Response to the reviewer's and editor's comments on the manuscript "Revisiting the Moisture Budget of the Mediterranean Region in the ERA5 Reanalysis"
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We thank the anonymous reviewer and the editor for their feedback. In particular, we really appreciate the editor taking the time to review the manuscript and avoiding further delays on the handling of our manuscript. We addressed all reviewers' suggestions in our revised submission, as detailed below in our point-to-point response (in black) to the reviewers' comments (in blue).

Reviewer 1

This is my second review of this work, which analyzes the moisture budget of the Mediterranean region using the ERA5 reanalysis. The authors made significant improvements in clarifying the novel contributions of the work, and in providing context for the stationary contributions to the hydrological cycle in the region. I therefore recommend accepting the paper, with some minor comments and suggestions.

Thank you for your positive evaluation and comments!

Sector mean plots (3, 11, A1): Strong land-ocean contrasts are seen in some of the components (transient eddy in particular). Therefore, there should be some sensitivity to the choice of zonal boundaries (10W—40E). For example, the transient eddy sector mean may vary substantially if the sector width would narrow/widen; the authors should address this concern. It might also be helpful to decompose the sector means into land and ocean averages, at least for some of the fields.

Thanks for bringing up this point. We chose our sector as described in the manuscript to be consistent with previous work, such as D'Agostino and Lionello (2020); Giorgi and Lionello (2008); Tuel et al. (2021). We conducted sensitivity studies and found that the emerging zonal-mean patterns are robust to different choices of the box boundaries, which might be more conventionally associated with the Mediterranean region. As an example, in Fig. R1 we show the zonal mean over the 5°W-35°E°N sector (to be compared with Fig. 3 in the revised manuscript). To the extent the chosen range is wide enough that the resulting zonal average is meaningful and representative of most of the Mediterranean region, results remain consistent with what discussed in the manuscript. We also thank the reviewer for suggesting to decompose sector means into land and ocean averages, but we believe that those patterns are sufficiently evident and more meaningful when looking at spatial patterns. We were also reluctant to add more figures (see point below).

Overall, there are 46 panels presented in the main text (not including appendices). At some point, it becomes hard to separate the wheat from the chaff. Here are some suggestions. Figure 4: given that the authors have established that the residuals are small, either Fig. 4c or 4d can be removed. Similarly, Fig. 4g is not very informative, as it is already shown in Fig.3. The same rationale can be applied to Figs. 12 and 13. Generally, using a 2D map to show the sector mean is not a good use of space. Figs. 7b and 8b can be shown as side panels with line plots.

