

General comments

This paper employs a variational method originally developed by some of the authors as an interpolating tool and later adapted for gap-filling High Frequency Radar (HFR) surface currents. The study's novelty lies in incorporating data from three distinct observing platforms (HFRs, drifters, and satellite altimetry) to generate a monthly surface current dataset for the Mediterranean Sea. The authors conclude that their newly generated dataset improves upon DUACS, the L4 gridded geostrophic surface current product derived from altimetric SSH observations. They state that their dataset captures additional dynamics compared to DUACS by integrating HFR and drifter data. Furthermore, they report observing a previously undocumented dynamical pattern in the Ionian Sea.

The overall aim of the paper is compelling. Using observational data for a basin-wide study of the Mediterranean is a valuable approach, because even though very relevant literature based on observations of the whole Mediterranean is available, research at such scale is more often based on numerical simulations. However, despite the interesting application of this novel methodology, the presentation of the results is unconvincing, and the writing quality currently falls a bit short of the standard expected for a scientific publication.

Specific comments

One of my main concerns relates to the spatial homogeneity and nature of the derived surface currents. While the authors assume their method captures additional dynamics than DUACS (supporting this claim by demonstrating an improved correlation with drifters compared to DUACS), the manuscript lacks a visualization of the drifter distribution used for the interpolation and for validation.

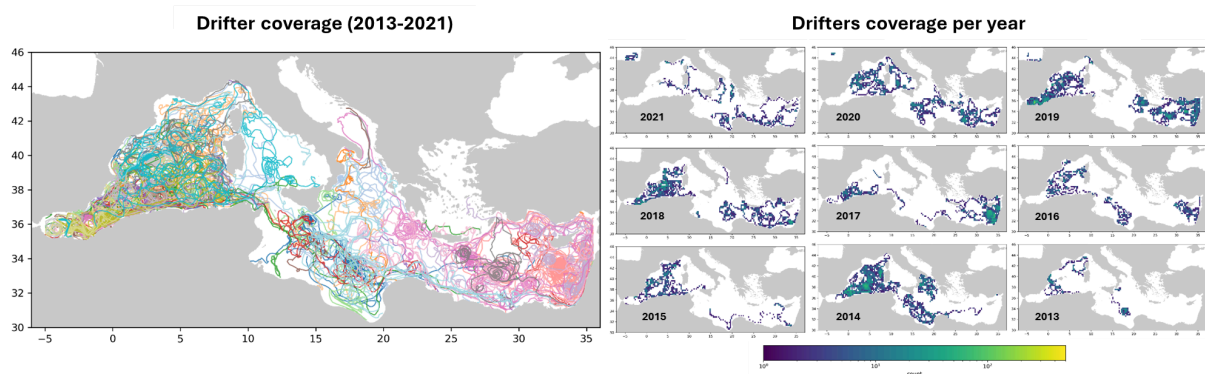


Figure 1 (Added to the revised manuscript): Drifter distribution for the interpolation (drifter distribution for validation is shown in Figure 4).

Thank you for pointing out this issue; we totally agree. The drifter coverage is a crucial aspect of the paper and must be clearly documented to get an accurate interpretation of the results.

The total drifter coverage is shown in Figure 1, left panel (note that all Figure numbers relate to this document and not the manuscript). As we can see, over the nine-year study period, the drifter's observations cover the majority of the Mediterranean basin with a slightly higher concentration on the western side. Importantly, the Adriatic Sea is barely observed, and the Tyrrhenian Sea is less covered than the other regions of the western basin.

When considering the coverage per year (Figure 1, right panel), the drifter observations are sparsely distributed, and the locations of the unobserved regions vary substantially from year to year. Therefore, it is difficult to associate the drifter-observation gaps with specific geographic regions and, consequently, with particular geostrophic current regimes.

The validation drifters are shown and discussed later in this document (Figure 3).

