Anonymous reviewer 2

Reviewer comments are in black, answers from the authors are in blue and corrections added to the manuscript are in green

The paper of **Ghani et al.**, entitled '*Revisited heat budget and probability distributions of turbulent heat fluxes in the Mediterranean Sea*' compared two surface heat budget estimates for the 2006-2020 period over the Mediterranean Sea recomputed by the authors with ECMWF and ERA5 bulk outputs (but the same SST). The paper presents also a statistical analyse of the sensible and latent heat fluxes with a characterization of their distributions and finally investigates the role of heat loss extremes.

This study has questioning conclusive remarks:

- The mention that *the heat budget closure hypothesis cannot be satisfied with coarse resolution (lines 457-458)* is not fully exact as shown by Table 1 where previous studies prove their quality to obtain negative heat loss in surface balanced by Gibraltar heat inflow. Possibly you would like to argue that a better representation of the heat budget is related to horizontal resolution; But there are many sources of improvements for representation of the heat budget terms: one is likely resolution, but sea surface and clouds/radiative schemes are also very important. This conclusion must be more carefully discussed in my opinion.

Thanks for your remarks. Yes, we agree that we didn't mention any other possible sources for improvement of the heat budget components. The radiative fluxes are featured with a level of uncertainty between two datasets probably due to cloud coverage, but we didn't carry further discussion in the conclusion which we will add after lines 457-458.

"In addition, it's known that the cloud coverage schemes differ between the two datasets and show a noticeable difference in the eastern Mediterranean Sea (Fig. A1), where cloud coverage distribution is denser in ECMWF data than in ERA5. This variation in cloud coverage highlights how different formulations, along with the spatial resolution of the atmospheric fields, influence cloud distribution and consequently affect the estimation of radiative flux fields."

- The statement that *the Mediterranean is still losing heat but only if using a(the) high-resolution ECMWF analysis (lines 459-460)* puzzles me. I am not sure this is a way to promote the results. The fact the Mediterranean Sea losses or not heat is something that can not be settle by only looking on one dataset. A very large analyse of a large amount of data is mandatory.

Thanks for your concern. In our study, we employed two datasets generated from one of the widely recognized atmospheric model variables applied in the Mediterranean Sea for forcing ocean forecasting models. The ERA5 reanalysis dataset, which is freely available and widely used within the scientific community, provides many atmospheric variables for model applications. However, the ECMWF operational analysis dataset is not publicly accessible, which limits the access the availability of long time series and several key variables, such as surface heat fluxes. Importantly, as our study is connected to the context of probable uncertainties arising from the atmospheric forcing variables in ocean forecasting, these two datasets were deemed the most relevant and were therefore selected for this study.

Please also clarify paragraph p10, lines 273-279. It is confusing to put here the finding is that the Mediterranean Sea still looses heat in surface, as you decided to follow the heat budget closure hypothesis that imposes this.

Thanks for your concern. We move this part to conclusion and insert in modifying phase this part after the line 459, P-18.

"Our initial question was: is the Mediterranean Sea in the past 15 years still losing heat at the surface? The answer is yes if we use a high-resolution ECMWF atmospheric analysis. Thus, comparing the net heat flux Qnet estimates derived from ERA5 reanalysis and ECMWF analysis dataset, using specific bulk formulas demonstrates an uncertainty in the results. This uncertainty, potentially linked to the spatial resolution difference between the two datasets, impacts the regional heat budget closure. In spite of having limitation in using only two but recognized atmospheric datasets, we are now able to address the question that the Mediterranean Sea in the past 15 years has still been losing heat at the surface. Therefore, notwithstanding the climate change warming, the Mediterranean still looses heat due to its heat budget closure constraint. However, it might be that it looses less than in the previous decades, and this will be the scope of more studies in the future"

I have also main concerns related to:

- the LH distribution (section 4.2). Fig. 5a shows surprisingly a quite large number of positive LH values for all locations. This means condensation, and supersaturation of air mass. This phenomenon is quite rare. It appears mandatory to check the LH values in these distributions. Also, for turbulent fluxes, the computation uses transfer coefficients independent from the wind (equation 9/10). Does this may affect your results in terms of SH/LH distribution shapes.

