# Shifting vertical structure of phytoplankton in the Sargasso Sea

Bob Brewin[1], Qi Zheng[1], Johan Viljoen[1], Ella Tanner[1], Xuerong Sun[1], Žarko Kovač[2] & Shubha Sathyendranath[3]

[1]University of Exeter, UK, [2]University of Split, Croatia, [3]Plymouth Marine Laboratory, UK

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## 1. Summary

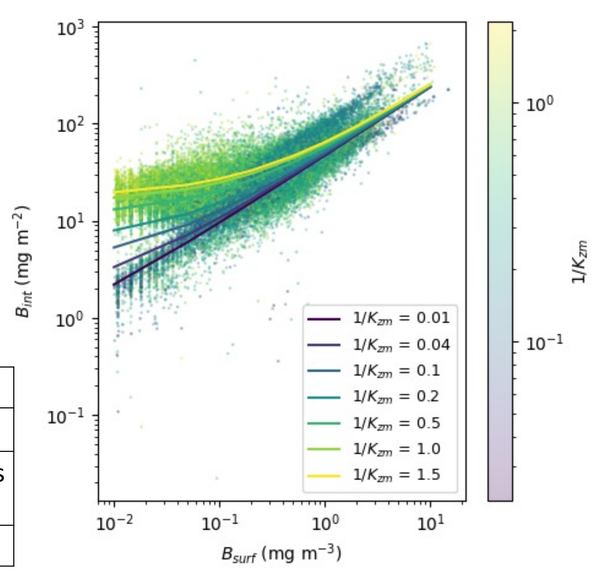
Since 2011, at the Bermuda Atlantic Timeseries Station (BATS), there has been an increase in surface ocean warming and a shoaling of the mixed layer (Lomas et al. 2022). This change has significantly altered the vertical structure of phytoplankton (Viljoen et al. 2024), reducing surface Chl-a, driven primarily by photoacclimation, and increasing subsurface Chl-a, thought to be related to enhanced biomass from increased subsurface light availability (Zheng et al. 2025). Here, we evaluate a very simple empirical model (Tanner et al. 2024) designed to quantify the integrated Chl-a concentration within the euphotic zone, from surface Chl-a, diffuse attenuation ($K_d$) and mixed layer depth ($z_m$) data. We show that the two terms of the model broadly reflect changes in surface and subsurface phytoplankton, by comparing output with two other models: a semi-empirical (conceptual) one (Brewin et al. 2022) calibrated to individual BATS profiles (Viljoen et al. 2024), and a two-layered NPZ box model (Zheng et al. 2025) validated at BATS. We show that all three approaches simulate a reduction in surface Chl-a and an increase in subsurface Chl-a at BATS since 2011. We then force the simple empirical model with satellite fields of surface Chl-a and diffuse attenuation (OC-CCI), and a mixed-layer depth reanalysis product (CMEMS global reanalysis, ORAS), to quantify the spatial extent of this shifting vertical structure.

## (1) Three models

Tanner et al. (2024)

$$B_{int} = \underbrace{\alpha {B_{surf}}^{\beta}}_{\text{Uniform Component } (B_{1,T})} + \underbrace{\frac{\gamma\epsilon[1/K_{zm}]}{\gamma\epsilon + [1/K_{zm}]}}_{\text{Non-uniform Component } (B_{2,T})}$$

| | |
|---|---|
| $B_{int}$ | Total integrated Chl-a (mg m$^{-2}$) |
| $B_{surf}$ | Surface Chl-a (mg m$^{-3}$) |
| $K_{zm}$ | Optical mixed layer depth [$K_d$ times mixed layer depth ($z_m$)] |
| $\alpha, \beta, \gamma, \varepsilon$ | Model parameters |

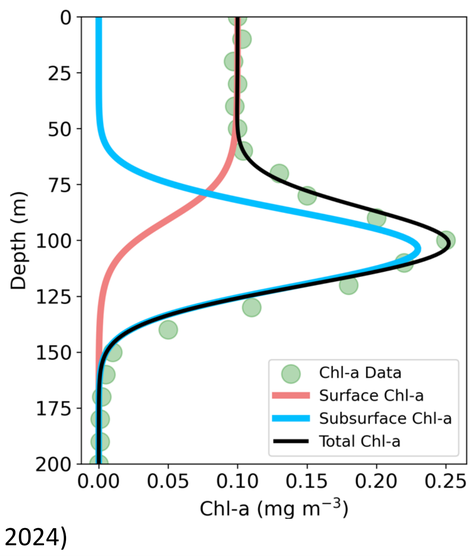



Calibrated to a global array of BGC-Argo floats (see Tanner et al. 2024)

Brewin et al. (2022)

