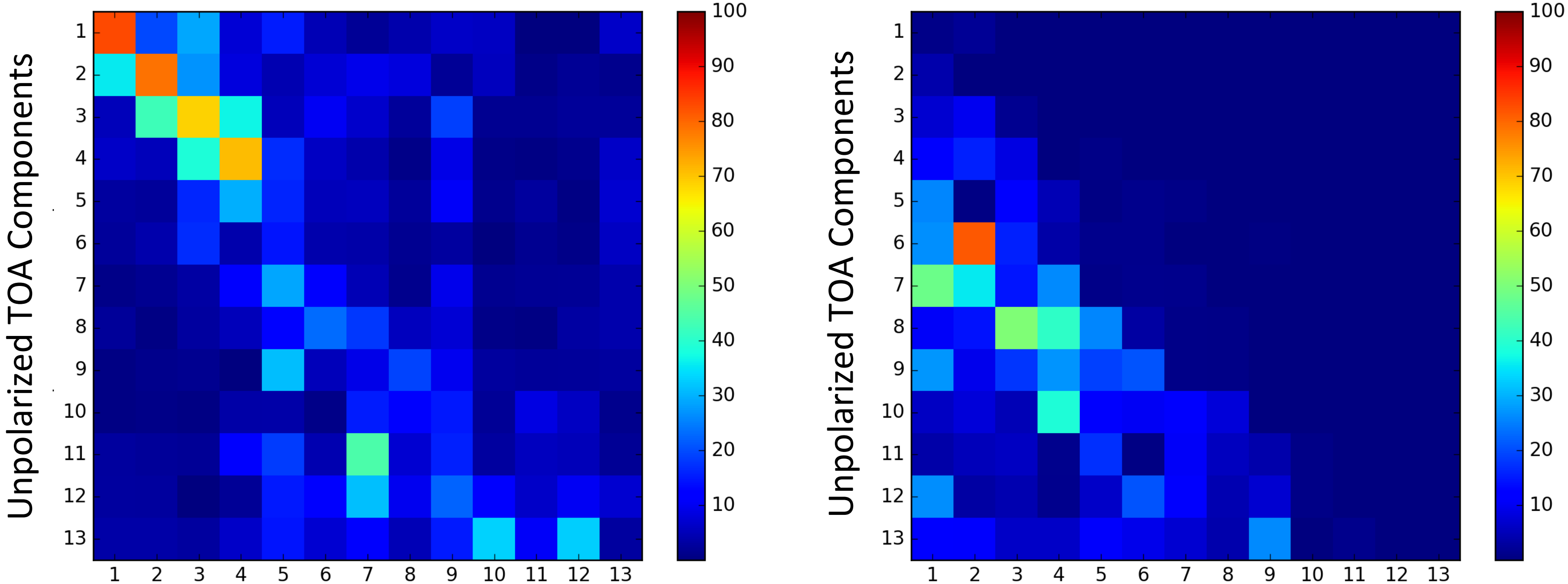

***Figure 7**: Matrices of the linear correlation coefficient (absolute values, in percent) between principal components (PCs) of the TOA unpolarized signal and (left) PCs of the unpolarized atmosphere-glitter signal and (right) PCs of total water reflectance, for the simulated ensembles. The first PCs of the TOA signal are strongly correlated with those of the atmosphere-glitter signal and, therefore, are not used in the mapping of water reflectance PCs, accomplished using neural network modeling.*

