### REFEREE #2

Dear Referee,

we would like to thank you for the careful reading of the manuscript and the constructive comments that substantially helped to improve and clarify the paper. Answers to all your comments are detailed hereafter. Corrections to the English grammar were adopted in the revised version of the manuscript according to the reviewer's recommendations, but are not reported or discussed here. All authors agree with the modifications made to the manuscript. The comments by the referee are reported in bold followed by our response (in blue). The text added to the revised manuscript is reported in italic font. The revised manuscript that includes track changes and line numbers is provided in pdf format.

In the following answers, we use 'Figure' to identify the figures in the updated manuscript and we use 'Plot' to identify the figures in this document.

The name of the experiments have been slightly modified, as reported in Table 1. They are used in the following answers and in the updated manuscript. We tried the names that you suggested, but they were hard to read throughout the text.

| Experiment name | sea surface temperature used ($T_s$) | computation of $C_D$ | computation of $C_E$ and $C_H$ | convective gustiness |
|---|---|---|---|---|
| COARE_S | SSTskin | COARE3.6 | COARE3.6 | Yes |
| ECMWF_S | SSTskin | ECMWF | ECMWF | Yes |
| NCAR | SST | NCAR | NCAR | No |
| ECMWF_NS | SST | ECMWF | ECMWF | Yes |
| CdNC_CeEC_NS | SST | NCAR | ECMWF | No |
| ECMWF_NS_NG | SST | ECMWF | ECMWF | No |

**Table 1.** Summary of the numerical experiments.

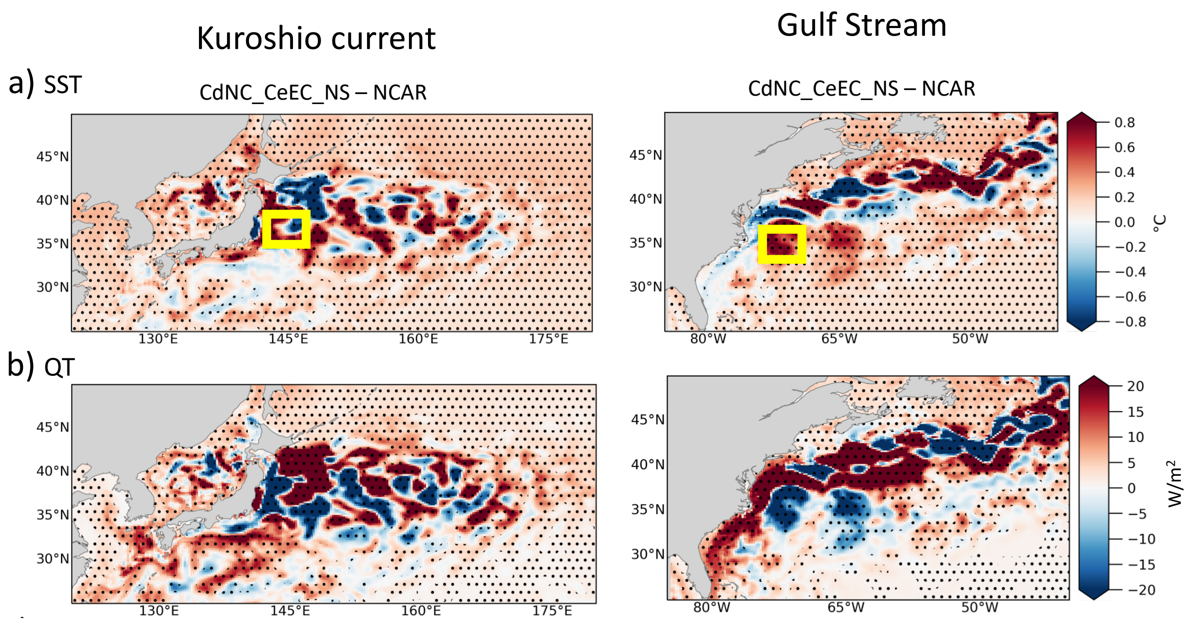
### Major comments

**1) A lot of effort is put in explaining quite successfully why there is a cold bias in the equatorial eastern Pacific and the EBUS regions between ECMWF and NCAR bulk schemes. However, very little attention is given to the strong differences in heat fluxes found over western boundary current (WBC) systems, which are known to be areas with strong air-sea interactions (See figure 2 of the manuscript). I invite the authors to dig a bit more in this direction and explore if there is a meaning in the spatial and temporal variability of this difference. If it was only noise, I would expect it to average to zero in an annual mean, but, indeed, it is visible in both ECMWF-NCAR and COARE-NCAR differences (figure 3).**

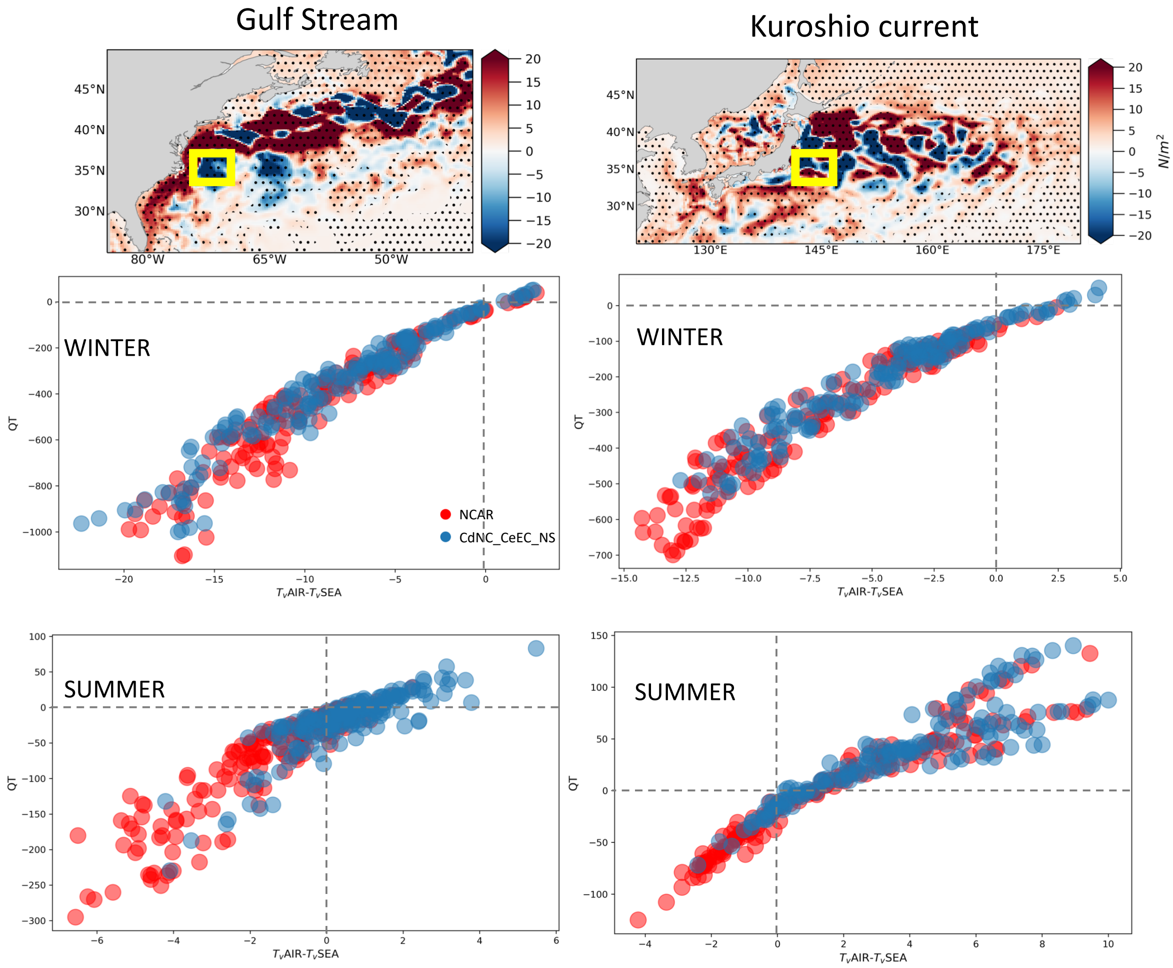
We agree with the referee that this study could benefit from a detailed analysis of the WBC systems , given the strong air-sea interactions that characterize them. Therefore, we analyze the total turbulent heat fluxes in the WBC region to highlight the effect of employing a different THF computation in CdNC_CeEC_NS and NCAR. To better understand the spatial variability over the WBCs regions, we focus on the differences in the surface sea temperature (SST) and total turbulent fluxes (QT) over the Gulf Stream and Kuroshio current areas as shown in Plot 1. Since the spatial patterns are quite heterogeneous due to mesoscale activities, we study the relationship between QT and the air-sea virtual temperature difference for the winter (DJF) and summer (JJA) seasons. We selected specific regions along the currents path (identified by the yellow squares in the following Plot1) . Plot 2 (middle and bottom rows) show the relationship for the grid points inside the yellow squares in Plot2 (top row).

