Deep--Sea Research I (xxxx) xxxx–xxxx

Contents lists available at ScienceDirect

Deep–Sea Research I

journal homepage: www.elsevier.com/locate/dsri

Seasonal to multi-decadal trends in apparent optical properties in the Sargasso Sea

James G. Allen[a,b,*], Norman B. Nelson[a], David A. Siegel[a,c]

[a] Earth Research Institute, University of California, Santa Barbara, Santa Barbara, California, USA
[b] Interdepartmental Graduate Program in Marine Science, University of California, Santa Barbara, USA
[c] Department of Geography, University of California, Santa Barbara, USA

ARTICLE INFO

Keywords:
Bermuda bio-optics project
Sargasso Sea
Ocean color
Phytoplankton
Chromophoric dissolved organic matter

ABSTRACT

Multi-decadal, monthly observations of optical and biogeochemical properties, made as part of the Bermuda Bio-Optics Project (BBOP) at the Bermuda Atlantic Time-series Study (BATS) site in the Sargasso Sea, allow for the examination of temporal trends in vertical light attenuation and their potential controls. Trends in the magnitude of the diffuse attenuation coefficient, $K_d(\lambda)$, and a proxy for its spectral shape reflect changes in phytoplankton and chromophoric dissolved organic matter (CDOM) characteristics. The length and methodological consistency of this time series provide an excellent opportunity to extend analyses of seasonal cycles of apparent optical properties to interannual and decadal time scales. Here, we characterize changes in the magnitude and spectral shape proxy of diffuse attenuation coefficient spectra and compare them to available biological and optical data from the BATS time series program. The time series analyses reveal a 1.01% ± 0.18% annual increase of the magnitude of the diffuse attenuation coefficient at 443 nm over the upper 75 m of the water column while showing no significant change in selected spectral characteristics over the study period. These and other observations indicate that changes in phytoplankton rather than changes in CDOM abundance are the primary driver for the diffuse attenuation trends on multi-year timescales for this region. Our findings are inconsistent with previous decadal-scale global ocean water clarity and global satellite ocean color analyses yet are consistent with recent analyses of the BATS time series and highlight the value of long-term consistent observation at ocean time series sites.

1. Introduction

The attenuation of sunlight with depth is closely linked to the biological, chemical, and lithogenic constituents in the water column and serves as a useful bio-optical parameter for characterizing a column of water (Smith and Baker, 1978; Morel, 1988). The spectrum of the diffuse attenuation coefficient for downwelling irradiance, $K_d(\lambda, z, t)$, has been modeled as a function of the sum of the constituents that contribute to light attenuation as

$$K_d(\lambda, z, t) = K_w(\lambda) + K_{chl}(\lambda, z, t) + K_{CDOM}(\lambda, z, t) \quad (1)$$

where $K_w(\lambda)$ is the diffuse attenuation due to seawater (Smith and Baker, 1981; Morel et al., 2007), $K_{chl}(\lambda, z, t)$ is the attenuation due to phytoplankton (Siegel et al., 1995; Siegel and Westberry, 2001; Morel and Maritorena, 2001), and $K_{CDOM}(\lambda, z, t)$ is the attenuation due to chromophoric dissolved organic matter (CDOM) (Siegel and Michaels, 1996; Siegel and Westberry, 2001; Morel and Maritorena, 2001). Utilizing satellite remote sensing techniques, ocean color in particular, to assess the biogeochemistry of the global ocean requires knowledge of the different contributions of these constituents to the attenuation of light in the water column. Furthermore, trends in these optical properties reflect changing ecological and biogeochemical processes (Szeto et al., 2011; Siegel et al., 2013). Hence characterizing the spatio-temporal variation of $K_d(\lambda, z, t)$ and its possible drivers provides an optical link between in situ observations and satellite ocean-color observations (e.g., Smith and Baker, 1978; Morel, 1988; Lee et al., 2005).