RMS Error on water reflectance retrieval at 443 nm

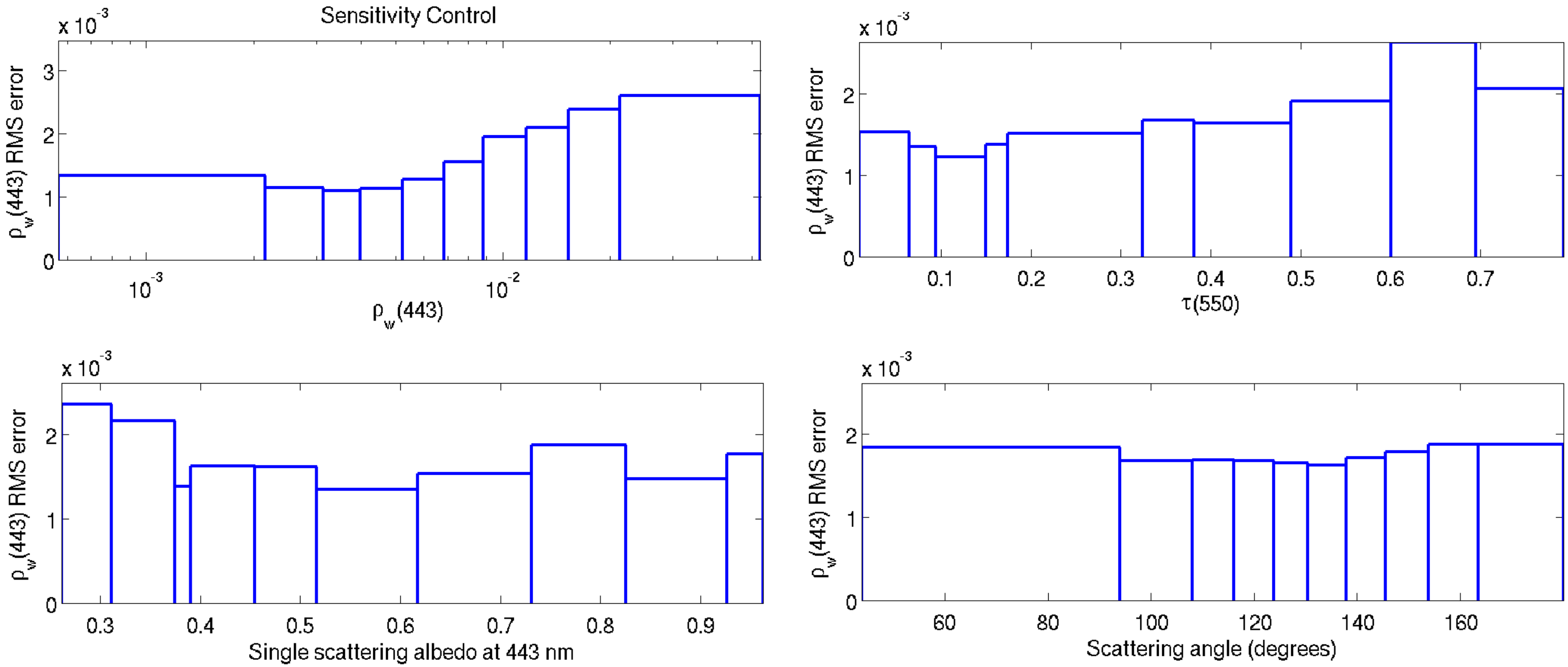

***Figure 8**: Left: Error on retrieved water reflectance at 443 nm, as a function of water reflectance, AOT, single scattering albedo, and scattering angle. The inversion is performed using the PCA-based scheme applied to TOA unpolarized reflectance in the PACE OCI aggregated spectral bands (UV to SWIR).*