Thank you for your observation. We used the anomaly of latent heat (LH) distribution with respect to daily season cycle, where exhibits positive and negative values. We believe, there is no condensation and supersaturation dynamics present in our data, as the computed LH time series remains consistently negative. Following Petenuzzo (2010), we used constant turbulent exchange coefficients, which are multiplied by stable and unstable condition parameters and updated based on the maximum and minimum wind speeds.

There are very large differences in SW (Fig. 1d, h). This is the main reason for the ERA5 positive budget (Tab. 1). From equation 2, I understand the differences come only from the cloud coverage C. Did you compare the cloud coverage fields in the two atmospherical dataset? Should the threshold to define clear sky be adapted and?

Thanks for your concern. Yes, we have analysed the difference in cloud coverage fields between ECMWF analysis and ERA5 reanalysis dataset. We agree that cloud coverage difference generated large variation in SW fields (Fig. 1 d, h). Here we present the maps of cloud coverage (A1). Addressing your comment, we add a part that referring to the difference in cloud coverage resulting from different cloud schemes in conclusion section, which is already described under the first comment's reply above. We would prefer not to change the clear sky Reed (1977) formula because the concept is to use same formulation with different atmospheric datasets.

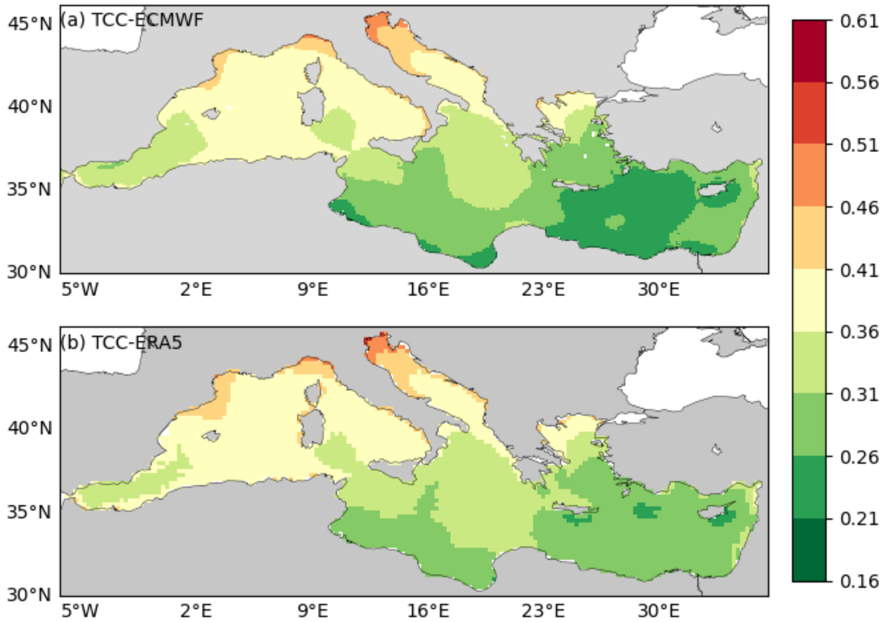

Figure A1: Total cloud coverage (%) mean computed for the period 2006-2020, a) ECMWF and b) ERA-5 input datasets.

For these two remarks, a larger discussion of what is mentioned p10, line 263-366 would be greatly useful.