Notably, the two experiments behave in a different way along the WBC. In both seasons, the relationship between QT and the air-sea virtual temperature difference in CdNC_CeEC_NS is clearly shifted with respect to NCAR. When the temperature differences are negative *($T_V SEA > T_V AIR$)*, CdNC_CeEC_NS shows lower temperature differences in terms of magnitude compared to NCAR. These results are consistent with the finding in the "Turbulent Heat Fluxes" section (i.e. 3.3 section) of the revised manuscript.

Plot 2 is included in the supplementary material as Figure S1 and the following text describes it in Section 3.3 (lines 354-359): *"…, the CE of CdNC_CeEC_NS, which is smaller than CE of NCAR (Figure 8a), induces weak evaporation. The resulting weaker heat loss to the atmosphere in CdNC_CeEC_NS with respect to NCAR implies a gain of heat by the ocean (positive regions in Figure 7a) of about 2W/m2 over low-latitudes and up to 6 W/m2 over mid-latitudes (Figure 7b). A similar process is acting also in areas where the annual mean pattern of QT is patchy due to the mesoscale activities in both in summer and winter seasons (e.g. in the Western Boundary Currents, Figure S1). In CdNC_CeEC_NS, the negative virtual temperature differences at the air-sea interface are smaller than NCAR, inducing weaker from the ocean to the atmosphere"*




Plot 1: Annual mean differences of a) SST, b) QT between CdNC_CeEC_NS and NCAR for Kuroshio current (left column) and Gulf stream (right column). Hatching indicates significant values (95% confidence level).

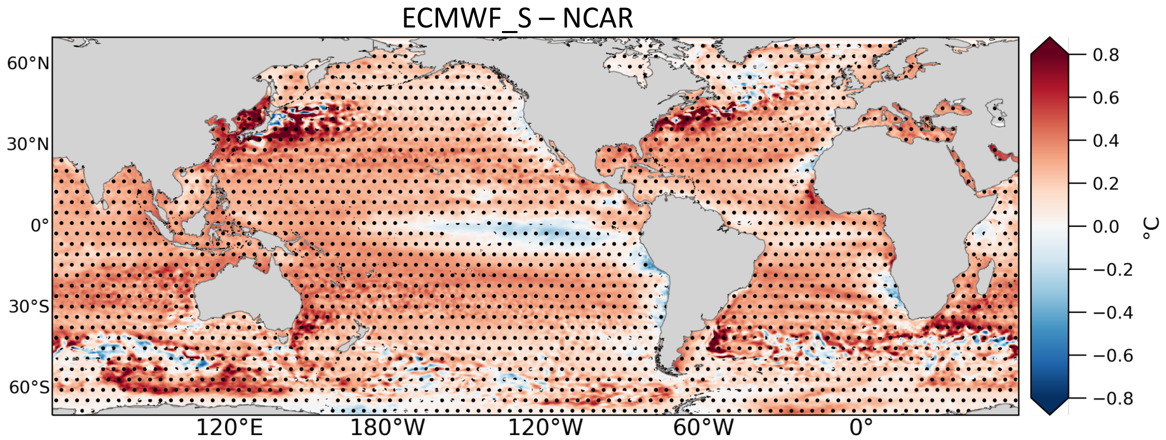



Plot 2: Zoom of annual mean differences of total turbulent heat fluxes (QT) between CdNC_CeEC_NS and NCAR experiments over Gulf Stream and Kuroshio current (top row); Relationship between total turbulent fluxes (QT) and the air-sea virtual temperature difference for selected grid points inside the yellow squares in CdNC_CeEC_NS (blue circles) and NCAR (red circles) in winter (middle row) and in summer (bottom row) for Gulf Stream and Kuroshio current.

**2) What are the limitations in running simulations that last one year only? Is there any dependence on the specific year (e.g. in terms of ENSO phase, or any other climatic mode)? What about the spinup of the model? Which year has been considered?**

We thank the referee for the comment and we apologize for the missing information in the manuscript. All the results presented in the manuscript are based on 1-year simulations (2016) with 1 previous year of spinup (i.e. 2015). The length of the simulations is long enough to identify the short-term impact of changes in the bulk parameterization on the upper ocean characteristics. We clarified this in the revised manuscript (lines 160-161): "All the experiments are 1-year long experiments, starting from January 2016 after 1-year of spinup." In order to prove the robustness of the SST differences simulated in the 1-year experiments , we extended ECMWF_S and NCAR experiments (following also suggestions by the Referee #3). Model results of 5 year long runs confirm that CdNC_CeNC_NS simulates colder SST at the equator and over the EBUS in CdNC_CeNC_NS (Plot 3). The following sentence was added (lines 211-212): "*This spatial pattern of SST differences persists when extending the simulations up to 5 years (not shown).*"

a) 5 years SST differences




Plot 3: Differences of the 5 year mean SST between ECMWF_S and NCAR experiments. Hatching indicates significant values (95% confidence level).

**2) With respect to Brodeau et al. (2017, B17 hereafter), the fluxes are computed using a dynamical SST field that responds to the atmospheric forcing. However, the atmospheric dynamics is known to respond to the SST even on daily and sub-daily time scales (see the review of Small et al., 2008, and some examples of applications in different areas of the world such as Li and Carbone, 2012; Gaube et al., 2019; Desbiolles et al., 2021). It would be interesting to discuss a fully coupled approach, as it has been shown that surface winds and clouds are affected by the SST structure on daily time-scales which, then, affect the SST and the surface turbulent fluxes back. This is only mentioned at the end of the manuscript and it should probably be included in the Introduction, as well. Moreover, the closed loop of this kind of ocean-atmosphere interactions has been proposed to be responsible for a three-to-six day oscillation (Strobach et al., 2020): I wonder if these oscillations are also observed here and whether they depend on the flux parameterizations.**

In accordance with the Referee's suggestion, we added a paragraph in the introduction about the fully coupled approach. We do agree that analyzing the impact of a modified SST on the atmosphere properties, i.e. winds and clouds, in a coupled system would be interesting. Nevertheless, the scope of this study is to investigate the role of the bulk formulations in a bulk-forced OGCM. This approach is still largely used by the ocean modeling community in a variety of applications.

As regards the three-to-six day oscillation, unfortunately we cannot analyze such high-frequency variability because the model output of our simulations was saved as a 5-day average. The new text in the introduction (lines 39-46) reads as : *"It is worth mentioning that the online prognostic approach does only partially close the air-sea feedback. Surface winds and clouds are affected by the SST structure on daily time-scale which, in turn, affect the SST and the TASFs (Desbiolles et al., 2021; de Szoeke et al., 2021; Gaube et al., 2019; Li and Carbone, 2012; Small et al., 2008). The closed air-sea feedback (hereinafter coupled approach) in the system might substantially impact the turbulent fluxes (Lemarié et al., 2021; Small et al., 2008), but the coupled approach is still not yet mature in the ocean model community. Recently Lemarié et al. (2021) implemented a first attempt of a simplified atmospheric boundary layer model (ABL) to improve the representation of air-sea interactions in*

*NEMOv4.2. However, the online prognostic SST approach is still largely used by the ocean modeling community in a variety of applications."*