Examples of retrieved and prescribed water reflectance spectra

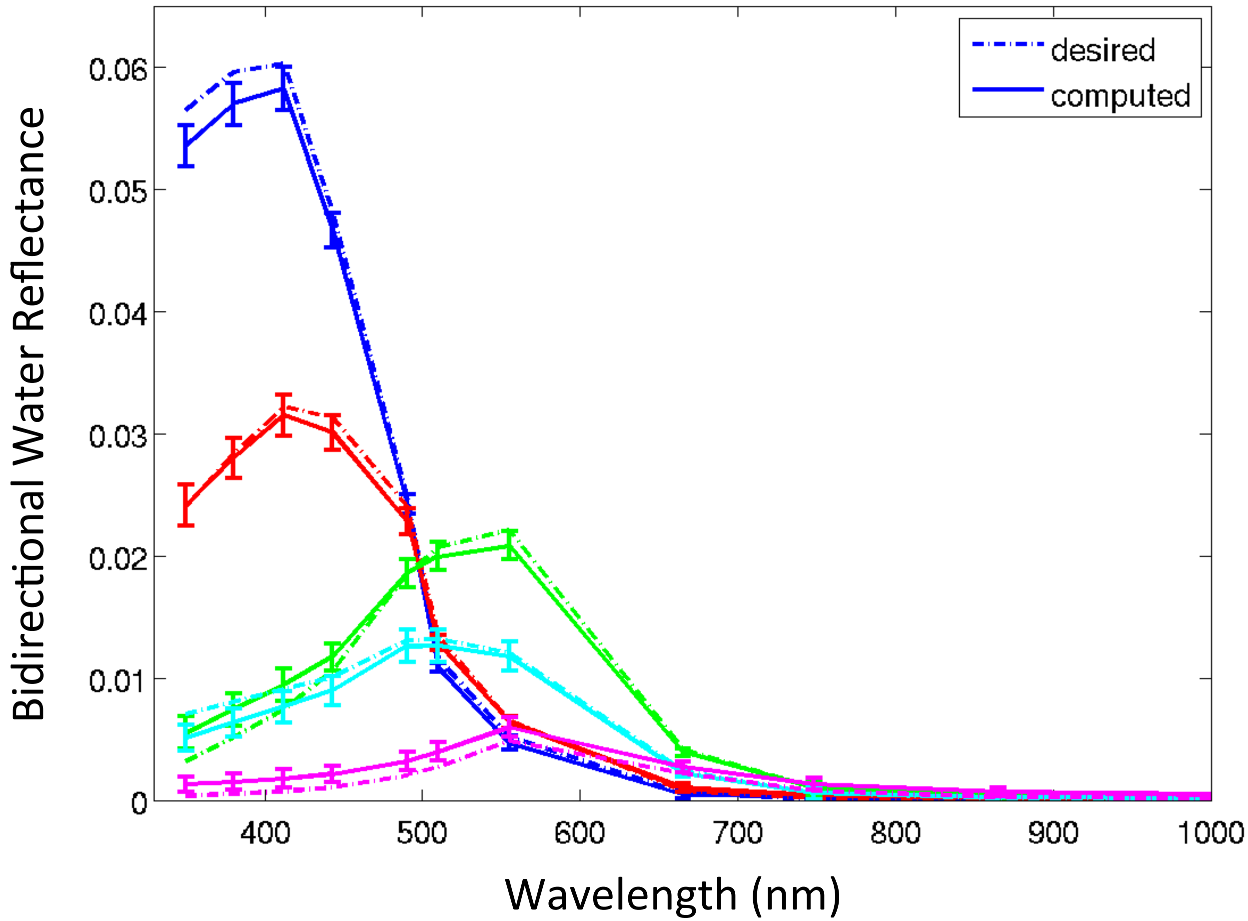

***Figure 9**: Example of above-water bidirectional water reflectance spectra retrievals in the PACE OCI aggregated spectral bands. Dashed curves are for desired spectra, plain curves stand for mean and standard deviation of estimated spectra under various atmospheric and geometrical conditions (2435 conditions).*

