We thank the two anonymous reviewers for their constructive criticism and helpful suggestions. Below are our responses to specific comments from each of the reviewers. Please note that since we were unable to generate a PDF of the manuscript in the "discussion" format, the line numbers in the response to the reviewers below refer to the PDF of the revised manuscript in "submitted" format (continuous line numbers). Text added to the revised manuscript is shown in red and parts of the text referred to in our responses are highlighted in bold.

Response to Anonymous Referee #1

Definition of export depth: Many studies use 100 m as export depth for simplicity and because it is a reasonable approximation of the euphotic zone depth in large parts of the open ocean. However, the depth of the euphotic zone shows significant regional and seasonal variation (Najjar and Keeling 1997; Buesseler and Boyd 2009) and large differences (> 100 m) between locations and/or seasons can significantly impact export estimates from fixed depths (Boyd and Newton 1999). Buesseler and Boyd 2009 advocate the computation of particle flux attenuation profiles relative to the bottom of the euphotic zone, not fixed absolute depths, and propose the adoption of a "best" definition of euphotic zone and sampling designs considering the spatial and temporal variation in the euphotic zone. During the analysis we also noticed that in a small but significant number of locations in the CCSM-BEC model, the maximum in POC production is close to or below 100 m, resulting in very poor fits of the exponential model to the CCSM-BEC POC flux profiles. Therefore, for the aforementioned reasons, we chose to use a more dynamic and mechanistically based definition of export depth (bottom of euphotic zone) as the depth at which POC production is equal to 1% of maximum POC production in the water column. The global mean of CCSM-BEC's spatially varying export depth is 110.4 m (Figure 4a) which is very close to the commonly used export depth of 100 m.

The use of a fixed export depth of 100 m tends to underestimate export fluxes in productive and/or higher latitude regions where the euphotic zone tends to be significantly shallower than 100 m and overestimate export fluxes in lower latitude oligotrophic areas where the euphotic zone is often deeper than 100 m. However, because of the very low particle flux in lower latitude oligotrophic areas, the overestimation of export in these regions is significantly smaller, in absolute value, than the underestimation at higher latitudes, resulting in an overall underestimation of global export fluxes. Thus, for a given global POC flux field, using a spatially and/or temporally varying export depth, as we did in our study, should produce global export estimates that are higher than those from studies using a fixed export depth of 100 m.

We included additional text in lines 138–142 (Methods) explaining our choice of export depth definition, and in lines 495–500 (Discussion) explaining the impact of constant vs variable export depth on estimates of global export.

Ballast hypothesis explanation: The explanation of the mechanisms (ballast and protection) involved in the "ballast hypothesis" was expanded to include a description of the observational evidence for it (lines 35–36).

Temporal variability in sediment traps: We meant to say that sediment traps do not provide adequate temporal resolution, not that they do not resolve temporal variability. The word "temporal" in line 54 was removed.

Exclusion of ice covered areas: In the analysis we excluded seasonally ice covered areas. The word "seasonal" was added in line 145.

Comparison of observations with other empirical algorithms: In the manuscript we compare observations of annual mean POC fluxes at 254 locations compiled by Lutz et al. 2007 with POC flux estimates from CCSM-BEC, the Lutz et al. 2007 model and from different implementations of a simple exponential model (Figure 10). We do not extend the comparison with observations to include other parameterizations, e.g. Suess 1980 and Pace et al. 1987, because comparisons of the Lutz data set and Lutz model estimates with these parameterizations can be found in Lutz et al. 2007.

Influence of domain choice on results: The CCSM-BEC domain regions (Figure 1) represent distinct oceanographic regimes or provinces and contain much of the same information on large scale spatial variation of environmental conditions as Longhurst 1998 biogeographical provinces and Sarmiento et al. 2004 biomes. The signals in the model results are also strong enough so that the broad spatial patterns in the controls of export and POC flux should not be significantly affected by relatively small differences in the domain regions. Therefore, the use of Longhurst 1998 provinces and/or Sarmiento et al. 2004 biomes instead of the regions defined on Figure 1 should not impact the results significantly but would substantially increase the complexity and difficulty of computations.

Given the well defined spatial patterns in the controls of export and POC flux and the broad similarities between the Longhurst 1998 provinces, Sarmiento et al. 2004 biomes and the regions in Figure 1, we expect that an analysis of the sensitivity of results to the choice of domain regions would not provide much additional information and would unnecessarily increase the size of the manuscript.