**3) In general, the fact that full ocean simulations are performed seems a bit underexploited.**

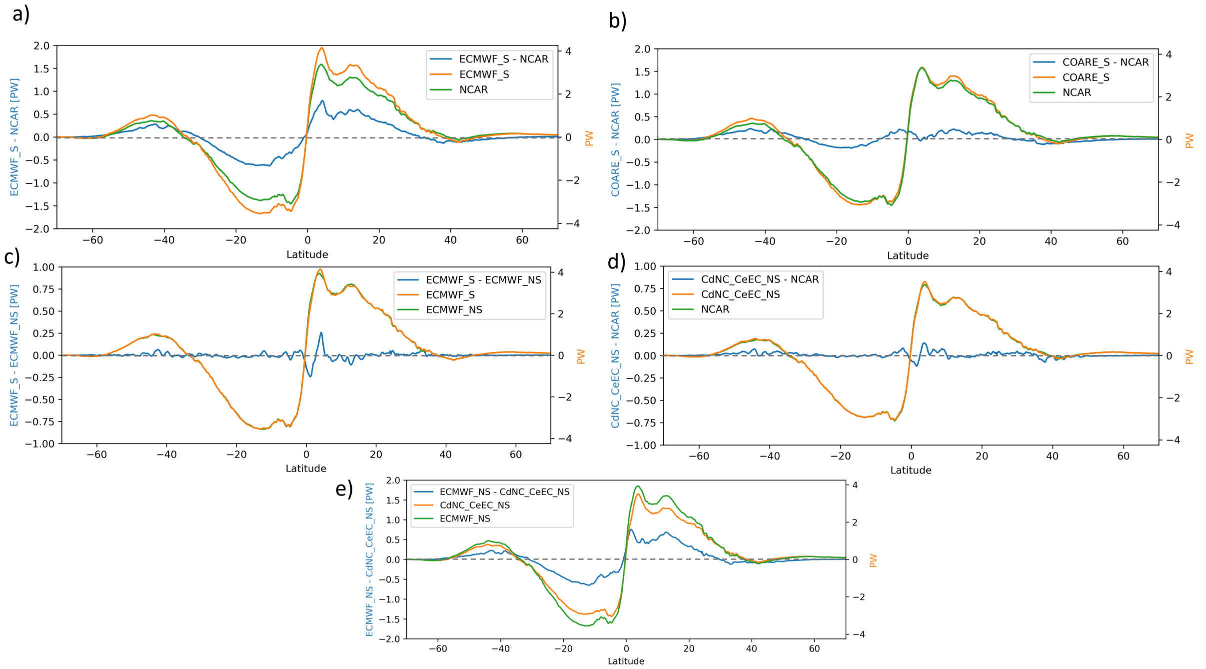
We agree with the referee that the oceanic responses might be more deeply exploited. Following also a comment from Reviewer#1, we extended the analysis on how modifications in the bulk parameterization influence the poleward transport of heat in the upper ocean. We computed it in the upper 100m of the global ocean and analyzed the differences among experiments (in Plot 4). The MHT in the ECMWF experiments is always higher compared to experiments that employ $C_D$ from NCAR formulation. ECMWF (with and without skin temperature) and NCAR-based experiments present the largest differences (Plot 4 a,e) that peak generally in the tropical band (about 0.8 PW, 20% of NCAR absolute value) where ECMWF wind stress is stronger than NCAR one. Global MHT in COARE_S and NCAR runs is comparable (Plot 4b), with differences lower than 0.3 PW. The transport differs only in the tropical latitude band in all the experiments that used the same $C_D$ (i.e. ECMWF_S and ECMWF_NS; NCAR and CdNC_CeEC_NS), and they are quite small (about 0.1 PW, Plot 4 c,d).

Plot 4 (a,b) has been included in Section 3.3 of the revised manuscript, as Figure 4c,d; Plot 4e is in Section 3.4 as Figure 11c.

The following text was added to describe Figure 4 (lines 219-225): "*Changes on the simulated SST can reflect on the temperature profile in the upper ocean and the distribution of heat on global scales. We have computed the global ocean heat transport in the upper 100 meters and compared it among experiments. Figure 4 (c,d) presents the meridional heat transport (MHT) as a function of latitude. The MHT is larger in ECMWF_S compared to NCAR mostly at all latitudes (Figure 4c), with the largest differences (about 0.8 PW, 20% of NCAR absolute value) in the tropical band* where ECMWF wind stress is stronger than NCAR one *(Figure 3a). COARE_S and NCAR compare well, with differences* lower than 0.3 PW *(Figure 4d). Then, we will focus only on the differences between ECMWF_S and NCAR to analyze in detail the relationship between TASFs and SST. We show differences in MHT only when relevant*."

The following text added in Section 3.4 (lines 313-317) describes Figure 11c: *" It is important to highlight that the differences in the wind stress are also responsible for the changes in the meridional heat transport. MHT differences between ECMWF_NS and CdNC_CeEC_NS resemble the differences between ECMWF_S and NCAR (compare Figure 4c and Figure 11c), with a higher transport in ECMWF_NS at all latitudes. The largest differences are located in the tropical region (up to 0.6 PW, about 18% of NCAR mean value), where the differences in meridional transport (linked to the equatorial upwelling) between the two experiments are likely maxima"*.

In addition, we included the following text in the conclusion section (lines 384-385): "*Stronger wind stress results in an increase of the poleward heat transport in the upper ocean, which a more pronounced increase in the ±20 latitude band.*"



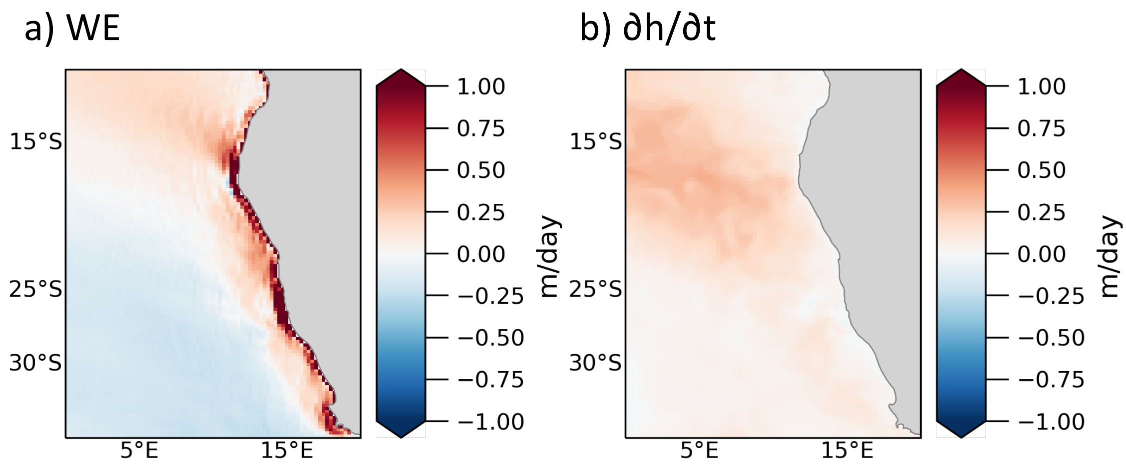

Plot 4: Global Meridional heat transport in the upper 100m ocean (values on the right y axis) and differences (values on the left y axis) between a) ECMF_S and NCAR, b) COARE_S and NCAR, c)ECMWF_S and ECMWF_NS, d) CdNC_CdEC_NS and NCAR, and e) ECMWF_NS and CdNC_CdEC_NS.

**I think that much more information could be extracted, for example when discussing the role of different wind stress and wind stress curl in controlling the surface cooling in the EBUS and equatorial regions. Would it be possible to disentangle the role of upwelling and the role of entrainment in this surface cooling? What about doing some heat budget in the oceanic mixed layer to understand what processes are mostly modified by the different bulk algorithms?**

These simulations might be surely used for more detailed analysis on global scales and in specific regions. The analysis of the heat budget in the mixed layer might add value to our study, but it would largely expand the scope of this study. The entrainment at the base of the mixed layer is composed of three terms: the entrainment due to the vertical velocity, the entrainment due to the tendency of the mixed layer depth, the entrainment due to lateral induction of the mixed layer depth (Vijith et al 2020). If we consider only the vertical components, the vertical entrainment velocity is the sum of the second term in the equation below, which is the vertical velocity associated with the wind stress (e.g upwelling process), and the first term, which is associated with mixed layer depth (h) deepening. So that the entrainment velocity can be expressed as (Alexander, 1992; Mendoza et al., 2005):

$$W_e = \frac{\delta(h)}{\delta(t)} + W_E \quad with \quad W_E = \frac{curl(\tau)}{\rho * f}$$

The two terms of the entrainment velocity are presented in Plot 5. As expected, the Ekman pumping velocity is positive, meaning that sea water is moving upward. The velocity associated with mixed layer depth tendency is also positive, meaning that the mixed layer deepens and promotes the entrainment of cold water from below. However, it is much weaker than the Ekman pumping velocity. Although this is just a preliminary analysis and a complete heat budget would be necessary to verify this hypothesis, this result suggests that the surface cooling is strictly linked to the upwelling process.




Plot 5: Ekman pumping velocity (WE) and the mixed layer depth tendency (∂h/∂t) in the CdEC_CeEC_NS experiment.

**4) The statistical significance of the differences between the experiments should be assessed. If the distributions are Gaussian, a t-test should be enough.**

Following this suggestion, we compute the 95% significance level of the differences. We added the significance in all figures (as haches).

