Reply to Reviewer#1

**Review for revised version of "Dakar Niño under global warming investigated
by a high-resolution regionally coupled model" by Koseki et al.**

After the second revision, I find the manuscript to be substantially improved, especially regarding the readability. However, the discussion of the relevant processes still needs more work.

Thank you very much for further careful reading and constructive comments. We revised the manuscript in response to the comments and provide point-by-point replies to each comment below. Please note that the track changes are highlighted in blue in the revised manuscript.

Major comments:

**There are several processes for the generation of Dakar Niños and Niñas discussed in the paper, namely local winds, upwelling (although this is somehow only touched on), surface heat fluxes and horizontal advection. It needs to become clear that and how these processes are connected. This starts as early as lines 40/41 in the introduction and continues throughout the manuscript.
Changes in the local winds can drive changes in upwelling, horizontal advection, latent heat loss and mixed layer depth but there are also components not (directly) related to local winds such as temperature gradients and shortwave radiation. At the moment, it is not clear to me what the main role of the winds is for generating SST anomalies and which part of the net surface heat flux is actually important.**

REPLY: Yes, local winds influence all terms of heat budget as shown in our heat budget analysis. Due to changes in the local wind variability between the present and future climate, we have already shown that vertical advection and horizontal advection terms are identically (but, secondarily) important in strengthening the SST variability in the focusing area. As shown in Fig. 5 and Oettli et al. (2016) shows, SST variability and meridional wind variability exhibit strong coherence, suggesting that SST variability is associated with wind variability. Additionally, as Oettli et al. (2016) discusses, surface heat flux also plays an important role in

inducing the SST variability. According to Oettli et al. (2016), shortwave radiation is the dominant factor, with latent heat flux being secondarily important.

As we noted in the previous revision, Oettli et al. (2016) does not specify the factors controlling the shortwave radiation variability (perhaps, cloud and/or dust from the Sahara). This remains an open question for future research. In response to the major comment below, we have divided the surface heat flux.

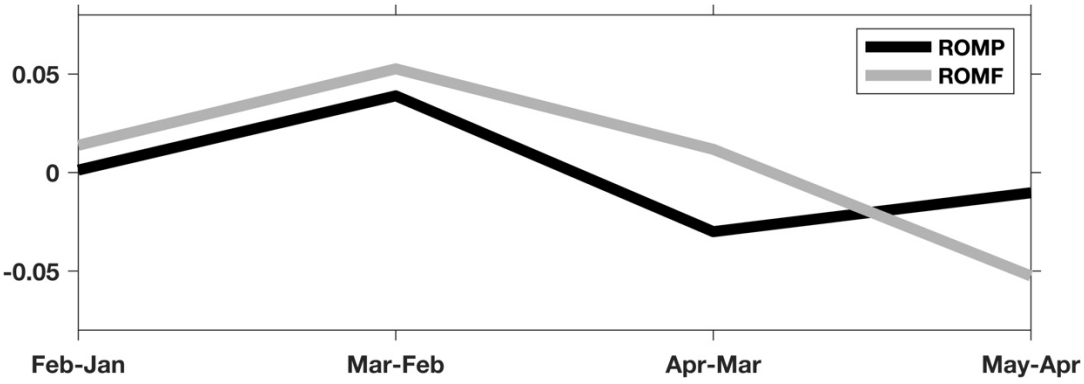
Specifically, I would suggest to start the heat budget analysis (Section 4.2) by saying that
a) variations in local winds are important for the generation of Dakar Niños and Niños (as shown in the previous section)
b) these wind variations can be connected to a number of processes, namely upwelling, ocean currents, and latent heat loss
c) that you perform a mixed layer heat budget analysis to determine which of these is most important
It is a bit confusing to start the section by pointing out the importance of heat fluxes as found by Oettli et al. (2016).

