# Response to Reviewer 2 comments

We wish to thank Reviewer 2 for dedicating time to carefully read our work and providing his/her feedback. We sincerely think his detailed comments helped us to improve the manuscript. Here it follows a point-by-point response to the reviewer's report (text in bold denotes the provided comments, while normal text denotes our response), associating with the revised manuscript with the track of the changes.

**In this paper Authors propose an updated scheme to simulate heat propagation at the ocean-atmosphere interface. The importance of the task is related to heat budget estimates, assimilation of satellite data.**

**The study proposes an interesting and important upgrade, but in my opinion there are points that could be improved:**

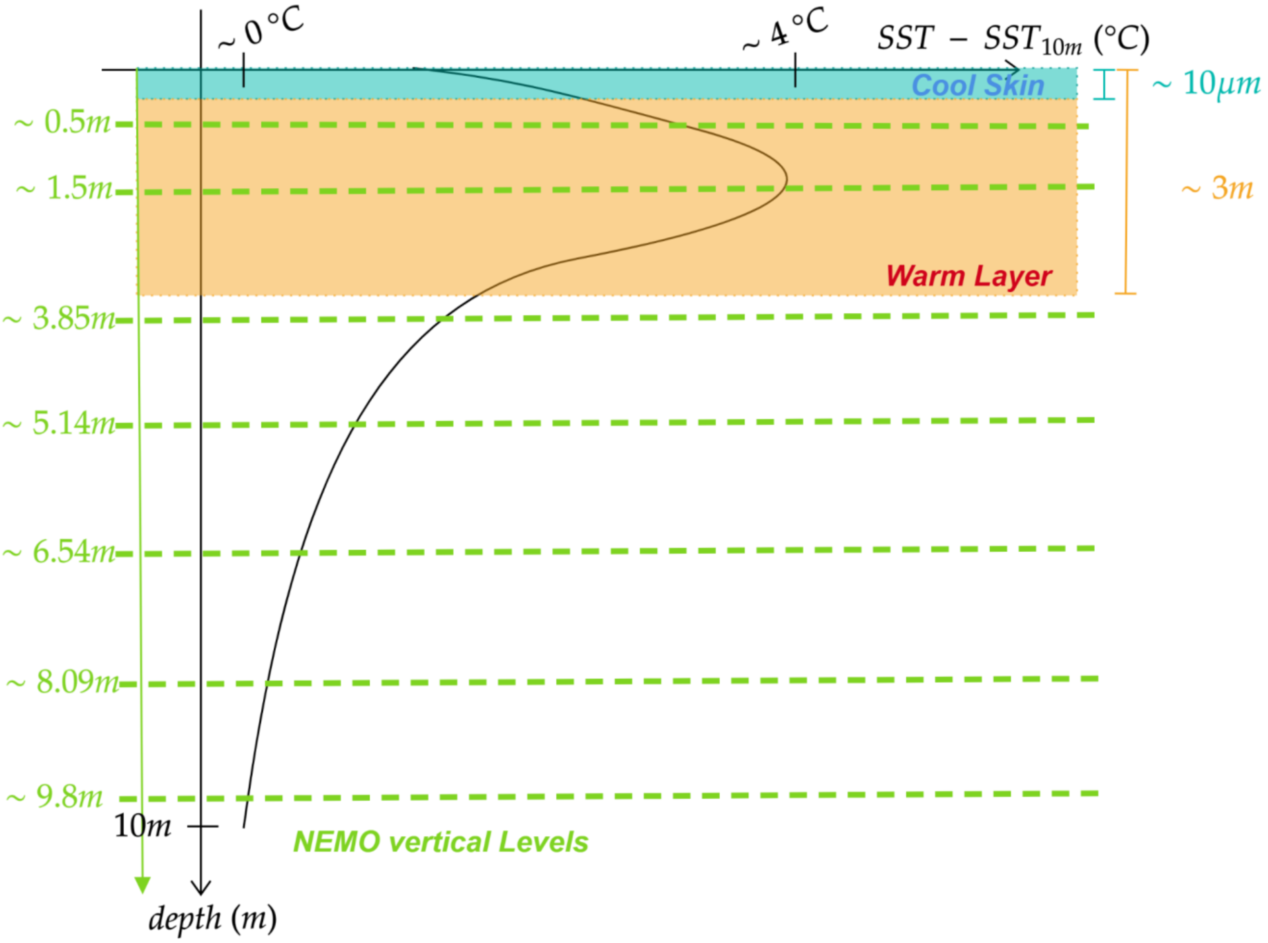
- **Description of the model/new parameterization. It would be useful to add a diagram illustrating the layers, the cold skin layer and the warm layer. In the description of the model (e.g. Eq 5 and 10) it would be useful to understand what the prognostic variables are and how this parameterization is related to the OGCM internal variables. (e.g. Nemo potential temperature). Nemo vertical discretization in the upper layer could be also shown in the diagram.**

