Responses to Reviewer 2

Below the complete reviewer comments are shown in black font along with detailed responses to each comment in blue font.

Review:

The manuscript by Wang and Coauthors investigates the impact of the assimilatio of satellite surface observations to both physical and biogeochemical variables in a coupled model of the Gulf of Mexico physical and biogeochemical dynamics. Independent (nonassimilated) profiles form five BGC-Argo floats are used for validation. Results provided in the manuscript highlight interesting aspects on the capability of DA (data assimilation) to effectively correct ocean simulations, on the difficulties arising in coupled physical and biogeochemical assimilation, and on the relevant role played by prior model calibration in DA. The manuscript is well written and of interest for the scientific community considering recent and foreseen upgrades in physical-biogeochemical ocean DA. My review is limited to few points (most of them minor) that I think will further improve the manuscript quality.

Since line numbers are corrupted in the manuscript file, in the comments hereafter they are indicated by # followed by the part of line number visible in the manuscript. Page numbers are also provided together with line numbers.

Response: We thank the reviewer for the constructive comments and suggestions which will be very helpful as we revise the manuscript.

I suggest to introduce the alternative parametrization of the light absorption in a different way. In the manuscript it is currently described as an alternative that has been considered after investigating the results of previous simulations. I think that presenting this formulation as an alternative since the beginning would better emphasize the role of prior model calibration. Thus, I suggest to describe the alternative formulation not in a temporal framework (i.e., without specifying that it has been applied after previous simulations) as it is currently done in the abstract and in the manuscript sections. In particular: i) the first paragraph of Section 3.3 could be moved and adapted to Section 2.4; ii) in Section 2.4 the Authors could indicate that five (instead of three) simulations were performed; iii) it can be further stressed through the manuscript that the alternative formulation for the light absorption was adopted to investigate the sensitivity of subsurface DA impacts to model calibration (and in particular to the light penetration formulation); iv) the abstract should be adapted accordingly.

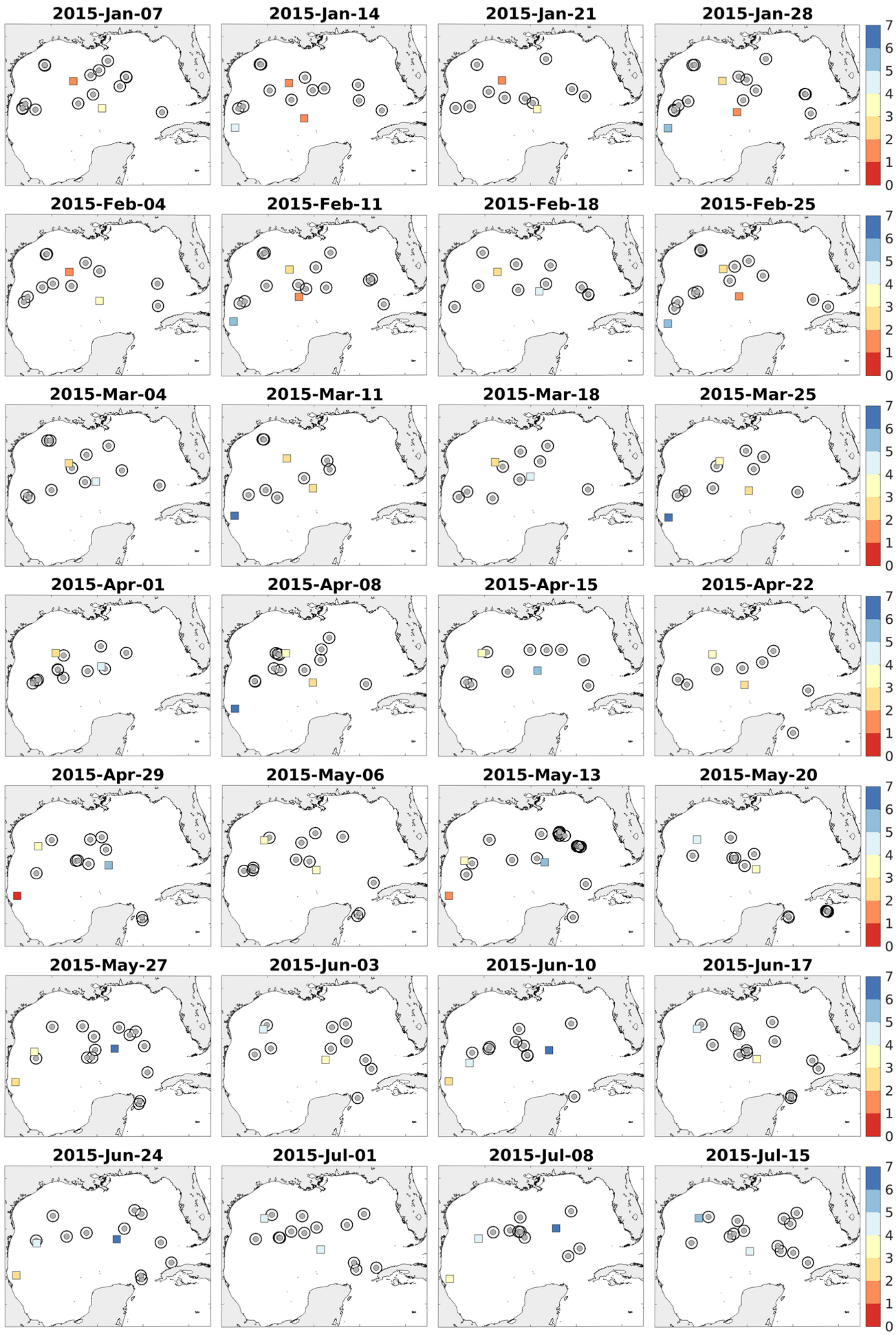
Response: Thank you very much for this constructive suggestion. We will revise it as suggested.