Aside from the two trajectories in the eastern basin shown in Figure 3, the spatial coverage remains unclear. This omission raises the question of whether the claimed improvement over DUACS is heavily skewed by the western basin, where HFRs are concentrated, and perhaps drifters are more abundant (or maybe not, but I think a figure is missing with this information).

Great point; we definitely agree with this. Indeed, the paper did not provide sufficient discussion regarding the validation coverage and the improvement over DUACS.

As explained later, the validation of 2021 was not optimal due to the inhomogeneous coverage of the validation drifters. Fortunately, we set aside drifter data for every year, so that we can easily compute the validation statistics for a different year using independent data without repeating the analysis. Thus, the validation against DIVAnd & DUACS has been repeated for a different year (2020) with more homogeneous spatial coverage of drifter data (Figure 4). The conclusion for the year 2021 (original manuscript) remains valid for the year 2020 (revised manuscript), as we observe a larger error of the DUACS product over DIVAnd compared to the independent drifters (Figure 2).

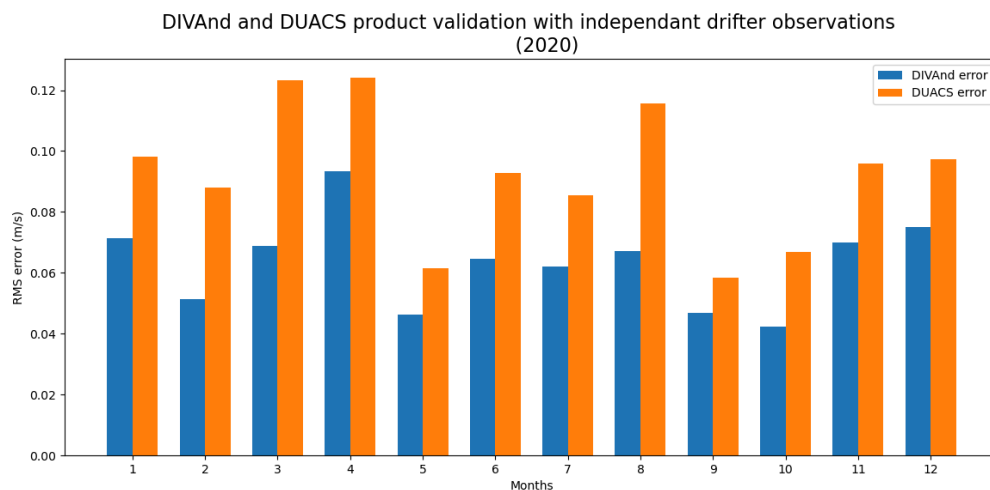


Figure 2: DIVAnd and DUACS Root Mean Squared Error comparison, corresponding to the validation with the independent observations of 2020.

To answer the question, we can point out that the validation has a lower error for DIVAnd, regardless of the drifters' position. In 2021, they are all situated in the western basin, while during 2020 they are distributed across the Western, the Ionian, and the Eastern basin. Both years perform better results than DUACS regarding the validation, providing better results over all those regions. We also notice that none of the validation drifters crossed an area covered by HFR observations, implying that the improvement quantified in the validation can not be directly related to HFR data. Therefore, we can conclude that the better agreement with independent drifter observations is not skewed by the western basin and is rather valuable for all of the region of the Mediterranean Sea.

The authors mention that the selection of the validation drifters is random. Can we be sure the selected drifters are well distributed across the basin? I recommend showing the drifter positions and investigating the regional differences between the DIVAnd product and DUACS. Do differences increase in the Western Mediterranean, where HFRs are present and drifters might be more abundant? I recommend the authors to review Poulain et al. (2012) (10.1175/JPO-D-11-0159.1) who already use drifters together with altimetry to study the circulation of the Mediterranean and make a good representation of the data they use.

Indeed, random selection can lead to heterogeneous coverage, which needs to be verified. This was not performed in the original manuscript, and we fully agree on its necessity.

