Response Letter for: Coastal Eddies as Vectors for Connectivity During the Summer in the Levantine Sea

We sincerely thank the Editor and the Reviewers for their continued careful and detailed evaluation of our manuscript and for their constructive comments. We appreciate the opportunity to further improve the manuscript. In response to the comments raised during this review round, we have revised the manuscript accordingly and provide a detailed point-by-point response below. The entire Methods and Results sections have been rewritten to improve clarity and readability. Additional figures have been added to the Results section in order to strengthen the narrative and to the Appendix in order to provide additional backing evidence to our findings. We believe that these revisions have further strengthened the clarity and presentation of the study. Reviewer comments are shown in bold, and our responses are presented in regular text.

Major Comments:

The authors claim an enhanced 'connectivity' in summer... The reader may expect a quantification of this contribution. Simply: how much compared to winter?

We thank the reviewer for this thoughtful comment. We agree that the significance of the observed transport events required clearer contextualization. The objective of this study is not to compare the magnitude of cross-shore transport between summer and winter nor to estimate the contribution to the cross-shore budget, but rather to investigate whether coastal mesoscale eddies can temporarily overcome the strong coastal–offshore separation that characterizes the Levantine Basin during summer stratification by transporting a coherent coastal water-mass signature into the oligotrophic offshore basin.

Winter and summer represent fundamentally different connectivity regimes governed by different physical processes. Winter connectivity is dominated by deep convective mixing and enhanced submesoscale stirring, whereas the present study focuses on episodic mesoscale transport occurring during the otherwise highly isolated summer period. We therefore consider a direct quantitative comparison between seasons to address a different scientific question that falls beyond the scope of the present work.

To better communicate this distinction, we have revised both the Introduction (L95) and the Discussion (L496-504) to emphasize that the primary comparison in this study is between offshore waters influenced by coastal mesoscale eddies and the surrounding offshore environment under typical summer conditions, rather than between summer and winter transport rates.

L3 chlorophyll are used, but L4 is used in figures. This should be clarified by using only level 3 data in figures, in order for the reader to see the associated

uncertainty. A sensitivity check to L3 versus L4 chlorophyll is expected for the reader, maybe in supplementary materials.

We thank the reviewer for this suggestion. We agree that the distinction between the L3 and L4 products and their potential influence on our results should be demonstrated more explicitly.

Rather than replacing the figures in the main manuscript with L3 imagery, we chose to retain the L4 product for visualization, as is common practice, because its gap-filled fields provide a more continuous and interpretable representation of the coastal mesoscale features, improving readability without affecting the analyses. To quantitatively evaluate the influence of product choice, we performed a sensitivity analysis using both L3 and L4 data.

We have added two new supplementary figures (Figs. A1 and A2) showing side-by-side comparisons of the L3 and L4 chlorophyll fields corresponding to the analyses presented in Figs. 2–6. In addition, Tables A1 and A2 quantitatively compare the principal metrics derived from each product. Table A1 compares the offshore eddy surface areas obtained using the detection procedure described in Section 2.2.1, while Table A2 compares the propagation velocities obtained using the frontal-boundary method described in Section 2.2.2. In both cases, the differences between the products are negligible (surface-area differences ~0.1% and nearly identical propagation velocities), demonstrating that the choice of L3 or L4 does not affect the interpretation or conclusions of the study.

We have also revised the Methods section to clarify that the quantitative analyses were performed independently using the same detection procedures, while the L4 product was retained in the main figures solely to provide a clearer visualization of the identified features (L104-107).

Methods should be compared with existing eddy detection methods. Numerous studies use SSH to detect eddies. In coastal areas SSH can be sometimes unreliable, and this is why comparison with chlorophyll-based methods can be interesting. The distinction between large offshore anticyclones (well-studied) and coastal eddies (understudied) is the main novelty which should drive the analysis.

We thank the reviewer for this helpful suggestion. We agree that the rationale for using chlorophyll-based eddy identification, and its relationship to conventional SSH-based approaches, required further clarification. We have therefore substantially expanded the relevant part of the Methods section and added six references to previous SSH-based eddy studies and to the spatial resolution and limitations of gridded altimetry products (L177-191).

