Chlorophyll concentration estimated from irradiance measurements at fluctuating depths

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Abstract

- a new method is presented to retrieve chlorophyll concentration (C) and a yellow substance factor (Y) from downwelling irradiance measurements made at fluctuating depths
- the method requires simultaneous data of downwelling irradiance at 3 wavelengths in the visible and depth
- in model simulations, C and Y were retrieved to within 1% using irradiances at 412, 443 and 555 nm
- in a practical application, this method was found to retrieve C qualitatively but not quantitatively
- this method can be used to interpret data from sensors attached to single-line, bottom-tethered moorings

Introduction

Optical moorings

- useful for vicarious calibration of ocean color satellite sensors
- provide measurements during cloudy periods
- numerous moorings are currently in operation

The problem

- some types of moorings can experience large fluctuations with depth (e.g., single-line, bottom-tethered moorings (**Fig. 1**))
- standard irradiance ratios (e.g., Ed(555)/Ed(443)) used in optical algorithms vary with depth even in homogeneous waters (**Fig. 2**)

JGOFS Moorings

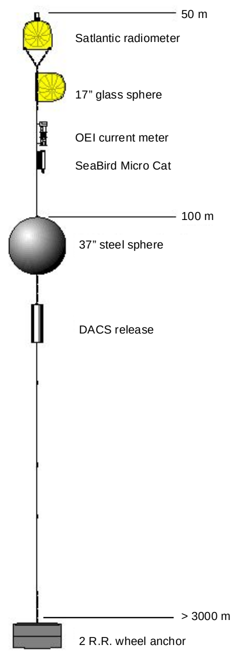

Figure 1: Schematic of optical moorings deployed in the Southern Ocean. *Courtesy of David Reinert (Oregon State University).*

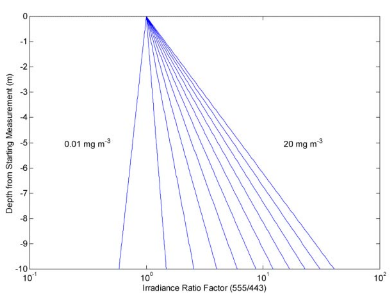

Figure 2: The relationship between the irradiance ratio factor for Ed(555)/Ed(443) and the distance from the reference depth for a range of values of C. The irradiance ratio factor describes the relationship between the irradiance ratio at some depth and the irradiance ratio at a reference depth. The values used for C ranged from 0.01 to 20 mg m^{-3} in steps of 2 mg m^{-3}. The value used for Y was 0.2. The value for C at which the irradiance ratio is independent of depth occurs at approximately 1 mg m^{-3}.

The model

The derived method proceeds as follows:

(1) calculate $\delta_{ji}K$ $[K(\lambda_j,z)-K(\lambda_i,z)]$ from the measurements using the relationship:

$$\delta_{ji}K = \ln[(Ed(\lambda_i,z_n)/Ed(\lambda_i,z_m))*(Ed(\lambda_j,z_m)/Ed(\lambda_j,z_n))]/(z_n-z_m),$$

where $Ed(\lambda,z)$ is the measured downwelling irradiance at wavelength λ and depth z, and the depths z_n and z_m are from measurements made in succession and close in time (<15 minutes apart).

(2) compare the $\delta_{ji}K$ calculated from measurements with $\delta_{ji}K$ calculated from an optical model. For measurements near the sea surface, an appropriate model is:

$$\delta_{ji}K = A(\lambda_i, \lambda_j) + B(\lambda_i, \lambda_j)C(z)^{0.65} + D(\lambda_i, \lambda_j)Y(z)C(z)^{0.65} + E(\lambda_i, \lambda_j)(0.0078-0.0042\log_{10}C)C(z)^{0.62},$$

where A, B, D, and E are spectral constants.

(3) choose one of two methods to solve for C(z) and Y(z):

Minimization method
(i) calculate the modeled $\delta_{ji}K$ for all expected values for C and Y
(ii) choose two different wavelength pairs that show differing relationships between $\delta_{ji}K$, C and Y (e.g., **Fig. 3**)
(iii) match the two values for $\delta_{ji}K$ calculated from measurements to the modeled values, within some chosen error range

Simultaneous equation method
Substitute the values of $\delta_{ji}K$ calculated from measurements into a set of simultaneous equation solutions. For measurements near the sea surface (and a mean cosine of 0.5), an appropriate set of solutions is:

$$C = [(\delta_{443,412}K - 0.686\delta_{555,443}K+0.0753) / 0.0746]^{1.54}$$ and
$$Y=(\delta_{443,412}K + 0.0049 - 0.0107C^{0.65}) / (-0.0625C^{0.65}).$$

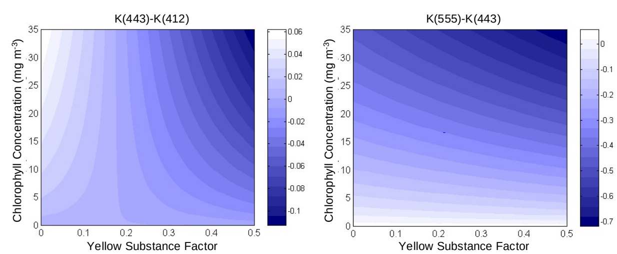

Figure 3: Relationship between $\delta_{ji}K$, C, and Y, over ranges of typical values for C and Y, for (a) $\delta_{443,412}K$ and (b) $\delta_{555,443}K$.

Application

- optical moorings were deployed in the Southern Ocean for 4 months as part of the US-JGOFS Southern Ocean program (**Fig. 1**)
- the moorings experienced depth fluctuations and variations in the magnitude of the irradiance near solar noon (**Fig. 4**)
- preliminary results of estimated chlorophyll concentration using this method are presented in **Fig. 4**
- the temporal trend of the estimated chlorophyll concentration agrees qualitatively with the temporal variation in surface chlorophyll concentrations as measured by SeaWiFS, however the magnitudes differ by a factor of 5.
- The quantitative disagreement between the SeaWiFS data and the mooring estimates may be caused by the poor resolution of the pressure data used.

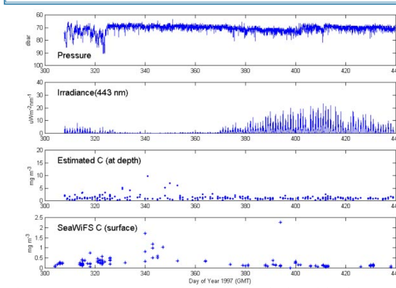

Figure 4: Data from an optical mooring deployed in the Southern Ocean in 1997 compared with SeaWiFS data. The data shown, from top to bottom, are the pressure variations experienced by the sensor, the measured downwelling irradiance at 443 nm, the estimated chlorophyll concentration at the sensor depth near solar noon using the derived method, and the surface chlorophyll concentration derived from SeaWiFS LAC and GAC data in the vicinity, respectively.

Conclusions

- a method was presented to estimate chlorophyll concentrations at the instrument depth from measurements of downwelling irradiance at fluctuating depths
- this method requires accurate, high-precision pressure and optical measurements at high temporal resolutions (< 15 minutes apart)
- C and Y can be estimated using this model by either using a minimization technique or a simultaneous equation technique
- an application of this method to data from the Southern Ocean showed qualitative agreement between the estimated chlorophyll concentration at the sensor depth and surface chlorophyll concentrations as measured by SeaWiFS.

Presented at Ocean Optics XIV, November 1998. Funded by NSF (95 30 507-OPP) and NASA (NAS 5-31360).