

Interactive comment on “A new parameterization for surface ocean light attenuation in Earth System Models: assessing the impact of light absorption by colored detrital material” by G. E. Kim et al.

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1 Response to General Comments

We are grateful for Referee #1’s comments.

Our response in this section mostly addresses the following statement from Referee #1:

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Restating the above paragraph more succinctly, if a “new parameterization” (implied by the word “new” to be better than existing) is a goal of the study, then the paper would benefit from a much more thorough motivation, presentation, discussion and validation of the parameterization itself. If the focus is Earth system and biogeochemical model results considering two different parameterizations (the way the paper reads now), the paper would benefit from backing off on promoting a “new parameterization”.

We agree that the main focus of the content in our paper and title are somewhat misaligned. The main focus of the study is the biological impact of adding more light attenuation in an ESM, rather than the new parameterization. We propose a new title for the study: “Quantifying the biological impact of surface ocean light attenuation by colored detrital material in an ESM using a new optical parameterization” and a new running title “Biological impact of increased light attenuation by CDM in an ESM”.

Per the reviewer’s suggestions, we also provide additional details about the new parameterization used in this paper. We motivate the need for this new parameterization with figure 1, which shows that chlorophyll-a and light absorption by colored detrital matter at 443nm, $a_{dg}(443)$, are uncorrelated for the subset of NOMAD data used in this analysis. These data meet the following criteria: (1) measurements of chlorophyll-a, light absorption by CDM and the diffuse attenuation coefficient for downwelling irradiance, k_d , were made concurrently and (2) chlorophyll-a data are derived from HPLC analysis. We restricted our analysis to samples analyzed by HPLC to use data derived from a consistent method of measurement.

In developing a new optical parameterization, the parameters for the best fit function to the k_d , chlorophyll-a and CDM data were found by minimizing the least squares distance between modeled and measured values using the Levenberg-Marquardt algorithm. Goodness of fit between the parameterized k_d values and the observed are

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shown in figure 2. A comparison to the Manizza (2005) parameterization is shown in the right hand side panel, using the 244 data points that meet the criteria mentioned in the previous paragraph. The color scheme matches locations according to a revised map of data stations (figure 3).

2 Response to Specific Comments

Pg 3907, Line 20. Technically the sentence should read “implicitly includes the light attenuation of all other aquatic constituents presumed to be directly in proportion with Chlorophyll”.

We will change the wording according to this suggestion.

Pg 3909, Line 6. Sentence indicates “variations in light attenuation in ESMs were previously attributed to phytoplankton pigment only”. However this is not technically true as pointed out by the authors (See pg 3907, lines 19-20, also Jerlov 1976 and Morel 1988).

We will change this to “variations in light attenuation in ESMs were previously attributed only to chlorophyll and implicitly aquatic constituents that vary in proportion to chlorophyll.”

Pg 3909, Line 19 CDOM only absorbs solar radiation within a small portion of the solar spectrum (i.e. the UV and blue wavebands). Suggesting that CDOM “accounts for a large fraction of the non-water absorption ‘especially’ in the UV and blue wavelengths” seems misleading. It is really ‘only’ in the UV and blue wavelengths.

We will change the wording according to this suggestion.

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Pg 3910, Line 25 The reason CDOM isn't included in the $K_d(r)$ parameterization isn't because CDOM absorption in red wavelengths is smaller than in blue-green wavelengths, it's because CDOM absorption in red wavelengths is extremely small compared to absorption by seawater and chlorophyll in the red wavelengths.

This is a good point. We will include the median absorption by particles (including phytoplankton) from the NOMAD dataset in Figure 1 of the manuscript to that shown here, figure 4. We will also include information about the absorption spectrum of water as measured by Pope and Fry (1997).

Pg 3915, Line 3. It is simply stated that the comparison is for "average results for the final 100 years of the model runs". Would be nice to know how that time period came about and how sensitive the results are to the time average.

One hundred years is long enough to average over most interannual variability in the model. For example, 20 years is not long enough because of the influence of El Nino decadal variability. We analyze the final 100 years of the model runs to eliminate the influence from spinup, which we consider to be the period of time it takes for a distinct signal to develop. For the model experiments discussed in this paper the spinup time is less than 50 years.

Pg 3915, Line 10. An artifact of the "new" parameterization is a decrease in attenuation due to the Chl component alone. So, in regions with little CDOM, the "new" parameterization that adds (CDOM) attenuation can actually result in decreased (overall) attenuation. The manuscript would benefit by an additional sentence or two commenting on this result. For example, is it an unintended consequence of the "new" curve (surface) fit? Does it make physical sense?

The two model runs presented in this study compare model runs using equation 5

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with and without the last term, which represents the attenuation by CDM. We do not present comparisons between the model output from the parameterization in this paper (equation 5) versus the parameterization used in previous studies (equation 3) because we felt that this information did not advance the central idea of this paper, which is to compare simulations of the ocean with and without the optical contribution of CDM.