The revised text now explicitly distinguishes the relatively small coastal mesoscale eddies investigated here (typically 30–40 km in diameter) from the

substantially larger mesoscale eddies commonly characterized using SSH in previous Mediterranean studies. In particular, we discuss studies from the Algerian Basin that successfully use altimetry to examine eddies approximately 60–130 km in diameter. We further note that, during the period considered here, the effective spatial resolution of the gridded altimetry product was approximately 14 km, limiting its ability to fully represent the smaller coastal features examined in this study, particularly in close proximity to the coastline.

We also now explicitly direct the reader to the comparison already provided in Fig. 1 (L187). In this figure, the smaller coastal eddies are clearly expressed in the chlorophyll field and, to a lesser extent, in SST, whereas only the largest offshore feature is clearly discernible in the SSH field. This direct comparison, together with the expanded discussion of existing SSH-based approaches, provides the rationale for using chlorophyll as the primary tracer for identifying and delineating the coastal transport features investigated here. We have also strengthened the distinction between these smaller coastal eddies and the larger, well-studied offshore anticyclones to more clearly emphasize the novelty of the present study (L594-601).

A confusion remain throughout the study, whether the authors study eddies (closed circulation contours at mesoscale) or filaments.

We thank the reviewer for pointing out this ambiguity. We agree that the inconsistent use of the terms “eddies” and “filaments” could cause confusion regarding the physical features investigated in this study. The manuscript focuses specifically on coastal mesoscale eddies, and we have therefore revised the manuscript throughout to remove references to “filaments” and consistently use “coastal mesoscale eddies” or “eddies,” as appropriate. This terminology is now used consistently in the Introduction, Methods, Results, and Discussion.

In situ data are not in accessible to reviewers in data availability section. This is now a requirement in Ocean Sciences

We thank the reviewer for highlighting this issue. All data sets (Satellite data from Copernicus, HF Radar data, Glider Missions M141 and M164 and *N800* Cruise samples) are now available through links to online repositories or the *Copernicus Marine Data Store* in the *Data Availability* section.

To clarify the points raised above, the added value compared to existing studies on these Levantine coast mesoscale eddies is vague. The most interesting results are not physical oceanography contributions, and they are not clearly highlighted in the abstract.

We thank the reviewer for this important comment. We agree that the added value of the present study relative to previous observations of coastal mesoscale eddies in the

Levantine Basin was not sufficiently emphasized, particularly in the Abstract (L6-16). Previous studies in the region have primarily documented these eddies based on their surface expression and circulation (e.g., Gertman et al., 2010; Efrati et al., 2013) (L79-81). The novelty of the present study therefore does not lie in the identification of these features, but in their integrated multi-platform characterization, combining HF radar, satellite observations, autonomous gliders, and ship-based biogeochemical measurements to resolve their three-dimensional physical and biogeochemical structure and demonstrate their role in transporting coastal water masses into the offshore Levantine Basin.

To address this comment, we substantially revised both the Abstract and the Results.

In the Abstract, we now explicitly identify the poorly characterized subsurface structure and biogeochemical footprint of these coastal mesoscale eddies as the knowledge gap addressed by this study. We also place greater emphasis on the principal findings, including the three-dimensional observations of warm coastal water transported offshore, the shoaling and broadening of the deep chlorophyll maximum from approximately 120–130 m in surrounding offshore waters to approximately 50 m within the eddies, and the accompanying biogeochemical signatures indicative of coastal-origin water. The HF-radar observations are now presented primarily as evidence of the coherent circulation and offshore propagation that enable this transport (L6-16).

The introduction further emphasizes the added value compared to previous studies (L79-81, 83).

The Results were also reorganized to better emphasize these novel observations. The glider observations are now presented as an integrated characterization of the physical and biogeochemical structure of the eddies, rather than as separate case studies (Sections 3.3.1, 3.3.2). The ship-based observations from the offshore N800 time-series station are presented as an independent observational dataset that corroborates the glider-derived chlorophyll redistribution while extending the observations by documenting concurrent increases in dissolved silica and inorganic particulate matter (including particulate Fe) associated with the passage of the eddies (Section 3.4). This revised organization highlights the complementary roles of the different observational platforms rather than presenting a series of case studies, and more clearly emphasizes the principal contribution of the study: the first integrated three-dimensional characterization of the physical and biogeochemical footprint of coastal mesoscale eddies in the eastern Levantine Basin.