Thanks for your feedback. But we are not sure about the line numbers, maybe it should be 263-266, because after line 291, it's another section and not related with above remarks. However, we propose to add additional text starting from line 266

"A higher spatial resolution is important for capturing many small-scale atmospheric and oceanographic features. In contrast, ERA5 comes with a horizontal resolution of ~31 km, which can smooth many small-scale features and underestimate the frequency of extreme fluxes, such as extremes that are often associated localized events – such as local wind flows, sharp air-sea temperature contrast and coastal orographic effects. With the 0.125x0.125 spatial grids, the ECMWF analysis dataset exhibits better representation of the influence of near-surface atmospheric variables, such as wind speed, air temperature and specific humidity gradient, as we notice this difference between the turbulent heat fluxes of the two datasets. In the Gulf of Lion, the local Mediterranean wind called Mistral wind influences the vaporization process significantly; a distinct gradient difference is visible in between the two datasets for latent heat fluxes (Fig.1 b & f). Even though the spatial distributions are identical in both datasets, ERA5's resolution indicates a reasonable variation in surface air-sea temperature gradient in the Alboran Sea, Adriatic Sea and Tyrrhenian Sea for turbulent heat fluxes"

Finally, even if I understand and find fair the objective of having the same fluxes computation method and same SST for both datasets, I would have appreciated a brief comparison with the SW, LW, LH and SH fluxes directly taken from ECMWF and ERA5.

We don't have the direct access to heat fluxes simulated in ECMWF analysis dataset and had requested earlier for this dataset. It would take sometimes to process and analysing at this moment, but we would be able to provide this in the revised version. Flux variables from ERA5 dataset are publicly available and presented the mean maps of those surface fluxes comparing to our computed ERA5 fluxes (Fig: A2)