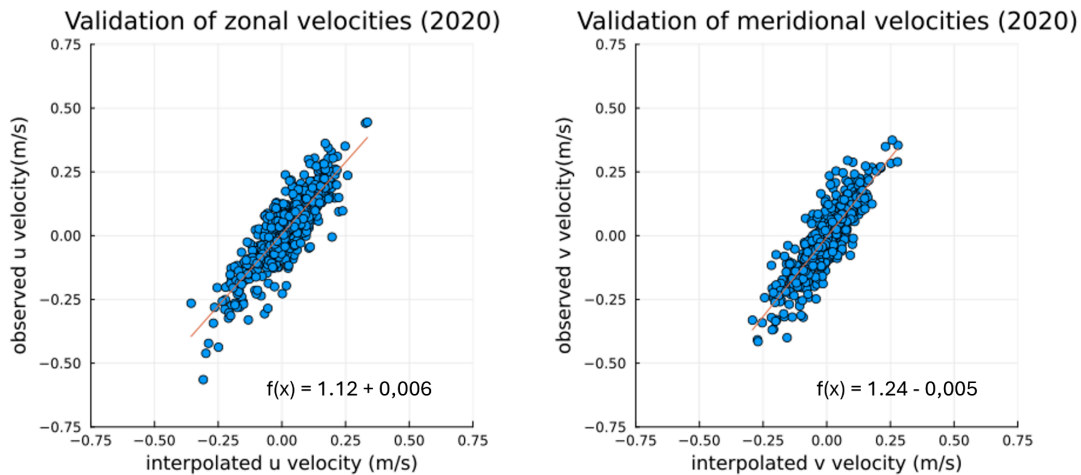


Figure 3: Comparison of the zonal and meridional velocities for the independent drifters and the corresponding velocities of DIVAnd. (2020). (Note that we swapped the x/y-axes following recommendations for the second review)

Originally, we selected 2021 for validation because it was the year with one of the largest numbers of drifter tracks set aside for validation. Those randomly chosen validation drifters were, by chance, all located in the eastern basin, limiting the representativity of the validation results. As correctly anticipated by the reviewer, the validation year 2021 turned out to be not optimal. We only considered the number of observations when choosing the validation year and did not pay enough attention to the spatial homogeneity of the independent observations.

To our advantage, we put more drifters aside than the one corresponding to 2021 (10% of the total amount among all years). Therefore, we changed the validation year, aiming for a year with homogenous data coverage of the independent observations. The year 2020 (the year with the 2nd largest data count) presented more homogenous spatial coverage than 2021, providing observations across the Levantine, Ionian and western basin with six different drifter tracks (Figure 3).