Minor Comments:

l.12, abstract: there is a confusion for the reader with "anticyclonic circulation", between the anticyclones detached from the coast and the basin-scale cyclonic circulation.

We thank the reviewer for pointing out this ambiguity. We have revised the Abstract to explicitly state that the HF radar observations refer to the coastal mesoscale eddies, rather than the basin-scale circulation. (L13)

l.57: For observations about mesoscale descriptions, Zodiatis et al. (2023) can also be commented in this paragraph, or Poulain et al. (2013) for drifters observations. More details from numerical studies (Verma et al., 2024 for instance) will be interesting.

We thank the reviewer for this suggestion. We have expanded the Introduction to provide additional context on previous observational and modeling studies of mesoscale circulation in the Mediterranean. Specifically, we added references to Poulain et al. (2013) and Zodiatis et al. (2022) describing drifter and hydrographic observations, respectively (L60-62). We also expanded the discussion of recent numerical studies (L63-65) by noting that only recently have regional models achieved sufficient spatial resolution to explicitly resolve the physical aspects of coastal mesoscale eddies and their interaction with the Levantine boundary current (Verma et al., 2024; Solodoch et al., 2023) although these models are not yet BGC coupled. This additional context better highlights the current state of knowledge and further motivates the need for the present observational study of the three-dimensional biogeochemical structure of these eddies.

l.67 : The present work focuses on mesoscale eddies, not filaments.

We thank the reviewer for pointing this out. To eliminate this ambiguity, we have replaced the term *filaments* with *coastal mesoscale eddies* throughout the manuscript. The revised text consistently reflects that the study focuses on coastal mesoscale eddies rather than filamentary structures.

l.71-76 : a bit messy, this seems to anticipate the discussion part.

We thank the reviewer for this observation. We revised this paragraph to improve its organization and remove unnecessary repetition. Specifically, we consolidated the study objectives into the opening sentence, removed the forward-looking description of the principal findings, and streamlined the presentation of the event-based approach (L82-89).

Section 2.1 : Grouping in situ versus remote-sensing (or alternatively Satellite/HF radar/in situ) would ease the reading. The present manuscript introduces alternatively remote-sensing and in situ.

We thank the reviewer for this suggestion. The order of the datasets in Section 2.1 has been revised to improve the flow of the Methods. HF radar is now presented immediately after the satellite observations, followed by the autonomous glider and ship-based measurements, avoiding the previous alternation between remote-sensing and in situ datasets.

l.96-98 : two lonely sentences which may need to be rephrased.

We thank the reviewer for this suggestion. The description of the SST and altimetry datasets has been revised and simplified (L113-119). In addition, following the reviewer's recommendation (see comment on ADT below), the manuscript now uses the Copernicus Absolute Dynamic Topography (ADT) product rather than SLA (L111), eliminating the need for the previous explanation of the SLA reference period.

l.106, 120 and 129 : Precise the exact time range of your event, or the period when data is available

We thank the reviewer for this suggestion. The temporal coverage of each observational dataset has been clarified in the Methods section. The manuscript now explicitly states the analysis periods for the satellite products (L120-124), HF-radar observations (L140), glider missions (L151-152), and N800 cruise measurements (L156), allowing the reader to clearly identify the time span associated with each dataset.

l.127 and 131 : 'N800' and 'RV Mediterranean Explorer' are proper nouns, you should put them in italic.

We thank the reviewer for pointing this out. The manuscript has been revised accordingly, and *N800* and *R/V Mediterranean Explorer* are now formatted consistently as proper nouns.

l.129 : Time coverage is unclear. N800 is a repeated monthly station from when to when ? The information actually lies only in l.280.

We thank the reviewer for pointing this out. The Methods section has been revised to clarify the temporal coverage of the N800 observations, stating that the station was sampled approximately monthly throughout 2020 and identifying the July and September dates analyzed in this study (L156). We also moved the description of the background calculation to this section, clarifying that the background variability was computed using profiles collected during the remaining stratified-season months, rather than introducing these methodological details later in the Results (L161-163).

l.130 : 'filaments' is unclear, as the study aims to study eddies.

We thank the reviewer for pointing this out. The terminology has been revised throughout the manuscript to consistently refer to the studied features as coastal mesoscale eddies, avoiding potential confusion with filaments.