Nonetheless, the reviewer is commenting on the observation that the parameterization used for the diffuse attenuation coefficient used in previous studies (equation 3) and the parameterization presented in this paper (equation 5) exhibit a different functional dependence on chl. The chl coefficient and exponent in equation 5 is smaller than the chl coefficient in equation 3. This was an expected result since the parameterization used in previous studies combined the attenuation by chl and CDM into a single chl term. Separating the contribution of those two aquatic constituents would give less weight to the chl term. The reviewer correctly conjectured that there are regions with little attenuation by CDM where the model run with the parameterization as presented in this paper (equation 5) results in decreased surface attenuation compared to a model run using equation 3. These results are shown in figure 5. Attenuation depth increased by an average of 0.9m in locations where the difference in attenuation depth was positive (chl&CDM minus model run using equation 3).

Pg 3921, Line 20. The manuscript states that impacts due to “altering the visible light field” are investigated. While this is technically correct, it seems that altering “attenuation of the in-water light field” is a more accurate description. The former can suggest the incident light field is altered, and that is not the case.

We will change the wording according to this suggestion.

Figure 2 The comparison of Equations 3 and 5 applied to NOMAD data could be

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clarified. First, given the NOMAD data are from 8 locations, coloring the data by location would help the reader interpret the true number of degrees of freedom. Second, the distribution looks extremely bimodal. If a handful of outlying points were removed the regression line looks like it would have a slope very near 1.0. It would be interesting to know the location of data points that fall well below the 1:1 line. Again, this could be indicated by color coding.

In response to the reviewer's comments, we provide a color-coded version Figure 2 from the manuscript. It is provided here in figures 3 and 6. We separate the observational data into 7 categories: (1) western Atlantic, northern cluster in black; (2) western Atlantic, southern cluster in green; (3) Antarctic peninsula in orange; (4) Southern Ocean in blue; (5) western Pacific in magenta; (6) stations across the Pacific ocean in red and (7) eastern Pacific in cyan. The locations of points that fall below the regression line are mostly black, green and cyan representing three different location clusters from the dataset.

Figure 12 The 40% decrease in irradiance at 145 m depth suggests a significant change. However, in absolute terms, back of the envelope calculations following Morel (1988) suggest that for a relatively large noontime surface irradiance value (1000 W/m^2) and a modest upper ocean chlorophyll concentration (0.1 mg/m^3), the net irradiance at 145 m depth is $<0.01 \text{ W/m}^2$, and most likely insignificant. Curves (probably on a log scale) should be added to Figure 12 showing absolute changes.

We propose to change the manuscript's Figure 12 to show the absolute changes in irradiance at depth, so as to more accurately portray the differences in irradiance. In figure 7, the irradiance plot is shown with semilog axes. Difference at 196m is zero.

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3 Response to Technical Corrections

Pg 3908 line 20. Text indicates “studies”, but then goes on to mention only a single study (Gnanadesikan and Anderson 2009).

We will change the language at the end of this sentence to apply to findings in both Gnanadesikan and Anderson (2009) and Manizza et al (2005).

4 Additional References

Pope, R. M. and Fry, E. S. (1997). Absorption spectrum (380–700 nm) of pure water. II. Integrating cavity measurements. *Appl. Opt.*, 36(33):8710–8723.

5 Figures

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Fig. 1. Scatterplot of in-situ chlorophyll-a and $a_{dg}(443)$ measurements from the NOMAD dataset. These data are from 244 stations where chlorophyll-a, $a_{dg}(443)$ and k_d were measured concurrently.

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Fig. 2. Scatterplots comparing observed $k_d(bg)$ from the NOMAD dataset and modeled $k_d(bg)$ using two different parameterizations. The modeled $k_d(bg)$ values are calculated from concurrent in situ chlorophyll-a and $a_{dg}(443)$ measurements corresponding to the observed $k_d(bg)$ values on the y-axis.

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Fig. 3. Map of stations with locations of the 244 in-situ measurements used to develop the $k_a(bg)$ parameterization with CDM, equation 5. Stations are spatially grouped and assigned an arbitrary color. These colors correspond to the scatterplots in figures 1, 2 and 6 of this response to the reviewer.

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Fig. 4. Median IOP spectra from NOMAD dataset and absorption spectrum of pure water in gray. In the visible spectrum, CDOM absorption is strongest in the blue and decreases exponentially with increasing wavelength. The absorption spectrum of pure water is 0.0434 m^{-1} at 530nm and increases to 0.6 m^{-1} at 700nm (Pope and Fry 1997). The absorption spectrum of particles (including phytoplankton), a_p , absorbs strongly in the red wavelengths compared to NAP and CDOM.

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Fig. 5. Difference attenuation depth [m]; χ^2 CDM minus model run using Manizza 2005 parameterization (eq. 3 from manuscript).

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Fig. 6. Comparison of equation 3 and equation 5 applied to NOMAD in situ chlorophyll concentration and $a_{dg}(443)$ measurements to calculate $k_d(bg)$. The 0.67 slope on the regression line indicates that when CDM is included, $k_d(bg)$ increases more rapidly than when it depends on chlorophyll concentration alone.

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Fig. 7. Profiles of the change in globally averaged irradiance and macronutrient concentration, chl-only minus chl&CDM. There is a decrease in irradiance and increase in macronutrients throughout the upper 200m.

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