I think that the comparison with independent BGC-Argo floats is a valuable aspect of the manuscript, however, it would be interesting to know the spatial-temporal distances of the non-assimilated profiles with respect to the assimilated ones. Did they cover similar areas of the gulf of Mexico? And in the same period? In my opinion clarification on this aspect would help to better understand and comment the relatively small impact of Argo profiles assimilation when compared to the independent BGC-Argo data. Moreover, this could help also in commenting the differences between the two maps of Fig. 6 (are the differences mainly located close to assimilated Argo profiles?).

Response:

Figure r1 shows positions of Argo profiles (gray dots) at each data assimilation cycle (e.g. 7 Jan 2015, the first update date in our data assimilative experiments) and BOEM profiles (colored squares) before the next one (e.g. from 7 Jan 2015 to 14 Jan 2015). The solid black circles represent areas within one localization radius (50km) from each Argo profile. Colors of squares represent the days of each BOEM profile after each data assimilation cycle. As shown in Figure r1, most of BOEM profiles are outside of one localization radius from the Argo profiles and therefore are barely updated by assimilating the Argo profiles. Figure r2 shows the root-mean-square-difference (RMSD) of temperature from each BOEM profile between two data assimilative runs ($RMSD = \sqrt{\frac{1}{n}\sum(DA_{Sat} - DA_{Argo})^2}$) The x-axis represents days of each BOEM profile after each data assimilation cycle and the y-axis represents distance to the nearest Argo profile. In general, the RMSD between two data assimilative runs decreases with the distance but shows no significant decreasing trends with the days after update. This means that the differences induced by assimilating Argo profiles can be well sustained locally by model dynamical adjustments. The overall similarities between two data assimilative runs in Figure 4 can be explained to some extent by the large distances between BOEM and Argo profiles. However, it doesn't mean that increasing the localization radius necessarily improves the data assimilation performance. The current localization radius was determined by initial tests in Yu et al. (2019).