Here, we take advantage of multi-decadal open ocean time series observations from the Sargasso Sea, where monthly hydrographic measurements began in June 1954 (Schroeder and Stommel, 1969). Since October 1988, the U.S. Bermuda Atlantic Time Series (BATS) has focused on carbon biogeochemistry at seasonal and decadal time scales (Steinberg et al., 2001; Lomas et al., 2013). In January 1992, the Bermuda Bio Optics Program (BBOP) began characterizing the ambient light field as a function of depth and time and to link changes in biogeochemical properties to remote sensing observations (Siegel et al.,

* Corresponding author.
E-mail address: jgallen@eri.ucsb.edu (J.G. Allen).

http://dx.doi.org/10.1016/j.dsr.2016.11.004
Received 8 May 2016; Received in revised form 10 November 2016; Accepted 16 November 2016
0967-0637/ © 2016 Elsevier Ltd. All rights reserved.

1995; Siegel and Westberry, 2001).

To date, BBOP has made more than two decades of nearly uninterrupted, monthly profile observations of apparent optical parameters in the Sargasso Sea. This extended dataset provides the ability to examine seasonal and interannual cycles of optical properties and provides context for the assessment of longer, multi-year trends. Here, we use optical data from the Sargasso Sea to assess seasonal changes and multi-year trends in both the magnitude and the spectral characteristics of light attenuation. We show long term linear increases for the magnitude of diffuse attenuation, but no significant trends in the blue light attenuation ratio. We conclude with a discussion of the relationship between the magnitude and spectral shape proxy of attenuation to phytoplankton and CDOM concentrations and the implications of this relationship on the bio-optical approach for characterizing upper ocean ecosystems.

2. Material and methods

The BATS study site is located around 31°35′N, 64°31′W, 75 km south-east of Bermuda in the oligotrophic waters of the Sargasso Sea. Biweekly to monthly cruises for BATS began in October 1988, with 16–20 cruises conducted each year, and BBOP observations began in January 1992. Vertical profiles of downwelling irradiance and upwelling nadir radiance spectra came from three profiling spectroradiometers deployed sequentially over the course of the time series: the MER-2040 [Biospherical Instruments, San Diego, California (Smith et al., 1984; Smith 1997)], the SeaWiFS Profiling Multichannel Radiometer (SPMR) [Satlantic, Inc. (Mueller et al., 2003)], and the Satlantic MicroPro multispectral profiling radiometer. The spectroradiometers were calibrated with the same standards three times per year at UCSB, and radiometric calibration uncertainties are less than 1% (O'Brien et al., 2000). Vertical optical profiles were collected over depth and wavelength intervals specific to each spectroradiometer. From 1992 to 00, the MER-2040 profiled to 200 m and sampled 12 wavelengths (410, 441, 465, 488, 510, 520, 555, 565, 589, 625, 665, and 683 nm) for downwelling irradiance, $E_d(\lambda,z,t)$, and upwelling radiance, $L_u(\lambda,z,t)$. From 1999 to 2009, the SPMR collected data in the upper 120 m at 8 wavelengths (380, 412, 443, 490, 510, 555, 665, and 683 nm), and from 2009 to 2012, the MicroPro collected data at the same 8 wavelengths down to 100 m.

Measurements of downwelling photosynthetically available radiation (PAR_d) at each depth were calculated by integrating downwelling irradiance over the visible spectrum (400–700 nm), or

$$PAR_d(z,\ t) = \int_{400}^{700} \frac{\lambda}{hc} E_d(z,\ \lambda,\ t)d\lambda, \tag{2}$$

where λ/hc is the conversion factor of an energy flux to a quantum flux. PAR_d values for the top 20 m of each cast were fit to a log regression to approximate $PAR_d(0^-,t)$, which was then used in calculations of the 1% PAR_d depth. Values of PAR_d were determined from the multispectral downwelling irradiance observations using trapezoidal integration over the visible range.

Vertical profiles for the diffuse attenuation coefficient for downwelling irradiance ($K_d(\lambda, z)$) were calculated and processed according to Siegel et al. (1995). Briefly, $K_d(\lambda, z)$ at each depth z is calculated as the inverse slope of a robust least squares regression of the natural logarithm of $E_d(\lambda, z)$ within a 5-m depth interval above and below the depth of interest. Only casts with a solar zenith angle $\theta_{sa} < 50$ degrees were included for analysis. To further reduce the impact of fluctuations in surface irradiance due to clouds and surface wave glinting, $K_d(\lambda, z)$ profiles were also median pass filtered over a 15 m depth window and subsampled at 5 m increments.