Relation between particle export and export depth: Yes, this is simply the result of longer (deep export depth) or shorter (shallow export depth) transit time of particles before being exported. The words "As expected, " were added to the beginning of the sentence on line 308 to emphasize the direct relationship between particle export and export depth.

POC labile fraction and remineralization length scale in the North Atlantic: The reason for the simultaneous variation in labile fraction and remineralization length scale in the North Atlantic and North Subtropical Atlantic (lines 366–369) is explained in lines 420–425 (Results) and in lines 583–586 (Discussion). An additional sentence explaining the reason for this variation was added immediately following the statement in lines 366–369 (lines 369–370).

MLR of export ratio (Table 2): The results of the multivariate linear regression excluding the ratio of $CaCO_3$ to POC in the exported material were added to Table 2 and a sentence explaining those results was added to the text (lines 435–436). The results of the multivariate linear regression in Table 2 are sorted in order of the amount of explained variance (most variance explained at the top) and more significant digits were added to the coefficients of determination in Table 2 so the reader can compare the differences in explained variance among the different combinations of factors. Text was also added in line 432 stating that the removal of the ratios of opal and dust to POC in the exported material from the regression result in negligible differences in explanatory power.

Comparison with observations (Section 3.4): As suggested by the reviewer, this section has been moved to the beginning of the Results and is now Section 3.1.

Missing references: Wilson et al. 2012 is already cited in the manuscript. Laws et al. 2011 has been included in Table 5 and in the Discussion.

Figures: The color bar and contour levels in Figures 4 and 5 (former Figures 2 and 3) were changed to increase contrast and the colored circles in Figure 5 (former Figure 3) were made bigger so they are easier to discern. The definitions of α, λ and f were included in the caption of Figure 5 (former Figure 3). The green line in Figure 7e (former Figure 5e) was difficult to see because it is very close to zero. The origin of the *x* axis in Figure 7e was moved to the left so the green line can be seen more easily.

Response to Anonymous Referee #2

Exponential model: In the manuscript we use the simple exponential model in two different ways. First we use it to "sumarize" the complexity of the CCSM-BEC particle flux model into a small set of parameters (α, λ and f) that are then used to describe and analyse the behavior of the CCSM-BEC model. The spatial and seasonal distributions of these parameters and their errors, and their relationship with environmental and biogeochemical factors give us insight into the processes and mechanisms controlling the export and transfer efficiency in the CCSM-BEC model (former Section 3.2, now Section 3.3).

We then use the exponential model, fitted to sediment trap measurements, in the skill evaluation of different models/parameterizations against observations. Comparison of models of varying complexity against observations gives us insight into the sources of bias and uncertainty in the different parameterizations, and tells us weather observations provide enough contrast and resolution to adequately evaluate models (former Section 3.4, now Section 3.1, and Discussion).

The explanation above was added to the end of Section 2.3 (Methods) to clarify the distinct uses of the exponential model.

Dust and "ecosystem effects": The reviewer is correct that dust is different from the other ballast minerals ($CaCO_3$ and opal) in that it does not have a biological source and therefore, its ballasting effects should be more easily distinguishable from ecosystem or community structure effects. The word "mineral" in line 573 was changed to "biomineral" to be more explicit about this distinction and the clarification above was added to the Discussion (lines 576–578).

In the manuscript, "ecosystem effects" refer to the effects of the phytoplankton community structure or relative abundance of the different phytoplankton groups on the vertical POC flux. It is also referred to as the effect of *ecosystem structure* throughout the manuscript. The ways in which community or ecosystem structure can affect export ratio and transfer efficiency are explained in detail in the Introduction (lines 37–46). To clarify that "ecosystem effects" refer to the effects of community structure, the words "community structure" were added between parentheses after the word "ecosystem" in line 575 in the Discussion.

Partitioning between "free" and associated and "soft" and "hard" fractions: Parts of the Appendix A1 were rewritten and expanded to better explain how the partition between "free" and mineral associated POC and between the "soft" and "hard" POC fractions is done in the CCSM-BEC model. The sentence in lines 107–109 was also modified to direct the reader to Appendix A1 for a more detailed description of the CCSM-BEC vertical particle flux model, including the routing of POC to the different subclasses.

Difference between NPP and POC production: In the manuscript, NPP is defined as the fixation of carbon by the phytoplankton groups through photosynthesis and POC production is defined as the production of *dead* particulate organic matter (detritus). The definition above has been added to Section 2.2 (lines 136–138).