The differences in RMSE of surface chlorophyll between two data assimilative runs are shown in Figure r3. Positions of the assimilated Argo profiles are superimposed. The major differences in the two data-assimilative runs are mainly located around the Argo profiles. Reasons for why assimilating the Argo profiles can degrade surface chlorophyll are given in our response to the reviewer 1 and in the discussion of our original manuscript.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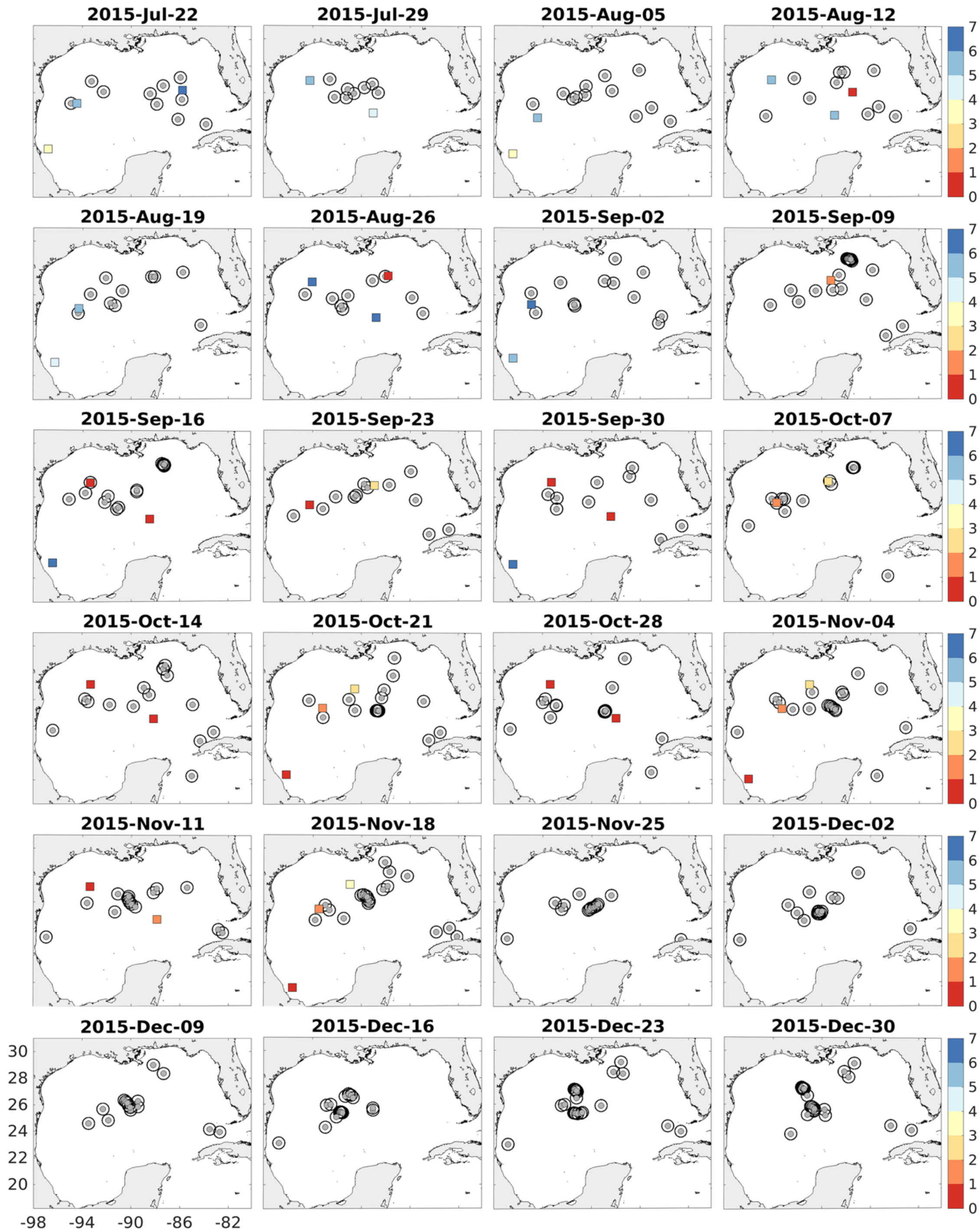

Figure r1 Positions of Argo profiles (gray dots) at each data assimilation cycle and BOEM profiles (colored square) before the next one. Solid black circles represent areas within one localization radius from each Argo profile. Colors of squares represent the days after each data assimilation cycle.