$K_d(\lambda, z)$ is an apparent optical property and is hence subsequently dependent on variations of the incident sky radiance distribution. The measured diffuse attenuation coefficients ($K_d(measured)$) were normalized to nadir illumination following methods developed by Gordon (1989). The normalized diffuse attenuation coefficient ($K_d(normalized)$) is estimated as $K_d(measured)$ divided by the diffuse downwelling distribution function, D_0, or

$$K_d(normalized) = \frac{K_d(measured)}{D_0}, \tag{3}$$

where

$$D_0 = \frac{f}{\cos\theta_{sw}} + 1.\ 197(1-f), \tag{4}$$

where f is the fraction of direct solar irradiance to the total and θ_{sw} is the refracted solar zenith angle. This normalization effectively removes the influence of the angular distribution of the incident radiance on values of $K_d(\lambda, z)$. Measurements of direct and diffuse irradiance were not available; hence, clear-sky, direct and diffuse incident irradiance spectra were calculated for each cast using a cloudless marine atmospheric model (Gregg and Carder, 1990) and assumptions for the top of the atmosphere irradiance spectrum (Thuillier et al., 2003), meteorological climatology (Kistler et al., 2001), and ozone climatology (McPeters et al., 2011). The f value used in Equation (4) were computed relative to the clear-sky model of f as

$$f = \left(\frac{E_s}{E_{s\ clear\ sky}}\right) f_{clear\ sky}, \tag{5}$$

where E_s and $E_{s\ clear\ sky}$ are the measured and modeled surface irradiance, respectively, and $f_{clear\ sky}$ is the fraction of direct downwelling irradiance relative to total surface irradiance as modeled using the Gregg and Carder (1990) algorithm. In what follows, values of $K_d(normalized)$ will be referred to as $K_d(\lambda, z)$ throughout the remainder of this paper. Implications of this normalization procedure are discussed in the Discussion section of this paper.

Observations of light absorption by water column constituents via bottle samples began at BBOP in the summer of 1995 (Nelson et al., 1998). Water samples for CDOM spectroscopy were filtered using 0.2-μm Nuclepore filters that had been prerinsed with 500 ml of Milli-Q (Millipore) water, then stored in acid-washed amber glass bottles with Teflon liner caps and kept in the dark at 4 °C until analysis (Mitchell et al., 2000). Estimates of CDOM absorption coefficient spectra were made with a Perkin-Elmer Lambda 18 spectrophotometer and matched 10-cm quartz-windowed cuvettes according to procedures documented in Nelson et al. (1998). Spectra were acquired from 280 to 700 nm, a blank baseline (Milli-Q) was subtracted, and the remainder was converted to absorption coefficients by converting to base e and dividing by the geometric path length of the instrument (0.1 m).

Water samples for the particulate absorption coefficient (4 l) were collected in dark Nalgene bottles, filtered onto 25-mm-diameter Whatmann GF/F glass fiber filters, and were immediately frozen in liquid nitrogen until analysis. Particulate absorption coefficient spectra, $a_p(\lambda)$, were determined using the quantitative filter technique (Mitchell et al., 2000). Optical density spectra (350–700 nm) were made with the Lambda 18 spectrophotometer, a blank baseline (Milli-Q) was subtracted, and the resulting baseline-subtracted optical density spectra were corrected for multiple scattering effects with a beta correction determined using methods described in Nelson et al. (1998) and Morrison and Nelson (2004). Detrital particulate absorption, $a_d(\lambda)$, was estimated using the same procedure after extracting these filters in methanol for a minimum of 4 h at room temperature (Mitchell et al., 2000). The phytoplankton absorption coefficient spectrum, $a_{ph}(\lambda)$, was determined as the difference between $a_p(\lambda)$ and $a_d(\lambda)$.

A subset of the BATS core measurements is used here. CTD profiles and water samples were collected and analyzed according to methods published in Steinberg et al. (2001) and Lomas et al. (2013). From those samples, Chlorophyll a concentrations were derived from high-performance liquid chromatography (HPLC) techniques outlined in Steinberg et al. (2001). The mixed layer depth (MLD) was calculated

Download English Version:

https://daneshyari.com/en/article/5764742

Download Persian Version:

https://daneshyari.com/article/5764742

Daneshyari.com