

## More about Inherent Optical Properties

*Inherent Optical Properties (IOP)* must be measured for development and validation of the ocean color semi-analytic case 2 chlorophyll *a* algorithm. This algorithm is based on an explicit theoretical function of the ratio of backscattering to absorption,  $b_b(\lambda):a(\lambda)$ . This ratio is also an important factor in the BRDF models underlying the exact normalization of water-leaving radiance for solar and viewing azimuth and zenith angles (Volume III, Chapter 4). Due to recent advances in instrumentation, it is now practical to routinely measure *in situ* profiles of *absorption*  $a(z,\lambda)$ , *beam attenuation*  $c(z,\lambda)$  and *backscattering*  $b_b(z,\lambda)$  coefficients. The scattering coefficient may therefore also be obtained as  $b(z,\lambda) = c(z,\lambda) - a(z,\lambda)$ . The IOP also provide critical factors in the Gordon and Ding (1992) model used to correct upwelled radiance and irradiance measurements for instrument self shading. Future algorithm development and validation experiments involving these algorithms must, therefore, include absorption, beam attenuation, and backscattering measurements. It is anticipated that new instruments, now under development and testing, will allow *in situ* measurements of the volume scattering function  $\beta(z,\lambda,\Psi)$  (Volume I, Chapter 2 and Volume IV, Chapter 5). Measurements of  $\beta(z,\lambda,\Psi)$  will be very useful in advancing remote sensing reflectance models and algorithms involving the BRDF (Volume III, Chapter 4).

The *particle absorption coefficient*,  $a_p(z,\lambda)$ , which is comprised of absorption by living, dead, and inorganic particles, is a useful variable for modeling the portion of solar energy that is absorbed by phytoplankton and bacteria. A laboratory spectrophotometer may be used to measure  $a_p(z,\lambda)$  of particles filtered from seawater samples collected at depth  $z$ , or it may be computed as the difference between *in situ* measurements with a pair of filtered (CDOM absorption) and unfiltered (total absorption) instruments.

The *colored dissolved material (CDOM) absorption coefficient*,  $a_g(z,\lambda)$ , is an important contributor to total absorption in many coastal waters. Because CDOM, variously referred to as *gelbstoffe*, *gilvin*, or *yellow-matter*, absorbs very strongly in the blue, its undetected presence can create large regional uncertainties in chlorophyll *a* retrievals from ocean color image data. The CDOM absorption coefficient  $a_g(z,\lambda)$  may either be measured *in situ* by installing a 0.2  $\mu\text{m}$  filter in the water intake port of an absorption and beam attenuation meter, or in the laboratory using a spectrophotometer to measure absorption by filtered seawater, typically over a 10 cm path.

The *non-pigmented particle absorption coefficient*,  $a_d(z,\lambda)$ , accounting for absorption of light by detritus (or tripton), represents a major loss of light which would otherwise be available to the phytoplankton component of the marine hydrosol. In many cases, absorption by detritus is a significant term in the marine radiative transfer processes, and its determination is useful for phytoplankton production models and for modeling the light field. The spectral absorption coefficient  $a_d(z,\lambda)$  using the  $a_p(z,\lambda)$  filters, after they are washed with hot methanol to remove phytoplankton pigments (Volume IV, Chapter 4).

### Definition of the coefficients of Absorption, Scattering and Beam Attenuation

Consider a narrow collimated beam, of cross-sectional area  $\Delta a$ , of monochromatic spectral energy flux  $\Phi_i(\lambda)$ ,  $\mu\text{W nm}^{-1}$ , incident normal to the  $xy$ -plane at the origin of Figure 2.2. As the flux is transmitted