We can provide a schematic diagram of the cool skin and the warm layer (see respectively panels a and b of the figure below), even if it is just a re-adaptation of the sketch given in Donlon et al., 2007.
Since the cool skin temperature difference is time-independent, that is the diagnostic part of the scheme, while the warm layer temperature difference is the prognostic variable, since its determination requires temperature difference both at time t and at the preceding time step.
By default, the parameterization is conceived to simply diagnose the skin SST within a simulation, without actually entering in the dynamics. For each of the simulations, we substituted SST in the first model level with the skin SST calculated from each scheme in the coupled ocean-atmosphere model. In the diagram below you can also notice that vertical levels within NEMO are not equally spaced (we didn't report them perfectly in scale with the underlying y-axis - the figure is just qualitative).
Not in order, we made the following modifications to the manuscript:

- Added the information about the unevenly spaced vertical levels of NEMO in the model description part, changing the text from
  "...72 vertical levels and a timestep…"
  to
  "...72 unevenly spaced vertical levels (the first and the last being respectively about 0.5m and 200m thick) and a timestep…"
  See LL 188-190.
- Added comments on diagnostic/prognostic variables within the schemes. We modified text from
  "...gets absorbed within the cool skin."
  to
  "...gets absorbed within the cool skin. Being time-independent, the cool skin temperature difference is a diagnostic variable in the scheme."
  See LL 231-232.
  And from
  "...for the cool skin and warm layer respectively."

to
"...for the cool skin and warm layer respectively. Being time dependent, the determination of the warm layer temperature difference at time t requires the knowledge of the one at the previous time step, and thus is the prognostic variable in the scheme."
See LL 278-280.

- Added comments on the protocol used (substitution of the SST with the skin SST in the coupled simulations). Text changed from
"...(provided in Table 1)."
to
"...(provided in Table 1). In cases where a skin SST scheme is active, we substitute the SST, i.e. temperature on the first NEMO level, with the skin SST coming out from the scheme."
See LL 338-339.
- We added the sketch in the introduction section (see Figure 1), with the caption
"Figure 1. Sketch of the cool skin and warm layer adapted from Donlon et al., 2007. Vertical discretization of NEMO levels is shown in green (not perfectly in scale with the underlying y-axis)."
Also, we insert a mention in the introduction section. Text modified from
"(the first model layer being only around 0.5-1 meter thick, e.g. the ocean model NEMO)."
to
"(the first model layer being only around 0.5-1 meter thick, e.g. the ocean model NEMO - see the sketch in figure 1)."
See LL 66.



- **Authors should provide a better description for the choice in the variability of the terms in the new approach. Considering the formula for the solar transmission equation, the exponents b_i should also be space/time dependent because light attenuation should be modulated by chlorophyll (and other optical constituents). This is suggested in Table 1 (R-G-B + chl e-folding) but this should be reported with a clear formula. This variability of attenuation coefficients b_i is directly connected to the change in d. In particular authors imply that transmission is not constant due the chlorophyll variability and then they assume "constant transmission throughout the basin, but with a spatially and temporally varying e folding depth and defines our new prognostic scheme for skin SST warm layer calculation". I think this is a central part of the work and should be better illustrated and explained.**

