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Interactive comment on "Steady-state solutions for subsurface chlorophyll maximum in stratified water columns with a bell-shape vertical profile of chlorophyll" *by* X. Gong et al.

X. Gong et al.

hwgao@ouc.edu.cn

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Reply to Anonymous Referee #1

1 General comments:

The study presented in this manuscript considers the parameter dependencies of subsurface chlorophyll maximum layers (SCML) in aquatic systems based on an analytical approach. Assuming a Gaussian shape of the Chl a profile leads to a set of analytical expressions that link the three parameters thickness, amplitude and depth of the SCML to phytoplankton growth and losses, surface irradiance and light attenuation, phytoplankton sinking speed and subsurface vertical mixing.

This new approach allows us to integrate previous results from a variety of studies. Some of the results confirm existing knowledge, others go beyond. Having analytical expressions for the functional relationship between SCMLs and various parameters is certainly very helpful. There are, however, a few points that need clarification and/or improvement, before I can recommend publication:

Response: We thank the helpful comments and revise our manuscript accordingly.

2 Specific comments

Comments—p. 9513: The discussion of the difference between SCM and SBM (subsurface biomass maximum layer) is weak. The text uses phytoplankton concentration and chlorophyll concentration as synonyms, an assumption which is not necessarily valid. This also leads to another point:

Comments—p. 9515: The model currency seems to be mg m−3 (according to Figure 1) but then the limiting nutrient N needs to be given in the same units as well (or a conversion factor needs to be introduced). In my view, the prognostic model variables P and N should be given in mmol N m−3, in which case it is more appropriate to talk about an SBML instead of an SCML.

Response: In the revised version, we rewrite the part to clarify the difference between SCM and SBM in Introduction, i.e., 'The subsurface biomass maxima (SBMs) are also common in stratified water columns. Since the chlorophyll-to-biomass ratio generally increases with depth in the euphotic zone, SCMs may not necessarily represent SBMs (Cullen, 1982; Fennel and Boss, 2003) and are usually deeper than SBMs (Fennel and Boss, 2003; Hodges and Rudnick, 2004). Both the subsurface maxima in chlorophyll and biomass are commonly believed to be formed in certain regions of the water column where two opposing resource (light and nutrient) gradients combined with vertically heterogeneous turbulent mixing is amenable for survival of phytoplankton. Although Fennel and Boss (2003) reported that the photoacclimation of phytoplankton can be another important reason for forming SCM in oligotrophic waters, many studies

BGD
11, C5834–C5840, 2014

still used SCM approximately to equal SBM (Klausmeier and Litchman, 2001; Sharples et al., 2001; Huisman et al., 2006; Raybov et al., 2010).'.

In the revised version, we will clarify the issue on a conversion factor between the units of mg/mˆ3 and mmol N/mˆ3) in the Method Section, i.e., Usually, the unit of Chl a concentration is mg/mˆ3, the concentration of phytoplankton and the limiting nutrient is in unit of mmol N/ mˆ3. A ratio of 1.59 g chlorophyll per mol nitrogen (Cloern et al., 1995; Oschlies, 2001) was adopted to convert to the same unit (mmol N/mˆ3) in the following equations.

Comments—I suggest the authors point out (e.g., in the discussion section), that several effects have been neglected: self-shading (p. 9516(09): self-shading is only included in this formulation, if the vertical concentration of P is constant, clearly not the case for the assumed Gaussian profile.), sinking of detritus as a separate compartment, etc. I find it quite remarkable that the 2-equation model reproduces some of the results of a more complex model with three equations (e.g., Beckmann and Hense, 2007). This fact should be mentioned explicitly.

Response: We will spell out the assumption and limitation in the newly added Section 4.2. Please see the revision.

Comments—p. 9519(04): I am unable to confirm the statement that zc1> z_m$-\sigma$. Instead, it seems to me that z_c_1 $\leq$ z_m $-$ σ. As a consequence, zo is not generally within the SCML interval [z_m $-$ σ, z_m + σ] (this is true only for K_v_2/wσ $\geq$ 1/2). This also affects equation (A2) and the arguments connected to it.

Response: Sorry for this typo, it is z_c_1$\leq$ z_m $-$ σ. In the revision, we will correct it and the arguments related. In equation (A2), the interval is [z_c_1, z_c_2] and therefore it is not influenced by this error.

Comments—p. 9538: in Figure 1, please indicate typical locations of zo, zm, zc1 and zc2 (rather than a depth in m – which is misleading anyway), as well as σ.

BGD
11, C5834–C5840, 2014

Response: Thank you very much for this helpful suggestion. We will use σ and these four depths, z_o, z_m, z_c_1 and z_c_2, instead of a depth in m in the revised Figure 1.

Comments—In general, the text could be more explanatory. For example, 9519(12-19) is not easily understandable and should be rewritten.