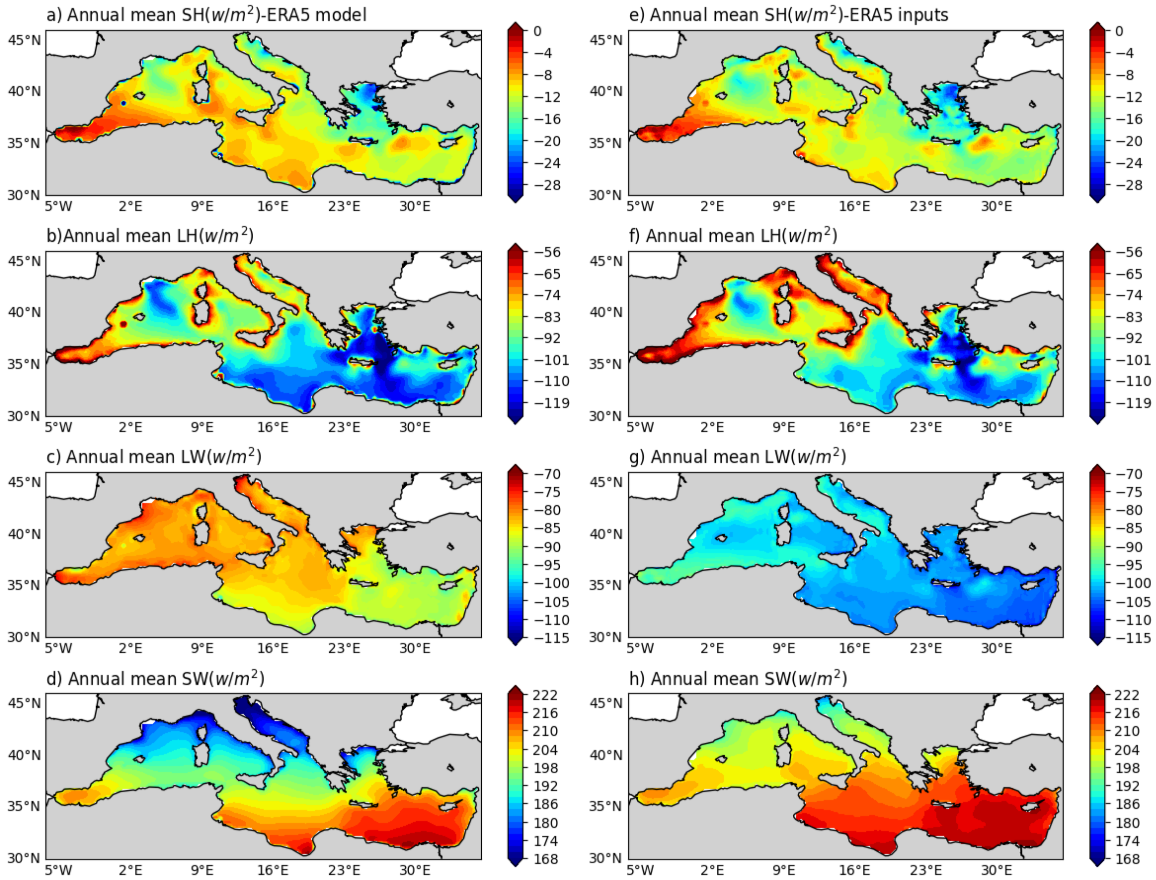

Figure A2: Mean annual heat flux components for the period of 2006-2020 computed from ERA5 fluxes (left, a to d) and ERA5 inputs (right, e to h) using equations (2-10)

The basin-averaged Q_{net} computed using ERA5 flux variables is 4.6 Wm-2, which is approximately same to the Q_{net} computed using ERA5 inputs (Table 1)

I put below some minor comments.

p5, eq.2: add information in text about the threshold; and unit for *C*.

- Corrected the eq.2 "if $C \geq 0.3$ m if $C < 0.3$", and added in text "C (%) is the cloud coverage and converted into fraction to apply the threshold of cloud coverages ($C \geq 0.3$ and $C < 0.3$) adopting the formula from Reed(1977)

p5, line 140: what is *sec* ?

- Sec represents secant ($\sec(\theta)$) of zenith angel of the Sun

p6, eq 8: why did you not use directly the specific humidity?

- We followed the exact formulation used in Large (2006) and Petenuzzo (2010) using dewpoint temperature data to compute specific humidity.

p7, line 189: *... the following* atmospheric near-*surface variables…*

- Corrected "the following atmospheric near-surface variables .."

Fig. 1: Could a column with difference maps for each term be added?

- The maps are based on their original spatial resolution, and we didn't regrid the atmospheric datasets into a common grid for the comparison.

P8, line 210-212: *... The largest mean sensible heat* gain *is observed… Gulf of Lion* loss *more…* [negative is heat loss]

- Corrected "The largest mean sensible heat gain is observed …….. Gulf of Lion loss more …"

p8, lines 221-223: The first reason for SW differences between Western Mediterranean and Eastern Mediterranean is the latitudinal position of each sub-basin.

- Added "The first reason for SW differences between Western Mediterranean and Eastern Mediterranean is the latitudinal position of each sub-basin. Furthermore, radiative heat fluxes using ECMWF and ERA5 datasets are connected to different cloud cover schemes. The difference in SW radiation between the western and eastern Mediterranean indicates this cloud cover variation, leading to a larger heat gain in the Eastern Mediterranean"

P8, line 227: *... presumably due to the* warm *Atlantic* surface *inflow…*

- Thanks for your observation and corrected : "presumably due to the warm Atlantic surface inflow…"

p13, line 328: From Fig. 4b μ is mostly positive. Please modify the sentence.

- Corrected "the location parameter (μ) exhibits mostly within positive value range while a small area in the Alboran Sea show negative values, ……"

P15, line 395: *...with long term climatology values for the extreme heat losses days...* : Could you precise how is built this climatology?

- Thanks for your concern and added "These extreme values were replaced with long-term daily climatological values (using equation 11) to the respective days of extremes heat losses occurred. After the replacement of extremes, the long-term basin-averaged Q_{net} was recalculated."

P16, line 400-401: The differences in Qnet between ECMWF and ERA5 is mostly due to differences in SW. Please review the whole paragraph.

