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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.

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Reply to Anonymous Referee #3

General Comments:

This study presents an interesting analysis of features of the sub-surface chlorophyll max and how they depend on environmental parameters. Given that the sub-surface chlorophyll max is a ubiquitous feature in the ocean and has implications for planktonic ecosystem processes, the results of this study are an important contribution to the field. The authors do a good job in the introduction of highlighting what previous work has been done in this area theoretically, and what the specific contribution of this study is.

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The results of the study are in general well presented and well organized, and many of the results provide important advancements in our conceptual understanding of what controls the sub-surface chlorophyll max. However, the two major weaknesses of this study, which should be addressed before I can recommend publication are: (1) a more explicit connection needs to be made between the theoretical results of this study and its applications in the field and (2) the entire paper suffers from grammatical errors. For the latter point, I have provided as many corrections as I could in the technical comments below, but the authors need to have a native English speaker carefully read this paper for more thorough editing. For the first point, I have made a few suggestions below for how the applications of this study for the field can be incorporated. With addressing these comments, I believe the paper will be much stronger and a great addition to the literature on this topic.

Response: We thank the helpful suggestions and comments. We will add a new Section 4.2 to link the theoretical results of this study and its applications in the field. This revised manuscript will be edited using the service provided by Elsevier WebShop English language editing. Please see the revision.

Specific Comments:

1. The part of this paper with the most potential for expanding the applicability beyond theory is in the results when it is discussed how this model can be coupled with satellite data (pg. 9522, line 18-19 of the Results). This is an interesting potential application of this type of model down the line (although as E. Boss points out, we are far from being able to obtain phytoplankton profiles from satellites.) Right now, this text is misplaced (in the Results) given that this analysis was not actually done. It would definitely strengthen the paper and make the applications of this model to the natural environment much more clear if the authors ran a quick analysis with some satellite data and some parameters from previously published field studies (to obtain w, Kv, etc.). Even though assumptions would be made, this type of quick analysis would give some idea of how real-world data could be incorporated into the model and thus be applied to the

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field. A comparison of the model results (in terms of the thickness, depth, and intensity of SCML) could be shown for different regions of the ocean and displayed in a new figure.

Response: Thank you for the suggestion. Combining some satellite data (K_d, I_0) and parameters obtained from previously published field studies (to obtain w, K_v, etc.), we will explore the applications of this model to three time-series stations in different regions, i.e., the South East Asia Time-series Station (SEATS) in the South China Sea, the Hawaii Ocean Time-series (HOT) station, and the Bermuda Atlantic Time-Series Study (BATS) site, please see the newly added Section 4.2 in the revision. Meanwhile, a comparison of the model results (in terms of the thickness, depth, and intensity of SCML) will be shown for the three different regions (Figure 2).

2. Another way the message of this paper could be strengthened, particularly for less mathematically-inclined readers, is for some of the important results to be reiterated in more intuitive terms in the discussion. Right now the discussion is largely more analysis, but I think there is an opportunity to re-emphasize some of the important points that were only briefly mentioned in the results. For example, it would be great to describe in non-mathematical terms, the conditions necessary for the existence of SCM (from section 3.1 in Results), which is very interesting but could be missed by many readers. Another important result that should be highlighted is the derivation of h and P_max (as shown in section 3.1 in Results) is irrespective of the form of the growth limiting function. Since functional forms in phytoplankton models are still debated in the literature, this is an interesting finding and the implications of it should be described more in the discussion.

Response: We will add a new Section 4.2 in the revised version to enhance discussion in terms of important points. For example, the conditions necessary for the existence of SCM will be re-emphasized in non-mathematical terms, i.e., 'Our model suggests that the necessary condition for the existence of SCM is the growth rate under the limitation of sea surface light intensity is larger than the loss rate in stratified water columns. This

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condition is identical with the result given by Fennel and Boss (2003) when vertical sinking is constant as a function of depth. This result indicates that in stratified water columns whether or not the SCM occurring has no relation with the sinking velocity of phytoplankton and the vertical diffusivity. Many numerical studies have reproduced the SCM phenomenon, of which the condition of SCM occurrence were met with variable values of the sinking velocity of phytoplankton and the mixing diffusivity (Huisman et al., 2006; Klausmeier and Litchman, 2001; Mellard et al., 2011).'.

3. I think the results could be better illustrated through some improvements to Figure 1. The concept behind Figure 1 I believe is very strong, but I think it would help tie the paper together more if some of the results were incorporated into the figure. For example, including the various depths in the figure (z_m, z_0, z_c1, z_c2) will help make these parameters more intuitive for the readers and showing where they are located in different situations (perhaps making three separate panels for the different scenarios considered?). The other note is that I believe "light-limitation" and "nutrient-limitation" are switched in the figure.

Response: Agree. In the revision, we will incorporate the various depths (z_m, z_0, z_c1, z_c2), as well as σ, in Figure 1. The notes of light-limitation and nutrient-limitation will be replaced with the marks of f(I) and g(N) in Figure 1 to avoid confusion.