**5) There are various differences with respect to the estimates shown in B17. In particular:**

1. **the authors consider a single year, whereas B17 consider the period 1982-2014;**
2. **the authors use ERA5 data to force NEMO, whereas B17 use ERA-Interim data;**
3. **COARE 3.5 is used here, and COARE 3.0 is used in B17;**
4. **Different versions of the ECMWF model are considered (cycle 40 and 41).**

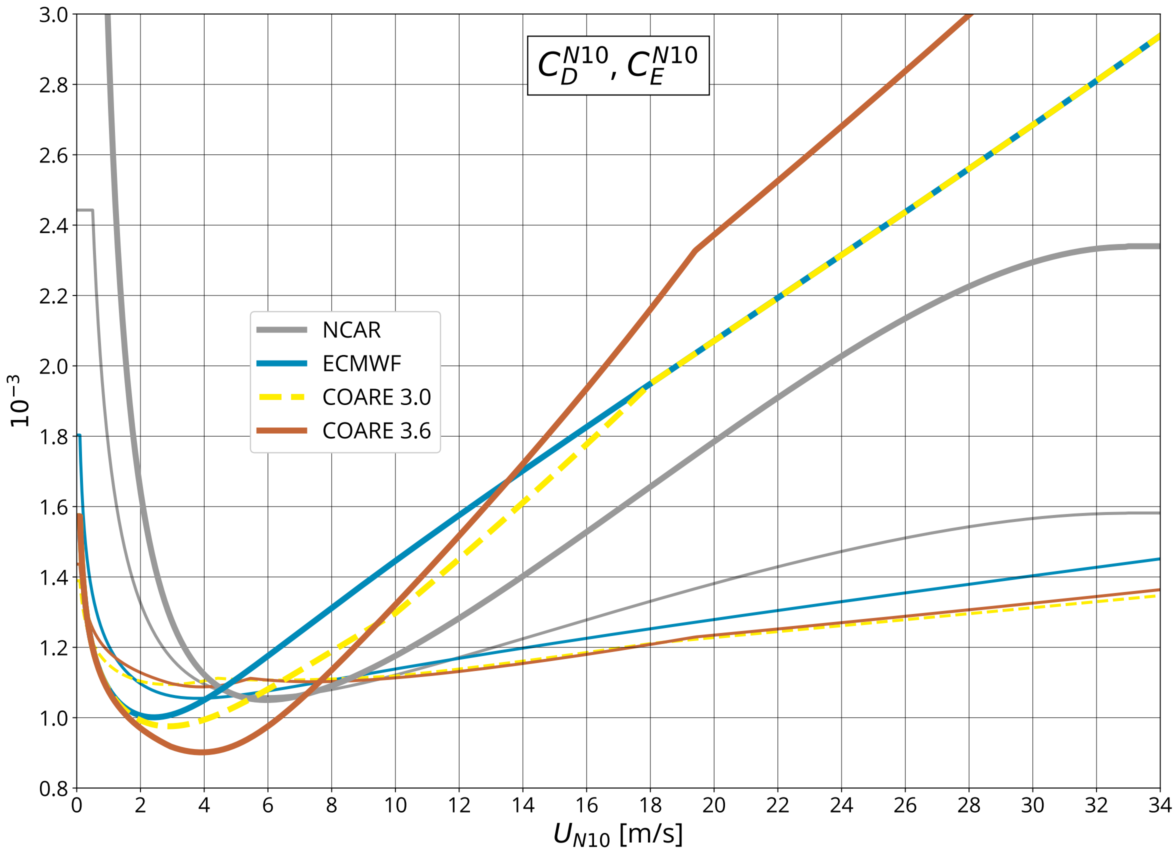
**For these reasons, I would be more cautious in comparing the present results with those presented in B17. Would it be possible, for example, to compute the heat fluxes using the local midnight SST throughout the day, to mimic the fixed-SST approach, as in B17, and compare these fluxes to the prognostic-SST ones? This would avoid all the limitations highlighted before, as the original data would be the same.**

We are fully aware of these differences and we completely agree that comparisons must be done more cautiously. We added a paragraph in section 3.5 to clearly list the discrepancies between the two setups and facilitate the interpretation of the results .

First, regarding point "4", no differences exist in the ECMWF algorithms between B17 and the present paper. The code source used for both studies originates from the AeroBulk package written by *Laurent Brodeau The*. ECMWF algorithm is based on the IFS documentation (doc and code for both cycles). *Brodeau* also introduced and ported all the bulk algorithms that he initially wrote for AeroBulk into the NEMO code, version 4.0 and onwards. We are not aware of any differences between cycle 40 and 41, and we have not introduced any in AeroBulk in anycase. We think that mentioning the IFS cycle was unnecessary and confusing since the true code in both studies originates from the AeroBulk package, so we removed the mention of IFS cycles and instead added mention of AeroBulk.

We modified the text as follows (lines 134-138): *"In this study, we focus on three bulk parameterizations implemented in NEMOv4.0: NCAR (Large and Yeager, 2009), COARE 3.6 (Edson et al. (2013) + private communication by Chris Fairall, hereinafter referred to as "COARE"), and ECMWF as coded in the Aereobulk package (Brodeau et al., 2017). All the codes to estimate TASFs in the NEMOv4.0 framework, originates from this AeroBulk package, which is completely open source and available at https://github.com/brodeau/aerobulk (Brodeau et al., 2017)."*

With respect to COARE3.0 used in B17, COARE3.5 introduces the developments of Edson *et al.*, 2013 which includes only modification on the drag coefficient $C_D$. Note that version "3.5" is also mentioned and briefly discussed in B17. The difference is shown in Plot 6 that is taken directly from the AeroBulk main page.




Plot 6: Neutral drag and moisture transfer coefficients for COARE 3.0 (yellow) COARE 3.6 (brown), NCAR (gray), and ECMWF (blue) bulk parameterizations (thick and thin lines, respectively), as functions of the neutral wind speed at 10m

When using COARE3.6, for a given near surface stability state, significantly stronger wind stress is expected above 15 m/s compared to COARE3.0, while slightly weaker wind stress is expected in calmer conditions, between 3 and 7 m/s. We see that "3.6" in the Figure 1a of the manuscript is the same thing as "3.5" when it comes to $C_D$ (compare Figure 1a and Plot 6). What we refer to "3.6" in AeroBulk introduces the latest improvements for $C_E$ and $C_H$ suggested by Chris Fairall (see response 4 of minor comments here below).

Finally, we think that your suggestion to recompute an "offline" version of the fluxes based on a SST extraction from the NEMO simulations would actually be an extremely thorough way to compare the "OGCM-online" and "prescribed-offline (B17)" approaches. However, it would represent a substantial amount of work that we do not think is fully justified in the present case, since the focus of our paper is more on "what to expect when choosing all these different algorithms and options to drive an OGCM with a prescribed surface atmospheric state?". We have been more cautious when comparing with B17 and we added the paragraph that lists the discrepancies between this study and that of B17.

We added the following text in Section 3.5 (lines 343-346): "*It is worth mentioning that there are few discrepancies in the bulk implementation between this study and Brodeau et al. (2017) . They used the COARE3.0 parameterization instead of COARE3.6 and, their simulations, performed for a longer (1982-2014) period, are forced by the ERA-Interim reanalysis instead of ERA5. Therefore, our scope in this comparison is only to qualitatively understand the negative feedback between the SST and the QT at play in our experiments.* "

## Minor comments

**1) There are typos throughout the text: I suggest a careful reading of the manuscript. Many maps are hard to read, because the contour lines often mask the color shading. I suggest:**

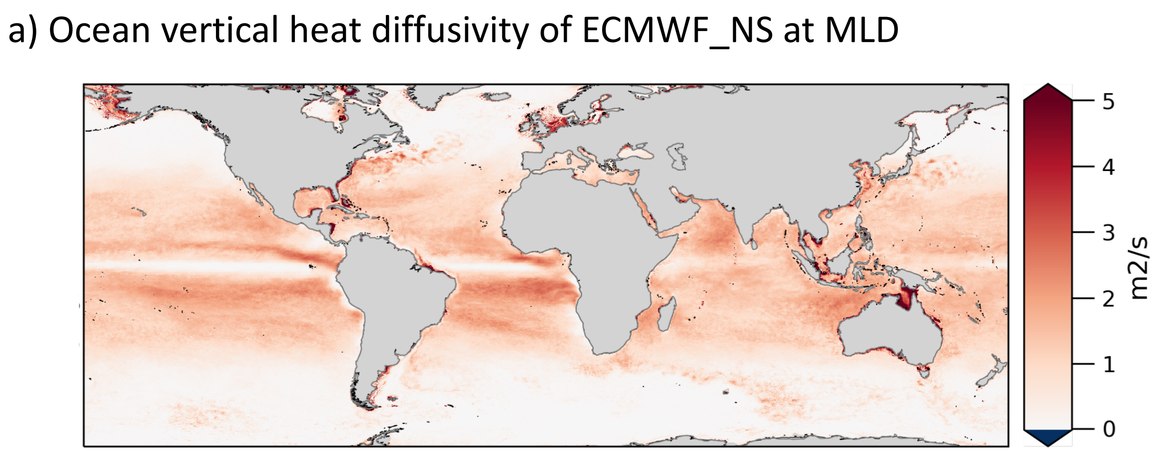
- **enlarging the maps (as currently done in Fig 5, at least);**
- **reducing the number of contour lines (or removing them, if not necessary);**
- **verifying that the contours are properly plotted and not broken at 180° or 0° longitude;**
- **removing the word 'exp =' in the titles, as it is redundant.**

We carefully checked the text and reproduced all the figures with higher resolution using a wider latitudinal range from 70°S to 70°N. We changed palettes, saturation and contours following the referee suggestions.