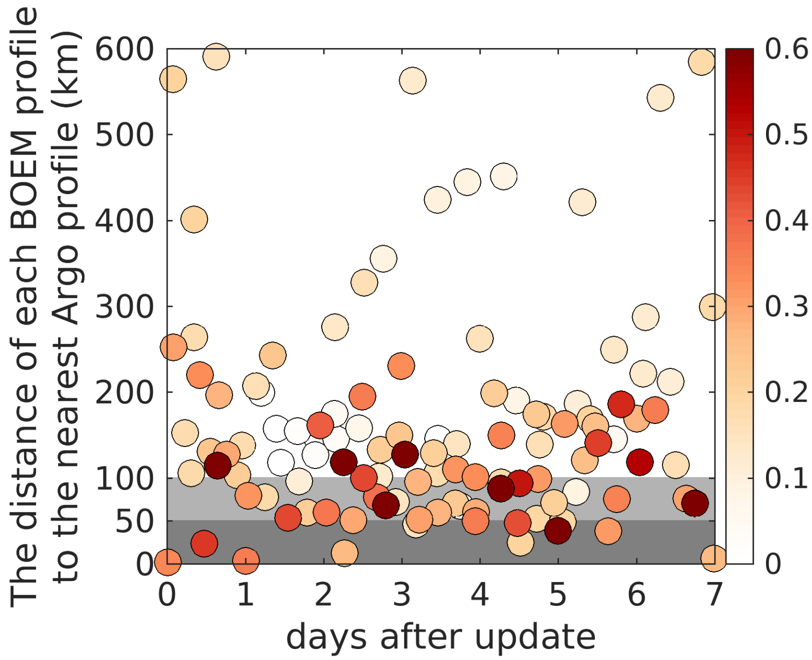

Figure r2 The root-mean-square-difference (RMSD) of temperature from each BOEM profile between two data assimilative runs, DAsat and DAargo (indicated by the color). The x-axis represents days of each BOEM profile after each data assimilation cycle and the y-axis represents distance to the nearest Argo profile

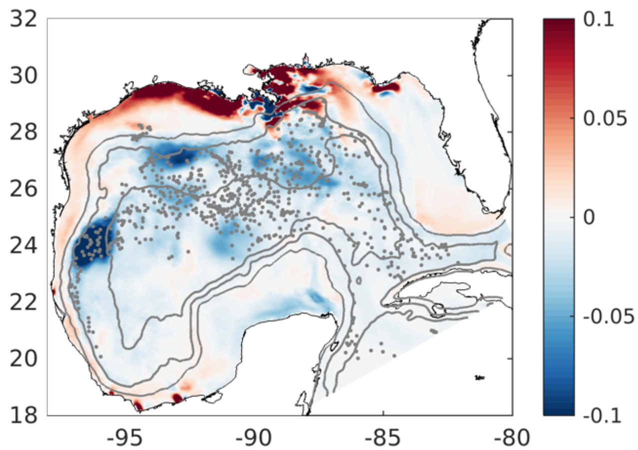

Figure r3 Differences in RMSE of surface chlorophyll between two data assimilative runs. Positive values represent improvements while negative values represent deteriorations by assimilating Argo profiles. Positions of Argo profiles are superimposed (gray dots).

I suggest to insert some comments in Sec. 3.3 about the impact of the alternative parametrization on RMSE with respect to satellite chlorophyll. Results of tab. 2 show that RMSE in Free_alt is slightly higher than in Free, but on the other hand the improvement due to the assimilation (DAsat_alt) is relatively higher. I think that this point could be further highlighted and commented in the manuscript.

Response: Agree, we will discuss it as suggested.

From the sentence at lines 18-19 (p. 1) in the abstract it seems that the model was tuned using BGC-Argo in the present. However, the tuning was made in Wang et al. (2020) (lines #08-#09, p. 4). Tha Authors should consider to rephrase the sentence in the abstract.
Response: We will rephrase the lines 16-21 in our original manuscript into:
"…… The multivariate Deterministic Ensemble Kalman Filter (DEnKF) has been implemented to assimilate physical and biological observations into a three-dimensional coupled physical-biogeochemical model, of which the biogeochemical component has been calibrated by the BGC-Argo floats data for the Gulf of Mexico. Specifically, observations of sea surface height, sea surface temperature, and surface chlorophyll were assimilated, and profiles of both physical and biological variables were updated based on the surface information……"

16 p. 1. I think that the correct term for biogeochemical Argo floats is BGC-Argo instead of BGC Argo. Please, check other occurrences in the whole manuscript.
Response: We checked the website of biogeochemical Argo floats (https://argo.ucsd.edu/expansion/biogeochemical-argo-mission/ and http://bgc-argo.ocean.dal.ca/). Both forms are correct. We will leave this as is in the manuscript.

94 p. 4. Probably Figure should be abbreviated with Fig. (please, check other occurrences).
Response: We will correct it as suggested.

