Monte Carlo Simulations of the Sea-surface Reflectance for Above-Water Radiometric Applications

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Abstract: Above-water radiometric measurements are used in ocean color applications for the determination of the *in situ* water leaving radiance L_w. Direct application of L_w is the validation of remote sensing products from satellite sensors like the Sea-viewing Wide Field-of-view Sensor (SeaWiFS), the Moderate Resolution Imaging Spectroradiometers (MODIS), the Medium Resolution Imaging Spectrometer (MERIS), the Visible Infrared Imager Radiometer Suite (VIIRS) and the forthcoming Ocean Land Colour Instrument (OLCI).

The Ocean Color component of the Aerosol Robotic Network (AERONET-OC) was specifically designed to support satellite ocean color validation activities through autonomous measurements performed from fixed platforms. AERONET-OC L_w is determined from: i. measurements of the total radiance L_t from the sea surface, which includes both the radiance emerging from below the sea surface L_w and a fraction ρ of the sky-radiance L_i reflected by the sea-surface in the field-of-view (FOV) of the sensor; and ii. sky-radiance measurements. The water leaving radiance is computed as $L_w = L_t - \rho L_i$, where ρ indicates the sea surface reflectance depending on sea state, illumination conditions and measurement geometry. AERONET-OC L_t measurements are performed with viewing angle θ=40° from nadir and relative azimuth ϕ=90° with respect to sun (both selected to minimize sun-glint perturbations). Accordingly, L_i measurements are performed with viewing angle θ=140° from nadir and relative azimuth ϕ=90°. AERONET-OC values of ρ are tabulated as a function of θ_0, ϕ_0 (i.e., the sun zenith and azimuth, respectively), θ, ϕ and the wind speed W conveniently used to describe the sea state.

This study illustrates the dependence of the term ρ on: i. the sensor FOV; and ii. its height *h* above the sea level. The analysis has been performed using a Monte Carlo code for Ocean Color Simulations called MOX, which allows for modeling the radiance distribution for user selectable sky-radiance and sea-surface configurations. The simulation domain is a three dimensional Cartesian system. The *x*- and the *z*-axis correspond to the wind blowing direction and the zenith direction, respectively. The *y*-axis forms a right-handed coordinate system. MOX simulations have been performed considering: i. FOV between 2° and 10°; and ii. *h* between 2 and 40 m. The sun zenith is 30°. The sea-surface geometry is defined by the Cox-Munk statistics for a wind speed of 5 ms^{-1} and considering gravity waves of 5 m length and 0.5 m height. Results indicate that the average value of ρ tends to reduce when increasing FOV (e.g., the ρ difference between FOV=4° and FOV=10° is ~8%). Instead, the standard deviation of ρ values at the same height z=*h*, but at different *x* and *y* positions (i.e., $\sigma_\rho(h)$), initially decreases when *h* increases. Above a certain *h* value, $\sigma_\rho(h)$ becomes constant (e.g., σ_ρ saturates at ~25 m when FOV=10°). This means that above that height the sensor "sees" a sea-surface distance along the *x*-axis at least equal to the length of the gravity wave. These results hence highlight the applicability of MOX simulations to analyze uncertainties and refine measurement protocols in above-water radiometry.

Keyword: Ocean color, remote sensing, radiative transfer, Monte Carlo simulations.