**Technical comments**

**1) L50: It is true that with the prognostic SST approach, there is a negative feedback between the heat fluxes and the SST, but having a dynamical ocean can also modify the heat fluxes in the other direction. Namely, the heat fluxes can be strengthened (in absolute value) with the upper ocean mixing. Is there a way to disentangle these two contributions?**

We thank the reviewer for this comment. The calculation of the heat budget should be performed to disentangle the contribution of the upper ocean mixing on the surface heat fluxes. Although, as previously mentioned, the analysis of the heat budget in the mixed layer might add value to our study, it would largely expand its scope and modify the focus of the paper. To compute an accurate heat budget we need higher model output frequency (higher than 5-day average) and additional variables in outputs, not saved for our experiments. To limit the time of the analysis and remain focused on objectives of this study, we analyzed the ocean vertical heat diffusivity ($m^2/s$) at the mixed layer depth as computed in the ECMWF_NS experiment (Plot 7) and show that it tends to zero over the interested area, suggesting that the ocean mixing is weak at the base of the mixed layer. However, these are not conclusive results , we do prefer not to include them into the manuscript.

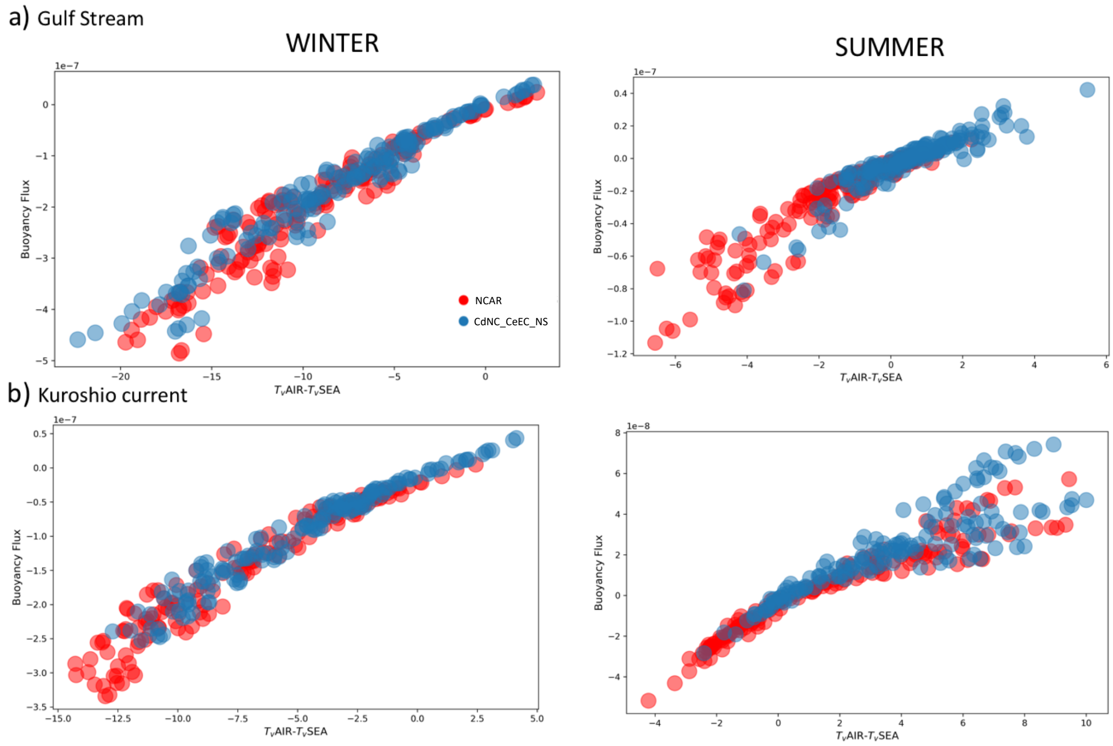



Plot 7: Ocean vertical heat diffusivity of ECMWF_NS at the base of ocean mixed layer depth.

**2) L97: $Q_T$ is dominated by $Q_L$ because $Q_L$ is much larger than $Q_S$. I wonder if the buoyancy flux, in which the sensible and the latent heat flux terms are comparable, is a more appropriate variable to consider. A recent example of its dynamical importance is the work by De Szoeke et al. (2021), where the buoyancy flux is shown to control the low-level cloud formation in the tropical Indian Ocean. This, then, has a significant influence on the surface fluxes.**

We thank the referee for suggesting this interesting paper. We computed the buoyancy flux (Equation 1 of De Szoeke et al. 2021) instead of QT in Plot 2 (middle and bottom rows) of this document. Plot 8 shows the relationship, for the grid points inside the yellow squares in Plot 2 (top row), between buoyancy flux and the air-sea virtual temperature difference in CdNC_CeEC_NS and NCAR in winter and in summer for Gulf Stream and Kuroshio current. In both seasons, when the temperature differences are negative ($T_V SEA > T_V AIR$), CdNC_CeEC_NS shows lower temperature differences in terms of magnitude than NCAR. This difference tends to make the CdNC_CeEC_NS ocean surface less buoyant than NCAR and it promotes weaker heat loss from the ocean to the atmosphere for the CdNC_CeEC_NS. Since these results using the buoyancy flux resemble the ones using the QT, we decided to add Plot 2 in the manuscript to be coherent with the rest of the text.

Moreover, it is important to note that our bulk algorithms do not need clouds coverage as input. To evaluate the direct impact of clouds coverage on surface fluxes we would need a coupled system with a proper atmospheric component.




Plot 8: Relationship between buoyancy flux (about 1E-7) and the air-sea virtual temperature difference in CdNC_CeEC_NS (blue circles) and NCAR (red circles) in winter (left column) and in summer (left column) for a) Gulf Stream and b) Kuroshio current.

**3) LL106-107: The explanation of the cool-skin effect is not very clear.**

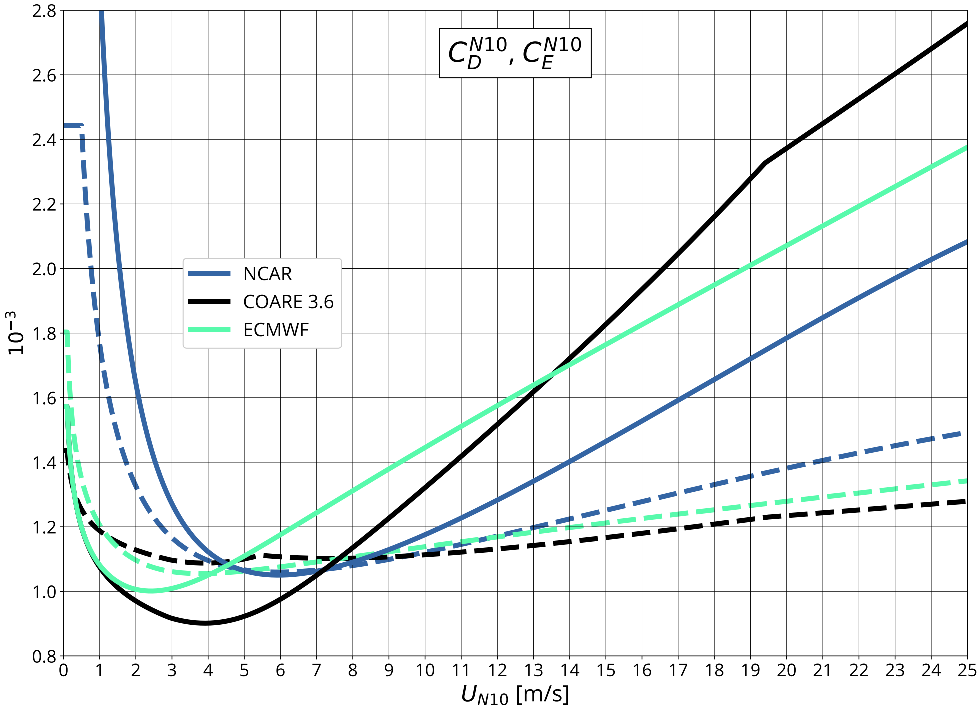
We thank the referee and we rephrased the sentence at lines 111-112 as: "*The cool skin is the cooling of the millimeter-scale uppermost layer of the ocean to ensure a steep vertical gradient of temperature which sustains the heat flux continuity between ocean and atmosphere.* "

**4) L124: Edson et al. (2013) introduced COARE 3.5 and not 3.6. This should be corrected throughout the manuscript.**

The most recent reference for the COARE formulation is actually Edson et al (2013). There is not a specific report or paper that describes the latest version 3.6. The COARE3.6 as implemented in NEMO (https://github.com/brodeau/aerobulk/blob/master/src/mod_blk_coare3p6.f90) was further modified based on private communication with C. Fairall. Correction done in the manuscript.