4. One last note is I think the authors should re-think about the placement of some of the text in different sections – right now it seems like some of the statements in the methods and results belong in the discussion and much of the discussion belongs in the results. For example, the paragraph (starting on line 4 of Pg. 9523 in the Results) belongs in the Discussion since it highlights the potential importance of this study, but no actual results are given. However, I think the Summary is very well-written and does a great job of emphasizing the importance of this work.

Response: We will reorganize a few parts in Method, Results and Discussion, please see the revision. For example, the paragraph (starting on line 4 of Pg. 9523 in the

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Results) has been moved to the newly added Section 4.2.

Technical (mostly grammatical) Comments:

Pg. 9519, line 4-6: it might help (particularly for less mathematically-inclined readers) to define the compensation depths in words so that the following argument about the location of maximum phytoplankton growth is clear.

Response: Thank you for the suggestion. We will add the definition of the compensation depths in the revision, i.e., 'Clearly, μ_m min(f(I), g(N)) - ε>0, in the interval (zc1, zc2). This indicates that subsurface net production occurs only between the two compensation depths where the growth rate μm min(f(I), g(N)) equals the loss rate ε. Beckmann and Hense (2007) found similar results by numerical model.'.

Pg. 9519, line 15-19: it is unclear how this discussion relates to the previous part of the paragraph.

Response: This paragraph will be rewritten as: 'We define T= σˆ2/K_v2 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= 2 K_v2/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(μ_m min(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).'.

Note that "nutrients" should be plural throughout when used as a noun.

Abstract, line 1-2: should be "referred to"

Abstract, line 9: should be "phytoplankton located at"

Abstract, line 12: should be "but independent of"

Abstract, line 14: "shrunk"

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Abstract, line 16: should be “parameters that are difficult to obtain from”

Pg. 9512, line 21: should be “conventionally referred to as”

Pg. 9512, line 24-25: “regions”

Pg. 9512, line 26: “with vertically”

Pg. 9513, line 7: “and was thin”

Pg. 9513, line 10: “Chl a was relatively low”

Pg. 9513, line 12: “SCM has attracted”

Pg. 9514, line 3: “variations in environmental parameters”

Pg. 9514, line 11: “for limiting nutrients and light”

Pg. 9514, line 24: remove “etc.” – too vague.

Pg. 9515, line 21: “Kv depends on depth in the following way”

Pg. 9516, line 6: “light and nutrients”

Pg. 9516, line 7: “if both the light limiting term”

Pg. 9516, line 9: “Because of absorption and self-shading”

Pg. 9516, line 12: “surface light intensity and Kd is the light”

Pg. 9516, line 15: “of the water column”

Pg. 9516, line 16: “white nutrients are replenished”

Pg. 9517, line 9: “between two locations”

Pg. 9517, line 10: “where Chl a is a certain fraction”

Pg. 9517, line 13: remove “respectively”

Pg. 9517, line 19: “which were located at the depths”

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Pg. 9517, line 20-21: this sentence is unclear, remove.

Pg. 9518, line 6-8: sentence needs to be rewritten, very unclear

Pg. 9518, line 10-11: rewrite as: “As described in eq (7), the depth of the SCML is defined as zm, that is, the location of the point-wise maximum value of Chl a.”

Pg. 9518, line 15-17: rewrite, not correct grammatically and not clear

Pg. 9518, line 17-18: “Gaussian function of the vertical”

Pg. 9518, line 20: “with the steady-state version of Eq. (1)”

Pg. 9518, line 22 “follows”

Pg. 9519, line 1: “Letting”

Pg. 9519, line 5: “are located”

Pg. 9519, line 12-13: needs to be rewritten

Pg. 9519, line 13-14: “We define T=sigËĘ2/Kv2 as the characteristic..”

Pg. 9520, line 1: “have supported this”

Pg. 9520, line 3: remove “the” before “numerical modeling

Pg. 9520, line 5: “used to solve for the”

Pg. 9520, line 8-9: “is at the location of equal limitation by nutrients and light”

Pg. 9520, line 11: “of SCML is located where phytoplankton growth is limited by light”

Pg. 9520, line 23: “equals the loss rate”

Pg. 9520, line 25: “equals the loss rate”

Pg. 9521, line 5: “into Eqs. (14)..”

Pg. 9522, line 16: “the water column”

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Pg. 9522, line 17: “a similar result”

Pg. 9523, line 19: “it is not surprising”

Pg. 9523, line 23: “many numerical modeling studies”

Pg. 9526, line 6-8: I would reword to be more clear “Equation (18) indicates that the parameter sigma is affected by changes in the vertical diffusivity: : :”

Pg. 9526, line 24: “phytoplankton is equal to the loss rate”

Pg. 9527, line 4: “a similar result”

Pg. 9527, line 15: “The second special situation occurs when the term: : :”

Pg. 9528, line 5: “is located at”

Pg. 9528, line 9: “in the case of”

Pg. 9528, line 21: “The third special situation occurs when ..”

Pg. 9530, line 5: “regions dominated by non-sinking phytoplankton”

Pg. 9530, line 8: “potential risk of climate change”

Response: Many thanks for your detailed corrections. The grammatical errors have been corrected in the revision; meanwhile 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/C5859/2014/bgd-11-C5859-2014-supplement.pdf

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