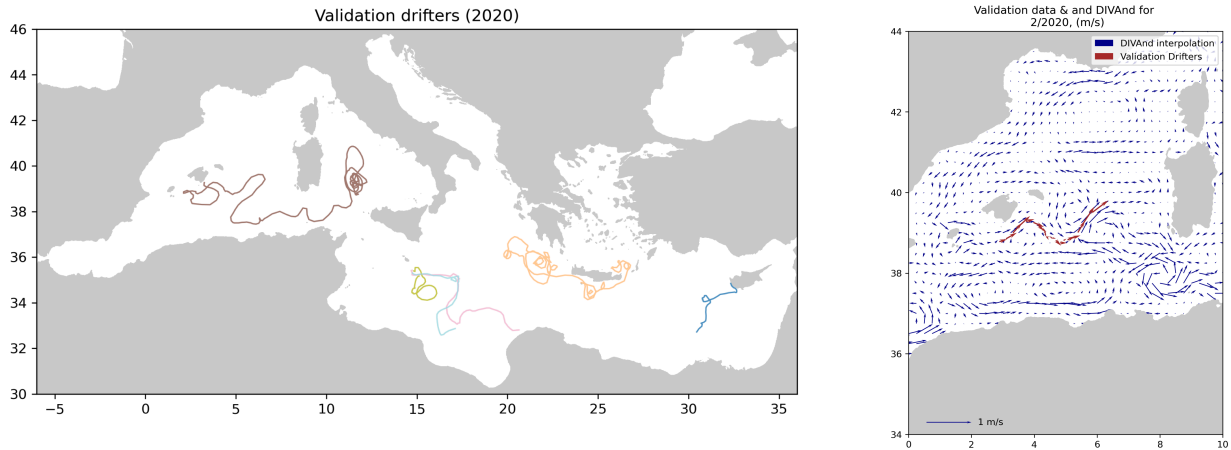


Figure 4: Validation figure with two different maps: (Left panel) Validation drifter of the year 2020. Each colour corresponds to a different drifter. (Right panel) Example of a validation drifter (red arrows) on the results of DIVAnd method (blue arrows)

The validation was conducted using the same methodology as applied in 2021. Our aim here is to improve the robustness of the validation and to assess how the validation metrics are affected by the change in the location of the independent observations. Importantly, the parametrization of the method is not modified from the validation performed in the manuscript.

The averaged RMSE for the validation during 2021 were 0.095 m/s and 0.082 m/s for the meridional and zonal velocities, respectively. For the 2020 validation, the RMSE values are 0.068 m/s and 0.065 m/s, indicating that the eastern side of the basin is harder to predict, and that the validation performance increases when the number of drifters is higher (Figure 1, right panel). The resulting correlations are 86.4 and 87.7% for meridional and zonal velocities, respectively. Regarding the regression lines derived from the validation scatter plots, the slopes are closer to one, decreasing from 1.28 and 1.34 (for u and v) to 1.12 and 1.24, respectively. An improvement is also observed in the intercept values, closer to 0 by an order of magnitude (Figure 3).

Following the reviewer's comment, the validation is now more representative of the whole Mediterranean Sea, and, incidentally, provided better results than the previous one computed over 2021. It indicates that the results are not skewed by the HFR, as none of the drifter tracks go to their location, but showing that the drifters' coverage might be the greatest contribution to the validation. Indeed, compared to the 2021 validation, only the drifter's spatial coverage has increased, which highlights their importance.

Further, regional differences were explored between DIVAnd and DUACS. This was computed with Root Mean Squared Difference (RMSD). We computed the RMSD with the addition of the meridional and zonal velocities in order to compare everything at once.

