Lab: Particulate Absorption, Scattering, and the beam attenuation with ac meters (Lab 3)
22nd *July 2013*

SAMPLES
Some groups will measure Darse-de-Villefranche water, the other will measure a culture of phytoplankton.

INTRODUCTION
The particulate absorption coefficient can be resolved into a phytoplankton component (phyt; primarily pigments) and a non-pigmented, absorbing particle component (NAP), a term introduced by Babin et al. (2003). NAP should be considered as absorption of non-methanol extractable materials, because water-soluble pigments such as the phycobilins are not removed from the filter pad by methanol. Absorption coefficients are additive, hence:

$$\mathbf{a}_{\mathbf{part}}(\lambda) = \mathbf{a}_{\mathbf{phyt}}(\lambda) + \mathbf{a}_{\mathbf{NAP}}(\lambda) \quad .$$

Phytoplankton absorption arises primarily from absorption by polar pigments, and can be decomposed into absorption by photosynthetic (PS) and photoprotective (PP) pigments by using fluorescence excitation technique (Culver and Perry, 1999), which we will not do in this lab:

$$\mathbf{a}_{\mathbf{phyt}}(\lambda) = \mathbf{a}_{\mathbf{PS}}(\lambda) + \mathbf{a}_{\mathbf{PP}}(\lambda)$$

NAP particles are composed of suspended inorganic mineral particles (min); organic particles including cell material that absorbs but it not extracted with methanol, detrital material and non-phytoplanktonic living organisms (d); and non-methanol extractable pigments such as phycobilins (other, typically assumed to be insignificant, which is not always true):

$$\mathbf{a}_{\mathbf{NAP}}(\lambda) = \mathbf{a}_{\mathbf{min}}(\lambda) + \mathbf{a}_{\mathbf{d}}(\lambda) + \mathbf{a}_{\mathbf{other}}(\lambda) \quad .$$

In practice, is difficult to physically separate these subcomponents; we will not attempt to do so. (N.B.: in older literature, the term detrital absorption, a_d, was commonly used in place of non-algal particles, a_{NAP}, and should not be confused with the a_d term above which does include living and non-living detrital organic matter.)

The particulate absorption coefficient can be resolved from total absorption and filtered absorption measured with an ac-9 and ac-s. While we will perform this in the laboratory, it can also be implemented in the field with:

(1) A single instrument – by taking a profile with the instrument, placing a filter on the intake port and profiling a second time. The difference between total and filtered absorption is the particulate absorption:

$$a_{part}(\lambda) = a_{Total}(\lambda) - a_{CDOM}(\lambda)$$

where $a_{Total}(\lambda)$ is understood to mean total absorption of particles minus absorption by water and CDOM.

(2) Two ac9s, one with a filter on its intake port. A single profile is performed and the two sets of observations are rectified for differences in flow rates (see Roesler and Boss 2008) and then the difference is used to compute $a_{part}(\lambda)$.

A third implementation of this approach, applied to a single instrument in-flow through mode

involves an automated filter switch into position at short intervals (see Slade et al. 2011). N.B.: the ac-instruments do not collect all the scattered light. Hence a correction that relies, in the least, on the simultaneous measurements performed with the c-side, needs to be implemented.

The volume scattering function, VSF or β, is a fundamental IOP that together with absorption, **a**, (and assuming no inelastic scattering) uniquely determines the subsurface light field for given boundary conditions (e.g. incoming light, bottom reflectance, etc.).

In this lab we will focus on the beam attenuation (c), the scattering coefficient (b), which relate to a (absorption) and β as follows:

$$b = 2\pi \int_{\theta_0}^{\pi} \beta \sin\theta d\theta$$

$$c = a + b$$

Where θ_0 is the acceptance angle of the instrument used (e.g. 0.93° for the ac-9).

As we learned for absorption, scattering can also be decomposed to the sum of scattering by different components of the medium under investigation. For seawater, its components – pure water, salts, dissolved materials, particles (inorganic particles, living and nonliving organic particles, bubbles) – all have important influences on scattering for a given condition. In general it has been found that pure water, salts, organic and inorganic material dominate scattering with bubbles being important during rough seas and where waves break.