**5) Fig1: Instead of using thin lines for the moisture transfer coefficients, thick dashed lines would be more visible and easier to distinguish from the drag coefficients. I would also suggest reducing the range of wind speed in panel (b) up to 22 or 25 m/s, as the focus is on the left side of the panel.**

Here the new Figure 1b:




Plot 9: Neutral drag and moisture transfer coefficients for COARE (black), NCAR (blue), and ECMWF (green) bulk parameterizations (thick and dashed lines, respectively), as functions of the neutral wind speed at 10m

**6) LL150-163: I would suggest removing the bullet points and use plain text, instead, to remove the repetitions and enable a smoother reading. Table 1 is already giving a schematic recap of the experiment setup. It is also not clear what is the difference between the parameterizations that use the absolute wind speed (as in experiments ECMWF_S, COARE_S, ECMWF_NS and CdNCAR_CeEC) and the parameterization that does not include the current correction (as in the NCAR experiment). It seems that the ocean surface currents are never used in this set of experiments (L169). Thus, it can simply be stated once, as this is not a parameter that changes. I also find the names of the experiments very confusing: what about making them more explicit with something like: CdEC_CeEC (instead of ECMWF_S), CdCO_CeCO (COARE_S), CdNC_CeNC_NS (NCAR), CdEC_CeEC_NS (ECMWF_NS), CdNC_CeEC_NS (CdNCAR_CeEC)? In this way, the differences among them are readily available in their names.**

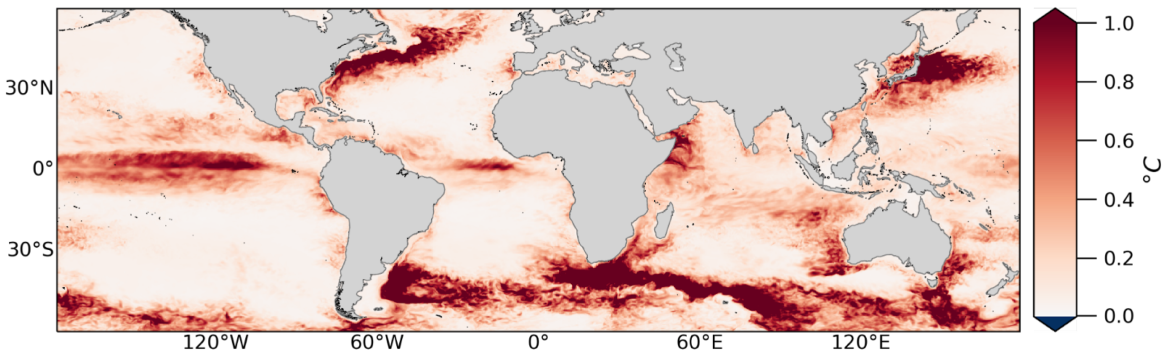
**Table 1: What about adding 'Experiment name' in the first row of the first column? A column indicating whether the gustiness in the computation of the wind stress is included would be useful.**

We agree with the reviewer, we removed the bullet points and we added a statement on absolute wind speed (lines 181-182): "*We use the absolute wind, e.g. all parametrizations do not include the ocean currents feedback to calculate wind in equation 1a.*"

**8) Fig4: The skin SST effect has a component at the daily scale. I wonder if, by considering the annual mean, the signal averages to zero. What about computing the temporal standard deviation of the difference SSTskin-SST?**

The annual mean is computed using 5-day mean model output. We computed the temporal standard deviation of the difference between SSTskin and SST between ECMWF_S and ECMWF_NS (Plot 10) and find that it is high in regions where the annual differences are highly patchy and not statistically significant (compare Plot 10 with Figure 5a). The annual differences are kept in the revised manuscript.

a) RMSE between SSTskin of ECMWF_S and SST of ECMWF_NS




Plot 10: Temporal standard deviation of the difference SSTskin-SSTdifferences between ECMWF_S and ECMWF_NS.

**9) LL202-207: The link between the figure and the text is not fully clear. By looking at the figure one might think that, on the annual average, there is an increase of SST when using the SSTskin correction (is the sign of the difference ECMWF_S-ECMWF_NS correct?), because of a dominant diurnal warming effect. This is in contrast with the statement that the cool skin effect is dominant over the warm layer one. Is the annual mean computed using hourly outputs? How is the mean warming interpreted? What about its spatial structure?**

The annual mean is computed using 5day mean model outputs. We reported an increase of the SST when the SSTskin is used in the computation of turbulent heat fluxes (Figure 5b). This is due to the fact that the SSTskin, used to compute turbulent heat fluxes in ECMWF_S, is colder than the SST, used to compute turbulent heat fluxes in NCAR (Figure 5a). The SSTskin is usually colder than SST because the cool-skin effect is dominant over the warm layer effect (Brodeau et al. 2017). The colder SSTskin in ECMWF_S with respect to ECMWF_NS SST yields a slightly weaker heat loss to the atmosphere due to the decreased NSHFs (mostly evaporation). Therefore, the resulting SST of ECMWF_S is warmer than the ECMWF_NS SST (Figure 5c).

**10) LL229-230: Is it 'higher heat absorption' or 'weaker heat loss'? The logical link between the latent heat considerations and the fact that it is the wind stress to be responsible for the observed cold SST pattern difference between ECMWF_S and NCAR is not clear.**

We thank the reviewer for the comment. It is weaker heat loss, so we modified the sentence. We agree with the reviewer, the logical link between the latent heat considerations and the fact that it is the wind stress that is responsible for the observed cold SST pattern difference between ECMWF_S and NCAR is not clear, so we removed the sentence.

**11) Fig6: Panel b) is not showing time series: the caption of the figure should be modified. From this figure one would not say that the mean excess QT is 10W/m2, as stated at line 221: where does this amount come from?**

We apologize for the mistake, we corrected it.

**12) L239: Up to now, it is not very clear which parameterizations use the gustiness correction in the computation of the wind stress. As noted above, this information could be included in Table 1 and some more details on how the gustiness is included in the scheme should be given.**

We changed Table 1 as reported at the beginning of this document.

**13) Fig8: I suspect that the gustiness correction is highly variable in time on daily or even sub-daily scale. As for the CSWL correction, thus, I am not sure that showing the annual mean of such variables is enough. Wouldn't it be of interest to show the variance or the RMSE of the two model setup to better display where this highly variable correction is relevant?**

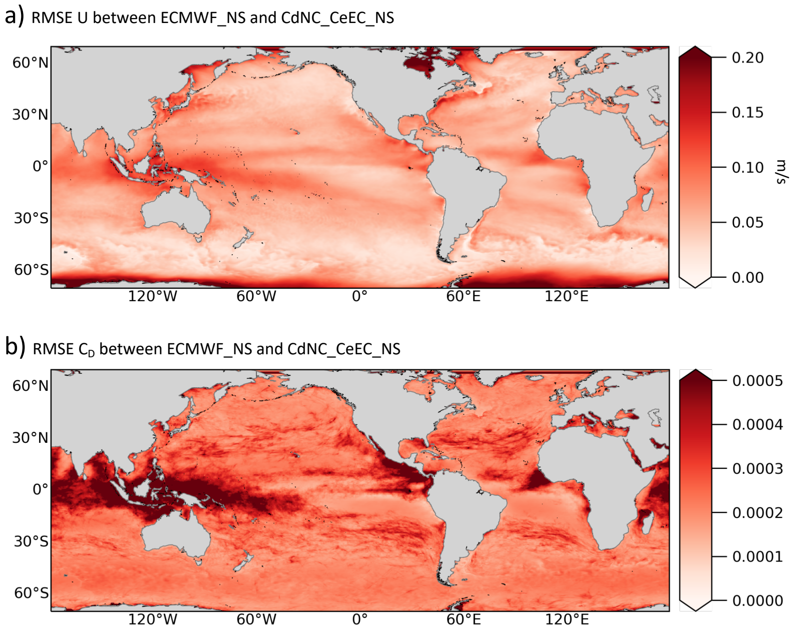
This suggestion allowed us to better understand the relevance of the different coefficients in the bulk algorithms. We calculated the RMSE of the differences in the wind speed (U) and drag coefficient ($C_D$) between the ECMWF_NS and CdNC_CeEC_NS experiments (compare Plot 11a below with Figure 9a,c). The spatial distribution of the RMSE of U (Plot 11a) resembles the annual mean differences of U between the two experiments (shown in Figure 9a). The RMSE of $C_D$ (Plot 11b) is large where the annual mean differences between ECMWF_NS and CdNC_CeEC_NS are negative (Figure 9b,c). In these regions, the differences in $C_D$ between experiments are highly variable in time and they could hide the relationship between U, $C_D$ and $\boldsymbol{\tau}$.