Section 2.1.3 : HF radar : what is its horizontal resolution and uncertainty ?

We thank the reviewer for this helpful suggestion. We have expanded the Methods section to include additional information describing the spatial resolution of the HF-radar observations. The revised text now specifies the nominal horizontal grid spacing of the

mapped currents, as well as the range and angular resolution of the underlying radial measurements, providing a more complete description of the dataset (L136-140).

Section 2.2, Methods : Methodology remains with missing references to figures, and some methodological details are found in the results section. Equations are not labelled.

We thank the reviewer for this helpful comment. The Methods section has been substantially reorganized to improve its flow and readability. Figure references have been added where appropriate and all equations are now separated into clear subsections in a step-by-step manner.

Methodological details previously described in the Results have been relocated to the Methods, for example, the description of the N800 background calculation (L161-163), including the use of profiles collected during the remaining stratified-season months to define background variability, has been moved from the Results to the Methods. Similarly, the methodology used to define the eddy boundaries from chlorophyll imagery is now described in the Methods rather than being introduced in the Results (Section 2.2.1).

l.201 : see previous comment, ‘anticyclonic circulation’ is misleading.

We thank the reviewer for pointing this out. The sentence has been revised to explicitly refer to the persistent anticyclonic mesoscale eddies (e.g., the Shikmona Gyre and Cyprus Eddy), thereby avoiding potential ambiguity with the regional circulation (L323).

l.203 : Earlier reference to complement Belkin et al 2022 might be Krom et al (1992)

We thank the reviewer for this helpful suggestion. We have added the earlier reference by Krom et al. (1992) to provide historical context and complement the more recent study by Belkin et al. (2022) (L326)**.**

l.204, again : ‘cyclonic features’ is vague, ‘cyclonic eddies’ would be more precise.

We thank the reviewer for pointing this out. The terminology has been revised to refer specifically to cyclonic eddies (L326).

Figure 1 : a summary map of station and glider transects would ease identification for the reader. For instance the reader needs to wait until Figure 7 to see location of N800 station.

We thank the reviewer for this helpful suggestion. Figure 1 has been revised to include the locations of the HF radar domain, glider transects, and the N800 station, providing an

overview of the observational datasets used in this study and allowing readers to more easily identify the sampling locations.

l.218-220 : Your analysis is based on Sea Level Anomaly currents. However in the Mediterranean Sea, for mesoscale eddies, ADT should be preferred to SLA to compute geostrophic currents. See Pegliasco et al (2021)

We thank the reviewer for this valuable suggestion. We agree that Absolute Dynamic Topography (ADT) is more appropriate than Sea Level Anomaly (SLA) for representing geostrophic currents. Accordingly, we have revised the manuscript and Figure 1 to use the Copernicus ADT product instead of SLA-derived currents.

l.240-275 : Again, these 3-lines paragraphs are difficult to read. The mixed description of the 2018 and 2022 events is also misleading.

We thank the reviewer for this helpful comment. Section 3.3 has been completely reorganized to improve clarity and readability. The descriptions of the 2018 and 2022 eddies are now presented in a more logical sequence, separating the physical characterization from the biogeochemical analysis and avoiding the interleaved presentation of the two events. In addition, the numerous short paragraphs have been consolidated into a more coherent narrative, improving the overall flow of the section.

Section 3.4 : this section is likely the most interesting of the manuscript, I suggest to deepen its relevance.

We thank the reviewer for this suggestion. Section 3.4 has been substantially revised to better emphasize the significance of the N800 observations within the overall narrative of the manuscript (L429-439). The section now opens by presenting the N800 time series as an independent line of evidence that complements the glider observations described in the previous section. The section has also been reorganized to separately describe the chlorophyll, nutrient, and particulate matter observations, improving the clarity of the results. Finally, the section now concludes with a paragraph highlighting how the N800 observations independently support the glider-derived evidence of offshore chlorophyll redistribution associated with coastal mesoscale eddies, while extending these findings by revealing the accompanying vertical redistribution of nutrients and particulate matter (L465-468).

l.246 and Fig.5-6 : Be more precise in the number of profiles. How many profiles are within eddies, in each event ? How many constitute the reference ? The reference period is quite small, 2 days in both events. Their positions could be highlighted on figures 3A-C and 4A-C.