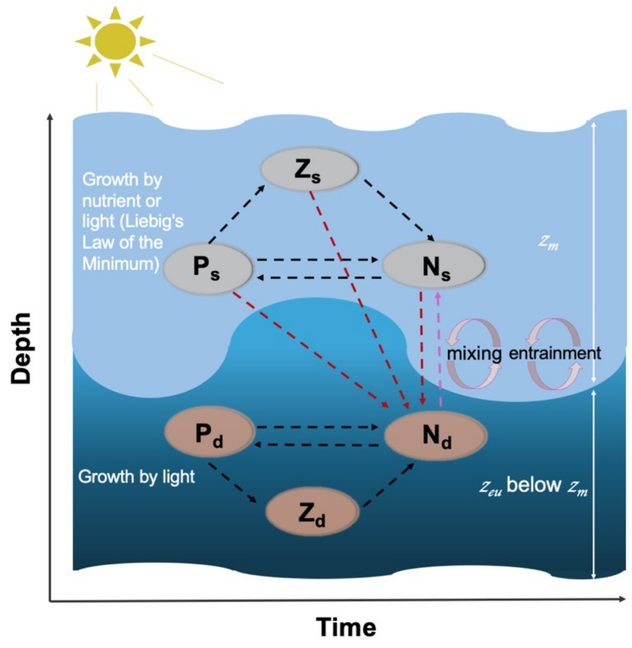
$$B^*(\tau) = 1 - \underbrace{\frac{1}{1 + \exp[-S_1[\tau - \tau_1]]}}_{\text{Rescaled depth-integrated chlorophyll } (B_{1,W})} + \underbrace{B^*_{2,m}\exp\left[-\left(\frac{\tau - \tau_2}{\sigma}\right)^2\right]}_{\text{Rescaled depth-integrated chlorophyll } (B_{2,W})}$$

| | |
|---|---|
| $B^*$ | Chl-a divided by $B_{surf}$ |
| $\tau$ | Optical depth ($K_d$ times depth z) |
| $\tau_1, S_1$ | Parameters of Sigmoid |
| $B^*_{2,m}, \tau_2, \sigma$ | Parameters for Gaussian |




Calibrated to individual BATS profiles (see Viljoen et al. 2024)

Zheng et al. (2025)

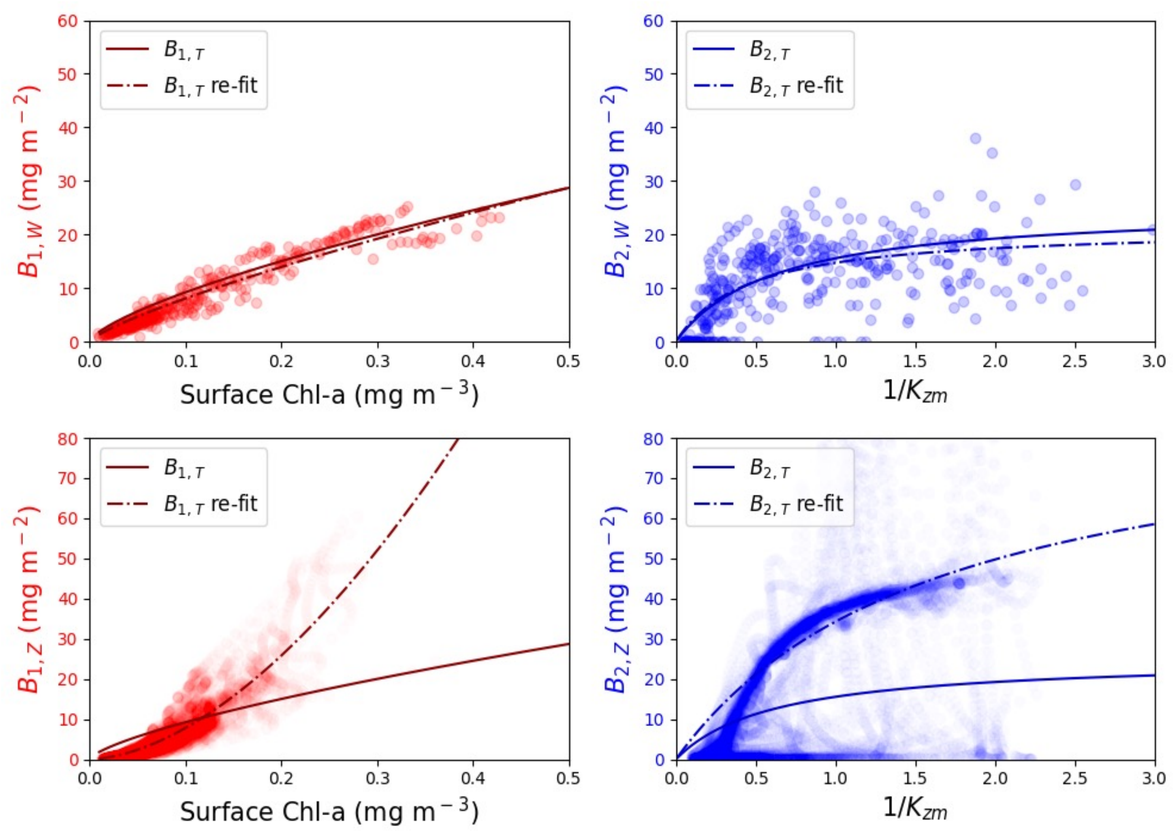



Depth integrated chlorophyll simulated for the mixed layer ($B_{1,Z}$)

