Platform perturbations in above-water radiometry

Stanford B. Hooker and Giuseppe Zibordi

A comparison of above- and in-water spectral measurements in coastal (but predominantly Case-1) conditions has shown that the uncertainty in above-water determinations of water-leaving radiances made from an offshore tower depends on the proximity of the above-water measurement with respect to the side of the platform. For purposes of this study the proximity of the sampling platform is parameterized as the perpendicular distance (denoted x) from the side of the sampling platform to the center of the area on the sea surface observed by the sea-viewing sensor, the so-called surface spot, which is set by the field of view of the radiometer (or the overlapping fields of view of a multiaperture sensor). Two above-water data processing methods were used to create a diagnostic variable (formulated for Case-1 waters only but also applicable to Case-2 conditions over short time scales) to quantify the presence of superstructure reflections. Based on the height of the tower, H, the analyses were partitioned into near- and far-field data sets ($x < H$ and $x > H$, respectively). The primary conclusions of the radiometric intercomparisons are as follows: (a) the maximum perturbations occur very close to the tower ($x/H \ll 1$), and, as x/H increases and approaches 1 (i.e., as the surface spot becomes as far away as the platform is high), the platform perturbations converge toward smaller and smaller values, and (b) within the far field ($x > H$) the platform perturbation is negligible, and a remote sensing 5% absolute accuracy objective can be satisfied.
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1. Introduction

Ocean color satellites[1] provide large-scale synoptic observations of biogeochemical properties of the upper layer in the open ocean (e.g., phytoplankton biomass) as well as continuous monitoring of other important parameters in the coastal zones (e.g., sediment load and dissolved colored matter). This global capability is accomplished through the determination of radiometric quantities. Specifically, the spectral quantities involved are the radiances measured at the top of the atmosphere, from which (after atmospheric correction) the spectral radiances emerging from the ocean surface—the so-called water-leaving radiances, $L_W(\lambda)$—are determined (λ denotes the wavelength).

The success of an ocean color mission is determined by the quality of the field data collected for calibration and validation purposes. For meaningful applications, the optical measurements must be of an extremely high radiometric accuracy. The Sea-Viewing Wide Field-of-View Sensor (SeaWiFS) project, for example, requires 5% absolute and 1% relative accuracies in the retrieved $L_W(\lambda)$ values,[2] and most ocean color sensors have the same or similar requirements. Although several continuous satellite- and ground-based activities are needed to ensure that the accuracy requirements are met,[3] the perspective here is related to field observations. Assuming that half of the total uncertainty budget is apportioned to the remote sensor and that the uncertainties sum in quadrature (the square root of the sum of the squares), the allowed uncertainty in the *in situ* data is approximately 3.5% ($\sqrt{5^2/2}$).

The primary sources of uncertainty for the ground truth part of the total uncertainty budget include (a) the measurement protocols used in the field; (b) the absolute calibration of the field radiometers (which must also be traceable to the National Institute of Standards and Technology for all U.S. ocean color satellites); (c) the conversion of the light signals to geophysical units in a data-processing scheme; (d) the stability of the radiometers in the harsh conditions to which they are subjected during transport and use; and (e) the environmental conditions encountered during data collection. Assuming ideal environmental conditions such that the last uncertainty can be neglected, the SeaWiFS ground truth uncertainty budget can be satisfied only if each of these uncertainties is of the order of 1–2% (four sources of uncertainty combined in a quadrature sum of 3.5% requires that each uncertainty be ~1.8%). As a general description, this degree of uncertainty constitutes the so-called 1% radiometry; in other words, uncertainty sources must be kept at approximately the 1% level if the overall uncertainty budget is to be achieved.

The difficulty of working at the 1% level is well demonstrated when one considers the magnitude of the perturbations in the proximity of a large structure as a specific example. This is an appropriate choice, because platform perturbations are a recurring problem for all optical methods. These perturbations are made more complex according to the Sun's orientation with respect to the structure, and they differentially influence the data obtained by above- and in-water methods. For example, from the perspective of the in-water light field, investigations within 5–10 m of an offshore tower show significant effects of the structure: approximately 3–8% for

S. Hooker (stan@ardbeg.gsfc.nasa.gov) is with the Laboratory for Hydrospheric Processes, Greenbelt, Maryland 20771. G. Zibordi is with the Joint Research Centre, Institute for Environment Sustainability, I-21020 Ispra (VA), Italy.