Table of parameterizations of POC flux: The information the reviewer is requesting about the different parameterizations of POC flux in Figure 3 is already presented in Table 6. We feel that repeating the same information in a new separate table in Section 2.3 (Methods) is unnecessary and would needlessly increase the number of tables in the manuscript. We expanded the description of the different parameterizations of POC flux that are compared against observations in lines 200–203. We also added a new column to Table 6 showing whether the different parameterizations are spatially variant or not.

Effect of temperature on POC remineralization scale (λ): There is significant latitudinal variation in temperature in the mesopelagic in CCSM, with temperatures at 590 m varying from below -2°C in polar regions to 9–14°C in the subtropical gyres (see Figure 1 below). The above clarification has been included in lines 416–418 in the manuscript.

Over 70% lithogenic material in sinking particles: The part of the text and model result (> 70% lithogenics in sinking material) the reviewer mentions refers to the North Subtropical Atlantic, not the Arabian Sea (Figure 7e, former Figure 5e). Comparison of Figure 1 and Figure 7e shows that we currently do not have sediment trap observations near that location to test that model result. This last point is discussed in the last paragraph of the Discussion.

Export estimate in line 489: The global export value of 21 Pg C yr^{-1} in line 489 is correct and refers to an estimate by Laws et al. 2000 using the model of Eppley and Peterson 1979. This clarification has been added to the text (line 490).

Effect of dust/lithogenic material on POC labile fraction (α) and remineralization scale (λ): In the current CCSM-BEC particle flux parameterization, the fraction of POC associated with dust is proportional to the vertical dust flux (Equations A4, A13) and is given by the POC/dust mass ratio for particulate matter (ω_{dust}, Table 7). This parameter does not depend on NPP and is held constant in the model. Thus, in regions of strong atmospheric dust deposition and low NPP, such as the North Subtropical Atlantic (and to a lesser extent, the North Indian Ocean), this parameterization could lead to unrealistically high fractions of POC associated with dust and an overestimation of transfer efficiency. The simpler exponential model captures the high transfer efficiency in these regions and expresses it in the form of low POC labile fractions ($\alpha < 90\%$) and long remineralization length scales ($\lambda > 250$ m). The constant proportionality between the dust associated POC and the vertical dust flux is a potential weakness in the model but we currently do not have the observational data to test it.

The above explanation was included in the Discusion (lines 595–603).

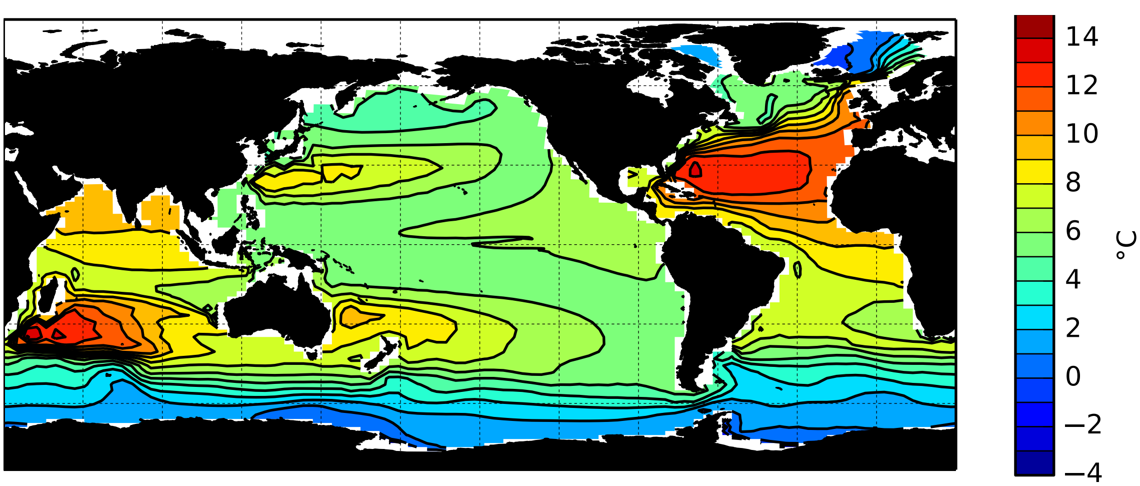

Figure 1: CCSM-BEC annual mean temperature at 590 m

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