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Abstract

The AERONET-OC network aims at producing standardized measurements of normalized water leaving radiance performed at different sites with identical measuring systems and protocols, calibrated using a single reference source and method, and processed with the same code. The current document provides guidelines for the identification and set-up of new systems complying with requirements for satellite ocean color applications.

Introduction

The Aerosol Robotic Network (AERONET) is a system of globally-distributed autonomous sun-photometers established in the early 1990s to support atmospheric studies at various scales through standardized measurements of the direct sun irradiance and sky-radiance (Holben *et al.* 1998). AERONET has been instrumental to the investigation of aerosol optical properties, the creation of global aerosol climatology, and the validation of atmospheric remote sensing products. Since 2006, the network has been expanded through a new component called AERONET – Ocean Color (AERONET-OC) which provides the additional capability of determining the radiance emerging from the sea — from which the so-called normalized water-leaving radiance, L_{WN}, is derived — with modified sun-photometers installed on offshore fixed platforms. The ultimate purpose of AERONET-OC is the production of *standardized measurements performed at different sites with identical measuring systems and protocols, calibrated using a single reference source and method, and processed with the same code* (Zibordi *et al*. 2006a).

In agreement with accuracy requirements for the Global Earth Observation System of Systems (GEOSS), AERONET-OC strengthens the capability to trace uncertainties in products from different Earth Observation (EO) systems by providing a time-series of highly consistent *in situ* data collected at coastal sites exhibiting different marine bio-optical properties (Zibordi et al. 2006b). General guidelines are here provided to help identifying and setup additional sites satisfying the AERONET-OC measurement requirements for satellite ocean color applications.

Description of AERONET-OC systems

The CE-318 autonomous sun-photometer measures: *i.* the direct sun irradiance $E(\lambda,\theta_0, \phi_0)$ as a function of λ, sun zenith angle θ_0, and sun azimuth angle ϕ_0, for the retrieval of the atmospheric optical thickness; and *ii.* the sky-radiance $L_i(\lambda,\theta',\phi)$ in a wide range of directions identified by the viewing angle θ' and azimuth angle ϕ, for the retrieval of the atmospheric scattering phase function. In addition to these atmospheric observations, AERONET-OC systems (i.e., CE-318 sun-photometers modified to meet requirements for above water radiometry) perform radiance measurements with a full angle field of view of 1.2° to determine the total radiance from the sea, $L_T(\lambda,\theta,\varphi)$, and the sky-radiance, $L_i(\lambda,\theta',\varphi)$, at relative azimuth angle with respect to the sun, φ, and with $\theta = \pi - \theta'$. A feature of the system, useful for applications independent from AERONET-OC, is the possibility of changing some of the parameters defining the measurement sequence (i.e., θ and φ, the gain for each channel, and the numbers N_T and N_i of above-water and sky observations for determining $L_T(\lambda,\theta,\varphi)$ and $L_i(\lambda,\theta',\varphi)$, respectively).

The most recent AERONET-OC system configuration performs ocean color measurements at the 412, 443, 488, 531, 551 and 667 nm center-wavelengths. Additional measurements are performed at 870 and 1020 nm for quality checks, turbid water flagging, and for the application of alternative above-water methods (Zibordi *et al.* 2002). These center-wavelengths and additionally that at 940 nm, were selected to guarantee basic AERONET atmospheric aerosol and water vapor monitoring capabilities, and to support essential validation activities for current ocean color EO systems.

In agreement with assessed measurement schemes, $L_T(\lambda,\theta,\varphi)$ and $L_i(\lambda,\theta',\varphi)$ values are determined at $\theta = 40°$ and $\varphi = 90°$. Larger φ values (e.g., $\varphi = 135°$; Mobley 1999), which are considered more appropriate than $\varphi = 90°$ for above-water observations, might lead to perturbations in radiometric measurements due to the deployment superstructure itself or its shadow. Details on the AERONET-OC sea-viewing measurement sequence were already given elsewhere (Zibordi *et al.* 2004). However, a summary is also provided here for the benefit of completeness.

Each sea-viewing measurement sequence, which is executed every 30 minutes within ±4 hours around the local noon, comprises:

i. A series of direct sun measurements $E(\lambda,\theta_0,\phi_0)$ acquired at all channels for the determination of the aerosol optical thickness $\tau_a(\lambda)$, a quantity required for the determination of $L_{WN}(\lambda)$;

ii. A sequential set of N_T sea-radiance measurements for determining $L_T(\lambda,\theta,\varphi)$ and of N_i sky-radiance measurements for determining $L_i(\lambda,\theta',\varphi)$, serially repeated for each λ.