- Corrected and reviewed "We observed the difference in basin-averaged Q_{net} values between ECMWF and ERA5 is primarily due to difference in SW, and the distribution of extremes is likely not significantly affected by difference in spatial resolution. The regions of negative heat loss, where potential extremes occur, are concentrated in the core zones of the Gulf of Lion and Aegean Sea in both Q_{net} from ECMWF and ERA5 whereas a similar pattern of heat gain is evident in the Alboran Sea (Fig 3). We believe that these winter extremes, featured by large negative heat loss values, significantly impact the Q_{net} (Fig. 6), where they arise from dense heat loss area generated by local Mediterranean wind flows (e.g., Mistral,) and air-sea temperature contrast. Furthermore, after replacing these extremes with long-term climatology, the recalculated yearly mean of seasonal climatology increased to +4 W/m, compared to -4 W/m2 when extremes were present. This confirms the influence of surface heat flux extremes in the Mediterranean net heat budget."

P17, line 424: ... *of -289* W/m^2 *(for k=0.75)...*

- Corrected: " -289 W/m2 (for k=0.75)"

p17, line 427: Please add the map of differences between Fig8 and Fig. 3a to put in evidence this result.

- Yes, we have added this new figure replacing Fig. 8

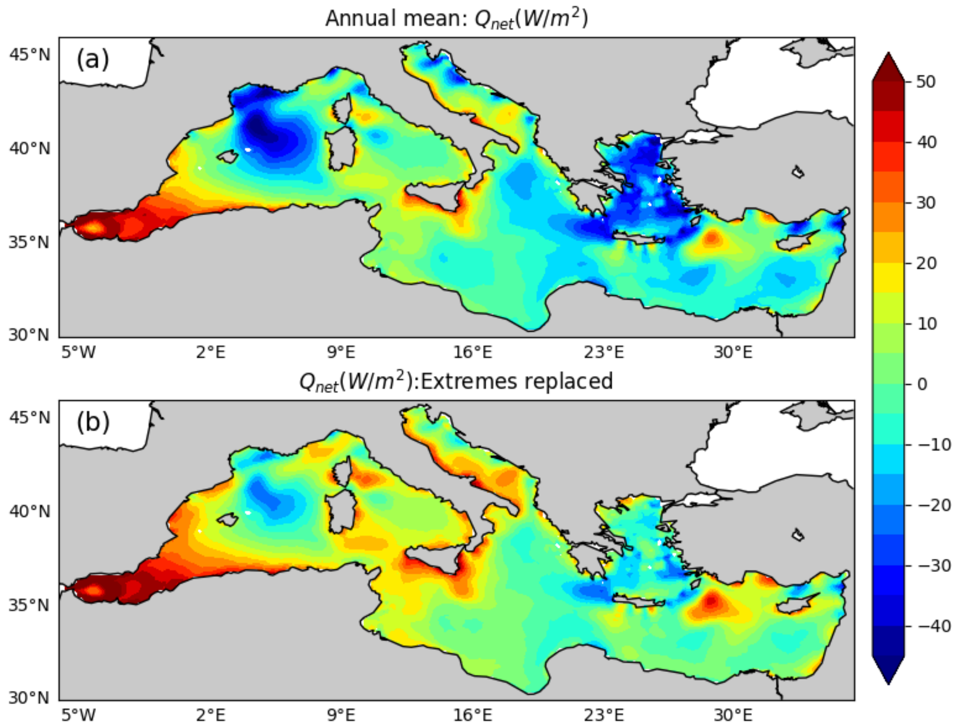

Figure 8: The annual mean (Q_{net}) after the removal of extremes showing significant reduction of negative heat fluxes in the Gulf of Lion, Adriatic Sea and Aegean Sea regions.

P19, line 486: minus sign is missing.

- Corrected : " -238 W/m2"