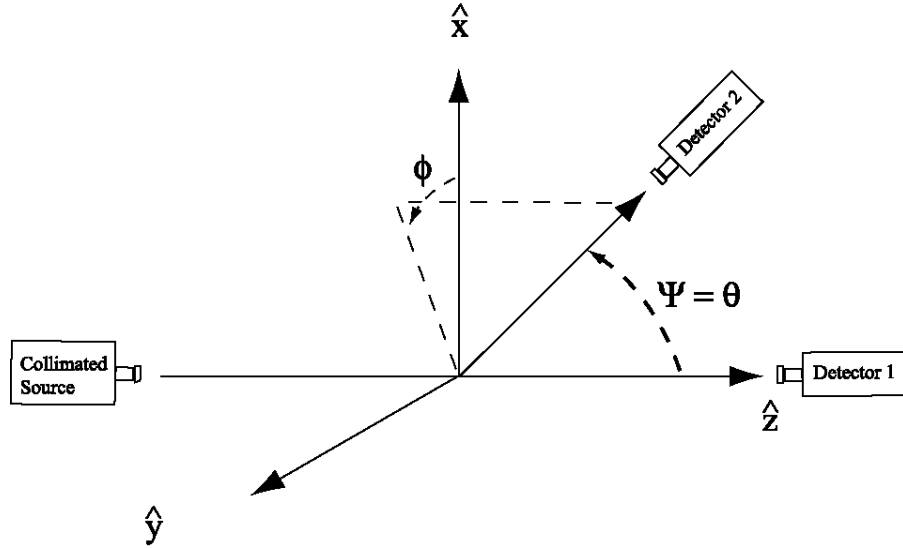


Figure 2.2: A local coordinate frame rotated to align the source and detector-1 locations along the z-axis. Detector-2, located in direction  $(\theta, \phi)$ , views the origin to measure radiant flux scattered from the transmitted beam through angle  $\Psi$ . This local coordinate system is usually adopted for beam transmissometers and instruments designed to measure the volume scattering function (VSF)  $\beta(\lambda, \Psi)$ , because the scattering angle  $\Psi$  is more easily visualized and computed in this framework than in the representation of Figure 2.1. For a beam transmissometer, the path length is simply the distance between the source and detector-1 along the z-axis. For a VSF meter, the working volume is defined by the intersection of the field of view of detector-1 with the beam geometry of the source.

over a distance  $\Delta z$  along the z-axis<sup>1</sup>, a fraction  $A(\lambda) = \frac{\Phi_A(\lambda)}{\Phi_i(\lambda)}$  will interact with and be absorbed by water molecules, or particles, another fraction  $B(\lambda) = \frac{\Phi_B(\lambda)}{\Phi_i(\lambda)}$  will be scattered out of the beam into other directions, and the remaining fraction  $T(\lambda) = \frac{\Phi_T(\lambda)}{\Phi_i(\lambda)}$  will be transmitted through the volume

$\Delta a \Delta z \text{ cm}^2 \text{ m}$ . The dimensionless fractions  $A(\lambda)$ ,  $B(\lambda)$ , and  $T(\lambda)$  are, respectively, the spectral absorptance, spectral scatterance, and spectral transmittance of the medium (*e.g.*, Mobley 1994). If there are no other sources in the medium,  $A(\lambda) + B(\lambda) + T(\lambda) = 1$ , and in the limits  $\Delta a \rightarrow 0$  and  $\Delta z \rightarrow 0$ , we may write

$$\lim_{\Delta a \rightarrow 0} \lim_{\Delta z \rightarrow 0} \left\{ \frac{\Phi_T(\lambda) - \Phi_i(\lambda)}{\Delta a \Delta z} = - \frac{A(\lambda) + B(\lambda)}{\Delta z} \frac{\Phi_i(\lambda)}{\Delta a} \right\}, \mu\text{W cm}^{-2} \text{ nm}^{-1} \text{ m}^{-1}. \quad (2.16)$$

Since by definition  $E(\lambda) = \frac{\Phi(\lambda)}{\Delta a}$ , (2.16) may be written in differential form in terms of incident spectral irradiance as

$$\frac{dE_i(\lambda)}{dz} = -[a(\lambda) + b(\lambda)] E_i(\lambda) = -c(\lambda) E_i(\lambda), \mu\text{W cm}^{-2} \text{ nm}^{-1} \text{ m}^{-1}, \quad (2.17)$$

<sup>1</sup> In the present context, the variable  $z$  in Fig. 2.2 does not correspond to depth in the water column, as it does elsewhere throughout this document. In Fig. 2.2 and the introduction of IOP, the  $z$ -axis defines only the direction of the optical path of radiant flux transmitted from the collimated source to “detector 1”, and the angular orientation of the coordinate frame in the medium is arbitrary and irrelevant.

where  $a(\lambda)$  is the *spectral volume absorption coefficient*  $a(\lambda) = \lim_{\Delta z \rightarrow 0} \frac{A(\lambda)}{\Delta z}$ ,  $\text{m}^{-1}$ ,  $b(\lambda)$  is the *spectral volume scattering coefficient*  $b(\lambda) = \lim_{\Delta z \rightarrow 0} \frac{B(\lambda)}{\Delta z}$ ,  $\text{m}^{-1}$ , and  $c(\lambda)$  is the *spectral volume beam attenuation coefficient*,

$$c(\lambda) = a(\lambda) + b(\lambda), \text{m}^{-1}. \quad (2.18)$$