In today's lecture you learned that the beam attenuation (excluding the contribution by water) has, to a large degree, a smooth spectrum because it is comprised of 1) CDOM with it characteristic smooth exponentially decreasing absorption and attenuation as function of wavelength and 2) particulate attenuation that in most oceanic conditions is well represented as a power-law function of wavelength:

$$c_{pg}(\lambda) = c_g + c_p \sim c_g(\lambda_0) e^{-s(\lambda-\lambda_0)} + c_p(\lambda_0)\left(\frac{\lambda}{\lambda_0}\right)^{-\gamma} \sim c_{pg}(\lambda_0)\left(\frac{\lambda}{\lambda_0}\right)^{-\gamma_{pg}}.$$

where c_{pg} is the total beam attenuation coefficient (less water), c_g is the beam attenuation of the dissolved material, c_p is the particulate beam attenuation, s is the spectral slope of dissolved attenuation, and γ is the spectral slope of particulate beam attenuation.

Since an absorbed photon is not scattered, the scattering coefficient of materials other than water (b=c-a) does not have a smooth spectrum as function of wavelength and has a shape whose local maxima and minima mirrors that of the particulate absorption spectrum (in reality, there exist some mismatch, termed 'anomalous dispersion', that can be seen in instruments with high spectral resolution, due to a change in the real part of the index of refraction near absorption maxima).

IN THE LAB:

1) Clean the ac-meter prior to measurements with lens paper and ethanol. Measure the temperature of every sample – **at the time of the measurement**, as it affects both absorption and scattering. Assume salinity is 38.

2) Run a Milli-Q water cal in both a-tube AND c-tube of the ac-meter. Save the files in your group folder.

3) Run filtered seawater **OR** culture filtrate in both a- and c-tubes (the one asso.

4) Run whole, unfiltered seawater **OR** culture in both a- and c-tubes.

In all cases collect about 1min of data. You will take the median of these to compute 1 spectra of each absorption and at

ASSIGNMENT (for instructions on how to analyze the data see below**)**
Coordinate with the other group with whom you simultaneously worked and make sure that the following questions are answered (that is, divide and conquer):

1. How did the pure water calibration for each ac-meter compare with the previous calibration?
2. Compute a_p and c_p for each set of observations – Compute the measured particulate attenuation and absorption as the difference between the measurements of whole samples and filtered samples (if you ran them at the same temperature, you will not need to temperature and salinity correct them. Why?)
3. Apply the following scattering corrections to the measured *particulate* absorption:

1. apply the spectrally flat correction by subtracting the a(715) or another NIR wavelengths offset from $a(\lambda)$.

2. apply the spectrally varying scattering correction (Zaneveld et al., 1994, method 3):

$$a_p(\lambda) = a_{p,measured}(\lambda) - b(\lambda) * \frac{a_{p,measured}(715)}{b_p(715)}$$

where $b(\lambda)=c_{p,measured}(\lambda) - a_{p,measured}(\lambda)$

3. apply the empirical spectrally varying scattering correction of Rottgers et al., 2013:

$$a_p(\lambda) = a_{p,measured}(\lambda) - \{a_{p,measured}(\lambda)\text{-}a'(715)\} * \frac{\left\{c_{p,measured}(\lambda)/0.56 - a_{p,measured}(\lambda)\right\}}{\left\{c_{p,measured}(715)/0.56 - a'(715)\right\}}$$

where $a'(715)=0.212\ a_{p,measured}(\lambda)^{1.135}$

N.B.: When backscattering measurements are available, there exists a correction for the ac-meters that uses those values, e.g., McKee et al., 2008. A paper by Leymarie et al. (2010), assessed the likely uncertainties associated with some of the different corrections.

4. How do the different particulate absorption estimate compare? Plot them on the same graph and assess the differences between them as function of wavelength (in absolute and relative terms).
5. Estimate chlorophyll form the absorption line-height at 676nm (see: Boss et al., 2007, Roessler and Barnard, 2013).
6. Compute the particulate attenuation spectra. Is it well fitted by a power-law? NB: the value of this exponent is related to a bulk size index of the particulate suspension (e.g. Boss et al., 2001).
7. Compute the particulate scattering spectra as the difference between attenuation and corrected absorption (try for all the different scattered corrected ones). Is it well fitted by a power-law?

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