#09 p. 4. Concerning the re-tuning of the half-saturation constant of nitrate, was it is done similarly to Wang et al. (2020), i.e. based on BGC-Argo? If not, could you explain how the updated value of the parameter was obtained?
Response: The half-saturation constant of nitrate was subjectively re-tuned based on the BGC-Argo floats. Specifically, we tested different values of this parameter and compared model results with observations. The parameter value will be used when it can well reproduce the observations. We will explain it in our revised manuscript.

#32 and L. #36 p. 5. I suggest to check if Equ. Is the correct abbreviation for Equation in Ocean Science Journal.
Response: We will revise it into Eq. following instructions of Ocean Science.

#53-#54, L. #61-#62 p. 6 and L. #58 p. 7. How were the values of observation errors defined? I suggest to add some references or details on criteria used.
Response: An observational error of 35% (or 30%) is a common practice to specify the error of satellite surface chlorophyll (e.g. Fontana et al., 2013; Ford, 2021; Ford and Barciela, 2017; Hu et al., 2012; Mattern et al., 2017; Santana-Falcón et al., 2020; Song et al., 2016; Yu et al., 2018). The observational errors of SSH and SST are also based on references (Song et al., 2016; Yu et al., 2018, 2019). We will add this in our revised manuscript as suggested.

#88 p. 7. Probably an and is missing in the sentence: zero mean and variance of 1.
Response: We will revise it as suggested.

#74 p. 11. I am not sure that the term subsurface is fully consistent here. Indeed, I would say that the model fails to simulate the high spatiotemporal variability also close to the surface, more generally the whole euphotic layer is affected by the issue.
Response: We think that this issue is more significant below the surface. Figure r4 shows chlorophyll near the surface (10m) from the BOEM floats and different model experiments. The coupled model either with or without data assimilation can in general well reproduce the spatiotemporal variability of chlorophyll except a few high values.

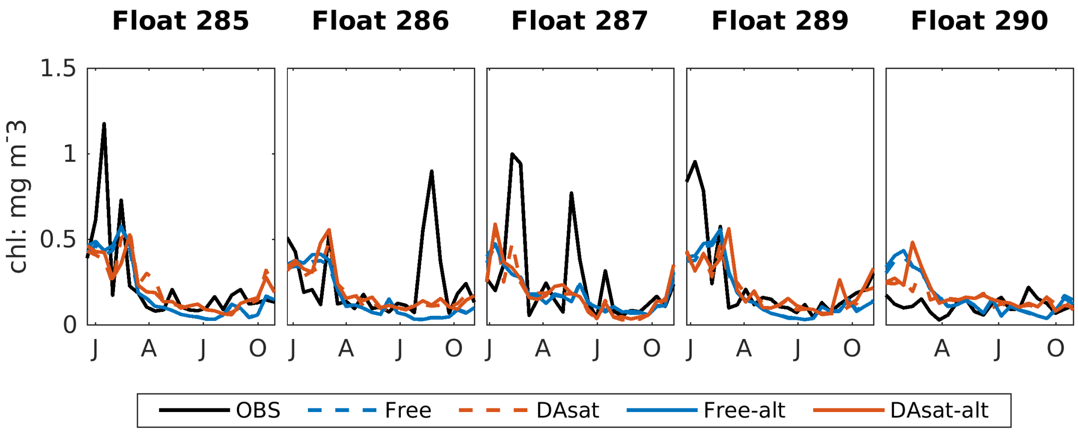

Figure r4. Time series of chlorophyll near the surface (10m) from the BOEM floats and different model experiments.

#94 p. 11. How were the two light attenuation parametrizations calibrated? Could you provide some details or references about?

Response: Parameters of the original light attenuation scheme ($Att=0.04+0.025\times chl$) is based on previous studies (e.g. Fennel et al., 2011, 2006) and the alternative light attenuation parameterization ($Att=0.027+0.075\times chl^{1.2}$) is subjectively tuned based on the BGC-Argo floats. We will add some explanation for the two light parameterizations in our revised manuscript.

#16 p. 12. Since the large use of BGC-Argo floats for model validation demonstrated in Salon et al. (2019), consider if it is relevant to add it in the listed references.

Response: We guess that the reviewer is referring to this paper "Novel metrics based on Biogeochemical Argo data to improve the model uncertainty evaluation of the CMEMS Mediterranean marine ecosystem forecasts". We will add this reference into our revised manuscript.

#62-#63 p. 14. As far as I know, in Goodliff et al. (2019) the muting of the multivariate update concerned not only chlorophyll but all the phytoplankton variables (whilst multivariate updated was maintained for nutrients and oxygen).

