Deep Chlorophyll Maximum Dynamics in the Black Sea

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Research Objectives

The presence of a subsurface layer of maximum chlorophyll (Chl) concentration, or deep chlorophyll maximum (DCM), is a widespread feature of the world ocean (Cullen, 2015), but the mechanisms of its formation and maintenance are still under debate.

Common understanding involves instantaneous factors, such as maximum growth resulting from a compromise between light and nutrient limitations. More recently, Navarro & Ruiz (2013) argued that the DCM is conditioned by the history of the bloom, and emerges in spring at a density corresponding to that of the winter mixed layer.

This second understanding depicts the DCM as a self-preserving structure that remains at a near constant density layer by preventing upward nutrient fluxes and downward light penetration. It would explain why chlorophyll profiles from the global temperate ocean and the Mediterranean Sea are stable on a density scale while their depth is highly variable.

The peculiarities of the open Black Sea environment, i.e. its strong and stable stratification and relatively low water transparency, make it an interesting site to study DCM dynamics and to confront these two understanding of the DCM dynamics.

Method

We use BGC-Argo data (2014–2019, ca. 1000 profiles) to characterize the vertical distribution of Chl in the Black Sea. The processing of raw fluorescence involved:

- applying a static sensor correction (Roesler et al., 2017);
- a correction for CDOM fluorescence based on deep fluorescence (Xing et al., 2017);
- correcting surface values for non-photochemical quenching (Xing et al., 2012)

These procedures are validated on the basis of an HPLC in-situ profile.

Conclusions

- We stress the importance of considering DCM dynamics for assessments of Black Sea productivity, as it dominates Chl distribution from April to October.
- The hysteresis hypothesis (Navarro & Ruiz, 2013) holds from April to May.
- During a second phase (July-September), biotic factors are responsible for an upward displacement of the DCM structure.
- On average (Mar-Oct), the DCM concentrates more than 50% the total Chl content within a 10 m layer centered at a depth of about 35 m.
- HPLC datasets should be consolidated in the Black Sea for BGC-Argo calibration.

References

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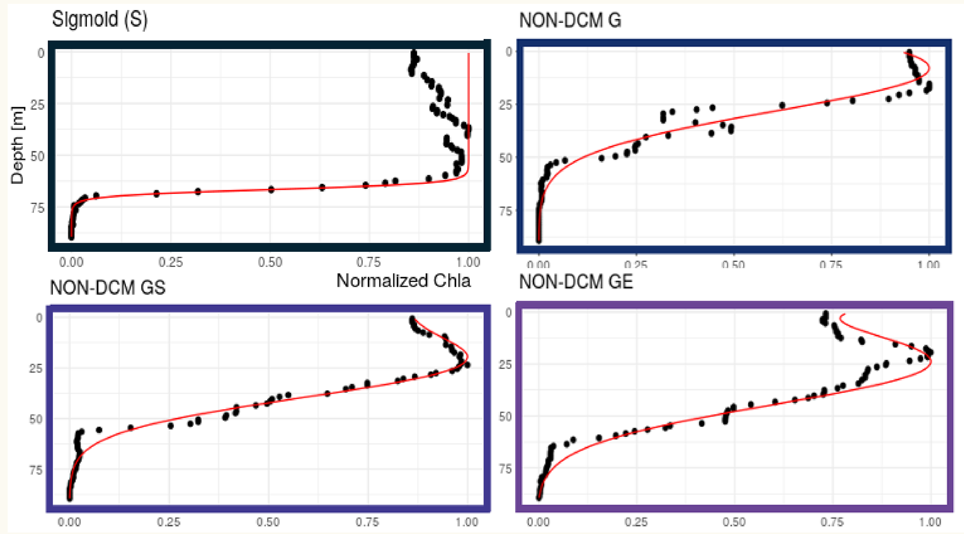
Morphology of Chl profiles