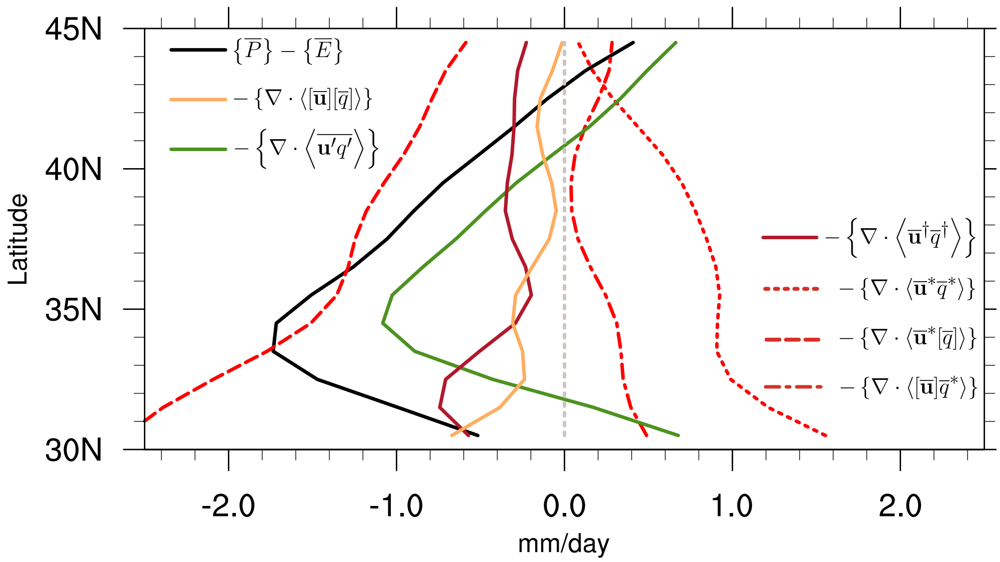

Figure R1: Climatological annual and zonal sector mean moisture budget across the Mediterranean region, with a modified narrower longitude range (5°W-35°E).

We thank the reviewer for their kind suggestion. We decided to condense the information previously conveyed in Figs. 4 and 5 into one figure (Fig. 4 in the updated manuscript). This has been achieved by adopting the same format as in Figs. 12 and 13 for the solstice means of the older manuscript (now Figs. 10 and 11). Please see Fig. R2. Similarly, for Figs. 7 and 8 of the old version, we followed the reviewer's advice and now show zonal averages as line plots on side panels, as shown in Figs. R3 and R4. Along the same lines and following a similar comment by the editor, we also removed Fig. 6 of the older manuscript and now just provide a short qualitative description.

L179 -10E $->$ 10W
L236 Evaporative body $->$ source of moisture
Figure 10 caption: day.

Thanks! Done!

Editor

The authors have addressed most of the reviewers comments, but based on the re-review of initial reviewer 2 (now reviewer 1) and my own reading and going over the response to initial reviewer 1's concerns , some additional points need to be addressed. Specifically, please address and justify the choice of zonal range for the averaging done in figures 3, 11, A1.

