Response to Reviewer 1:

This is my second review of the manuscript, which I find slightly improved with respect to the first version. I still find points that I would like authors to consider.

Thank you for your positive, minor comments. They helped us to attain a more robust and complete version of the manuscript. The responses to the specific comments can be found below.

As for my comment on the validation and criticism of Figure 2 in the previous review (" From Figure 2, it is difficult to conclude that both patterns agree satisfactorily, partially because of the poor resolution of the figure. Rather, the agreement seems to be only moderate if not arguable"), I still maintain the same objections. In particular, about the poor quality of the Figure. Velocity vectors are not distinguishable, and where they are, its size indicates a sluggish –and unrealistic- surface flow no greater than 1 or 2 cm/s according to the bottom-right reference vector.

We would like to highlight that the issue posed by the reviewer is mainly due to a visualization problem. For that reason, for the revised version of the manuscript, a new version of Figure 2 has been created (Figure 1R). In this case we set the bottom-right reference vector to 8 cm/s (instead of 5 cm/s, as it was previously). We use this scale as a compromise between the AVISO and ROM grid resolution. In ROM, the resolution decreases from about 7 km near Gibraltar (comparable to AVISO) to about 20 in the Eastern Mediterranean. In the new figure it can be seen that ROM is able to simulate the main features of the ocean circulation in the Western Mediterranean (our area of study), especially the mesoscale activity in the Alboran Sea, with a good representation of the main features of the circulation in the Tyrrhenian Sea.

It is also the rare practice of using different spatial resolution and time-averaged periods to compare AVISO and ROM data. The new sentence included in the caption neither helps, rather it puts more grain in the mill: if authors have compared the same period, why don't they show the coincidental period instead of two different?

In our former response to a similar comment that arose in the previous review we showed a series of figures in which it was clear that the differences between using slightly different time periods or exclusively considering the coincidental time period between AVISO and ROM for the validation were minimal and did not have an impact on the extracted conclusions. However, following the reviewer's request, we have generated a new version of Figure 2 for the revised version of the manuscript. This new figure (Figure 1R) only includes the time period which coincides in both AVISO and ROM (1993-2005) and, as stated above, to improve the visualization of the velocity field, the velocity of the reference vector found to the bottom right of the figure has been set to 8 cm/s.

In addition to this, for clarity, in the introductory paragraph of the Results Section of the revised version of the manuscript we state the following: "For estimating ROM present-day climate we use the last 30 years of the historical run, namely from 1976 to 2005, which is widely used as reference period for present climate, then we assess circulation changes by comparing this reference period with the future one (2070-2099). However, for the validation we use the 1993-2005, as this period is coincidental with the AVISO satellite altimetry gridded product". Furthermore, in Section 3.1, in which the Mediterranean Sea circulation is validated, the subsequent sentence has been added: "We remark that the time period chosen for this validation is made to match with AVISO data availability (1993-2005)". Finally, the parts of the text where we mentioned that the mismatch between the time periods used in AVISO and ROM was due to the lack of AVISO data until 1993 have been correspondingly removed to be consistent with the new version of Figure 2.