For this reason, we computed the correlation between the $C_D$ differences and the $\boldsymbol{\tau}$ differences for the ECMWF_NS and CdNC_CeEC_NS runs. The correlation is always significant with positive values, (Plot 12b). The higher the difference in $C_D$, the stronger the difference in wind stress.

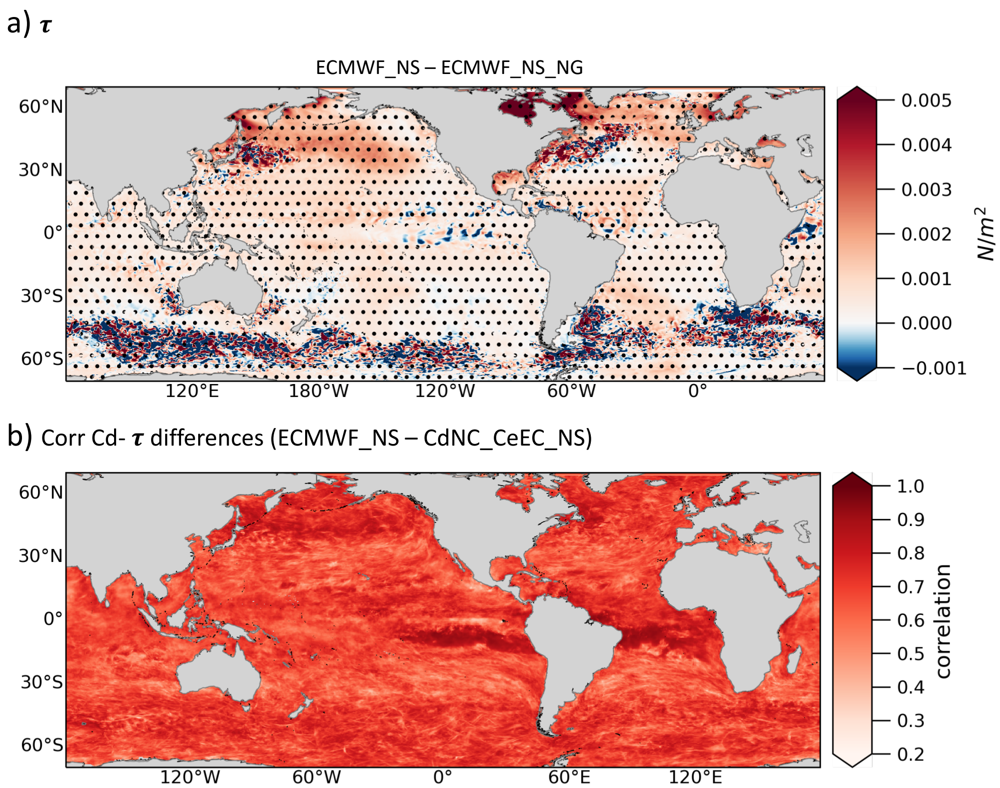
Moreover, to evaluate the effect of the convective gustiness on the wind stress (following a suggestion by the referee #1), we performed an extra ECMWF run where convective gustiness is switched off (it is named ECMWF_NS_NG). Plot 12a compares the wind stress in the "original" ECMWF_NS and the new ECMWF_NS_NG. Results confirm that wind stress is stronger almost everywhere when the convective gustiness is included in the U calculation. We added Plot12a as FigureS2 in the supplementary material.

The following text was added in manuscript (lines 289-295): "*In regions where the differences in* $C_D$ *and wind stress are opposite (e.g. the north-west and south-west Pacific and Atlantic ocean, Indian ocean, Baja California), the high time-variability of the* $C_D$ *differences (not shown) could hide the relation between* $C_D$ *and* $\boldsymbol{\tau}$*. In addition, including the convective gustiness in U calculation strengthens the wind stress in ECMWF_NS. Both hypotheses are verified, the* ECMWF_NS *experiment presents a stronger wind stress almost everywhere over the global ocean compared to a twin experiment where the convective gustiness is not used in the computation (Figure S2) and the correlation between* $C_D$

*differences and wind stress differences is always significant and positive (not shown). The higher the difference in* $C_D$*, the stronger the differences in wind stress."*

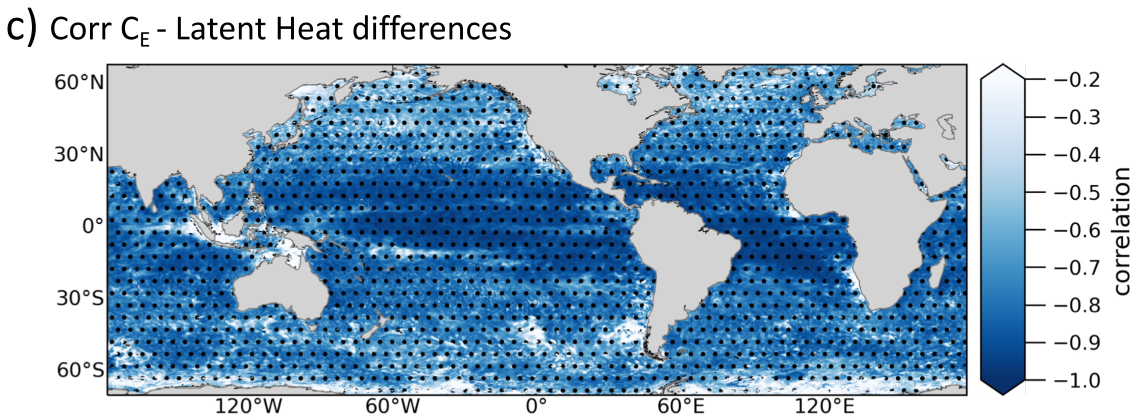



Plot 11: a) Root Mean Square Error of a) wind speed (U) b) drag coefficient ($C_D$) differences between *ECMWF_NS and CdNC_CeEC_NS.*




Plot 12: a) Root Mean Square Error of a) wind speed (U) b) drag coefficient ($C_D$) differences between *ECMWF_NS and CdNC_CeEC_NS. Hatching indicates significant values (95\% confidence level).*

Moreover, to be coherent with the previous finding, we performed the correlation between $C_E$ and latent heat differences between CdNC_CeEC_NS and NCAR (Plot 13). The correlation is always high, significant and negative. The lower the difference in $C_E$, the stronger are the differences in latent heat. This finding is coherent with our result that the QT in CdNC_CeEC_NS is higher by ~1W/m2 than NCAR due to a lower $C_E$ (i.e. the ocean in CdNC_CeEC_NS is less evaporative), which leads to higher latent heat (i.e. the ocean in CdNC_CeEC_NS gains heat).