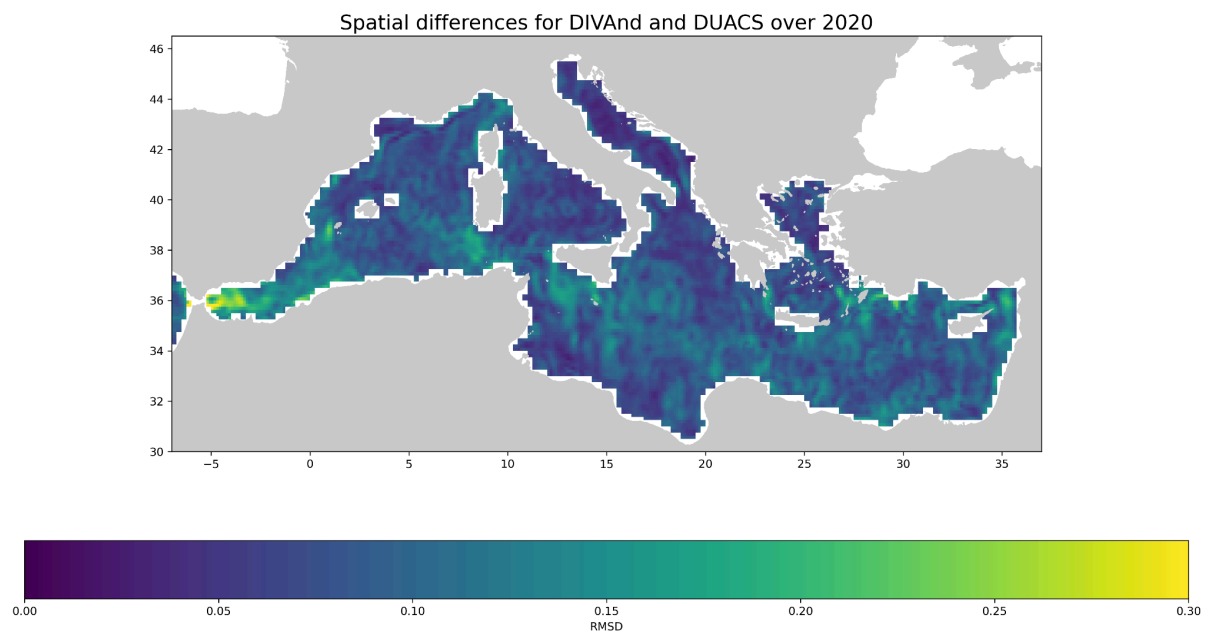


Figure 5: Spatial difference between DUACS and DIVAnd computed with Root Mean Squared Difference.

Figure 5 shows that the differences are not regionally localized but are relatively uniformly distributed across the domain. However, two regions attracted our attention. First, the Alboran Sea shows larger differences compared to the rest of the basin, corresponding partially to the coverage of the Gibraltar HFR. This region is known to be highly energetic and variable across the seasons, which can explain the larger values of the RMSD. Further, we can spot the signature of the Ibiza HFR around 29°N, 1.5°E. It indicates the difficulty of predicting the surface currents in the channel with the geostrophic assumption, as it is highly impacted by sub-mesoscale currents. Regarding the Ebro and the North Western Tyrrhenian HFR, it is difficult to spot any specific signature in the RMSD pattern. Those radars observe continental slope currents which are consistent over time and well resolved through altimetry. We are not surprised to not spot any significant differences with DIVAnd for those locations. We conclude here that the HFR are more impactful when they observe energetic and highly variable currents, while the altimetry is able to reproduce consistent currents.

About the nature of the results: what are the calculated currents: total currents, something in between total and geostrophic? And, as mentioned earlier: would this definition be homogeneous throughout the entire basin, or does it depend on the density of HFR and drifter data versus altimeter observations? I think this question should be clarified.

This is indeed an important point; the original manuscript was not sufficiently clear. The definition of the estimated current is always important to be stated to help the reader to understand the objective of the paper. The aim here is to estimate surface currents as close as possible to the total currents as the High Frequency Radars and the drifters provide this information.

However, as we have concluded in the first point of this review, the drifters' observations are scattered across the domain and the altimetry, albeit incomplete, is sometimes the only information available (derived in geostrophic currents). Therefore, we cannot pretend to compute only total currents with the available observations (as the direct measurements of currents, including the ageostrophic current components are insufficient at this time and spatial scale).

Nonetheless, our method extends precious information over the observations to maximize the exploitation of the drifters and HFR. From this perspective, we make optimal use of this information and give the closest surface current maps to total currents. Yet, as soon as we are 137km (correlation length) away from a drifter track/HFR observation, the influence decreases, and the computed current is predominantly geostrophic.

Additionally, we measure the error against lagrangian drifters, which are, by definition, following the total current, but averaged per day. The error is then measured against the closest information that we have of the total current.

This will be stated (in a shorter way) at the end of the first section.

The authors focus some of their subsequent analysis on the eastern basin, concluding their product outperforms the "less variable" geostrophic product. I believe it would be more interesting if the authors provided a robust quantitative analysis rather than relying solely on their figures to claim that the observed differences are genuinely attributable to their product capturing a wider range of dynamics than DUACS.