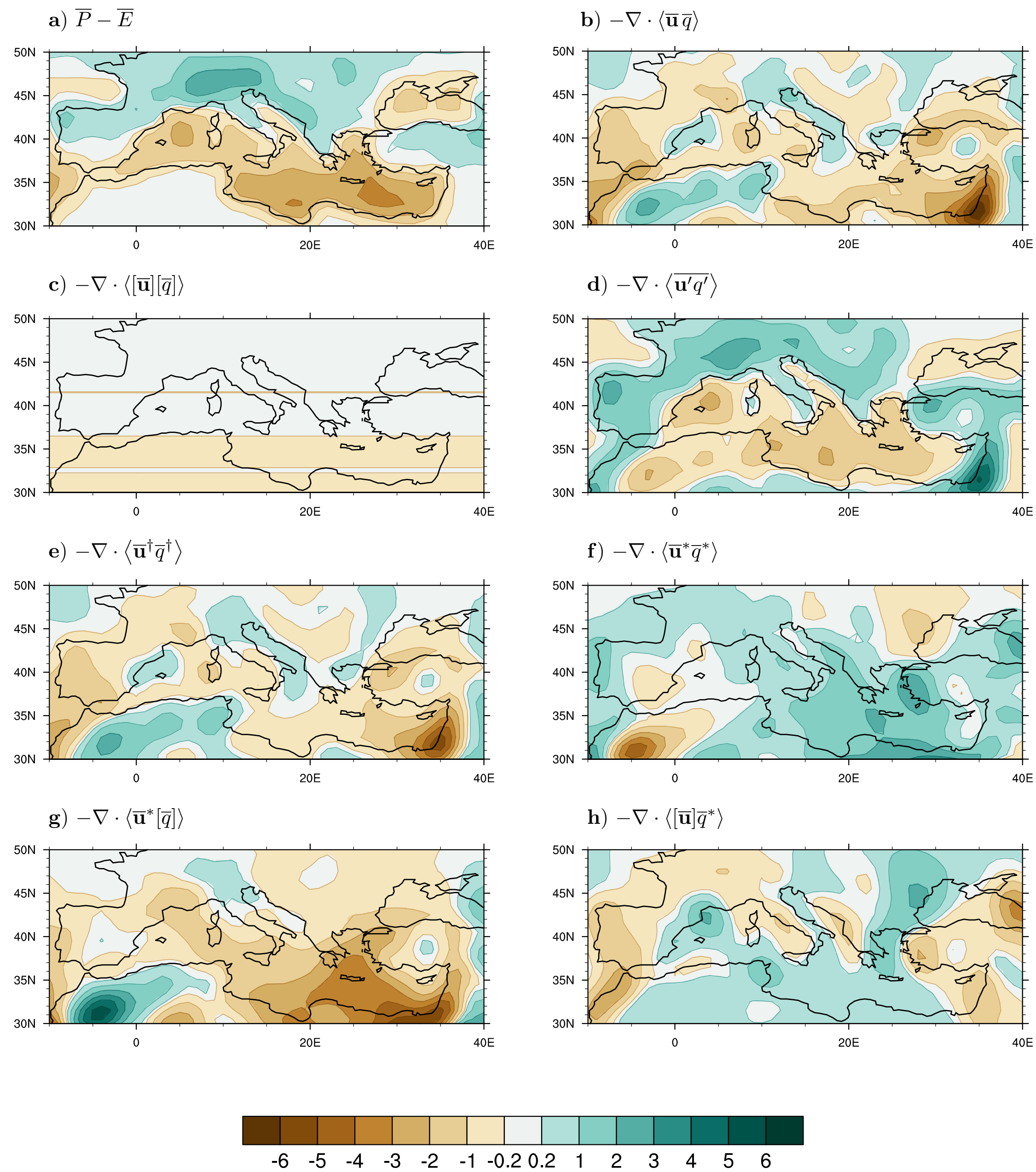

Figure R2: Annual mean climatological moisture budget in the $1979-2020$ period from ERA5: a) $P-E$, b) monthly mean flow, c) zonal mean flow, d) transient eddies, e) total stationary eddies and its constituent components arising from f) pure stationary eddies, g) transport of zonal mean moisture by the zonally anomalous circulation, and h) transport of zonally anomalous moisture by the zonal mean circulation. Units are millimeters per day.

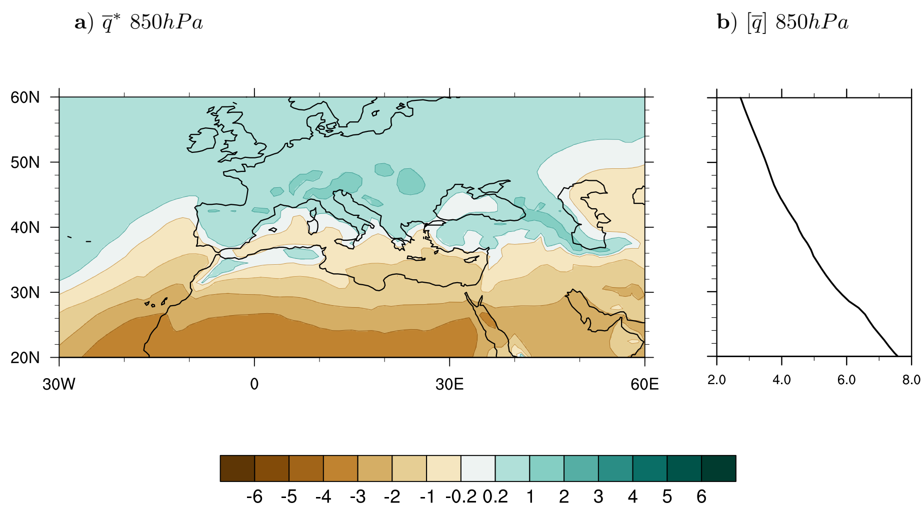

Figure R3: Annual mean climatological low-level (850 hPa) a) zonally anomalous moisture and b) zonal-mean moisture from ERA5 in the $1979-2020$ period. Units are $g\,kg^{-1}$.