REPLY: Thank you very much for the suggestion. Now, we reconstructed the introductive part of the heat budget analysis. Please see lines 314-315. To highlight the difference and similarity with Oettli et al. (2016), we have retained the sentence at 316.

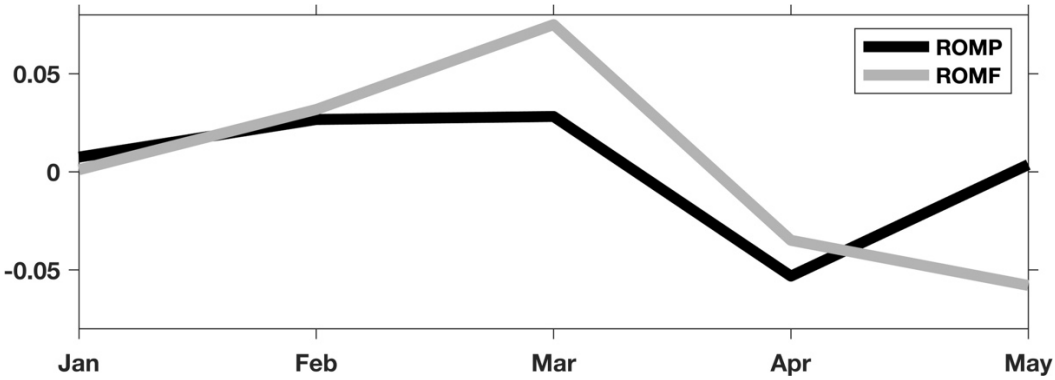
Given the high correspondence between SSTs and subsurface temperatures over at least the upper 100m of the water column during Dakar Niño and Niña events (Fig. 6, 7), I find it very hard to believe that vertical processes are not important for the generation of the events as stated later with respect to the heat budget analysis. I rather suspect that a large part of the vertical term (especially mixing) is buried in the residual which is probably quite large. How much of dT/dt do the advection and heat flux terms actually account for, i.e. how large is the residual term in the heat budget?

REPLY: We agree that the mixing and entrainment processes are important in inducing the SST variability. According to Oettli et al. (2016), entrainment is also important factor for the SST variability. However, our available data is limited to monthly intervals and there is no output of entrainment and higher order variables. We have added this at lines 316-317 and 327.

Since entrainment and mixing are more enhanced around mixed-layer depth or thermocline depth, deeper connection with the Dakar Index does not necessarily mean that entrainment and mixing are stronger in the future than in the present. In Fig. R1 and R2, the Dt/dt estimated from monthly data and the sum of the explicit heat budget analysis (horizontal advection, vertical advection, and heat flux) are presented. Please note that R1 shows the DT/Dt for the difference of Feb-Jan, Mar-Feb, Apr-Mar, and May-Apr. From these plots, it seems that the residual term could be positive, but its magnitude is smaller than horizontal advection and surface heat flux from January to February. In March, the residual term can be negative. Therefore, in the ROM simulations, the residual term is not a main source for inducing Dakar Niños. The residual term includes not only entrainment, but also more higher-order terms. Again, accorgint to Oettli et al. (2016), the entrainment is a secondarily important role and we can suggest that the entrainment alone does not explain the enhancement of Dakar Niño under global climate in our simulations. However, this analysis is based on monthly-mean data, which is too coarse to capture the full complexity of the heat budget. Therefore, we will need to analyze high-frequency data explicitly. For those reasons, in this paper, we focus on the heat budget that we showed in the previous revision.



FigR1. The SST tendency difference between Dakar Niño and Niña, D(SST)/dt (K/day) is estimated from monthly SST composite.



FigR2. Monthly composite difference between Dakar Niño and Niña for sum of the explicit terms of the ehat budget (horizontal advection, vertical advection, and surface heat flux). The unit is K/day.