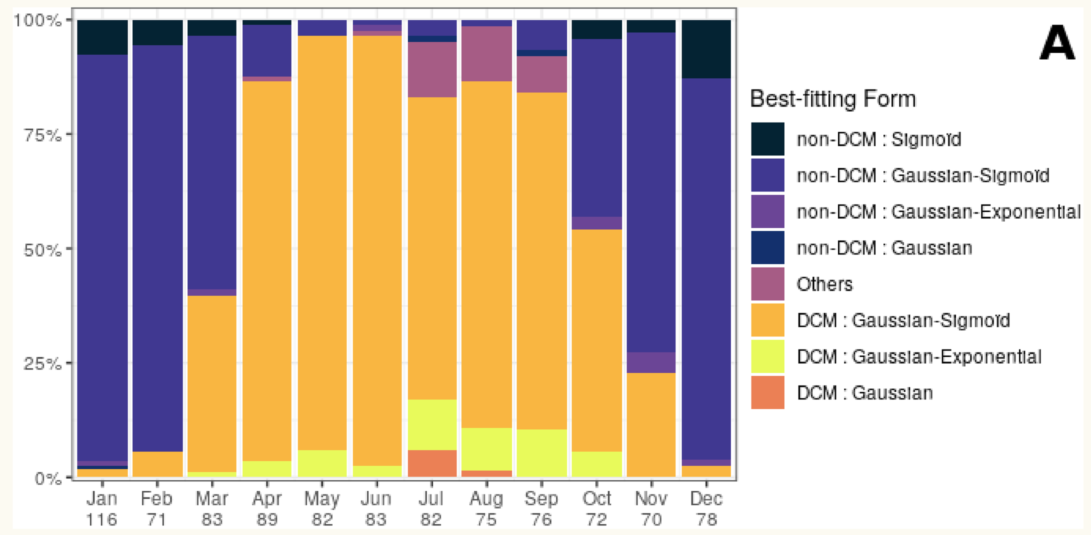
Chl profiles were classified in terms of best-matching analytic forms. In addition, we adopted a definition for DCM profiles that requires a Chl concentration at the DCM that is at least 30% larger than surface Chl concentration.

No patterns could be identified in the spatial distribution of these forms across the central basin. The seasonality of DCM dynamics can thus be considered to be spatially homogeneous in the Black Sea.

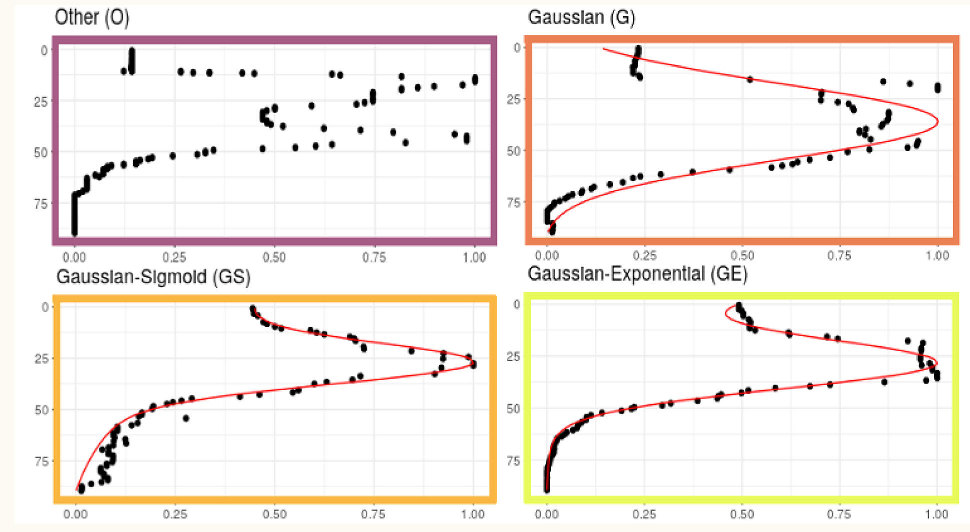
Examples of Non-DCM profiles



Monthly occurrences



Examples of DCM profiles



A DCM season in the Black Sea

Vertical coordinates

We used three systems of vertical coordinates to characterize the DCM seasonal dynamics.

