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Variability in optical particle backscattering in contrasting bio-optical oceanic regimes

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Abstract

Variability in the optical particle backscattering coefficient (b_{bp}) is investigated in oceanic waters from two sites, namely the BOUée pour l'acquiSition d'une Série Optique à Long termE site in the northwestern Mediterranean Sea and the Plumes and Blooms stations in the Santa Barbara Channel off Southern California. Data from these two sites span two orders of magnitude in b_{bp} and likely cover typical open ocean values. A significant relationship is found between b_{bp} at wavelengths of 442 and 555 nm and chlorophyll concentration. However the large spread in this relationship makes chlorophyll a poor predictor of b_{bp}. The relationship between b_{bp} and the particulate beam attenuation coefficient at 660 nm is tighter for both sites, indicating covariability of the particle size ranges that determine both coefficients. A detailed study of the seasonal changes of the b_{bp} vs. chlorophyll relationship reveals that this bio-optical relationship might be best described as a succession of distinct regimes with rapid transitions from one to another. The backscattering ratio ($\tilde{b}_{bp}$; the ratio of b_{bp} to total particulate scattering, b_p) ranges from about 0.2% to 1.5%, which is similar to previously reported values. The relationship between $\tilde{b}_{bp}$ and chlorophyll was not significant, while values of the backscattering ratio varied spectrally.

Optical backscattering refers to the scattering of visible electromagnetic radiation in the backward direction with respect to the direction of propagation. The backscattering coefficient, b_b (m^{-1}; see Table 1 for symbol definitions and units), is an inherent optical property (IOP; Preisendorfer 1961) and a function of the volume scattering function (VSF), $\beta(\lambda,\theta)$ (VSF with units m^{-1} steradian^{-1} [sr^{-1}], where θ is the scattering angle [$\theta = 0$ for the direction of propagation] and λ the wavelength), through

$$b_b(\lambda) = 2\pi \int_{\pi/2}^{\pi} \beta(\lambda,\theta)\sin(\theta)d\theta \qquad (1)$$

Seawater, inorganic and organic living or nonliving particles, and bubbles all additively contribute to b_b. Determining how the relative contributions of these components vary as a function of the physical and bio-optical state of oceanic waters remains an elusive task (Stramski et al. 2004). This work focuses on the role of particles with regard to optical backscattering. In the following, coefficients pertaining to pure seawater will be identified by the 'w' subscript, whereas 'p' will indiscriminately indicate particles, and 'φ' will specifically refer to phytoplankton. Hence, backscattering by particles, b_{bp}, can be described as follows:

$$b_{bp}(\lambda) = b_b(\lambda) - b_{bw}(\lambda) \qquad (2)$$

The scattering coefficient of pure seawater (b_w, with $b_{bw} = b_w/2$) has been reassessed by Zhang et al. (2009) and Zhang and Hu (2009). Their parameterization includes the effects of temperature and salinity. It is used here and provides very close results compared to the work of Twardowski et al. (2007). The shape and magnitude of the particle VSF for angles $> 90°$—hence, the magnitude of b_{bp}—are determined by the concentration of particles, their index of refraction (composition), their shape, and by the particle size distribution (PSD) over the size range that matters for the wavelengths under consideration. To remove the first-order effects of particle concentration, the particle backscattering ratio (or backscattering probability) is defined as

$$\tilde{b}_{bp}(\lambda) = b_{bp}(\lambda)/b_p(\lambda) \qquad (3)$$

where b_p is the particulate scattering coefficient.

The importance of determining spectral values of b_{bp} in the ocean stems from the tight link to essential physical and chemical characteristics of particles (Boss et al. 2004*a*,*b*). Accurate determinations of b_{bp} carry information about the composition of particles (Twardowski et al. 2001; Boss et al. 2004*b*) and potentially information on the relative contributions of living and nonliving (mineral) particulates. When spectral b_{bp} measurements are available, parameters of a log-linear PSD can be estimated (with some limitations; Kostadinov et al. 2009). Understanding the PSD has tremendous importance because it provides a measure of the structure and functioning of the pelagic ecosystems (Le Quéré et al. 2005; Kostadinov et al. 2010), can be used to constrain particle sinking rates, and can aid in elucidating the ocean's role in carbon sequestration.

Accurate b_{bp} determinations are also of paramount importance for the interpretation of the remotely sensed signal provided by satellite-borne ocean color sensors

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