Dear Editor, Dear Reviewers,

Thank you for taking the time to review our manuscript and for providing comments, we appreciate this very much. Your comments have been very constructive and have made a significant contribution towards improving our manuscript.

Please find below our response to the individual reviewer's comments. The original comments are numbered (e.g. R1C1 – Reviewer 1, Comment 1 and R2C1 – Reviewer 2, Comment 1) and shown in black italic text. Our response is shown in blue normal text. There are two versions of the updated manuscript available, one version which shows the changes and one clean version. Please note that when we refer to line numbers in our responses below, we refer to the new line numbers in the clean version of the manuscript. We have also included 14 additional references in the revised manuscript, as follows:

Additional References:

1. Bidigare, R.R., Ondrusek, M.E., Morrow, J.H. and Kiefer, D.A.: In vivo absorption properties of algal pigments. Proc. SPIE, 1302, 290-302, doi:10.1117/12.21451, 1990.

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3. Fennel, W. and Sturm, M.: Dynamics of the western Baltic, Journal of Marine Systems, 3, 183-205, https://doi.org/10.1016/0924-7963(92)90038-A, 1992.

4. Fournier, G.R. and Forand, J.L., Analytic phase function for ocean water, Proc. SPIE 2258, Ocean Optics XII, https://doi.org/10.1117/12.190063, 1994.

5. Freda, W. and Piskozub, J., Improved method of Fournier-Forand marine phase function parameterization, Optics Express, 15(20), 12763-12768, https://doi.org/10.1364/OE.15.012763, 2007.

6. Gallegos, C.L., Werdell, P.J and McClain, C.R.: Long-term changes in light scattering in Chesapeake Bay inferred from Secchi depth, light attenuation and remote sensing measurements, Journal of Geophysical Research, Oceans, 116, C7, https://doi.org/10.1029/2011JC007160, 2011.

7. Gregg, W.W. and Rousseaux, C.S.: Directional and spectral irradiance in ocean models: effects on simulated global phytoplankton, nutrients and primary production, Front. Mar. Sci., 22, 3, https://doi.org/10.3389/fmars.2016.00240, 2016.

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10. Kirk, J.T.O.: Light and Photosynthesis in Aquatic Systems, 3rd Edition, University Press, Cambridge, 649pp, 2011.

11. Meier, H.E.M., Modeling the pathways and ages of inflowing salt- and freshwater in the Baltic Sea, Estuarine Coastal Shelf Science, 74(4), 717-734, https://doi.org/10.1016/j.ecss.2007.05.019, 2007.

12. Omstedt, A., Pettersen, C., Rodhe, J. and Winsor, P., Baltic Sea climate: 200 yr of data on air temperature, sea level variation, ice cover, and atmospheric circulation, Clim. Res., 25(3), 205–216, https://www.jstor.org/stable/24868400, 2004.

13. Rozwadowska, A. and Isemer, H.J.: Solar irradiation fluxes at the surface of the Baltic Proper. Part 1. Mean annual cycle and influencing factors, Oceanologia, 40(4), 307-330, 1998.

14. Zielinski, O., Llinas, O., Oschlies, A. and Reuter, R.: Underwater light field and its effect on a one-dimensional ecosystem model at station ESTOC, north of the Canary Islands, Deep Sea Research II; 49, 17, https://doi.org/10.1016/S0967-0645(02)00096-6, 2002.

Reviewer 2:

General comments

R2C1:

1) Very nicely and very much in details written general (published) and theoretical information but much less in the actual information. In particular, this novel bio-optical module the authors introduce, use and evaluate is currently described in words with references to equations in the Theory subsection. Even though the Theory section is nicely written, it would be more straightforward to explicitly formulate the model equations with proper citations in the subsection 2.3 (as a separate subsubsection) and remove then subsection 2.2 (Theory). Especially, if this "Bio-Optic" module is presented for the very first time. If it was already published and evaluated, please provide the related reference.

Agreed, we have streamlined the introduction section and combined the Theory subsection with the description of the Bio-Optic model (refer to section 2.2, 2.2.1 and 2.2.2). We also clarify how Bio-Optic is a new option within the ECOSIM model and provide appropriate references linking the two (see section 2.2.2., lines 304 - 313).

R2C2:

Looks like the ROMS-BioOptic model code used in this study is not easily accessible (is not easy to find) given the provided general link https://www.myroms.org (Is it within EcoSim?)

The generic version of the Ecosim/BioOptic code is accessible via the general link (https://www.myroms.org) within the Ecosim module. The update Ecosim module which includes the biofeedback options, is currently archived with at Zenodo (see link under data availability) but will be incorporated into the standard ROMS release in due course.

R2C3:

2) Some more details could be given w.r.t. setting the radiation model MOMO used for the evaluation of the heating rate estimates (see specific comments).