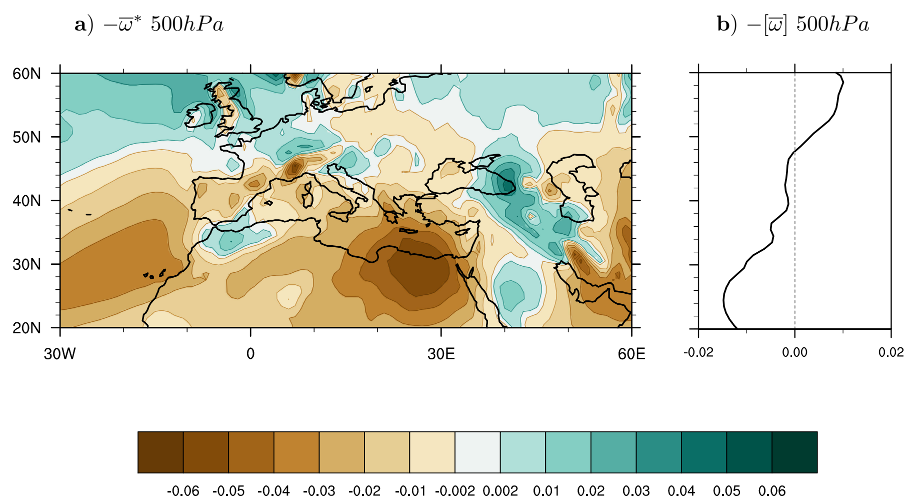

Figure R4: Annual mean climatological mid-tropospheric (500 hPa) a) anomalous vertical velocity and b) zonal-mean vertical velocity from ERA5 in the $1979-2020$ period. Units are $Pa\,s^{-1}$. Note how here we show negative pressure velocity; hence, positive values (green) denote ascending motion and negative values (brown) denote descending motion.

Many thanks for pointing this out. We now provide references for this choice of latitude-longitude box. Please also see our response to Reviewer 1's first point.

I agree with the reviewer that reducing the number of plots will make the paper easier to follow. Specifically, please consider plotting the sector mean averages alongside the 2-D fields and also maybe marking the averaging region.

Thanks! Please, see our reply to Reviewer 1's second point.

I also found a few points that are confusing that need to be addressed: 1) Figure 6 is not really described in the text, and the comment on line 267 which initially I thought were meant to refer to figures 6 and 7, because figure 6 shows the circulation, but it is also showing the smaller domain.

Thanks you. We indeed removed Fig. 6 as per your suggestion.

2) I am confused by the explanations of the different cancellations of the moisture flux terms between the stationary eddies and the zonal mean moisture advection by the zonally varying flow, as described for example in the response file on page 5 at the top (first full [paragraph starting on line 5). Figure 7 in the manuscript suggests the meridional gradients of the zonally symmetric and zonally varying moisture fields are oppositely signed so the same zonally varying moistions will have opposing meridional advections, which is one cancellation. It is much more confusing to understand this cancellation if we look at the divergence (vertical velocity) where what matters is the sign of the moisture component. Actually, the two terms, divergence times the zonal mean moisture and divergence times the moisture zonal anomaly will only cancel where the zonal moisture anomaly is negative, because the zonal mean moisture has to be positive. The total flux term is teh sum of the advection and the divergence, as you rightly noted, but the physical explanation of the cancelation is done while mixing the advection, the divergence and the total flux terms together.

Yes, you are completely right. Given that the zonally anomalous moisture (q^*) varies primarily in the meridional direction, and that its gradients have opposite sign to those of the zonal mean moisture ($[q]$), the same zonally anomalous horizontal motion ($\mathbf{u}^*$) results in opposing meridional advection of q^* (due to the pure stationary term) and meridional advection of $[q]$. In our previous explanation, we focused primarily on the vertical advection (horizontal divergence) term, even if we did acknowledge the important contribution of horizontal advection (which we also show explicitly).