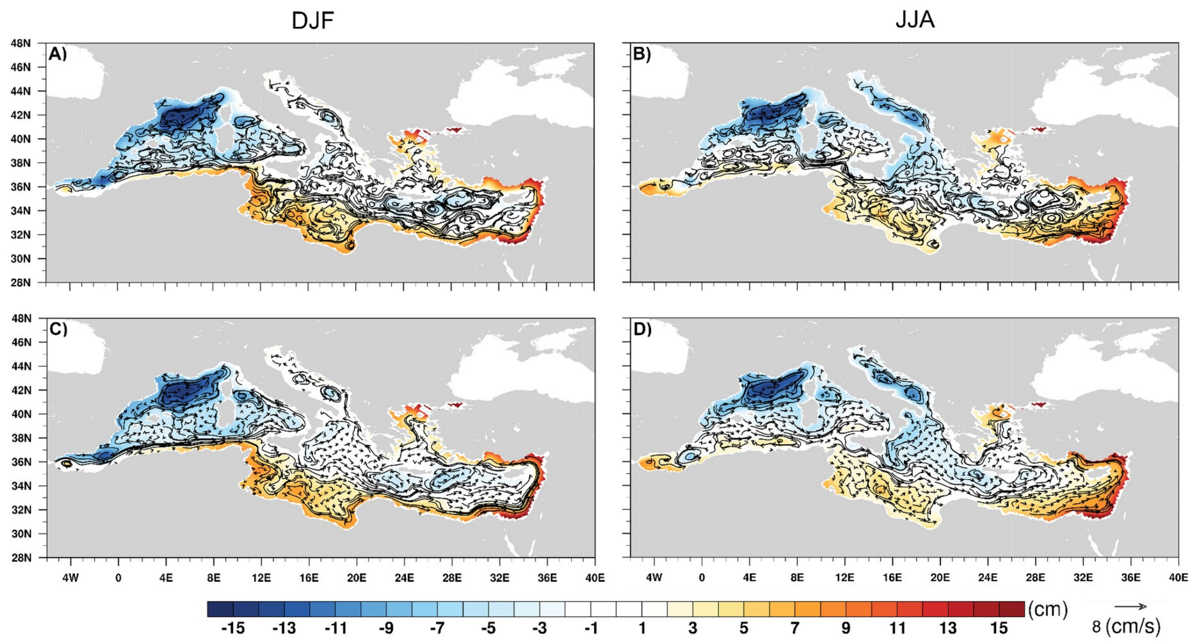

Figure 1R: Winter (left column) and summer (right column) averages of present-day geostrophic circulation (vectors, cm/s) and sea-surface height (SSH, colors, cm) from AVISO (A, B) and ROM (C, D). For comparison we use the 1993-2005 period, when both model and observed data are available.

The positive contribution of the figure is the similarity of the patterns of large spatial-scale circulation, but the comparison is not so good for the mesoscale. All in all, Figure 2 is of little help for validation. Quite probably, ROM results are better than what can be inferred from the Figure and, therefore, my suggestion is to remove it and show the results of the good correlation found between SSH from ROM and AVISO mentioned (but not shown in the current version) in lines 172-173 instead.

As it can be appreciated in Figure 1R (Figure 2 of the revised version of the manuscript), ROM provides quite a realistic representation of the basin-scale circulation and its seasonal variability compared to AVISO. Major gyres are also well represented, but the reproduction of mesoscale-size structures is limited by ROM horizontal resolution, which is fair in the western basin (7 km in the Alboran Sea) but relatively low in the Eastern basin (25 km), as shown in Fig. 1 of the manuscript. ROM ocean resolution shows up in the mesoscale representation: mesoscale-size structures are properly reproduced in the Western basin and in the Adriatic Sea, and not so good in the Eastern basin. In short, ROM captures the most prominent dynamical structures depicted from AVISO data, but not all the secondary ones. This was also the case in previous works addressing the Tyrrhenian surface circulation (e.g., de la Vara et al., 2019). The differences between the representation of the dynamical structures in ROM and AVISO is, as explained above, due to the lower resolution of the ocean model relative to AVISO altimeter data. However, this should not be problematic given that the main aim of this work is to study the changes induced in the Tyrrhenian circulation in response to climate change. Despite those differences, good correlation is found between the SSH from ROM and AVISO in both seasons (0.73 for winter and 0.67 for summer).

In response to this comment, the information presented in the above paragraph has been incorporated in Section 3.1 of the revised version of the manuscript. We would like to highlight that the seasonal values of the correlation coefficients for ROM and AVISO SSH taking into account the entire Mediterranean Sea for the 1993-2005 time period have been included in the text, following the reviewer's suggestion (see Table 1R). Since Figure 2, as mentioned above, has been improved and the reasons for the differences in the quality of the representation of mesoscale structuctures has been explained in the revised version of the manuscript, for clarity and consistency with Figure 3, we prefer to keep this figure in the manuscript.

		Correlation coefficients
AVISO-ROM (1993-2005)	DJF	0.73
	JJA	0.67
AVISO-ROM (1976-2005)	DJF	0.71
	JJA	0.66

Table 1R. Winter and summer correlation coefficients found between the SSH from AVISO and ROM for the time periods specified. In the upper row, data for both AVISO and ROM extend from 1993 to 2005. In the lower row, AVISO data expands from 1993 to 2005 and ROM data from 1976 to 2005.

The other point in my previous review concerned the forecasted freshening of the Atlantic inflow through Gibraltar. A clarifying sentence is now mentioned in section 3.3, which is OK. However, since this freshening (which is central to the augmented stratification in the Tyrrhenian Sea) is a result imported from previous works, the suitable place for that sentence/comment seems to be the model setup section, where water exchange through the straits of Gibraltar and Dardanelles is mentioned. Obviously, some comments can be maintained in section 3.1, but readers will be grateful for being informed in advance.

Thank you for your constructive comment. In the revised version of the manuscript, in the Model Setup, where MPIOM, the ocean component of ROM, is described, the following is stated: "As the atmospheric domain is large and encompasses most of the North Atlantic, MPI-ESM influences the oceanic properties through the large-scale forcing on the atmospheric component of ROM. In turn, the large-scale North Atlantic Ocean climate change signal can propagate into the Mediterranean through the open Strait of Gibraltar. This is relevant as it allows accounting for the surface freshening signal projected by the driving MPI-ESM in the eastern North-Atlantic at the end of the 21st century (Parras-Berrocal et al., 2020)".

The fourth and last conclusion of the manuscript relates to this issue. It is said that water flowing through the Corsica Channel "presents a stronger stratification than at present due to a generalized warming with a saltening of intermediate waters" and the consequences the stratification could possibly have in the formation of deep water in the Gulf of Lions. However, the inclusion of a map with differences in Figures 6 and 8 (good idea showing that map!!) indicates that most likely the main contributor to the future enhanced stratification is the reduced surface salinity. No mention to this fact is made in the conclusion, and it should be done. Hence, the relevance of explaining the source of the low surface salinity of the Atlantic inflow in the introduction section.

We agree that these are indeed good contributions to the manuscript. Following the reviewer's advice, in the last bullet of the Conclusions Section we now state: "In the future, the northward water transport across the Corsica Channel towards the Liguro-Provençal basin becomes smaller than today. Also, water that flows through this channel presents a stronger stratification than at present. The reason for this is twofold. On the one hand, a generalized freshening of the Atlantic waters inflowing through Gibraltar causes a reduction of the Mediterranean sea-surface salinity (e.g., Parras-Berrocal et al., 2020). On the other hand, a warming with a saltening of intermediate waters. These changes potentially contribute to the interruption of deep water formation in the Gulf of Lions by the end of the century (Parras-Berrocal et al. 2021)".

To take into account the second part of the comment, in the Introduction Section of the revised manuscript we now the state: "A great advantage of the ROM configuration used in this study is that it represents an open Strait of Gibraltar (see Fig. 1) allowing the propagation of Atlantic Ocean climate change signals into the Mediterranean Sea (Parras-Berrocal et al., 2020; 2021). This is of uttermost importance as the surface freshening of the eastern North Atlantic, which is a robust feature within CMIP5 RCP8.5 projections (Levang and Schmitt, 2020; Soto-Navarro et al.; 2020), may have profound impacts on the Mediterranean Sea (Parras-Berrocal et al., 2020; 2021) in general and on the Tyrrhenian Sea in particular".

References:

de la Vara, A., Galan del Sastre, P., Arsouze, T., Gallardo, C., and Gaertner, M.A.: Role of atmospheric resolution in the long-term seasonal variability of the Tyrrhenian Sea circulation from a set of ocean hindcast simulations (1997–2008), Oce. Mod., 134, 51-67, doi:10.1016/j.ocemod.2019.01.004, 2019.

Levang, S.J., Schmitt, R.W.: What Causes the AMOC to Weaken in CMIP5? J. Clim., 33 (4), 1535-1545, doi: 10.1175/JCLI-D-19-0547.1, 2020.

Parras-Berrocal, I., Vazquez, R., Cabos, W., Sein, D., Mañanes, R, Perez-Sanz, J., and Izquierdo, A.: The climate change signal in the Mediterranean Sea in a regionally coupled ocean-atmosphere model, Ocean Sci., doi: 10.5194/os-2019-42, 2020.

Parras-Berrocal, I., Vazquez, R., Cabos, W., Sein, D., Alvarez, O., Bruno, M., and Izquierdo, A.: Will deep water formation collapse in the North Western Mediterranean Sea by the end of the 21st century?, Earth and Space Science Open Archive, doi:10.1002/essoar.10507698.1, 2021.

Soto-Navarro, J., Jordá, G., Amores, A., Cabos, W., Somot, S., Sevault, F., et al.: Evolution of Mediterranean Sea water properties under climate change scenarios in the Med-CORDEX ensemble, Clim. Dyn., 54(3), 2135-2165, doi:10.1007/s00382-019-05105-4, 2020.

Response to Reviewer 2:

This is my second review of this manuscript. My main concerns with the first version were related to the model description, its validation and the explanation of the reduction in the sea-surface salinity (SSS) described in the results and partially responsible of the increase of the stratification in the Tyrrhenian basin. In their response, the authors have addressed most of these points satisfactorily, although I still have a couple suggestions that in my view could help clarify these aspects of the paper. Therefore, I recommend the publication of the article after a minor revision of these points.

Thank you for your positive, minor comments. They helped us to attain a more robust and complete version of the manuscript.

Regarding the model validation, in their response to my previous comments, the authors show that the model currents and SSH are well correlated with AVISO, and also with the CMENS reanalysis product, especially in the winter season (using the spatial correlation). They also show that ROM model improves the SSS estimation with respect to MPI-ESM–LR for the whole Mediterranean, and performs a relatively good representation of the SSS salinity seasonal cycle and interannual variability. However, they do not include any of these results in the revised version of the MS. I understand that including the new figures and describing the results is not necessary and would increase the extent of the manuscript, but it could be included in the supplementary information, with a short summary of the main results in the main text. That would give the reader a better idea of the model accuracy.

We agree that this information could be interesting for the reader. As to the correlation coefficients between the Mediterranean SSH from ROM and AVISO, these have been included in the last paragraph of Section 3.1 (see Table 1R). In addition to this, by the end of the Model Setup Section we now state that this ROM configuration has been extensively validated in Parras-berrocal et al. (2020), but to ease the reading we provide in Supplementary Material the validation of seasonal and interannual SSS variability. The figures included in the Supplementary Material have been briefly described.

		Correlation coefficients
AVISO-ROM (1993-2005)	DJF	0.73
	JJA	0.67
AVISO-ROM (1976-2005)	DJF	0.71
	JJA	0.66

Table 1R. Winter and summer correlation coefficients found between the SSH from AVISO and ROM for the time periods specified. In the upper row, data for both AVISO and ROM extend from 1993 to 2005. In the lower row, AVISO data expands from 1993 to 2005 and ROM data from 1976 to 2005.

With respect to the freshening of the Atlantic waters inflowing through Gibraltar. The authors justification is that it is also reported by Parras-Berrocal et al., (2020, 2021) and Soto-Navarro et al. (2020). In the case of the works of Parras-Berrocal et al., they analyze the same simulation studied here so of course they find the same results. Soto-Navarro et al. (2020) studied an ensemble of climatic simulations (historical and 21st century projections) for the Mediterranean Sea, and, indeed, they find that some of them project is a decrease in the SSS in the Western Mediterranean in the future. These authors hypothesize that this could be caused by the freshening of the North Atlantic surface waters as a consequence of the ice melting in the Arctic. Is this the hypothesis assumed here? I miss a couple of sentences in the new version of the article regarding the physical interpretation of this important result. In addition, are there other papers in the literature showing similar results, i. e., a reduction of the SSS in the Northeastern Atlantic by the end of the 21st century? Which are the explanations given in these previous works? I think that a short paragraph in the results or discussion section summarizing previous results about this point would be very interesting and would clarify one of the main results of the article.

Thank you for your comment. To account for it, we have introduced some changes in Section 4.2 in the revised version of the manuscript so that now the information is clearly presented. In particular, we state the following: "The decrease in surface salinity in the subpolar North Atlantic and in the eastern limb of the North Atlantic subtropical gyre is a robust feature of CMIP5 multimodel ensemble (Levang and Schmitt, 2020; Soto-Navarro et al., 2020) and the establishment of its causes is matter of intense research. Very recently Sathyanarayan et al. (2021) pointed out that besides changes in surface freshwater fluxes, changes in salinity in the Atlantic may be related to changes in wind-stress and circulation, which in turn are related to changes in surface warming. Finally, they remark that the projected AMOC weakening may play an important role".

References:

Levang, S.J., Schmitt, R.W.: What Causes the AMOC to Weaken in CMIP5? J. Clim., 33 (4), 1535-1545, doi: 10.1175/JCLI-D-19-0547.1, 2020.

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Parras-Berrocal, I., Vazquez, R., Cabos, W., Sein, D., Alvarez, O., Bruno, M., and Izquierdo, A.: Will deep water formation collapse in the North Western Mediterranean Sea by the end of the 21st century?, Earth and Space Science Open Archive, doi:10.1002/essoar.10507698.1, 2021.

Sathyanarayanan, A., Köhl, A., Stammer, D.: Ocean Salinity Changes in the Global Ocean under Global Warming Conditions. Part I: Mechanisms in a Strong Warming Scenario, J. Clim., 34(20), 8219-8236. Retrieved Nov 9, 2021, from https://journals.ametsoc.org/view/journals/clim/34/20/JCLI-D-20-0865.1.xml, 2021.

Soto-Navarro, J., Jordá, G., Amores, A., Cabos, W., Somot, S., Sevault, F., et al.: Evolution of Mediterranean Sea water properties under climate change scenarios in the Med-CORDEX ensemble, Clim. Dyn., 54(3), 2135-2165, doi:10.1007/s00382-019-05105-4, 2020.