Response: We rewrite the part to make it more explanatory, i.e., We define T=σ2/Kv2 as the characteristic vertical mixing time scale in half of the SCML thickness (Gabric and Parslow, 1989; Bowdon, 1985). Let the length scale be L= 2K_v_2/w, which determines the scale height of the phytoplankton distribution (Ghosal and Mandre, 2003). Thus, the right hand terms of Eq. (13) can be rewritten as 1/T+w/(2L). In other words, the maximum net growth rate of phytoplankton, max(μmmin(f(I), g(N))-ε), is determined by the vertical mixing time scale (T) and the time taken by a phytoplankton sinking (w) through lengths (2L). We also make revision throughout the whole manuscript to enhance our analysis. Please see our revised version.

3 Technical corrections

9515(17): "etc." refers to which processes and factors?

Response: Sorry for the typo, we have removed "etc.".

9515(19): it should be explicitly mentioned that w is positive in the chosen coordinate system.

Response: In the revision, we will spell out this, i.e., w is the sinking velocity of phytoplankton, which is non-negative in the chosen coordinate system and assumed to be constant with depth.

9523(03): what does "etc." include – the list not so long that it could not be given completely.

Response: In the revision, we will list all the terms including sinking velocity of phyto-

BGD

11, C5834–C5840, 2014

plankton w, vertical diffusivity below the surface mixed layer K_v_2, loss rate ε, maximum growth rate μ_m, recycling rate α, half-saturation constant for light K_I.

9523(19): “environmental factors (..., , ...)” the loss rate of phytoplankton ε is not really an environmental factor as it includes natural mortality.

Response: We will replace environmental parameters with model parameters in the revision.

9524(01): it should be added that the Taylor series is truncated after the linear term.

Response: Agree. This sentence will be revised as ‘To simplify, by Taylor expanding eˆ(K_d σ) at σ=0 and truncating the Taylor series after the linear term, i.e., eˆ(K_d σ)=1+K_d σ+Î£(σˆ2), Eq. (18) can thereby be rewritten as ...’.

9530(21): it should be mentioned that this approximate equation is derived from equation (2). Furthermore, it seems to be dimensionally incorrect (even if we assume that P and N have the same unit): the left hand side has is in mg mˆ(−3) sˆ(−1) while the right hand side is in mg mˆ(−2)sˆ(−1).

Response: This approximate equation is derived from equation (2), and Equation (A1) has been modified as $\int(\mu$_m min(f(I),g(N))-$\alpha\varepsilon)$P(z)dz≈K_v2 dN(z)/dz |_z .

9512(12): “but independence of” should be “but independent of”.

9512(16): “parameters difficultly obtained from on-site observations” should probably better be “parameters which are difficult to observe on site”.

9512(24): “SCM is commonly believed” should be “An SCM is commonly believed” or “SCMs are commonly believed”.

9513(02): “reason forming” should be “reason for forming”.

9513(12): “SCM has been attracted” should be “The SCM has attracted”.

9513(25): “thickness of SCML” should be “thickness of the SCML” or “thickness of

BGD
11, C5834–C5840, 2014

SCMLs".

9514(03): "variations of environment parameters" should be "variations of environmental parameters".

9518(20): "stead" should be "steady".

9518(23): the factor of the first term on the right hand side should be $-$Kv2/σ4, instead of $-$Kv2/σ2 .

9519(21): "the depth of the SCML must occur below or equal to the depth for phytoplankton having the maximum growth rate" should be something like "the depth of the SCML maximum lies at or below the depth of maximum phytoplankton maximum growth".

9520(03): "the numerical modelling can support" should be "numerical modeling results support".

9520(19): "et al." should only be used in the context of unnamed co-authors of a paper, not instead of "etc.". Besides, it would be better to give a complete list here (as it is not too long).

9522(18): "provided" should be "provide".

9523(04): "appendixes" should be "appendices".

9523(19): "it is not surprised" should be "it is not surprising".

9524(14): with "should be identified by μm/2" the authors probably mean "depends on μm/2".

9524(16): "half-saturate constant" should be "half-saturation constant".

9524(19): "In summarize" should be "In summary" or "To summarize".

9525(19): "can be infered" should be "can be inferred".

BGD
11, C5834–C5840, 2014

9525(01): “is constant with varying surface light intensity” simpler “does not depend on surface light intensity”.

9528(15): “the thickness of SCML thickens” should be “the thickness of the SCML increases” or “The SCML thickens”.

Response: Many thanks for your detailed correction. The revised manuscript will be edited using the service provided by Elsevier WebShop English language editing. Please see the revision.

Please also note the supplement to this comment:
http://www.biogeosciences-discuss.net/11/C5834/2014/bgd-11-C5834-2014-supplement.pdf

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