Thank you for pointing out this lack of information. Indeed, we raised this conclusion only with a visual comparison between DIVAnd and DUACS results. This statement in the original manuscript was not supported by quantitative analysis. Therefore, we decided to compute the variability of the different fields to quantify our statement. To tackle this problem, it is important to define a reference to state if the reproduced variability is closer to the truth or not. To this end, we used the independent drifters of 2020 (i.e., validation drifters) and computed the standard deviation of the meridional and zonal velocities, respectively.

u-standard deviation of the drifter = 0.135 m/s

v-standard deviation of the drifter = 0.127 m/s

As those drifters are independent to the analysis, they will be used as a proxy for the real variation of the field (We note that their variability is probably reduced during the processing, as the observations are averaged per day).

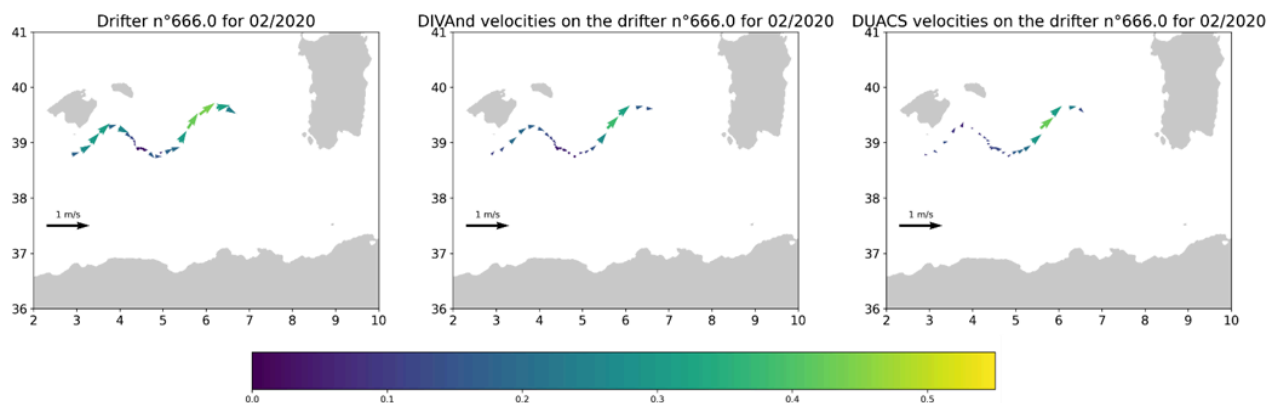


Figure 6: Comparison of the (left) drifter velocities (middle) DIVAnd onto the drifter position (right) DUACS velocities onto the drifter position.

To have a comparison with DIVAnd and DUACS, we will compare the standard deviations of the different velocities at the same location. To do so, we interpolated DUACS and DIVAnd results linearly onto the drifter track (Figure 6), and we made the same calculation. As our statement was "DUACS is less variable (than DIVAnd)", we compared the standard deviation of DIVAnd and DUACS.

It is important to note that the drifter standard deviation is computed over daily drifter measurements while DIVAnd and DUACS standard deviations are computed over monthly means. This induces a difference in their values, as DUACS and DIVAnd are smoothed by the monthly average and therefore present lower std values.

u-standard deviation of DUACS = 0.098 m/s

v-standard deviation of DUACS = 0.082 m/s

u-standard deviation of DIVAnd = 0.101 m/s

v-standard deviation of DIVAnd = 0.089 m/s

The lowest values (i.e., the lowest standard deviation) were indeed found with DUACS for both of the component of the velocity, while DIVAnd standard deviations are only slightly higher and closer to our ground truth. This quantifies that DIVAnd is only marginally more variable around its mean than DUACS, which is closer to the independent drifter values. In the revised manuscript, we will include this information and relativize our original statement.

Additionally, we computed the Total Kinetic Energy (TKE) of the same measurements (independent drifter of 2020). We will compare the kinetic energy of the validation drifters to the energy retained by DIVAnd and DUACS to see if our method better retains the current speed compared to the altimetric product.