I find the discussion of the heat budget analysis (Section 4.2) partly confusing and I am not sure if there maybe was a mix-up of the legends. If the black lines show ROMp, horizontal advection appears much more important than the surface heat fluxes (in contrast to what is stated in line 330). The black lines also show a stronger heat flux damping in April than the grey line (in contrast to what is stated in lines 358/359).

REPLY: Probably, our explanation was a bit confusing. Between January and March, surface heat flux (dot lined) and horizontal advection (solid line) in ROMP (black) are roughly comparable while the peak timing is different. We rephrased that part. Please see lines Regarding lines 358/359, yes, that was wrong. We deleted that sentence.

Also the components of the net surface heat flux need to be looked at individually. If shortwave radiation would be dominant (as indicated in line 336), how does this fit with the importance of the local winds?

REPLY: Thank you very much for raising this point. As shown in Fig. R3, we have divided the surface heat flux into 4 components. First, regarding the line 336, which concerns about Oettli et al. (2016), our ROM simulation might underestimate the shortwave radiation contribution due to the poor representation of aerosol (which are fixed to climatology).

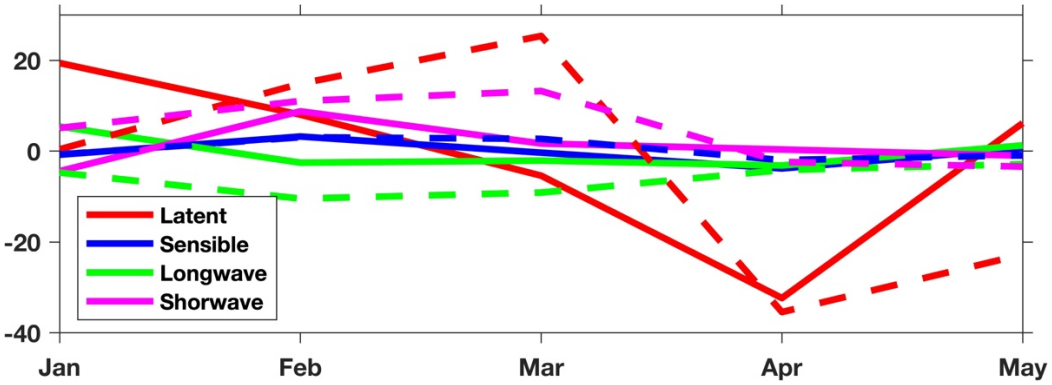


Figure R3: Monthly time series of lag-composite difference of latent heat flux (red), sensible heat flux (blue), longwave radiation (green), and shortwave radiation (magenta) for ROM_P (solid) and ROM_F (dashed) with the Dakar Index box. The unit is W/m^2.

In the present climate (sold lines in Fig.R3), latent heat flux is dominant from January to February, with shortwave radiation also playing an important role in February. Sensible and longwave are quite minor. This timing aligns with the results of Oettli et al. (2016). However, as we mentioned above, their result shows the dominance of shortwave radiation, while our result shows a more modest shortwave contribution, partially due to the poor representation of aerosol variability.

In the future climate (the dashed lines in Fig. R3), latent heat flux is responsible for enhancement of surface heat flux in March, with shortwave radiation also contributing to the future increase of the heat flux. At present, the processes cause the shortwave anomaly and the enhancement in the future are unclear. Possible processes are cloud and aerosol changes, but this is out of scope of our study and will be investigated in future work.

We added Fig.R3 as Fig.12 and descriptions on this discussion. Please see lines 356-372, 24, and 387. Please note that some texts on dust and the references are also moved to this part so that the flow of discussion become fluent.

Minor points:

a) Please indicate units in Figure 1.

REPLY: Added in the caption.

b) In lines 107 to 110 the seasonal migration of the SST front is described as a result of the seasonal cycle of the Canary Current and changes in the

location of upwelling. Doesn't it also reflect the seasonality of the upwelling strength?