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clear-sky conditions and as much as 20% under overcast conditions.[4] Similar levels of uncertainty have also been estimated for in-water measurements from a ship.[5]

Although in-water optical measurements have been used successfully for deriving water-leaving radiances and are continually used for calibrating and validating remote-sensing products from ocean color sensors,[3] above-water measurements form an alternative that remains to be similarly exploited. For both approaches an extensive set of ocean optics protocols (hereafter referred to as the Protocols) was recommended,[6] revised,[7] and updated.[8–10] If there is an area of the sea surface that is free of perturbations from the measurement platform, the basic above-water approach assumes that the total radiance measured at the uncontaminated sea surface, $L_T(\lambda)$, is a combination of $L_W(\lambda)$ plus two sources of reflected light, or glint: the sky and the Sun. If one minimizes the latter by pointing the measurement instruments at least 90° away from the Sun's plane (but not into any perturbations associated with the platform), the only quantity needed for retrieval of $L_W(\lambda)$ from $L_T(\lambda)$ is an estimate of the contribution of the sky's radiance, $L_i(\lambda)$.

From a measurement perspective the above-water approach is more restrictive than the in-water one, because there is no reliable mechanism for floating an above-water system away from a measurement platform (which is easily and effectively accomplished for an in-water system), so all above-water measurements are made in close proximity to a large structure. Furthermore, above-water systems cannot be deployed in arbitrary locations, because a stable and accessible mounting location is needed to ensure the required precision for pointing the sensors with respect to the Sun, the sea surface, and the sky. Note that the accessibility requirement becomes less important for a robotic system because only limited visits associated with maintaining the equipment are required; there is no need for an operator to satisfy the pointing requirements because this is done automatically.

The proximity of the sampling platform is parameterized as the perpendicular distance (denoted x) from the side of the sampling platform to the center of the area on the sea surface observed by the sea-viewing sensor, the so-called surface spot, which is set by the field of view (FOV) of the radiometer (or the overlapping FOVs of a multiaperture sensor). All above-water methods require the sea-viewing radiometer to be pointed away from the Sun to prevent specular reflection of sunlight, or sun glint. Consequently, the orientation of the apparatus that positions the sea sensor with respect to the Sun as well as with respect to the sampling platform determines how far the surface spot is away from the sampling platform and, thus, the magnitude of x.

For a system affixed to the edge of a sampling platform (perhaps mounted on the railing) and free to rotate, the sea-viewing sensor's FOV traces out a circular arc on the sea surface. Assuming no unusual geometry (such as a corner mount on a square platform oriented obliquely to the solar plane) and a nadir-viewing angle of ~40° (the usual case), the possible values of x range from approximately 0, the full-angle FOV (FAFOV) of the sensor must view only water and no part of the sampling platform, to a maximum value that is approximately equal to the height of the sensor above the water. Note that the maximum x value is obtained when the sensor is pointed 90° away from the side of the platform (i.e., when it is oriented perpendicular to the superstructure).

The Protocols recognize[10] that the above-water "radiance measurements should be made from a location that minimizes both the shading and reflections" from the platform superstructure, but they do not provide any guidance as to how to determine when platform perturbations have been appropriately minimized or what levels of contamination are considered acceptable. The Protocols suggest, however, that "a good position for measuring the water-leaving radiance may often be found near the bow of the ship." Although this clearly suggests a location where the cross-sectional area of the sampling platform is minimized and provides a viewing orientation that allows the sea-viewing sensor to measure an undisturbed sea surface (even when a vessel is underway), it does not provide any instructions as to how to site an above-water system on an alternative, more symmetrical structure, such as an offshore oceanographic tower. More importantly, no metrics are provided in terms of a conveniently measured aspect of the sampling, such as x or the azimuthal pointing of the sensor, to permit an individual investigator to determine what portion of the sampling space will yield sufficiently uncontaminated data for calibration and validation activities.

For above-water measurements (recall that the sea-viewing sensor is never pointed directly into a shadow), platform perturbations are a combination of three effects: (a) the shadow cast by the platform outside the FOV of the sensor but within the attenuation path lengths defined by the inherent optical properties of the water, (b) the interaction of the upward (in-water) radiant field with the submerged portion of the platform, and (c) the reflections off the sea surface from the interaction between the downward (above-water) radiant field and the exposed superstructure. The last-named effect is expected to be the most important for above-water measurements, because the Sun and the sky are the light sources for the final perturbation and they are significantly more intense than the in-water radiant field.

Because the perspective adopted here is based on the 1% radiometry needed for calibration and validation exercises, the thresholds or quantification limits are tied to keeping uncertainties at the 1% level. The objective of this study is to determine empirically the magnitude and the spatial extent of the perturbation—principally the superstructure reflection—from an offshore tower. The culmination of the inquiry is to provide sampling metrics for establishing what data, collected as part of a generalized above-water methodology, will not be contaminated with platform perturbations above the 1% level, thereby permitting their use in calibration and validation activities.