Depth is used in BGC-Argo data.

Density is used in the Black Sea as stratification strongly structures biogeochemical processes.

PAR Using absolute irradiance, instead of the usual euphotic depth (1% of surface PAR) makes more sense from a physiological point of view.

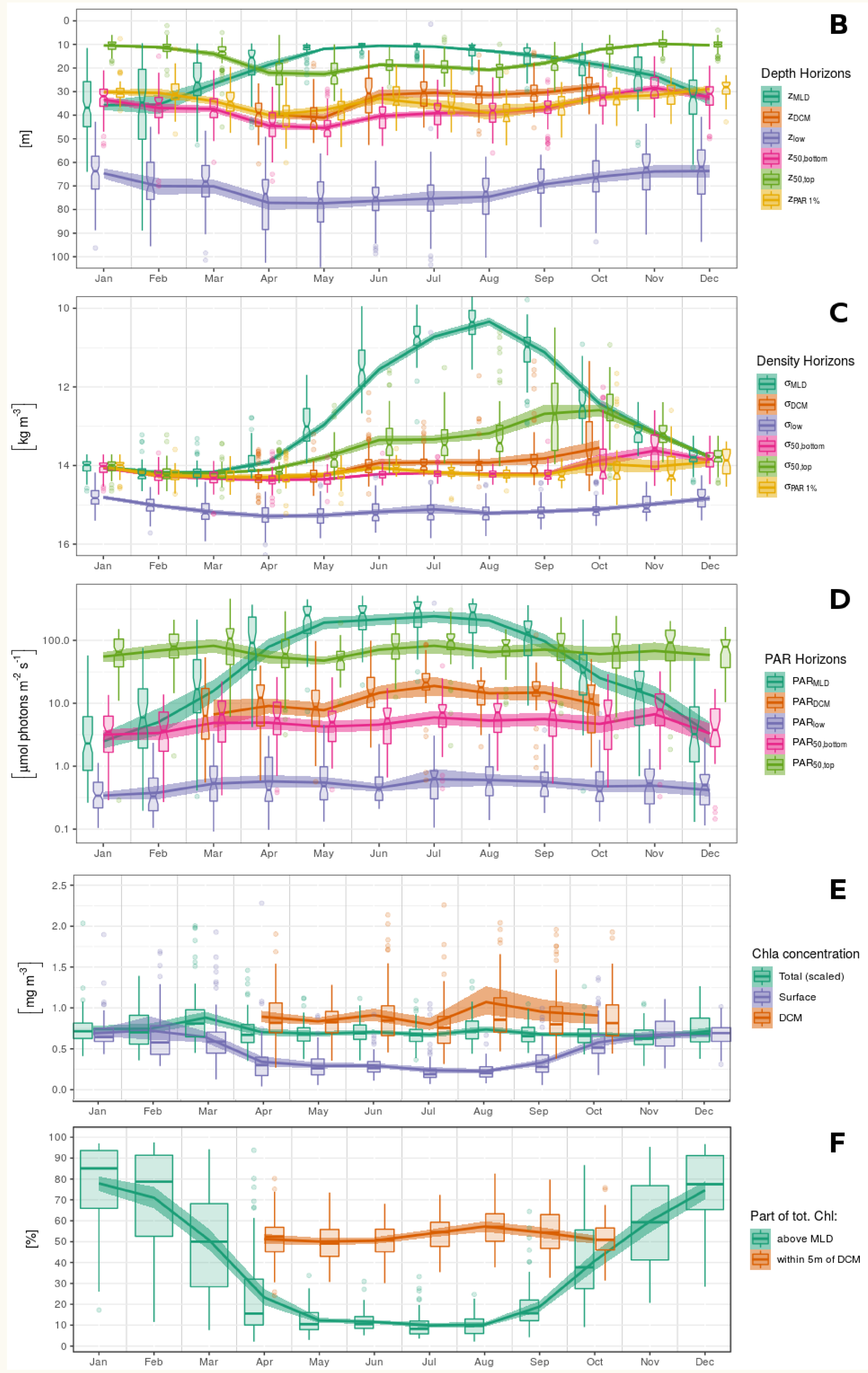
Horizons of Chl profiles

MLD The mixed layer depth is defined by a density difference with respect to surface.