If the sun is cloud covered, and consequently $E(\lambda,\theta_0,\phi_0)$ measurements are automatically stopped because of the low irradiance detected, the whole measurement sequence is cancelled. The sky and sea measurements for determining $L_i(\lambda,\theta',\varphi)$ and $L_T(\lambda,\theta,\varphi)$ are performed with N_i=3 and N_T=11, respectively: the larger number of N_T measurements, when compared to N_i, is suggested by the higher environmental noise (mostly produced by wave perturbations) affecting the former measurements during clear-sky.

Deployment requirements for AERONET-OC radiometers

The accurate sun-tracking required for SeaPRISM measurements imposes that the deployment platform is a grounded structure. Deployment positions on any grounded structure with height and shape minimizing sea-spray contamination of the measuring unit, are those allowing for unobstructed sea observations at the maximum possible distance from the superstructure at the time of overpass of ocean color EO systems. Optimum deployment positions are hence in the upper most western part of superstructures. Recalling that the minimization of superstructure perturbations in above-water radiometric measurements requires observations of the sea surface at distances at least equal to the superstructure height (Hooker *and* Zibordi 2005), it is suggested that AERONET-OC systems are deployed through dedicated platforms extending a few meters outside the main structure.

AERONET-OC systems are operated from fixed platforms like lighthouses, oil derricks, and research towers, normally located in coastal regions. As a consequence the use of AERONET-OC L_{WN} to assess satellite ocean color radiometric products might be challenged by: *i.* high spatial variability of seawater bio-optical properties; *ii.* bottom reflectance in shallow waters; *iii.* adjacency effects in satellite data products due to the high albedo of the nearby mainland with respect to that of the sea.

Differences of orders of magnitude between satellite and ground spatial resolutions might affect the comparability of space and *in situ* data products. The related uncertainties can be quite marked in coastal regions exhibiting a high heterogeneity in the spatial distribution of bio-optical properties. But, assuming random changes in spatial and time variability of marine bio-optical properties, the uncertainties can be minimized by increasing the number of *in situ* observations either in space or time, and producing match-ups with averaged *in situ* data. It is however expected that, without averaging *in situ* observations, comparisons performed with a relatively vast number of match-ups would exhibit larger uncertainties (i.e., scattering) with respect to averaged *in situ* data, but the same systematic differences (i.e., bias).

Bottom reflectance in shallow waters might lead to an overestimate of L_{WN} in both satellite and *in situ* data products. This suggests that operational *in situ* radiometric observations for the assessment of satellite ocean color products should be collected at coastal sites not appreciably affected by bottom perturbations. A study (Zibordi et al. 2009), specifically focused on AERONET-OC measurements and relying on the equation proposed by Maritorena *et al.* (1994) to quantify the bottom effects in subsurface reflectance data, presented the water depths at which L_{WN} measurements are increased by 1% by bottom perturbations due to a Lambertian seabed with reflectance ρ_b=0.10. Results indicate effects lower than 1% for depths larger than approximately 50 m. At smaller depths, the uncertainties mostly depend on the seawater optical properties. For instance, with diffuse attenuation coeficient K_d=0.1 m^{-1} and water reflectance R=0.05, the perturbation is lower than 1% for a bottom depth larger than 20 m.

Adjacency effects are due to the contiguity of surfaces with different spectral albedo and are an additional source of uncertainty in optical remote sensing. In the case of marine regions, these effects produce an increase of the radiance detected from space over the sea nearby the coast and largely vary in space with the spectral albedo of the land surface, the aerosol load and the observation and illumination geometries (Santer and Schmechtig 2000). These perturbations are small in the blue spectral region because of the closeness between land and sea albedo. Differently, perturbations become very high in the near infrared. A study (Zibordi et al, 2009) generically addressed the overestimate of the sea spectral albedo derived from space at nadir view as a function of the distance from the coast assuming a continental aerosol and two half-Lambertian-surfaces (i.e., land and sea). Results determined for typical coastal conditions characterized by continental aerosol, cropland-urban ecosystem and sun zenith θ_0=30°, indicate that the absolute sea albedo determined from space at approximately 5 nautical miles from the coast is overestimated by 4 and 5% at 667 and 551 nm, respectively, and by more than 20% at 870 nm. At 10 nautical miles from the coast the overestimate falls below 2% at 551 and 667 nm, and 10% at 870 nm. These purely illustrative results based on theoretical analysis suggest that, as a rule of thumb, observations performed at distances greater than 5-10 nautical miles from the main land might be considered suitable for validation studies even though perturbations due to adjacency effects might be expected in satellite products. *In situ* measurements performed at shorter distances are however valuable to support investigations on the minimization of adjacency effects in satellite derived data products.

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