Agreed, more details on how MOMO was configured for our experiment are provided in the text (lines 360 - 374), as follows:

"MOMO simulations were performed at relatively high angular resolution (twenty-seven angles in the atmosphere between 0 and 88 degrees plus nine additional angles in the ocean to cover the angular domain of total internal reflection) to allow for an accurate calculation of the in-water light field. Up to 120 terms were used for the Fourier expansion of the azimuth dependence of the light field. The oceanic vertical structure in MOMO has been chosen identical to the ROMS-Bio-Optic vertical structure, i.e., the light field has been calculated at the thirty-one ROMS-Bio-Optic layer boundaries located between 0 and ca. 90 m. Absorption and scattering coefficients for phytoplankton, CDOM, and detritus are taken directly from ROMS-Bio-Optic output. Spectral resolution was done in steps of 5 nm between 400 nm and 700 nm. Two Fournier-Forand phase functions (Fournier and Forand, 1994; Freda and Piskozub, 2007) with differing backscattering to scattering ratios have been applied to phytoplankton (bb/b = 0.001) and detrital material (bb/b = 0.1), in line with phase functions measured by Siegel et al. (2005) for various Baltic Sea coastal waters. Seasonal heating rates were derived from MOMO simulations at the Bornholm Basin location and compared to the corresponding fluxes from ROMS-Bio-Optic in order to assess the suitability of the simplified treatment of radiative transfer in the latter and the implications of not resolving the full directionality of the light field therein. MOMO results are presented for the 38° solar incident zenith angle, representative of late spring to mid-summer in the Western Baltic Sea (Figure 12)."

R2C4:

3) Temperature observations at the "Oder Bank", "Darß Sill", "Arkona Sea" and "Bornholm Basin" stations provided by the German Maritime Agency (BSH) and Denmark Meteorological Institute (DMI) could be presented in the "in situ observations" subsection. Please provide the related references.

Agreed, we have clarified our model evaluation strategy (section 2.4, lines 375 - 393) and included relevant references for the in situ observations.

R2C5:

4) Are there actual satellite CDOM, phytoplankton total chlorophyll, Kd products available for the year 2018 (the year of your interest)? What about using Sentinel 3 observations?

Yes, we have updated the results section with a more comprehensive evaluation of our model output using the Sentinel 3 OLCI 300m Level 3 chlorophyll, phytoplankton and non-algal particle absorption, and diffuse attenuation coefficient, K_d490 products on two consecutive days in May 2018 when a bloom event took place in the Arkona Sea (section 3.2, Figure 5, Figure 6, Table 2).

R2C6:

5) I would recommend changing the format of the result visualization from 3D (as it currently Figures 4 -8) to 2D. The 3D representation does not add anything in comparison with 2D one but hides some information. Hovmöller diagram might suit better for the results depicted in Figure 9 (I agree with the first reviewer)

We have considered the reviewer's suggestion to update the Figures 4 – 8 to 2D (now Figures 8 - 12) but do not agree. We do not think information is being hidden, but actually find the 3D presentation provides a better view on the spectral response of inherent and apparent properties of the constituents. We prefer to keep these figures in 3D.

We have updated Figure 9 (now Figure 13) to a Hovmöller diagram.

Specific comments

R2C7:

L17-18: please double check and correct if required: currently it reads as both phytoplankton and CDOM effects dominate in summer.

We have re-worded this to clarify the statement, as follows (lines 17 - 19):

"… find that while phytoplankton and CDOM both contribute to surface heating in summer, phytoplankton dominates the OSC contribution to heating in spring, while CDOM dominates the OSC contribution to heating in autumn."

R2C8:

L120: you could cite also Fasham et al., 1990

Agreed, we have added the Fasham et al., 1990 reference to lines 157 and 892.

R2C9:

L126: I would suggest removing Equation 2 as not used in the current study.

Agreed, Equations 1, 2 and 3 have been removed as part of restructuring and streamlining the Introduction.

R2C10:

L137: Could Equation 3 be removed? Do you use this equation? A related equation used in the current study could be shown in the subsection dedicated to the "Bio-Optic" module.

Agreed, see response to R2C10 above.

R2C11:

Figure 1: Were the observations marked as red dots used for evaluation or only the observations from the four stations (marked green dots)?

The red dots were used to prepare the monthly CDOM absorption climatology, details provided in Appendix B1. The green (now blue) dots show the location of the sites we use in the model evaluation.

R2C12:

The material from Subsection 2.2 Theory could be adjusted in the subsection dedicated to the "Bio-Optic" module.

Agreed, see response to R2C1 above.

R2C13:

L287: reference is required if exists

This is clarified in response to R2C1 above.

R2C14:

L303-304: what is assumed/used as information on "clouds, water vapour and aerosols, the surface roughness"

We have clarified these details in section 2.2 as follows (lines 281 - 288):

"Light energy just beneath the sea surface is calculated using a derivative of the RADTRAN code described in Gregg and Carder (1990) as a function of the model's meteorological forcing (i.e. wind speed, relative humidity, air temperature and pressure), and cloud cover, atmospheric gases (i.e. water vapour, ozone, oxygen), marine aerosols and the surface roughness and reflectance at the ocean-atmosphere interface. A constant percentage of 0.3 % cloud cover is assumed for clouds, while 1.5 cm precipitable water is assumed for water vapour. The underlying algorithms used to compute ozone, water vapour and oxygen absorption coefficients are described in detail in Gregg and Carder (1990). Marine aerosols are computed according to the simplified version of the Navy marine aerosol model, also described in detail in Gregg and Carder (1990)."

R2C15:

L311: provide information on how a and b for phytoplankton, detritus and CDOM are explicitly calculated, show also the function used to calculate the average cosine (L309)

We have clarified how absorption and scattering are calculated, along with relevant references which include the function for the average cosine in section 2.2. The following text has been added (lines 292 - 303):

"The spectrally-resolved downward light stream, Ed(λ,z) is calculated according to Eq. (10) and is attenuated by absorption, a, and scattering, b (forward, b and backward, bb) of the OSCs. Phytoplankton and detritus both absorb and scatter light. Phytoplankton absorption is calculated for the four functional groups as a function of biomass, weight-specific pigment absorption coefficients (Figure 1b, Bidigare et al., 1990) and packaging effect (Bissett et al., 1999b; Kirk, 2011). Detrital absorption is calculated as an exponential function of wavelength (Gallegos et al., 2011). Phytoplantkon and detrital scattering and backscattering are accounted for as total particulate scattering and backscattering according to Morel (1991) and Morel (1988), respectively (see Equations 16 and 17 in Bissett et al., 1999b). CDOM only absorbs light and is calculated as a function of CDOM concentration and the weight-specific absorption coefficients adapted from Kowalczuk et al. (2005b) (Figure 1a). The average cosine is modified with depth as a function of absorption and backscattering. This is simplified as a linear function of the optical depth between two levels (see Equation 22 in Bissett et al., 1999b). The total scalar irradiance, E0(λ,z), which is the light available to phytoplankton, is calculated following Eq. (5) after Morel (1988)."

R2C16:

L347: you could list the observed characteristics here explicitly

We have added some text to summarize the important characteristics of the physical model (lines 350 - 352), as follows:

"It captures the annual cycle of temperature and salinity in the Western Baltic Sea and episodic inflows of saline, oxygen-rich North Sea water which control the salinity content and stratification in the Baltic Sea and are important for ventilating the deeper basins of the Baltic Sea (Omstedt et al., 2004; Meier, 2007)."

R2C17:

Table 1 reads somehow repetitive to the text. While you could still extend the table by information related to "Bio-Optic" module setup, including information on spectral resolution. Information used for evaluation can be summarized in a separate table (if required, it will support the subsection 2.5). There you could also provide the details on satellite data used.

Agreed, we have moved the details of the model configuration into Appendix A and clarified which in situ and satellite data products are used for the evaluation in section 2.4.

R2C18:

L357-359: please provide the setup details on the MOMO simulations

See response to R2C3.

R2C19:

L393: I suggest removing “using Eq. (11)” as the equation follows

Agreed, the text has been removed.

R2C20:

L402: I suggest removing “using Eq. (12)” as the equation follows

Agreed, the text has been removed.

R2C21:

Section 2.5.1 could be shortened. The sampling details (e.g. L384-391) if not used for the discussion can be moved into Supplementary material).

Agreed, we have moved these details into Appendix B1.

R2C22:

In this section, BSH and DMI observations could be presented.

The in situ observations used for the model evaluation have been clarified (see section 2.5).

R2C23:

What about data from Meler et al. 2016?

This is clarified in section 2.5.

Subsection 2.5.2 Remotely sensed data:

R2C24:

Are there products available from other satellite missions (e.g. Sentinel3) for the year of your interest 2018?

Yes, see our response to R2C5.

R2C25:

Could Figure 2 be moved to the Supplementary or Appendix since not presenting results of the study, although supporting the discussion? Instead, in the Result section the authors could show and discuss the CDOM (TChla, Kd) distribution simulated by the model.

Agreed, we have created Appendix B to describe the details of the climatologies used in the model evaluation. Meanwhile, we have updated the results section with a more comprehensive evaluation of the model output, see section 3.2.

R2C26:

L446-448: please provide references to the BSH and DMI observations

This is clarified in section 2.5, see our response to R2C22.

R2C27:

Figure 3 captions: detail the legend (abbreviation used in the Legend)

Figure 3 (now Figure 4) has been updated and legend abbreviations have been clarified in the figure caption.

R2C28:

Table 2: Please extend the title to clarify that the goodness of fit statistics is provided for the simulated sea surface temperature.

The table caption (now Table 1) has been extended to clarify that the statistics are provided for modelled versus observed sea surface temperature °C as follows (line 424):

“Table 1: Model versus observed sea surface temperature (°C) statistics.”

R2C29:

Figure A1: please provide related labels (a, b, c, d) to be consistent with the figure caption.

Agreed, the figure has been updated with labels a, b, c, d.

R2C30:

Figure A1 could be moved to the main manuscript as model evaluation results and could be extended (or revised 2 upper panels) by comparing with more collocated with MERIS (or Sentinel 3) surface matchups (not only for the four stations).

This figure (now Figure 7) has been moved into the main results section as part of the update to the model evaluation.