As for the cancellation arising from the vertical advection terms, as you mentioned in your comment, what matters is the sign of the zonally anomalous moisture, given that zonal mean moisture is positive at all latitudes. Hence, the cancellation must arise where we have dry moisture anomaly (negative q^*). This is, for instance, what is seen over the Mediterranean Sea itself. We have tried to clarify all of these points in our revised version. Please see lines 310-320.

3) I do not understand the sentence starting on line 310: "In particular..." How can anomalous

descent lead to a moisture flux convergence, unless it is convergence in regions adjacent to the descent. Or do you mean that the divergence in a dry region enhances the initial moisture anomaly ?

As discussed in our reply to your comment above, we have significantly modified the paragraph with a physical explanation of the canceling tendencies between the pure stationary term and the term arising from transport of zonally averaged moisture by the zonally anomalous circulation. The confusing sentence now reads: "The drying effect of the zonally anomalous divergent circulation is reduced by the pure stationary term in regions of reduced moisture availability ($\overline{q}^{*}_{850} < 0$)". We hope this new sentence, and related discussion, clarifies any pending confusion.

4) Response to the comment about the local Hadley cell paper by Li et al- I think what the reviewer meant is that the Hadley cell descent mechanism often invoked for the Med. being a dry region (along with the Hadley cell expansion being a main cause for future drying) is according to your results not the leading explanation, because the stationary waves are much more dominant than teh zonal mean overturning term. However, if you take a more lax definition of the Hadley circulation as the overturning divergent circulation, then can you say that the Hadley circulation descent is a leading drying process for the Mediterranean? It is possible to discuss this qualitatively, by simply looking at the Li et al papers or the papers they reference to see if the Mediterranean is indeed a mean ascent region in the annual mean, and then in the solstice seasons. Making this quantitative requires I think dividing the fluxes into rotational and divergent, and maybe regressing on the regional Hadley cell, and I agree is beyond the scope of your paper.

Motivated by this comment, we have conducted preliminary analyses on the regional overturning circulation. That is, we have divided the flow into rotational and divergent components and computed the longitudinally varying meridional streamfunction from the divergent component, following, for instance, Zhang and Wang (2013). The vertical velocity associated with this regional meridional overturning can then be computed as the streamfunction meridional derivative. The result is shown in Fig. R5. Please note that, because of ongoing issues with the Climate Data Store, we downloaded only a subset of the years used in this study (2000-2020 rather than 1979-2020). We, however, believe this result will not change significantly if we extend the analysis to all years. We see that while there is indeed descent over the Mediterranean region, it is weak and much smaller than the total descent (Fig.R4). The same holds true for the solstice seasons. This leads us to conclude that the regional meridional overturning does not capture all zonal asymmetries of the mean flow and their influence on the net precipitation of the Mediterranean region. We have added the discussion of this preliminary analysis on Lines 439-449 of the revised manuscript.