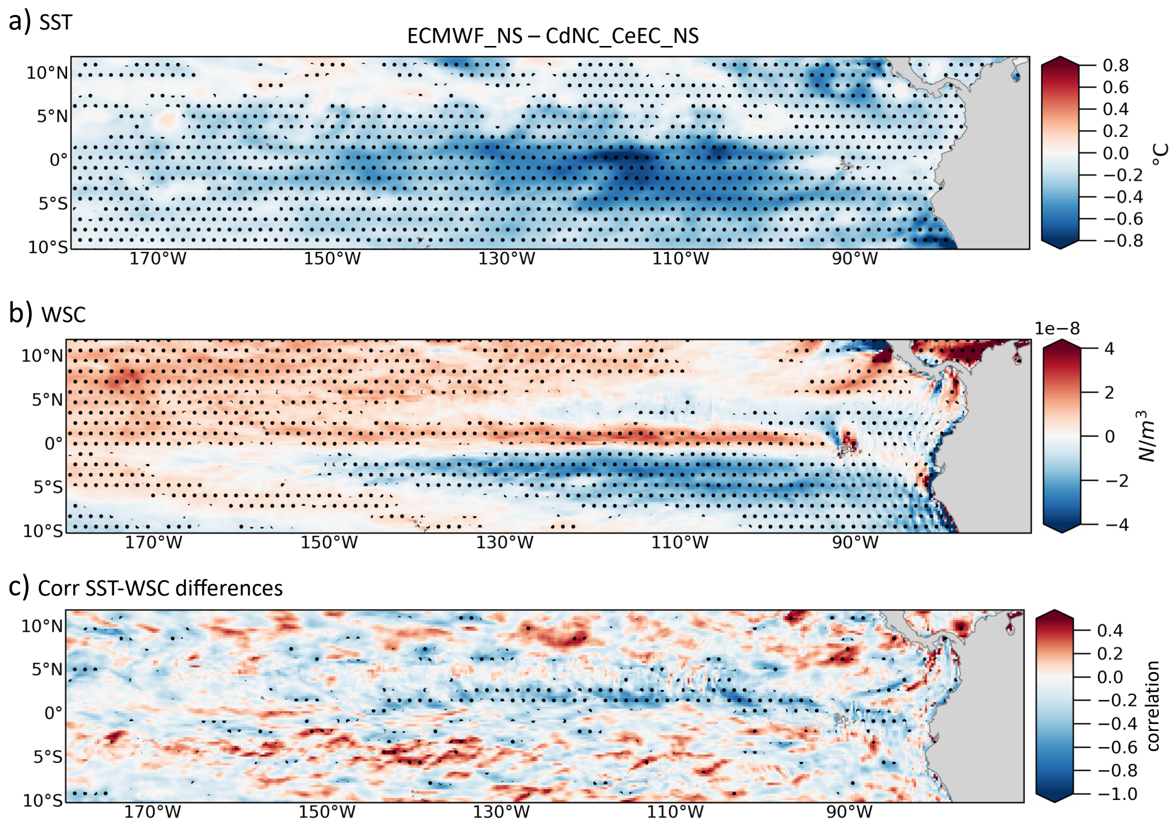



Plot 13: Correlation between $C_E$ and latent heat differences between CdNC_CeEC_NS and NCAR. Hatching indicates significant values (95% confidence level).

**14) L260: As the outputs of the ocean model are available, would it be possible to quantify the contribution of the surface cooling due to the modified Ekman suction between the configurations? Can a scaling between the anomalous wind curl and the anomalous SST cooling be derived?**

Following this suggestion, we correlated the SST and the wind stress curl differences between ECMWF_NS and CdNC_CeEC_NS (Plot 14c).

A strong negative correlation appears at the equator. High differences in the wind stress curl (positive north of the equator in Plot 14), correspond to negative SST differences between experiments. We added this figure in the supplementary material as Figure S3 and we added the following text in the manuscript(lines 302-304): "*We found this relation significant north of the equator: the stronger positive wind stress curl in ECMWF_NS than* CdNC_CeEC_NS *results in a colder SST in ECMWF_NS compared to* CdNC_CeEC_NS *(see correlation map in Figure S3).*"




Plot 14: Annual mean differences of a) SST and b) wind stress curl (WSC) between ECMWF_NS and CdNC_CdEC_NS; b) correlation between SST WSC differences differences ECMWF_NS and CdNC_CdEC_NS. Hatching indicates significant values (95% confidence level).

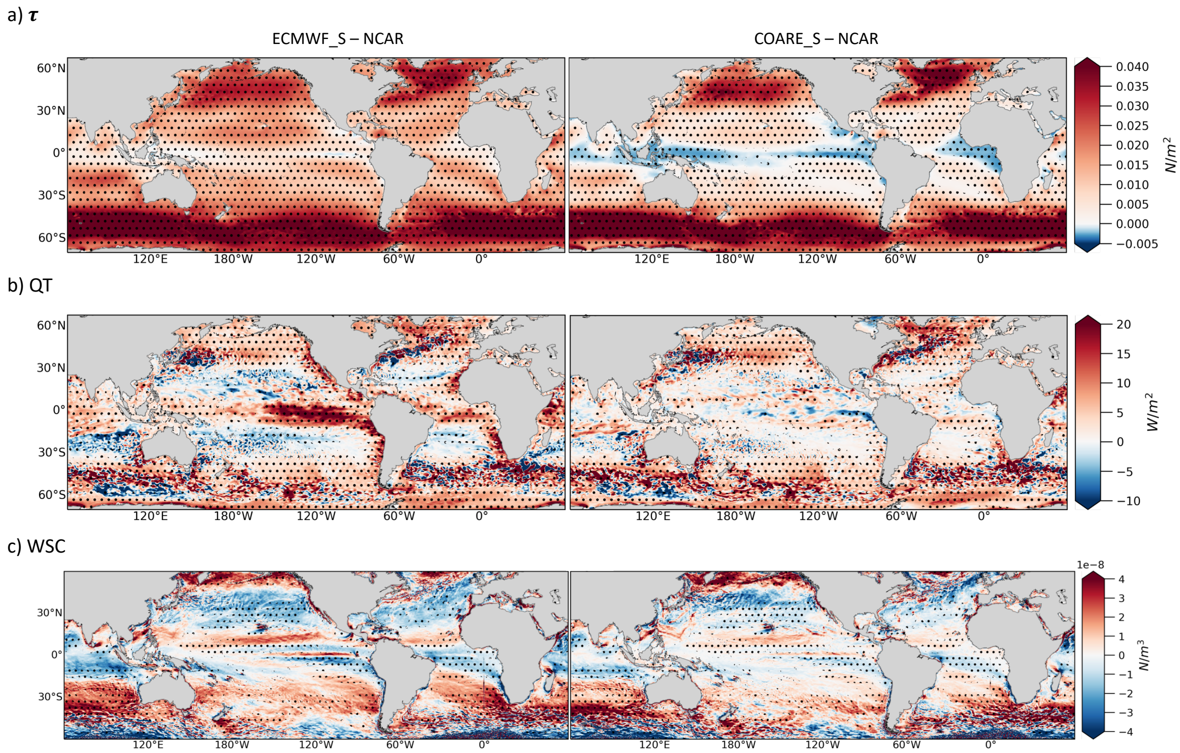
**14) Figure 2 is not described in the main text, please do. What is its link with the SST bias? The name of the experiments should be kept consistent throughout the text. Here, for example, 'COARE3.6_S' should be replaced with 'COARE_S', or its correct name. It should be clarified (and motivated) whether the annual mean of the percentage difference or the percentage difference of the annual means is computed.**

**LL185-192: This paragraph is rather general and could be moved backward in the manuscript. One would expect here to find a reasoning on figures 2 and 3, such as why such patterns are observed, which specific reasons could explain them and their relationship, etc.**

**LL277-289: By looking at figure 2 one would expect stronger differences in the SST in the COARE-NCAR comparison, and not in the ECMWF-NCAR one. What about showing the mean difference of the wind stress (not in percentage) and, maybe, the mean difference in wind stress curl, as it relates to the upwelling?**

In accordance with the Referee's suggestions, we changed Figure 2 (now Figure 3 in the revised manuscript) as Plot 15 below. We plotted annual mean instead of percentage, and we added the WSC differences between experiments. Text has been added to describe Figure 3 (lines 202-208): "*Figure 3 shows the differences in total turbulent heat fluxes, wind stress and wind stress curl, from ECMWF_S and COARE_S with respect to NCAR. ECMWF_S wind stress is slightly weaker with respect to NCAR over the equatorial band and it is stronger elsewhere (Figure 3a). In COARE_S the wind stress is weaker than*

*NCAR over a broader region with respect to ECMWF_S, namely over the areas characterized by calm wind conditions (see Figure 1). The wind stress curl (W SC) patterns are similar for the two pairs of differences (Figure 3c), they differ only for their magnitude. As regards the QT differences (Figure 3b), a gain of heat for ECMWF_S is a clear feature over the Pacific and Atlantic equatorial regions and over EBUS with respect to NCAR."*




Plot 15: Annual mean differences between experiments of a) wind stress (τ ) and b) total turbulent heat fluxes (QT ) and c) wind stress curl (W SC) between ECMWF_S and NCAR experiments (left) and COARE_S and NCAR experiments (right). Hatching indicates significant values (95% confidence level)

**15) Then, is there a contribution to the surface cooling from an increased entrainment of cold waters in the OML (oceanic mixed layer) because of a stronger wind stress?**

We already answered this in the "Major comments" section, answer number 3.

**16) Fig9: Panel (a) is it the annual mean of the percentage variation or the percentage variation of the annual mean?**

The annual mean of the percentage variation.

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