We thank the reviewer for this helpful suggestion. The Methods section has been revised to explicitly state the number of glider profiles used to characterize both the eddy

interior and the offshore reference for each event (L240). In addition, Figures 3 and 4 have been updated to indicate the reference regions used for the anomaly calculations.

l.281 : month selection is somehow vague. Each month is only constituted by a single profile, and you only have 2 profiles in background conditions.

We thank the reviewer for this comment. Indeed the N800 station was sampled monthly throughout 2020, the precise dates in which the station was sampled depended on ship availability and sea conditions. One profile per parameter is sampled and shown, the exact methods can be found in Ben-Ezra et al. (2024). The background conditions however are calculated from all stratified months (April-November based on D'Ortenzio et al., 2005), excluding only July and September during which there were eddies.

Fig.5-6-7 : Comparison between events is misleading, because axes do not share the same limits. Furthermore chlorophyll in N800 stations are in microg/L while gliders are in mg/m3. Also it would help the reader to remind that Fig.5-6 are from glider transects.

We thank the reviewer for this helpful suggestion. The axes have been amended so Figures 5 and 6 match. Chlorophyll in N800 (Figure 7) station has been changed to **mg/m3** to be consistent with Figures 5 and 6. The fact that the profiles in Figures 5-6 are from glider observations has been added to the respective figure captions.

l.326 : Numerous studies on eddy propagation - dedicated to the Mediterrean Sea - can be added and discussed here.

We thank the reviewer for this suggestion. We have expanded the Discussion to place the observed eddy kinematics within the broader context of Mediterranean mesoscale eddies. In addition to the general framework of coherent eddy dynamics described by Chelton et al. (2011), we now cite Sutyrin et al. (2009) and Poulain et al. (2021), which document the propagation and persistence of Mediterranean anticyclonic eddies. The revised text highlights that, despite differences in size and propagation rates, the coastal eddies examined here exhibit the same fundamental kinematic characteristic of coherent vortices—internal rotational velocities that substantially exceed their translational speed—allowing them to retain trapped water masses during propagation (L486-489).

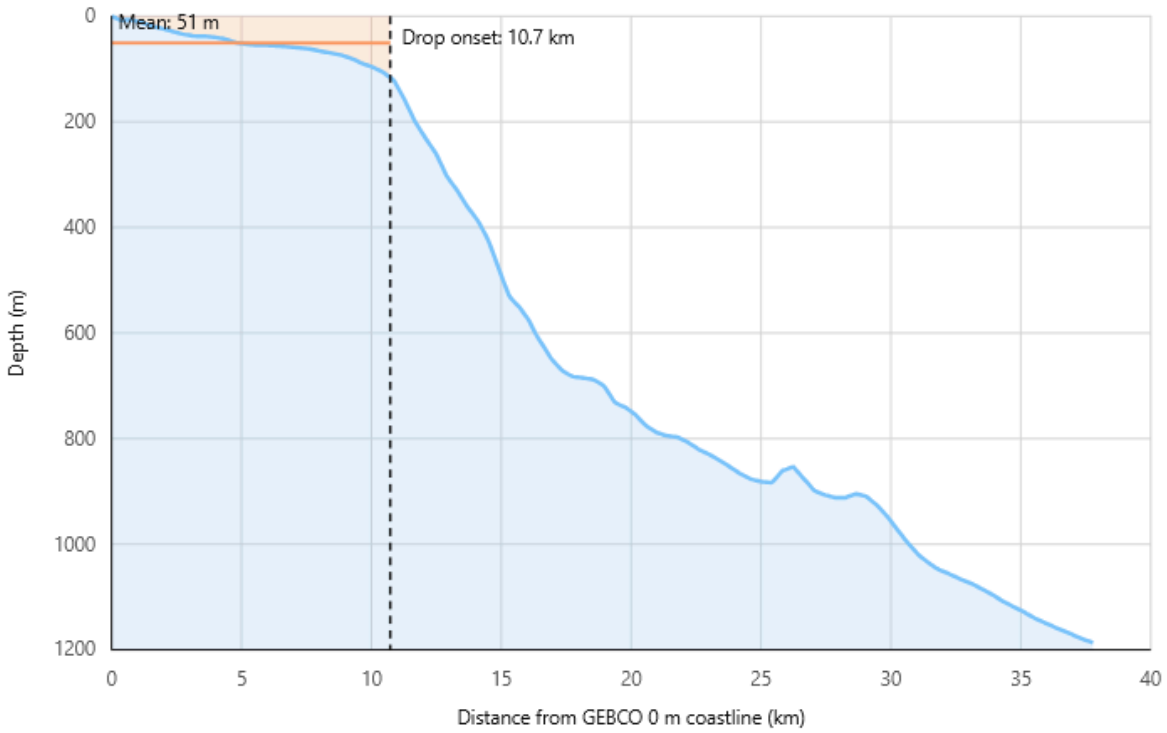
l.349 : The 3 references cited all investigated eddies using SSH, calling for comment on this. Only Espinosa-Carreon et al (2012) focus on coastal eddies in Southern California. More generally, what are the main differences between these coastal eddies in the ultra-oligotrophic Levantine Basin compared to other coastal systems ?