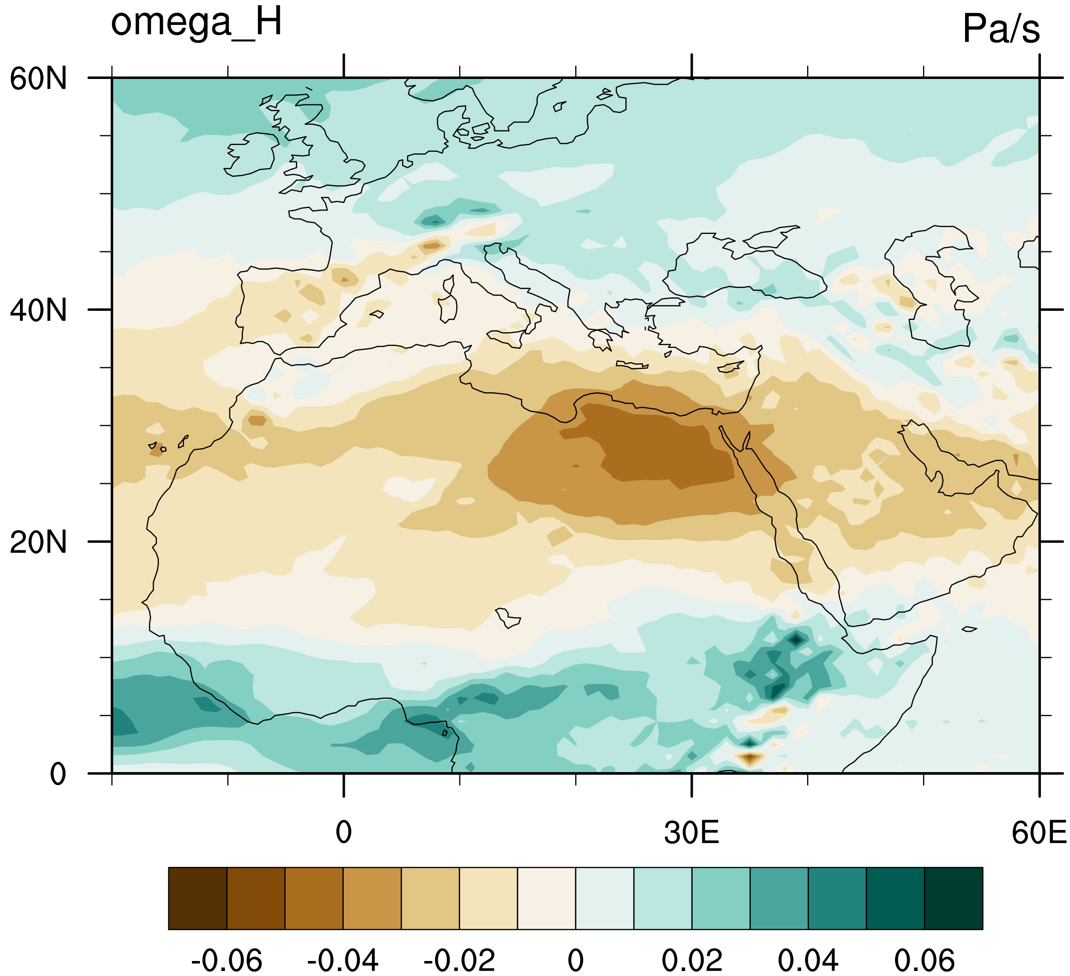

Figure R5: Annual mean climatological mid-tropospheric (500 hPa) vertical velocity $Pa\,s^{-1}$ associated with the regional overturning streamfunction. Note how here we show negative pressure velocity; hence, positive values (green) denote ascending motion and negative values (brown) denote descending motion.

References

D'Agostino, R. and Lionello, P.: The atmospheric moisture budget in the Mediterranean: Mechanisms for seasonal changes in the Last Glacial Maximum and future warming scenario, Quat. Sci. Rev., 241, 106 392, 2020.

Giorgi, F. and Lionello, P.: Climate change projections for the Mediterranean region, Glob. Planet. Change, 63, 90–104, 2008.

Tuel, A., O'Gorman, P. A., and Eltahir, E. A.: Elements of the Dynamical Response to Climate Change over the Mediterranean, Journal of Climate, 34, 1135–1146, https://doi.org/10.1175/JCLI-D-20-0429.1, 2021.

Zhang, G. and Wang, Z.: Interannual Variability of the Atlantic Hadley Circulation in Boreal Summer and Its Impacts on Tropical Cyclone Activity, Journal of Climate, 26, 8529 – 8544, https://doi.org/10.1175/JCLI-D-12-00802.1, 2013.