REPLY: We agree. The changes primarly affect the seasonality of upwelling rather than the Canary Current. We have modified the text and added that this shift is associated with the migration of the ITCZ. The updated text now reads as follows Please see lines 107-110.

"This seasonal meridional migration of the SST front is linked to the seasonal cycle of the Canary upwelling system (Cropper et al., 2014; Pardo et al., 2011; Sylla et al., 2019) and is associated with the northward migration of the Intertropical convergence zone in the summer months, which displaces the surface water masses meridionally."

c) CMIP models are coupled climate models, not Earth system models which typically include more components such as biology (e.g. line 134)

REPLY: Corrected.

d) In Figure S2(b) there is some weird color shading at the shelf.

REPLY: Corrected.

e) In Figure 4, please use the same y-axis for all subplots.

REPLY: Corrected.

f) I noticed some curious clustering of events in ROMp (Fig. 4b) with three consecutive Dakar Niños followed by five consecutive Dakar Niñas. Any idea what this might be related to?

REPLY: At this moment, we do not have any clear explanation. However, consecutive events like these might suggest longer-time scale climate variability, such as Atlantic Multi-Decadal Oscillation (AMO). While AMO is out of scope in this study, its influence could be one of future studies on Dakar Niño.

g) Related to my major comments above, the relation between upwelling, subsurface temperatures and SSTs needs to be explained before getting to Figure 5.

REPLY: Before Fig. 5, we have only presented the connection between SST and surface wind connection as in Fig. 5 without showing any vertical structure. Therefore, we would think that mentioning SST and subsurface temperature before Fig.5, it might disrupt the flow of the story.

h) Somewhere in the discussion of Fig. 5, please state that that this means that Dakar Niños are related to weakened Northeasterly trade winds.

REPLY: Thank you for the suggestion. We added some texts. Please see line 201.

i) The word "penetrates" in line 234 suggests that the warming comes from the surface and is transported downward. Is this the case? It could also be the other way around - a subsurface anomaly that is impacting the surface by vertical advection and mixing.

REPLY: We agree. Therefore, that changed to "is detected" because there is no evidence of water penetration from the surface to the subsurface.

j) To compare the heat budget analysis from the model to ORA-S5 reanalysis, vertical velocities can be calculated from the divergence of the horizontal velocity field (as done in many studies).

REPLY: We agree. However, the ORAS5 analysis is just a supplement suggested by another reviewer and the result of re-analysis is already provided by Oettli et al. (2016). The ORAS5 is not our main purpose of this study. In addition, while many studies take this approach, using monthly-mean data and calculation from the divergence might cause further uncertainty in the result. Therefore, we prefer to show only the two explicit components of the ORAS5.

k) Explain how variations in mixed layer depth are related to the importance of surface heat fluxes (line 356/357).

REPLY: The heating rate from surface heat flux is divided by the depth of mixed layer *D*, meaning that thinner layer during Dakar Niño compared to Niña, can amplify the warming effect of the surface heat flux. We have added this explanation. Please see lines 353-354.

l) In the Discussion, Chang et al. (2023) is cited. Please comment on how their results align with what you find.

REPLY: In the two sentences preceding the citation of Chang et al. (2023), we described the differences in future response between Benguela Niño (Prigent et al., 2023) and Dakar Niño (our findings). There, we also mention importance of comparative studies between southern and northern upwelling regions. Chang et al. (2023) is one of the examples showing the difference between south and north, supporting our suggestion for future comparison studies. In addition, their study is about climatology of upwelling, not about inter-annual variability.

Specific comments:
- line 20: "wind stress, which is"

REPLY: Corrected.

- line 29: "The cold water of the southward flowing Canary Current and the…"

REPLY: Corrected.

- line 86: There is no red rectangular in Fig. 1.

REPLY: Changed to "yellow".

- line 101: "panel"

REPLY: Corrected.

- line 146: "identical" instead of "identically".

REPLY: Corrected.