We thank the reviewer for this helpful comment. The revised manuscript discusses the reasons why SSH was not used to identify the coastal eddies investigated in this study, including their relatively small size, rapid evolution, and close proximity to the coastline,

which together limit their detectability in gridded altimetry products (L181–195). The Discussion also addresses the principal distinction between the Eastern Mediterranean and previously studied coastal systems, emphasizing the unique ultra-oligotrophic background conditions of the Levantine Basin and their implications for the biogeochemical significance of coastal eddy transport (L575–585).

l.359 : Does this depth of about 50m match the average depth of the shelf ?

We thank the reviewer for this insightful observation. The depth of approximately 50 m is indeed comparable to the average depth of the continental shelf in the study region. To clarify the significance of this observation, we have expanded the Discussion (L529-533) and added a supplementary figure (from a different series of cruises) showing representative cross-shelf chlorophyll sections (see Figure A4 and Methods L175-180). These observations demonstrate that the chlorophyll maximum is typically bottom-associated over the continental shelf before deepening beyond the shelf break to form the characteristic offshore DCM. This supports our interpretation that the shallower chlorophyll structure observed within the eddy retains a coastal shelf signature after offshore transport.



Section 4.3 : Could you estimate an evolution timescale of these coastal structures ? Another explanation to their difficult detection in SSH is their fast evolution.

We thank the reviewer for this comment. We agree that the relatively rapid evolution of these coastal eddies likely contributes to their limited detectability in gridded SSH products. Compared to the larger open-ocean mesoscale eddies commonly identified from satellite altimetry, the coastal eddies investigated here are smaller, propagate and

evolve more rapidly, and remain in close proximity to the coastline, all of which reduce their representation in the relatively coarse-resolution SSH fields. Consequently, their evolution can only be reliably followed using higher-resolution surface tracers, primarily ocean-color imagery and, when thermal contrast is sufficient, SST. Based on these observations, the characteristic lifespan of the surface expression of these coastal eddies appears to range from several days to approximately one week, although the available observations do not allow a more precise determination of their full lifetime. We have revised the Discussion accordingly (L594-601).

Conclusion and opening : Considering that you propose an estimated chlorophyll export of about 1500 to 3500 kg per eddies, could you estimate the average formation rates of these eddies ? How many are formed per year, and what is the total export / year ?

We thank the reviewer for this suggestion. We considered estimating an annual chlorophyll export by combining the event-scale chlorophyll anomalies with an average eddy occurrence rate. However, we concluded that such an estimate would require assumptions that are not supported by the available observations. The chlorophyll export associated with individual coastal eddies depends on numerous factors, including the location of eddy formation, chlorophyll concentrations at the time of formation, eddy size and intensity, the strength of the coastal boundary current, and the physical and biogeochemical conditions encountered during offshore propagation. Consequently, both the magnitude of export per event and the annual occurrence rate are expected to vary substantially from year to year. We therefore consider any annual extrapolation to be highly uncertain and potentially misleading. For this reason, we have retained the chlorophyll estimates as event-scale quantities and explicitly clarify in the manuscript that they should not be interpreted as an annual export budget. We identify a systematic multi-year detection and tracking analysis as a necessary future step toward quantifying the cumulative annual contribution of these coastal eddies to offshore exchange.