DCM The depth of the DCM is obtained as a parameter of the fitted analytical forms.

low The lower limit of Chl is identified as the lower depth with [Chl]>0.01 mg m^{-3}.

50,bottom/top : The "bulk" of Chl content is defined as the smallest vertical range gathering 50% of the vertically integrated content. These horizons mark its lower and upper limits.



Aggregated diagnostics from individual profiles. Box plots indicate monthly medians and interquartile ranges. Continuous lines indicate monthly means and their 95% confidence interval.

Seasonal phases

In winter, the MLD extends beyond the euphotic depth (**B**). The DCM appears at the base of the MLD in March, in agreement with the general Sverdrup theory.

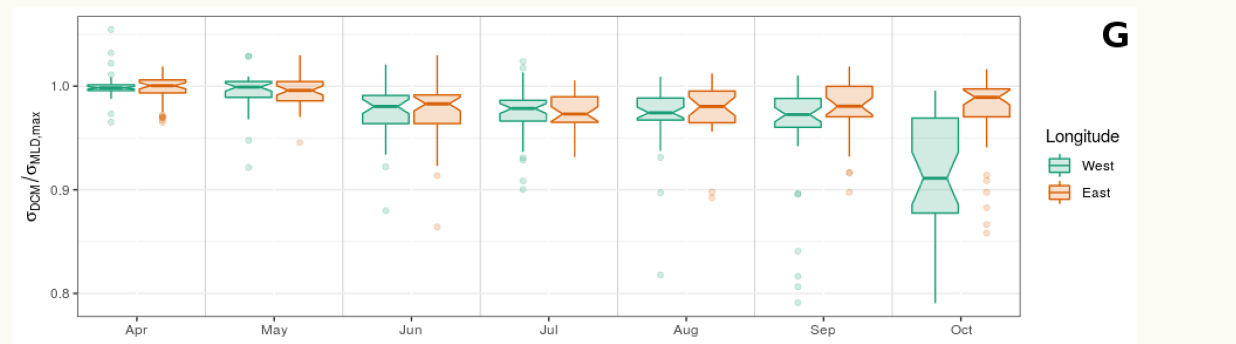
April–May The DCM remains close to the density layer of winter MLD (**C**). A large spread in DCM depth on light and depth scales (**A**,**C**) suggests that density-driven factors sets the DCM depth. This is confirmed by the ratio $\sigma_{DCM}/\sigma_{winterMLD}$ obtained from individual profiles (**G**).

June–August In June, the average Chl profile shifts towards a structure that remains stable through the summer. This shift involves :

- hints of photoacclimation (particle back-scattering data, not shown);
- appearance of Gaussian profiles (**A**), and depletion of surface Chl;
- upward DCM displacement on both depth and pycnal scales (**B**,**C**),
- upward DCM displacement on the irradiance scale (**D**),
- a decrease in the spread of irradiance values at the DCM,
- an increase of Chl content around the DCM (**E**,**F**).

This shift opposes the response expected from increased surface incoming irradiance and reduced nutrient upward flux, which suggest strong contribution of biotic factors, such as phytoplankton species succession Mikaelyan et al. (2018) and/or changes in grazing pressure.

In October, end of the DCM season, the DCM evolves away from the density layer of the winter MLD. A marked spatial gradient is denoted (**G**), suggesting an influence of lateral nutrient inputs.



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