- line 147: Please also refer to Fig. S1.
REPLY: Added.

- line 149: “enhancement” instead of “reinforcement”
REPLY: Corrected.

- line 163: no comma after especially
REPLY: Deleted.

- line 171/172: either “we investigate” or “are investigated”, not both
REPLY: Deleted.

- line 176: “agrees well” or “is consistent with”
REPLY: Corrected.

- line 177/178: Please specify the length of the time series again here.
REPLY: Done.

- line 195: “using a reanalysis product” (maybe specify which product)
REPLY: Done.

- line 195: “Dakar Niños are…”

REPLY: Done.

- line 197: Please rephrase, e.g. “In January, SST anomalies from ERA5 averaged over the Dakar Niño box are positively correlated with SSTs along the west African coast as well as southwesterly surface wind anomalies. The correlation strengthens in March which is the peak of the event.”

REPLY: Rephrased.

- line 200: “significant” or “pronounced” instead of “more dominant”
REPLY: Corrected.

- line 201, 210: “The area positively correlated with SST shifts westward…”
REPLY: Corrected.

- line 214: A word is missing after “coastal”.

REPLY: Added “Ekman divergence”

- line 218/219: “decreases to 0.4 at 100m depth (Fig. 6a).
REPLY: Corrected.

- line 219: “deeper in the water column” instead of “more deeply”
REPLY: Corrected.

- line 248: The increase from ROMp to ROMf is actually strongest in April.
REPLY: Changed to “March to April”.

- line 259: “In contrast” instead of “Inversely”

REPLY: Corrected.

- line 260: I would say that it actually decreases.
REPLY: Corrected.

- line 274: “becomes” (typo)
REPLY: Corrected.

- line 275: “of the cool anomaly”
REPLY: Added.

- line 276: “the land-surface”
REPLY: Corrected.

- line 276 and 278: “towards the west” instead of “more westward”
REPLY: Corrected.

- line 279: A word is missing after “much”
REPLY: Corrected to “larger”.

- line 289: “can also be seen”

REPLY: Corrected.

- line 290: “the SLP anomalies show”
REPLY: Corrected.

- line 293: “in particular in the case of…”
REPLY: Corrected.

- line 311: “investigate” or “examine” instead of “question”
REPLY: Corrected.

- line 314/315: either "we considered" or "is estimated", not both
REPLY: Deleted “we consider”

- line 319: “the bottom of the ocean mixed layer”
REPLY: Corrected.

- line 320: “and just below”
REPLY: Corrected

- line 321: “Q is the net…”
REPLY: Corrected.

- line 324: “missing” instead of “missed”
REPLY: Corrected.

- line 347: It’s not clear what “almost identical” is referring to. Present and future? Please specify.
REPLY: This is both of advection term. Here, we added “the magnitude of enhancement in the future”

- line 349/350: What does “remains secondary” mean? Does this refer to the future simulation?
REPLY: This is not correct explanation. We deleted that sentence.

- line 357/358: What is meant by “more persisting”?
REPLY: Here we meant SST anomaly associated with Dakar Niño. As Fig.5 shows, the SST anomaly (correlation with Dakar Index) is still high value in April. Because of more heating in March in the future, the SST anomaly can survive in April in ROM_F than ROM_P.

- line 364: “an intensification of interannual SST variability in the…”
REPLY: Corrected.

- line 365: “increase in the amplitude of…”
REPLY: Corrected.

- line 367: “is in contrast”
REPLY: Corrected.

- line 369: “coastal” instead of “coast”
REPLY: Corrected.

- line 381: A part of the sentence seems to be missing.
REPLY: “that” is removed and changed to “teleconnections”

- line 385: “modes such as”
REPLY: Corrected.

- line 389: please rephrase “will be desired”
REPLY: Changed to “will be necessary”

- line 399: I guess “performed” is meant (instead of demonstrated)

REPLY: Corrected.