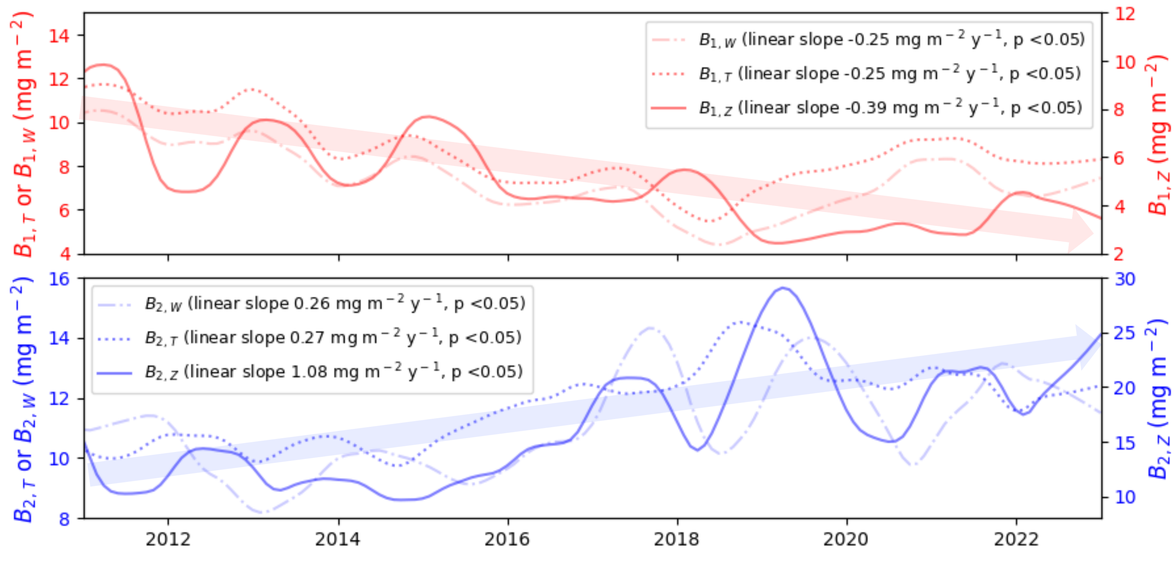
Depth integrated chlorophyll simulated for a layer below the mixed layer and above the euphotic zone depth ($B_{2,Z}$)

Validated using BATS data (see Zheng et al. 2025)

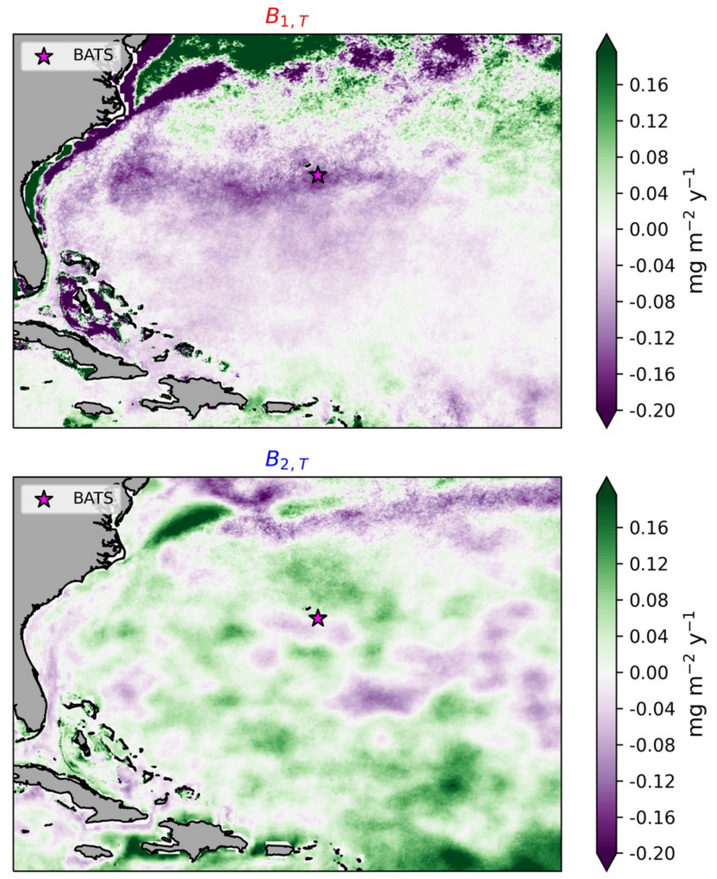
## (2) Similar functional forms among models (BATS data)




## (3) Similar deseasonalised trends post 2011




## (4) Spatial reconstruction of trends post 2011




The model of Tanner et al. (2024) was forced with monthly satellite fields of surface Chl-a and diffuse attenuation (OC-CCI), and a mixed-layer depth reanalysis product (CMEMS global reanalysis, ORAS). Annual maps were produced from 2011-2023, for the two terms ($B_{1,T}$ and $B_{2,T}$). Linear regression was then applied per grid point.

Trends agree with those observed at BATS and indicate changes occurred over a broad spatial scale.

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