Compared global performance using total or unpolarized reflectance

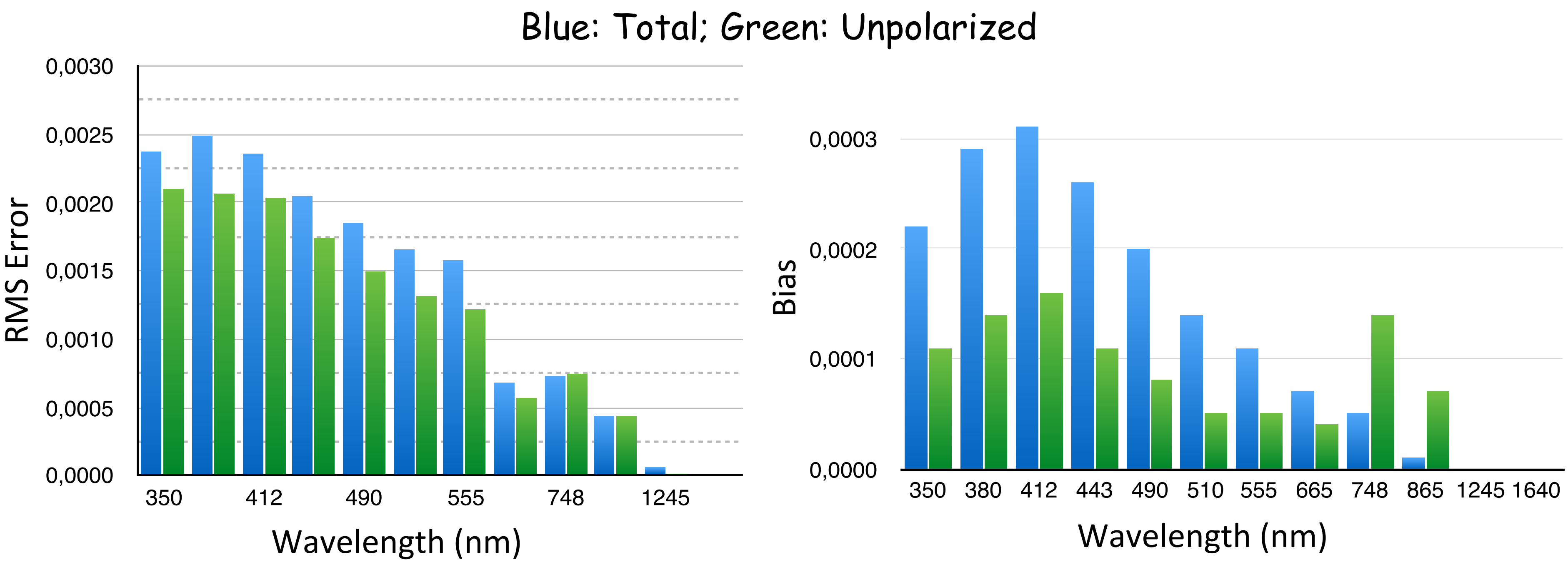

***Figure 10**: Performance of the PCA-based atmospheric correction algorithm for PACE OCI aggregated bands (UV to SWIR). Left: RMS error; Right: Bias. RMS error and bias are significantly reduced using TOA unpolarized reflectance, by 15-20% and 30-60%, respectively, in the UV and visible.*

CONCLUSIONS

-Ocean color remote sensing can be accomplished using top-of-atmosphere (TOA) unpolarized reflectance instead of total reflectance. Using unpolarized reflectance the contribution of the water body to the TOA signal is generally enhanced, except over optically thick atmospheres (due to multiple scattering), making atmospheric correction easier.

-This defines a new paradigm for remote sensing of ocean biogeochemical variables. By using unpolarized reflectance, Sun glint much less an issue, and determination of the aerosol model is facilitated by using polarization information in addition to spectral information in the NIR-SWIR in standard schemes. Bio-optical relations using unpolarized water reflectance, however, remain to be determined.

-PCA-based atmospheric correction applied to simulated data in the PACE OCI aggregated bands indicates significant improvement in total water reflectance retrievals when using TOA unpolarized reflectance, with RMS errors reduced by 15-20% in the UV-visible. Method can also be employed when sensors (or combinations of sensors) have only a limited number of spectral bands with polarization information, a possibility for PACE.