TKE drifters = $0.01661 \text{ m}^2/\text{s}^2$

TKE DUACS = $0.00794 \text{ m}^2/\text{s}^2$

TKE DIVAnd = $0.00882 \text{ m}^2/\text{s}^2$

As expected, DIVAnd, supported by the drifters, retains more energy than DUACS, ultimately closer to the independent drifters. Indeed, we support that the presence of the drifters within the interpolation framework of DIVAnd helps the current field to retain more energy compared to the derived geostrophic velocity. We support that it is one of the main reasons for our method to be more accurate in the validation (Figure 2) and influence the standard deviation to be slightly higher.

It would be interesting to relate the "twin gyres" section and, the conclusions the authors make, with existing literature. Menna et al., 2026 (<https://doi.org/10.1088/2515-7620/ae558a>) and references within could provide information to make a more complete discussion of the effects of warming waters on the dynamics of the Mediterranean Sea, and particularly the Ionian Sea.

Thank you for giving those literature references. From this advice, I retain three of them that are closely related to our study: The work of Menna et al. (2026) (10.5194/egusphere-egu24-18229) is indeed highly relevant. In addition, we also reference the findings of Gacic et al. (2021) (10.5194/os-17-975-2021) and Terzic & Vilibic (2026) (10.3389/fmars.2025.1718186). These authors mention the variation of the thermohaline circulation of the basin, which is likely to be related to the apparition of the twin gyres (TGs). Those references support rapid changes over the Ionian basin, which is also our statement over the 2013-2021 period.

The Menna et al. (2026) conclusions explain how much salinity and temperature increased recently (2013-2023) in the Ionian Sea and the implications it has specifically on a cyclonic gyre in the south Adriatic Sea. It mentions the increasing gradients of salinity due to the shorter periods of anticyclonic circulation of the North Ionian Gyre (NIG) and explains the increasing role of salinity within the surface and thermohaline circulation.

Gacic et al. (2021) stated that mesoscale activity is closely related to the dense water discharge and to the mixed layer depth of the Ionian Sea, which also supports our conclusions.

On the same idea, Terzic & Vilibic (2026) discussed the effect of the recent abrupt shift (2021-2023) of the saline and temperature content of the sea. It reduces the contrast between the surface and the intermediate water, influencing the vertical circulation and the long-term heat and salt content of the basin.

On our side, we will remove the sentence that ends at [235] (manuscript line), which is a mistake, especially considering Menna et al. 2026, Gacic et al. 2021, and Terzic & Vilibic (2026) results.

From a general perspective, the Ionian basin is undergoing critical changes over the last ten years, and those emerging gyres are a phenomenon related to the strong thermohaline changes observed. The Atlantic Waters (AW) will generate each year stronger gradients with the Levantine Surface Waters (LSW) and will deeply change the thermohaline circulation of the basin. More than translating great thermal and saline changes in the Ionian basin, those cyclonic gyres could have some influence over the deep marine heatwave, maintaining heat by feeding them at depth, while the western gyre could help the water to recirculate to the surface.

To echo the Menna et al. (2026) conclusions, we could say that the inflow of AW probably has a positive influence over the eastern gyre and a negative to the western one, while LSW has a negative influence over the eastern one and a positive one on the western gyre.

Other comments

- I would recommend the authors to be more concise in general, and particularly with the review presented in section 2.

We thank the reviewer for this remark. We have removed repeated information between Section 2 and Section 4.3, and the remainder of the text has been revised, with several sections shortened accordingly. We agree that the manuscript is long and contains a substantial amount of information. However, after discussion among the co-authors, we consider that it is difficult to discuss basin-scale results without providing adequate context. We acknowledge that this contextual material could constitute a literature review in its own right, as the topic could be extended considerably. Nevertheless, we believe that the description of each zone is necessary for a proper discussion of the results, and that the literature review remains short compared to the amount of information available.