We already addressed this point in responding to Reviewer 1 comments:

See LL 309-326 at the end of section 3.3: where we modified the text from

"From this viewpoint, choosing a value of d = 3 m while using the solar extinction formulation as in Soloviev, 1982 or Soloviev and Schlussel, 1996 would lead to underestimate the penetration of solar radiation into the warm layer. Another possibility, as in the case of the NEMO module for radiation calculations (Jerlov, 1968, Morel et al., 1989, Lengaigne et al., 2007), is to reconstruct a chlorophyll profile from its surface values and employ an R-G-B scheme to calculate radiation as a function of depth. From eqn. (13) with only 4 terms (one for chlorophyll, and three for R-G-B), one can numerically derive the e-folding depth using chlorophyll variations and the R-G-B light extinction coefficients taken from lookup tables in the source code.

This would give a constant transmission throughout the basin, but with a spatially and temporally varying e- folding depth and defines our new prognostic scheme for skin SST warm layer calculation. Everything else is left unchanged, both the refinements of Takaya et al., 2010 (T10 hereafter) and the A02 model for cool skin."

to

"From this viewpoint, choosing a value of d = 3 m while using the solar extinction formulation as in Soloviev, 1982 or Soloviev and Schlussel, 1996 would lead to underestimatinge the penetration of solar radiation into the warm layer. Another possibility, which constitutes our modification to the scheme already implemented in NEMO, is to reconstruct a chlorophyll profile from its surface values following what is already implemented in the NEMO module for radiation calculations (Jerlov, 1968, Morel et al., 1989, Lengaigne et al., 2007), and employ an R-G-B+Chl-a scheme to calculate radiation as a function of depth. Then, from eqn. (13) with only 4 terms (one for chlorophyll, and three for R-G-B, expressed in lookup tables), one can numerically derive the warm layer reference depth as the e-folding depth of the light extinction profile (see Fortran source files in the Zenodo repository, de Toma (2024)).

This would give a constant transmission throughout the basin, but with a spatially and temporally varying e-folding depth and defines our new prognostic scheme for skin SST warm layer calculation, thus embedding in it the ocean color information coming from Chl-a. Everything else is left unchanged, both the refinements of Takaya et al., 2010, which include the effect of Langmuir circulation and a modification of the Monin-Obukhov similarity function under stable conditions (T10 hereafter), and the A02 model for cool skin, which has been demonstrated to improve the scheme respectively under wavy and windy conditions."

The Zenodo repository reference is

Vincenzo de Toma. (2024). Skin Sea Surface Temperature schemes in coupled ocean-atmosphere modeling: the impact of chlorophyll-interactive e-folding depth. Intermediate results and scripts to produce the figures. Zenodo. https://doi.org/10.5281/zenodo.10818183

**Below I report some technical points.**

**P2 Line 64 “Simplified approaches” rather then “Simplified models”**

Changed accordingly. See LL 70 of the manuscript with the track of the changes.

**P4 Line 114 “regions where the percentage of model data is higher than 50% have been masked out both in 115 CMEMS MED DOISST and our experiments”**

**Not clear “higher than 50%” higher in respect to what?**

This data is a combination of SEVIRI and the MedFS system, using this latter as first guess for the optimal interpolation where SEVIRI data are insufficiently sampled. Changed accordingly, from

“...regions where the percentage of model data is higher than 50%...”

to

“...regions where the percentage of valid SEVIRI measurements is lower than 50%...”

See LL 139 of the manuscript with the track of the changes.

**P6 Lines 183 and 185 please put units of measure of quantities considered.**

Added, text modified to

“...in which the subscript *w* refers to water properties, *T* is seawater temperature (*K*), $K_w$ ($m^2 s^{-1}$) is the turbulent diffusion coefficient, $k_w$ ($m^2 s^{-1}$) is the molecular thermal conductivity, $\rho_w$ ($Kg\ m^{-3}$), $c_w$ ($J\ Kg^{-1} K^{-1}$) are respectively seawater density and heat capacity per unit volume, *R* ($W\ m^{-2}$) is the net solar radiation flux, defined as positive downward.”