Response: True. In their study, they muted the multivariate update of phytoplankton, zooplankton, and detritus. We will correct it in our revised manuscript.

Fig. 10, I suggest to insert measurement units (at least in the caption).

Response: We will revise it as suggested.

Accordingly to comment 1, I think that in Discussion and/or in the Conclusion the need of an a priori well calibrated model could be further stressed by the results obtained using the alternative light attenuation parametrization, since it is an example of how DA benefits can be limited by a parametrization that it is not fully consistent with the modelled processes.

Response: Thank you for this suggestion. We will stress it as suggested.

Reference:

Fennel, K., Wilkin, J., Levin, J., Moisan, J., Reilly, J. O. and Haidvogel, D.: Nitrogen cycling in the Middle Atlantic Bight : Results from a three-dimensional model and implications for the North Atlantic nitrogen budget, GLOBAL BIOGEOCHEMICAL CYCLES, 20, 1–14, doi:10.1029/2005GB002456, 2006.

Fennel, K., Hetland, R., Feng, Y. and Dimarco, S.: A coupled physical-biological model of the Northern Gulf of Mexico shelf: Model description, validation and analysis of phytoplankton variability, Biogeosciences, 8, 1881–1899, doi:10.5194/bg-8-1881-2011, 2011.

Fontana, C., Brasseur, P. and Brankart, J. M.: Toward a multivariate reanalysis of the North Atlantic Ocean biogeochemistry during 1998 – 2006 based on the assimilation of SeaWiFS chlorophyll data Toward a multivariate reanalysis of the North Atlantic Ocean biogeochemistry during 1998 – 2006 based on, Ocean Science, 9, 37–56, doi:10.5194/os-9-37-2013, 2013.

Ford, D.: Assimilating synthetic Biogeochemical-Argo and ocean colour observations into a global ocean model to inform observing system design, Biogeosciences, 18(2), 509–534, doi:10.5194/bg-18-509-2021, 2021.

Ford, D. and Barciela, R.: Global marine biogeochemical reanalyses assimilating two different sets of merged ocean colour products, Remote Sensing of Environment, 203, 40–54, doi:https://doi.org/10.1016/j.rse.2017.03.040, 2017.

Hu, J., Fennel, K., Mattern, J. P. and Wilkin, J.: Data assimilation with a local Ensemble Kalman Filter applied to a three-dimensional biological model of the Middle Atlantic Bight, Journal of Marine Systems, 94, 145–156, doi:10.1016/j.jmarsys.2011.11.016, 2012.

Mattern, J. P., Song, H., Edwards, C. A., Moore, A. M. and Fiechter, J.: Data assimilation of physical and chlorophyll a observations in the California Current System using two biogeochemical models, Ocean Modelling, 109, 55–71, doi:https://doi.org/10.1016/j.ocemod.2016.12.002, 2017.

Santana-Falcón, Y., Brasseur, P., Brankart, J. M. and Garnier, F.: Assimilation of chlorophyll data into a stochastic ensemble simulation for the North Atlantic Ocean, Ocean Science, 16(5), 1297–1315, doi:10.5194/os-16-1297-2020, 2020.

Song, H., Edwards, C. A., Moore, A. M. and Fiechter, J.: Data assimilation in a coupled physical-biogeochemical model of the California current system using an incremental lognormal 4-dimensional variational approach: Part 3—Assimilation in a realistic context using satellite and in situ observations, Ocean Modelling, 106, 159–172, doi:https://doi.org/10.1016/j.ocemod.2016.06.005, 2016.

Yu, L., Fennel, K., Bertino, L., Gharamti, M. El and Thompson, K. R.: Insights on multivariate updates of physical and biogeochemical ocean variables using an Ensemble Kalman Filter and an idealized model of upwelling, Ocean Modelling, 126, 13–28, doi:https://doi.org/10.1016/j.ocemod.2018.04.005, 2018.

Yu, L., Fennel, K., Wang, B., Laurent, A., Thompson, K. R. and Shay, L. K.: Evaluation of nonidentical versus identical twin approaches for observation impact assessments: an ensemble-Kalman-filter-based ocean assimilation application for the Gulf of Mexico, Ocean Science, 15(6), 1801–1814, doi:10.5194/os-15-1801-2019, 2019.