- The size of the text in Figure 1, as well as the arrows in some of the quiver plots is too small in the printed version.

This remark is appreciated; the numbers on the colorbar in Figure 7, the arrow size, and the colorbar numbers of Figure 10 are increased.

- There has been an expansion of the HFR network since 2021 that would perhaps be useful to augment data in the central Mediterranean (CALYPSO, Granitola..).

Thank you for noticing; this would be useful for further work, for example to extend the current work to the latest dataset.

- If the selection of the drifters used for validation is random, as explained in section 3.4, why do the authors mention they validate the results of year 2021? Please, clarify.

This is a good point. As clarified earlier in this document, the drifters were selected randomly over the whole period, and seeing that the randomly obtained drifters during 2021 were in a decent number, we used those. As shown in the new validation brought here, validation drifters were also available for 2020.

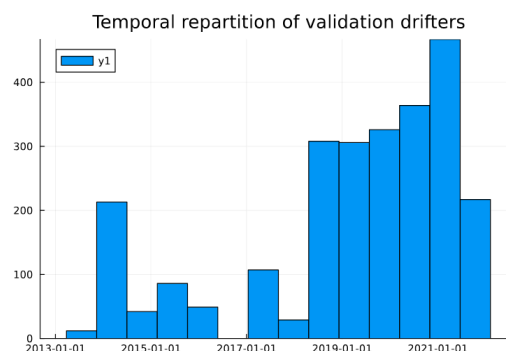


Figure 7: Temporal repartition of the randomly selected independent drifters.

- The correct acronym of High Frequency Radar is HFR.
- Please, revise the use of the words “First” and “Further”.

Both of the previous points will be corrected.

- [45] Why capitalize the words satellite and drifter?

Thank you for pointing out this typo, which will be corrected in the revised manuscript.

- [115] “reversion” should probably be reversal?

Certainly! This was changed.

- [200] the field that match --> the field that matches. This type of grammatical error appears throughout the document, please check.

Thank you for noticing; we had a more in-depth review of the English grammar within the text.

- [335] The authors mention the drivers of the northward flow through the Balearic Islands are not known, but I believe there are several publications discussing the inflow of AW through the Ibiza Channel (Pascual et al., 2002, Aguiar et al., 2019, Juza et al., 2025). The second author of this paper is a co-author of Aguiar et al., 2019. Please, review.

Thank you for providing interesting literature that has been missed. Juza et al. (2025) evidenced that the AW modified water was dominant in the Ibiza channel surface transport and found seasonality at the monthly scale for this transport. Our conclusions align as we also observed a dominance with a southward flow at the annual scale. The southward transport is associated with late summer, following Juza et al. We note that this trend is valuable for a large amount of time, while smaller events have a major influence in the dynamics

- Figure 10. If possible, avoid using the jet colormap, as is not adapted for color-blind people.

Thank you for pointing out this problem. We wanted to highlight clearly all the temperature fronts, which is the reason why we first chose this colorbar. Actually, the used color is not “jet”; it is “turbo”. Turbo is an update of “jet” that is supposed to provide a better color contrast. However, we have changed to a colorbar that is safer regarding this issue: RdYlBu_r (red-yellow-blue).

- 420] Why do the authors need interpolation to select a subset of their results?

There might be a misunderstanding here. Our text is probably not clear here. No interpolation was done here. As mentioned in the text, we say [422] “we selected a spatial subset of the results”.

- [465] I am not sure “gyral circulation” is the most scientifically rigorous term.

Thank you, indeed. We changed “gyral circulation” for “circulation dominated by gyres”.

- [470] I would say the effect of the mixed layer depth on the surface dynamics is far from being just a hypothesis?

Of course, but in the case of the seasonal variations at the Mediterranean Sea scale, we were not sure if it is the only explanation. We could reformulate the idea saying "The mixed layer depth variation influences the seasonal cycles of the surface currents, giving conditions for deep and stable currents in winter and inducing instabilities during summer."