See LL 209-211.

**P6 Line 191 “assuming this constant” which constant, maybe the const in eq 2?**

**Please clarify.**

Yes, exactly.

**P7 Lines 212,214 please put units of measure of the symbols.**

Added, text modified to

“where $\lambda$ is the Saunders’ proportionality constant, *Q* ($W\ m^{-2}$) has already been defined above, $\tau/\rho_w$ ($m^2\ s^{-2}$) is the kinematic stress (ratio between wind stress module and seawater density), and $v_w$,($m^2 s^{-1}$) $k_w$ ($m^2 s^{-1}$) are respectively the kinematic viscosity and thermal conductivity of seawater.”

We left unspecified the dimensions of the Saunders’ constant because they are given by dimensional analysis.

See LL 239-243.

**P7 Line 230 Eq 8 is not clear. Please write better the argument of \phi function.**

modified text from

“...depending on the sign of its argument:...”

to

“...depending on the sign of its argument, which is the ratio of the vertical coordinate to the Monin Obukhov length *L*:...”

See LL 264-265.

**P8 Line 241 "Assuming a temperature of dependence"**

**Please explain better.**

Sorry, there was a typo. Eliminated the word "of" give sense to the sentence. Changed from

"...Assuming a temperature of dependence.."

to

"...Assuming a temperature dependence…"

See LL 273.

**P8 Lines 245,246 I would specify if the equations are coupled e.g "In ZB05 scheme (Zeng and Beljaars, 2005), eqs. (5, 10) are the coupled equations for the cool skin and warm layer respectively." As already reported above, it would be useful to make clear which prognostic variables are taken into account.**

Thanks, changed accordingly. Text modified from

"In ZB05 scheme (Zeng and Beljaars, 2005), eqs. (5, 10) are the equations for the cool skin and warm layer respectively"

to

"In ZB05 scheme (Zeng and Beljaars, 2005), eqs. (5, 10) are the coupled equations for the cool skin (diagnostic part) and warm layer (prognostic part) respectively."

See LL 277-278.

**P8 Line 246 " within this layer" which layer? Maybe "these layers"?**

Changed from

"within this layer"

to

"within the warm layer"

See LL 280-281.

**P12 Line 337 "Looking at the mean profile averaged over all grid points in the given area, the agreement is better for all simulations during summertime months, both for the eastern and the western region (see figs. 8c, 9c), showing in particular that the modradnemo simulation outperforms the nemoskwrite one"**

**I don't see where modradnemo simulation outperforms the nemoskwrite one, they seem equivalent in terms of skill, could authors be more quantitative? Some tabulated skill metric could be useful.**

We thank the reviewer for this observation. It can be noticed from vertical profiles that the purple curve (modradnemo) is slightly closer to the blue curve (EN4) than the red curve (nemoskwrite). This is especially true in the central part of the med sea for summertime months, also when you look at RMSE on the upper 15m (see figures 10d, 10e).

**P12 line 376 "On the other hand, in the western Mediterranean all simulations tend to overestimate the signal, with our modified scheme doing a better job. "**

**Could authors be more quantitative, adding some statistics to support their statements?**

Sentence extended. From

“...doing a better job.”

to

“...doing a better job with respect to the nemoskwrite case, with an average profile which is about 0.4°C closer to the EN4 profile.”

See LL 429-430.

**Figure 2 panel (a) the plot could be improved. I suggest putting the z axis vertically (with negative ticklabels for depth as used in equations).**

Thanks for the suggestion; however, we’d prefer to keep the plot as it is, mainly for three reasons. First, Solar transmission is a function of depth, calculated as a sum of exponentials (inverting this function would not be as straightforward as one can think at first impression). Second, like this, it highlights that depth is the independent variable, and therefore has been placed on the x-axis. Lastly, being a log-log plot negative values would make no sense, since the logarithm function is defined for positive values of its argument.

**Figure 10. Region 0 should be removed, it’s not a sea region.**

Thanks, changed accordingly. See figure below: