Author's response

We would like to thank the three reviewers for their constructive criticism and comments, which enabled us to correct and improve the manuscript.

We have taken into account all suggestions for improving the text.

We have modified and improved the figures according to the reviewers' suggestions. Some figures (vertical velocities, distribution of physical and biogeochemical parameters at the level of individual interfaces for several stations) are new. A table on the abundance of the different particle size classes observed by the UVP has been added as supplementary data.

We have modified the introduction by deleting a paragraph on double sediment diffusion, which is active in areas with very strong gradients, and by completing another paragraph by providing the hydrological and hydrodynamic context of the region.

We have restructured the Materials and methods section by grouping together, as suggested, all the hydrological and optical measurements made during the PERLE3 campaign and by the profiling float. A new paragraph on the selection of representative stations has been added at the end of this section.

The results section has retained the same structure but has been expanded in response to the reviewers. Instead of showing vertical velocity profiles for two stations, we have chosen to illustrate the variability of vertical velocities for all stations with a histogram.

The results section retains the same three subsections, dealing respectively with circulation and thermohaline staircases, the effect of staircases on particulate matter distribution and deposition, and the potential effect of staircases on biogeochemical activity.

The first subsection has been reworded to link our observations to the literature, to modulate the effect of eddies on staircases, and to emphasise the persistence of thermohaline staircases at depths greater than 1000 m.

Three new figures detailing the evolution of physical, particulate and biogeochemical parameters at density interfaces for three different stations (7, 9 and 11) now replace the examples originally chosen for station 9. They are used to illustrate the other two subsections.

The second subsection on particulate matter has been reworded to emphasise the effect of density gradients on particulate matter dynamics.

The third part on biogeochemistry has been expanded to better explain the degradation processes that can occur at these interfaces and the consequences for nitrate fluxes.

Part of the conclusion has been reworded.

A number of references have been added.

Responses to comments from Reviewer #1

Overview

The manuscript by Durrieu de Madron et al. presents CTD, ADCP and optical profile data along a section crossing the Tyrrhenian Sea and investigates salt finger staircase effects on particulate and dissolved matter distribution. I believe that the measurements would be interesting to the community. The analysis and results are generally well presented and the figures are clear. However, in some instances, the conclusions are fairly speculative, there are inconsistencies or redundancies, clarifications are lacking or phrasing is deficient. Therefore, I recommend a detailed revision based on the comments below.

We thank the reviewer for his constructive comments. We have tried to respond to all of his comments and have provided detailed answers to his questions. A number of references have been added or changed in response to suggestions. Note that the names of the water masses described in the manuscript have been modified to be in line with the latest recommendations published in the article by Schroeder et al. (2024) A consensus-based, revised and comprehensive catalog for Mediterranean water masses acronyms. Mediterranean Marine Science, Vol. 25 No. 3, 783–791.

1 General comments

a) I would suggest replacing 'salty' with 'saline' throughout
Done

b) Replace 'shipborne' and 'ship-borne' with 'shipboard' throughout
Done

c) Revise tenses for consistency; e.g., 'The first ADCP was' (line 180) [...] The second ADCP is' (line 182)
The concordance of tenses has been checked throughout the text.

d) Add longitude as an upper x-axis on depth-distance section plots, for better reference to the map.
The position of stations has been added at the top of each section, making it easier to link to the map.

e) You could support the claims of staircase persistence with low measured microstructure derived dissipation rates and diapycnal diffusivity in Ferron et al. 2017 https://doi.org/10.1002/2017GL074169
This reference was used in the first part of the discussion dealing with the circulation and thermohaline staircases.

2 Specific comments

Line 15: Replace 'will be' with 'is' to have a consistent tense
Corrected

Line 45: ocean, temperature
Corrected

Line 48: are on the order
Corrected

Line 57: Replace 'Such thermohaline diffusive convection' with 'This' – diffusive convection refers to the double diffusive process opposite to salt finger formation.
Corrected

Line 63: Perhaps add some references to support these numbers
We cite the paper by van der Boog et al (2021) which provides temperature and salinity ranges at the interface levels of thermohaline staircases.

Line 80: during their
Corrected

Line 102: (Falco
Corrected

Line 104: references
We added several references showing the presence of Tyrrhenian thermohaline staircases.

Line 108: cuts across
Corrected

Line 119: water column with and without staircases, respectively, between
Corrected

Line 122: , with depth in color.
Corrected

Line 125: Shipboard
Corrected

Line 129: with a shipboard rosette
Modified by 'mounted on a rosette carrying 22 twelve-liter Niskin bottles'

Line 131: Profiler UVP
Corrected

Line 133:2 cm vertically
Corrected

Line 134: ◦C and 4 × 10 − 5? S/m, and
Corrected: – 2.10^{-4} °C (4.10^{-5} S/m), and

Line 135: ◦C and 3 × 10 − 4? S/m, respectively.
Corrected: 2.10^{-3} °C (3.10^{-4} S/m), respectively.

Line 138:] and resolution
Corrected

Line 147: Define the quantities in the parenthesis. Maybe provide some details on the validation, e.g., how many samples over how many profiles.
Corrected. The sentence now reads 'A good correlation was observed with bottle measurements over the entire water column collected during the cruise at station PERLE3-10 (R^2= 0.99, N=27 samples, $p <10^{-5}$, $NO3_{SUNA}$ = 0.991× $NO_{3\ btl}$ – 0.116).'

Line 155: clarify what '#l−1' means
Corrected. # L^{-1} means number of particles per litre.

Line 159: and−α denotes?
Corrected. The missing parameter has been added.

Line 163: represent up to
Corrected.

Line 176: scans
Corrected.

Line 186:2 km given mean ship speed of…
Short-term averaged data (2 min) were used to calculate the mean horizontal current every 2 km along the ship's path, regardless of the ship's speed.

Line 187: various quality criteria (references?)
Corrected. The sentence now reads 'various quality criteria (i.e., thresholds on vertical velocity error, vertical shear, correlation, minimum percentage of valid ensembles, Kermabon et al., 2018).'

Line 187: Bathymetry (Etopo 1 resolution?) was incorporated in the processing to account for
Corrected. The sentence now reads 'Bathymetry (Etopo 1 with 1 arcminute resolution) was incorporated in the processing to account for bottom detection.'

Line 191: S-ADCP not defined (line 180?)
Corrected. This acronym is now defined as it first appeared in the previous paragraph.

Line 199: downward looking
Corrected.

Line 203: which is a
Corrected.

Line 207: What are w and g, how are all these parameters estimated? Perhaps give a bit more detail if you are going to include the equation.
The equation has been corrected. w and g are simply indices to differentiate between losses due to absorption in water (w) and geometric dispersion (g).

Line 211: (I assume) CTD (singular)
Right. Corrected.

Line 225 and 226:-4 in exponents
Corrected.

Line 261: Give source, date (or is it an average over the whole period?) and spatial resolution for mean absolute dynamic topography
A sentence has been added in the caption of Fig. 3: 'The product is the European Seas Gridded L 4 Sea Surface Heights and Derived Variables product, interpolated to a 3.75 arcmin grid, provided by the Copernicus Marine Environment Monitoring Service (CMEMS).'

Line 263: Clarify how this is both SADCP and LADCP?
Corrected. The legend clearly states that this is the combined S-ADCP and L-ADCP data.

Line 269: Delete 'In terms of vertical current velocities'
Done.

Line 326: What are the horizontal gray lines?
The horizontal grey lines highlight the interfaces of the thermohaline staircases. It has been clarified in the legend.

Line 338: Delete 'the double diffusion phenomenon by'
Done.

Line 339: Delete 'The analysis of the'
Done.

Line 340: Delete 'and position'
Done.

Lines 362–363: delete
Done.

Line 366: Replace 'strongest processes' with something more specific like 'thickest salt-finger-induced thermohaline staircase structures'
Corrected.

Line 371: Replace 'particulate' with 'particular'
Corrected.

Line 378: Replace 'more diffuse' with something like 'less evident'
Corrected.

Line 379: Replace 'diffuse convection' with 'diffusive convection'
Corrected.

Line 382: internal gravity waves
Corrected.

Lines 383–385: 'Our observations show that the presence of significant staircase structures down to 2000 m can also be influenced by mixing induced by cyclonic eddies present in the basin.'
Please rephrase. This is not true as written since you did not measure or estimate mixing, it is just speculative based on the existence of steps/eddies.
We agree that this statement is based solely on the co-occurrence of the presence of the eddy and the absence of thermohaline staircases, and that there is not necessarily a causal relationship. However, we could argue for this effect based on the results recently published by Yang et al. (2024), who showed that the presence of thermohaline staircases in the Caribbean Sea is often perturbed by subsurface mesoscale eddies. We have rephrased our discussion to this topic and only suggested possible interactions between thermohaline staircases and oceanic processes based on this work.
In this section we mostly focus on the spatial and temporal stability of thermohaline staircases in the central part of the basin (according to our observations and the literature); a stability that is likely to have a notable effect on the settling and transformation of particulate and dissolved material, which we detail in the following sections.

Yang, S., Zhang, K., Song, H. et al. Disruptions in thermohaline staircases caused by subsurface mesoscale eddies in the eastern Caribbean Sea. Nature Communications Earth & Environment 5, 408 (2024). https://doi.org/10.1038/s43247-024-01577-3

Line 386: What is the evidence for 'the intensity and variability of the currents in the transition zone'?
We have no direct evidence, from ADCP measurements during the cruise, of an intensification of currents variability in the transition zone below the eddy. Our hypothesis was that the effects of a deep eddy could intensify turbulence and disrupt the development of thermohaline staircases. However, in the absence of additional data to support this hypothesis, we decided to modulate it, and only recall, based on the work of Yang et al (2024), the idea that eddy could interact with thermohaline staircases.

Line 390: Unclear what is meant by 'the lower part of the salt finger region'
By the lower part, we mean the region at a depth of more than 1000 m. This entire section has been rewritten.

Line 391: Unclear what is meant by 'the central Tyrrhenian thermohaline steps observed in the heart of the basin interior' and how this relates to the PERLE observations.
Previous studies (Zodiatis and Gasparini, 1996; Falco et al., 2016; Durante et al., 2019; Taillandier et al., 2020) confirm the observations obtained during the PERLE cruise in the sense that thermohaline staircases are strongest in the central part of the Tyrrhenian basin and are weaker or absent along the edges of the basin. We modified the text accordingly.

Lines 417–432: Fig. 5 does not show a particle size spectrum, what is the evidence for these claims? Replace 'spectrum' with something like 'vertical distribution'.

We are actually interested in the variation of the slope of the particle size distribution or spectrum, and do not present size spectra as such. The calculation and significance of the slope of the particle size spectrum is explained in section 2.1 on UVP data. We have corrected the terminology in the text.

Line 427:92.6 µm?
Right. Corrected.

Line 428: similar particle distribution with depth below the…
Corrected.

Line 442: m2
Rather than indicating vertical gradients, here we indicated the density difference at the interface between two staircases.

Line 447: The current vertical velocity estimates on the order of mm/s [this is probably below what can be resolved]
Figure 4 shows a histogram of the vertical velocities recorded over the whole section. The velocities vary between +15 and -15 mm/s with a rms of 4 mm/s. Such velocities are of the order of what can be solved with L-ADCP.

Line 448: homogenize their abundance with depth
Corrected.

Line 484: delete 'Based on this study'
Corrected.

Line 487: define all the variables in the equation
Done

Lines 478–501 and Fig. 13: Clarify that these are exclusively double diffusive fluxes, and they assume very small turbulence intensity (i.e., small turbulent diapycnal diffusivity).
Done

Line 493–494: Not clear what is meant by 'It is conceivable that the release of additional nutrients at the upper interfaces increases the local vertical gradient, thereby enhancing diffusive fluxes.'
We have now clarified this idea by changing the previous sentence by the paragraph:
Indeed, we hypothesize that the increase in microbial mineralization activity, occurring within the context of thermohaline staircases, releases nitrates among others. These nitrates can temporarily accumulate, creating bubble-like pockets of higher concentration (i.e. enriched microenvironments). The resulting increase in the nitrate concentration gradient enhances diffusive upward fluxes (as the underlying waters are richer).

Line 497: each density vertical gradient
Done

Line 500: Replace 'making it possible to' with 'and used to'
Done

Line 501: add something like: 'Double diffusive nitrate fluxes across each interface are annotated in blue'
According to the remarks, the legend is now:
Estimated double diffusive nitrate fluxes across each interface (annotated in blue and expressed in µmol/m²/d) from station 9. The blue arrows indicate the direction of the flux and sizes are proportional to the intensity. In red: the vertical profile of the specific volume anomaly ($\sigma\theta$ in kg/ m-3) delimiting homogeneous and gradient zones. The grey points correspond to nitrate measurements by the SUNA, while the blue squares are the values averaged over 1 m for each point at the upper and lower interfaces, and used to calculate the nitrate gradient in the shaded areas.

Line 504: examines the effect of observed weakly
Corrected.

Line 505: delete ’phenomena’
Corrected.

Line 520: resolved down to
Corrected.

Lines 522–523: i.e. are homogeneous at depths corresponding to thermohaline staircases.
Corrected.

Line 524: caused by salt finger staircases
Corrected.

Lines 532–533: matter, contributing to upward diapycnal diffusive fluxes of oxygen and nitrate.
Corrected.

Responses to comments from Reviewer #2

Review of EGUsphere-2024-3436 paper: Effect of double diffusion processes in the deep ocean on the distribution and dynamics of particulate and dissolved matter: a case study in Tyrrhenian Sea by Xavier Durrieu De Madron and coauthors

General Comments

This study presents and discusses various marine data collected in the spring of 2020 during the PERLE-3 cruise, and sheds light on the relationship between double diffusion, in the form of salt fingers, and particulate and dissolved matter in the Tyrrhenian Sea. The authors present and analyze hydrological, hydrodynamic, particulate, and dissolved data covering a section of the south-central Tyrrhenian Sea. They then focus on two different stations, one with and one without staircases due to salt fingers. They find that the steps influence the size and distribution of particulate and dissolved matter, which in turn can affect biological activities.

This study makes an interesting contribution to the growing understanding of the role of double diffusion processes in the ocean. The data are well characterized, the methods are clearly presented and the conclusions are innovative and substantial. However, some improvements could enhance both the text and the figures to increase the overall quality of the presentation. Moreover, it would be beneficial to publish the data.

We thank the reviewer for his constructive comments. We have tried to respond to all his suggestions and we have detailed our answers to his questions.

Specific Comments

Introduction

- The organization of the introduction is somewhat challenging to follow, as it shifts from discussing particulate matter to staircases, then to sedimentation and to staircases again.

We have modified the introduction by deleting a paragraph on double sediment diffusion, which is active in areas with very strong gradients, and by completing another paragraph by providing the hydrological and hydrodynamic context of the region.

- The fourth paragraph (starting from line 64) seems unnecessarily lengthy, as it discusses plumes while the focus is on the deep ocean.

This paragraph has been removed

- It would be beneficial to include a brief overview of the circulation of water masses in the area, as this would help explain the local salt finger processes. Additionally, all acronyms used later in the text should be defined in the introduction.

An overview of water masses and general circulation in the Tyrrhenian Sea has been added. The names of the water masses described in the manuscript have been modified to conform to the latest recommendations published in the article by Schroeder et al. (2024) A consensus-based, revised and comprehensive catalogue for Mediterranean water masses acronyms. Mediterranean Marine Science, Vol. 25 No. 3, 783–791.

- The third paragraph (starting from line 50) on double diffusion presents only one reference. Please add more references, particularly in the definition of the process (e.g., Radko has published numerous papers on the theoretical aspects of double diffusion).

A couple of relevant references to articles and reviews on double diffusion have been added.

Material and Methods

- Section 2.1: The title would sound better as 'Thermohaline and Optical Data'

(consider adding 'and Derived Index'). It should also include both shipborne CTD data and Argo float data, as they represent the same type of data collected using different probes.

We have changed the title of the paragraph and integrated the data collected by the profiling float as suggested. We have also included the paragraph on staircase detection.

- Lines 149–150: The majority of parameters described seem to be unused in the subsequent analysis. Please highlight where and if they are utilized, or consider removing them.

The parameter names have been corrected.

- Transmissometer Paragraph (lines 152–168): This paragraph could be better structured. Additionally, what about particles in the 10 to 80 µm range?

The paragraph was split to distinguish the data from the transmissometer from that obtained from the UVP. We described in more detail the data collected by the transmissometer. The transmissometer measures all the particles that pass through the beam, but because of the abundance of the finest particles, it is more sensitive to them.

- Section 2.2. (from line 178): I suggest titling this paragraph simply 'Acoustical Data' to match the style of the preceding paragraph. Moreover, please define both L- ADCP and S-ADCP at the beginning and use consistent terminology for each type of ADCP.

We have changed the title of the paragraph as suggested. The acronyms L- ADCP and S-ADCP have been clarified.

Results Section 3.1

- Please ensure consistent use of physical units throughout the manuscript. For instance, both µmol and µM are employed in the initial paragraphs. I have attempted to highlight every discrepancy in the text revision for your reference.

We have checked the consistency of the units throughout the text and the figures.

- As previously mentioned, it would be beneficial to include a brief discussion in the introduction regarding the circulation and names of water masses in the Tyrrhenian Sea. Defining these terms solely in the captions detracts from the overall fluency of the text.

A presentation of the main water masses and general circulation in the Tyrrhenian Sea has been added to the introduction.

- Regarding the figures, it would enhance their legibility to incorporate references in the cross-basin section figures. For example, I suggest utilizing a different color to highlight the isolines mentioned in the text or integrating the names of the water masses, similar to the TS diagram (Fig. 1). Ideally, figures in scientific papers should be self-explanatory, presenting all necessary information for the reader to comprehend them.

The names of the water masses have been integrated into the temperature and salinity cross-section figures.

- Please provide specific references for the subfigures. For example: 'The warmer, saltier, and oxygen-depleted core of the LIW is located at depths between 300 and 600 m, as illustrated in Fig. 2 (sections a, b, and c),' each time you describe the illustrated parameters.

Thanks, we provided specific references for the subfigures throughout the text.

- In Figure 3, the units are missing. Additionally, in Figure 2, incorporating colored lines, symbols, or labels within the section could facilitate quicker identification of eddies.

Figure 3 has been corrected to add the missing units, a reference for geostrophic velocities. The legend now states the origin of the altimeter products.

- At line 267, stations 09 and 20 are introduced for the first time. It may be beneficial to present these stations earlier in the document (perhaps in section 2.1) and provide a brief explanation for their selection (presumably because they are the most representative). Furthermore, consider adding the station names within Figure 4 to enhance reading clarity.

Indeed, we chose these two stations as representative of the most contrasting profiles, i.e. with and without marked staircases. Subsequently, in the discussion section 4.2 Effect of staircases on particle distribution and settling, we present several examples based on zooms of staircase structures for three different stations (stations 8, 9 and 11).

We have provided a brief explanation of their selection in a new section at the end of the material and method section (2.3 Selection of representative stations).

- In Figure 5, acronyms must be defined in the text upon their initial use before appearing in the figures (for instance, LPM has not been defined). As with the other results figures, please consider adding visual references to the two selected stations, such as corresponding lines on the cross sections.

Corrected. The acronyms BAC and LPM were defined when they first appeared in the text.

- Lines 289–290: Is this statement conjecture or a well-established fact? If it is the latter, please provide a citation to support the claim. Additionally, it would be prudent to include a brief definition of micronekton, as it has not been mentioned previously, and the intended scientific audience may include researchers in abiotic studies.

The contribution of the micronekton to the deep scattering layer is well known. More detail and references have been added in the text.

Results Section 3.2

- Lines 316–318: Could you please provide additional explanation for this highlight?

This observation of a decrease in the Junge parameter as a function of depth, indicating a greater relative abundance of larger particles compared to finer ones, has been modified. While the decrease is significant and comparable for all stations between 800 and 2000 m depth, some stations, such as station 20, show smaller local variations between 1000 and 1600 m. The reasons for this remain unexplained, so we have removed this point from the text.

- Figure 6: I recommend enlarging the text size, as it may be challenging to read depending on the medium used by readers.

Corrected

- Line 341: Did you intend to reference Figure 8 instead?

Indeed. Corrected

- Lines 343–346: Please rephrase this sentence for clarity, as it currently lacks precision.

Corrected. The sentence now reads, 'During the PERLE-3 cruise, distinct thermohaline staircases are observed between 600 and 2000 m depth, primarily in the central region of the basin (Fig. 8a). These staircases are notably absent in two areas: near the western slope of the basin and beneath the deep anticyclonic eddy located at about 12° E. The absence of staircases extends to 1000 m depth beneath this eddy.'

- Lines 284–351: The temporal and spatial stability of Tyrrhenian staircases has been documented in several studies (such as Johannessen and Lee, 1974; Molcard and Williams, 1975; Molcard and Tait, 1977; Zodiatis and Gasparini, 1996; Falco et al., 2016; Durante et al., 2019; and Taillandier et al., 2020; and more). It would be advantageous to highlight this consistency with existing literature, or alternatively, to include this information in the Introduction section.

Thanks. Information on the presence and permanence of staircases in the Tyrrhenian Sea and references have been included in the introduction.

- Additionally, please consider incorporating the graphical positions of the two eddies in Figure 8 and adding titles to the maps, such as 'Cruise' and 'Floats.'

We added the labels 'Cruise' and 'Float' to distinguish the two sets of data. We have omitted to add the position of the eddies to avoid making the figure too complex.

Discussion 4.1

The content in paragraphs 382–393 contains qualitative speculation and should be rewritten, as it lacks sufficient adherence to the presented results.

It is important to distinguish between what constitutes a measured result (and where to locate it in the previous text) and what represents a conjecture. While I understand this paragraph relates to Results Section 3.2.2, both sections require restructuring and more substantive argumentation to enhance coherence. Consider these questions: Can you demonstrate a definitive influence of the eddies on staircase structures, or is it merely a qualitative correlation? Did you select station 20 due to its proximity to the 12 E° eddy, with the intention of investigating the relationship between the eddy and the potential development of steps? If this is the case, please state it explicitly to clarify your speculative assertions regarding their interaction.

Additionally, you mention that vertical currents behave as expected (line 270). In what manner can they visibly alter the formation of staircases (line 387), particularly since there are no staircases present at the station nearest the eddy? Can you compare your cast in station 20 with other previous data of the same station? A potential approach could involve starting from the persistence of the center-basin staircases and hypothesizing that the absence of staircases at your station 20 (and possibly adjacent stations, are you able to show them for comparison?) may also be attributable to the presence of the eddies and their associated stronger currents. This interpretation reflects my understanding of this segment of the discussion.
For your reference, a relevant study examining the relationship between a Meddy and staircases is presented in Hebert (1988).
We chose Station 20 to study the relationship between the eddy and the potential development of staircases. It is one of the few deep stations, along with shallow stations near the basin boundaries, where there are no staircases above 1000 m. This station is in close proximity to the 12° E eddy.
We agree that this statement is based solely on the co-occurrence of the presence of the eddy and the absence of thermohaline staircases, and that there is not necessarily a causal relationship. However, we could argue for this effect based on the results recently published by Yang et al. (2024), who showed that the presence of thermohaline staircases in the Caribbean Sea is often perturbed by subsurface mesoscale eddies. We have rephrased our discussion on this topic and only suggested possible interactions between thermohaline staircases and oceanic processes based on this work.
In this section we focus mainly on the spatial and temporal stability of thermohaline staircases in the central part of the basin (according to our observations and the literature); a stability that is likely to have a notable effect on the settling and transformation of particulate and dissolved material, which we detail in the following sections.

Yang, S., Zhang, K., Song, H. et al. Disruptions in thermohaline staircases caused by subsurface mesoscale eddies in the eastern Caribbean Sea. Nature Communications Earth & Environment 5, 408 (2024). https://doi.org/10.1038/s43247-024-01577-3

Discussion 4.2
Please consider including a description of the size classes presented in either the text or a table for clarity.
A summary of the particle abundance, categorised by size class, from the UVP measurements at all sampling stations is given in Table 1 in the supplementary material.

Discussion 4.3
Lines 488–489: Since you are comparing your results with those of Taillandier et al. (2020), it would be beneficial to also reference Durante et al. (2021) in this paragraph. The study analyzed heat and salt fluxes of staircases in a nearby area and over a broader portion of the water column, yet it found the strongest thermohaline fluxes occurring within a similar depth range (700 m – 1600 m) as the one you selected.
Thank you for suggesting this work of Durante et al. (2021), which we have now included in the comparison with the study conducted by Taillandier et al. (2020). These results confirm the influence zone of the staircases from a physical perspective and therefore significantly strengthen our approach.

Technical Comments
Please refer to the attached paper. Consider these comments as a complement to Reviewer #1's feedback.

Responses to comments from Reviewer #2

Major comments:

I was quite enthusiast reading the abstract. After reviewing the manuscript, I liked the part about the influence of the eddy on the stratification of the Tyrrhenian Sea. However, I'm disappointed by the main focus of the study, which concerns the concept of particle retention by the occurrence of staircases. I find the figures associated with station #9 are unconvincing and inconclusive. In addition, the authors build some interpretations on the sole basis of 4 steps of a single profile (steps of sta. #9), while a significant number of other stations of that same cruise exhibit staircases. Not much is said about the other profiles, especially in terms of particle retention. Those other profiles should also be used to improve the robustness/representativity of the nitrate fluxes associated with staircases.

Note that I fully agree with the process of retention, decrease of the settling velocity, particle aggregation and consequences for the microbial community when there are strong density gradients that act more or less as a barrier: this is physical, no problem.

My criticism is that there is a lack of clear evidence of a retention and associated increase in mineralization on the sole profile presented in this study (#9 with staircases). It seems to me that there is no clear perturbation of the large scale gradients (AOU, nitrate) that are shown on Figs. 7 (and 6) for instance. At the scale of the steps of the staircases, we find the same gradient signs that are simply enhanced since a step 'connects' two homogeneous regions that have been mixed by the salt-fingering process.

I expected the study to exhibit higher concentration of small scale particles, an increase in nitrate, a decrease in AOU at the base of a mixed region just above a step, or, in a step. I see no such significant anomalies, just local gradients at steps that follow the sign of the large scale gradient, with a larger amplitude induced by the adjacent convectively mixed regions, in the same way that salinity and temperature gradients are very locally enhanced between these mixed regions.

We agree that a demonstration based on a single profile could be misleading, or in any case insufficiently conclusive. In the first version submitted, we chose to limit the figures to 2 stations considered to be the most representative, and this was undoubtedly not sufficient. Given the resolution limitations of the sensors and the variability of the environment, it is often difficult to clearly identify anomalies in particle, nitrate and oxygen concentrations that reflect retention and mineralisation at density interfaces. It's also clear that there must be a time delay in these phenomena. The intensity of mineralization (nitrate production and oxygen consumption) varies over time and must result in a patchy distribution that is impossible to capture at current observation scales.

We now present the complete profiles for two stations (station 20 without significant staircases and station 9 with marked staircases) and close-ups of the staircases of three different stations (stations 8, 9 and 11). We have added the numbers of these stations to the sections and have provided a brief explanation of their selection in a new section at the end of the material and method section (2.3 Selection of representative stations).

We believe that the impact of these physical barriers on biological activity is made more credible by the addition of these profiles.

Further comments are provided below.

Detailed comments:

Fig. 4: The down- and up-casts estimates of vertical velocity are remarkably consistent on profile a, and somewhat less on profile b between 150–250 m and 500-1100 m. Is it physical and in that case what is the source of the variability?

The upcast typically provides lower quality data than the downcast, due to the wake effect of the ascending CTD package disturbing the water column, as well as potential temporal changes in ocean conditions (internal mixing, energy dissipation of currents) between the two casts.

We have simplified this section by presenting figure 4, which shows a histogram of the vertical velocities, and by pointing out in the text the range and standard deviation of vertical velocities.

l. 282: ' … the downward movement of water around the anticyclonic eddy': interesting! Can this be also evidenced on a 2D-plot transect of the vertical velocity (as a supplementary subplot of Fig. 3)?

Possibly also visible on theta plot Fig. 2A, no?

Anticyclonic eddies play a significant role in the subduction and transport of water masses. Planktonic particles and biomass in anticyclonic eddies tend to follow isopycnal surfaces, resulting in vertical displacement (Rubio et al., 2005. A field study of the behaviour of an anticyclonic eddy on the Catalan continental shelf – NW Mediterranean – . Progress in Oceanography, 66, 2–4, 142–156; Samuelsen et al., 2012. Particle aggregation at the edges of anticyclonic eddies and implications for distribution of biomass. Ocean Science, 8, 389–400). However, this is not the subject of this work.

l. 288–291 + Fig. 5c: we rather observe a mimima between 200–300 m, no? The maxima are below. Is the zonal fragmentation of the mimina 'tongue' between 200–300 m caused by the upward motion of the large reflectors at night? Maybe a slight reformulation is needed to clarify.
The fragmentation of the backscatter index into 'tongues' of lower intensity between 200–300 m is related to diel vertical migration (also known as upwelling) of some organisms during the night.

l. 292 and Fig. 5d: I'm not an expert in this field. A short explanation of the reasons we expect such a distribution would be welcome. Thanks!
The distribution of particles suspended in the ocean is often characterised using the Junge index (denoted α), which fits a power law to the particle size distribution, with steeper slopes (higher α) indicating a dominance of smaller particles over coarser particles. The higher Junge index observed at depths of approximately 200 to 1000 metres on the section indicates that the pool of particles present in the water is dominated by smaller particles. This predominance decreases at greater depths.

l. 384–385: 'the presence of significant staircase structures down to 2000 m can also be influenced by mixing induced by cyclonic eddies…': Is it the eddy that breaks the staircase structure that was in place, or the fact that the eddy was formed in a region without any staircase structure that is later advected in the middle of the Basin? Do we know where it was generated?
We believe that the eddy either broke the structure of the staircase that was in place, or prevented the formation of stairs.

l. 399: 'a significant reduction in the abundance of fine particles as seen by transmissometry (BAC) under each interface': The decrease is across the interface, not under (under = the mixed layer)
Right. Corrected

l. 401 and following, Fig. 9–10 and observations: If I understand, we are looking at the variation across a step (=interface). If I look at the difference in abundance between just above a step minus just below the step, there is no clear rule, even for the two smallest size ranges on Fig. 9; for the two smallest sizes <128 µm: first step = increase with depth, second step = decrease with depth, third step = increase, for Fig.10: decrease with depth. I'm a little puzzled by the concept of 'retention' of small particles when 'simply' looking at Figs 9 and 10. Given the terminology used here, I would have expected to see a peak of small particle abundance within a step or immediately above the step. This does not happen. The overall abundance profile decreases with depth in the absence of staircases (Fig. 5 sta #20). In the step region, this overall profile is mixed in the convective regions associated with the salt finger. A step is not associated with an increase (retention) of small particles, it is just a strong gradient connecting two convectively mixed regions (just as the temperature over a step shows larger local gradients than it would if there were no adjacent mixed layers due to the double diffusion process)… Am I wrong in thinking that if there is retention, the time for small particles to aggregate and possibly become heavier, I should then see an increase in the abundance of small particles at the base of a mixed region above a step?
You are right, the increase in the abundance of small particles on the stairs was not clear on the profiles presented previously, but as we explained above, the option was to present a limited number of figures. We recognise that this was unwise and have now added close-ups of the various parameters at the level of density interfaces for different stations. But it should not be forgotten that this is a variable environment, and that the scales involved are difficult to grasp with current measuring equipment.

l. 447: 'The vertical velocities of the current … likely to alter the settling of particles': not sure to correctly understand the idea. You mean that a layer that is connectively mixing has down- and up-ward currents at very small scale, what can homogenize the distribution of small scale (almost neutrally buoyant) particles, preventing their deposit at the base of the convective region??

This is indeed what we wanted to express. Neutrally buoyant particles are likely to be homogenized with the mixed layer between two density interfaces.

l. 459 and following: OK for mineralization process, consumption of oxygen, release of nutrients. So what do we expect? Increase in AOU just above a step, since a step acts as a barrier, or across a step, the time for small particles to cross it at a reduced downward velocity? It is not clear from what is said on the process of increase mineralization.

We have reformulated and detailed this part of the discussion on the impact of staircases on biogeochemistry: 'The presence of thermohaline staircases appears to affect the sedimentation pattern of particles; promoting particle retention and aggregation, increasing the time particles spend in the water column. These structures also create distinct microenvironments with gradients of oxygen and nutrients, which are believed to be the result of the degradation of particulate organic. This effect is illustrated for three separate interfaces in figures 9 to 11. It can be then hypothesized that the increase in particle residence time favours the remineralization process, which releases nutrients while consuming dissolved oxygen through heterotrophic respiration. Depending on the conditions and with a sufficiently long stability period, these activities can lead to localized oxygen depletion and an increase in AOU. In our data, this effect is clearly observed in the shallower staircases, between 750 and 900 m, at station 09 (Fig. 11, bottom row). For deeper interfaces for stations 08 and 11, at around 1200 m (Figs. 9 and 10, bottom row), the increase in AOU and the potential accumulation of nitrate are masked by a stronger vertical oxygen gradient and higher nutrient concentrations compared to shallower depths. Moreover, biological activity within these deeper staircases is also reduced due to the decreased lability of organic matter with increasing depth (Ghiglione et al., 2009; Karl et al., 1988).

The persistence of these staircase structures allows sufficient time for significant biogeochemical transformations to occur. Arístegui et al. (2009) and Nagata and Kirchman (1997) showed that in deep marine environments, the degradation kinetics of organic matter, which vary according to temperature, oxygen availability, and microbial composition, can range from a few days to several months. This can lead to the local accumulation of nitrates, creating pockets of higher concentration and intensifying vertical double diffusive nitrate fluxes toward upper layers. However, observing these accumulations with the present resolution and precision remains challenging.'

Arístegui, J., Gasol, J. M., Duarte, C.M., Herndld, G. J., 2009. Microbial oceanography of the dark ocean's pelagic realm. Limnology & Oceanography 54, 1501–1529.

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Ghiglione, J.-F., Conan, P., Pujo-Pay, M., 2009. Diversity of total and active free-living vs. particle-attached bacteria in the euphotic zone of the NW Mediterranean Sea. FEMS Microbiology Letters 299, 9–21.

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Nagata, T., Kirchman, D. L., 1997. Roles of Submicron Particles and Colloids in Microbial Food Webs and Biogeochemical Cycles within Marine Environments, in: Advances in Microbial Ecology. Springer, Boston, MA

Thiele S, Fuchs BM, Amann R, Iversen MH 2015. Colonization in the Photic Zone and Subsequent Changes during Sinking Determine Bacterial Community Composition in Marine Snow. Appl Environ Microbiol 81,

For the first two upper steps (Fig. 11), there is an increase in AOU across the step, for the third step around 875 m, the AOU is constant or slightly decreasing, and for the fourth large step the AOU strongly decreases across the step. For the nitrate, there is some increase across the upper three steps but the large scale gradient shows an increase with depth; therefore, it is difficult to conclude that the increase in nitrate across the steps is associated with an increased mineralisation process due to particle retention by just looking at those figures. The difficulty may be due to the presence of large scale gradients, that may mask the signal as described al l. 463. Looking at other profiles with staircases may provide more convincing evidences.

You are right, which is why we added close-ups of the various parameters at the level of density interfaces for different stations as suggested.

Minor comments:

Fig. 1a: add the ship route on the map. According to Fig. 3b, it seems that there is an interruption of the zonal 'linear' progression of the ship around the eastern edge of the anticyclonic eddy…

Corrected. We have added the ship's route and explained the brief deviation to the north (recovery of the profiling float) on the station map in Figure 1.

For all transect figures (Fig. 2, 3c, 5, 8): add the station number on the upper abscissa.

We have added the station numbers to the station map in Figure 1 and also along the upper abscissa of the sections.

l. 254 the typical maxima looks like more 10–15 cm/s on Figs 3bc, rather than 30 cm/s. Maybe the exceptional value of 30 cm/s is very locally reached along a slope, but this is not evidenced on Fig. 3.

The values of 30 cm/s are indeed surface speeds observed both by ADCP measurements and derived from altimetry measurements at the level of the eddies. We have corrected the text to indicate representative speeds values.

Fig 3a: give the meaning of the arrows and provide their scale and the source of the data (gridded geostrophic currents from…) + plot the ship route on this map

The arrows indicate the direction and magnitude of the surface geostrophic currents. The origin of the product is now indicated in the figure caption. A scale has been added.

l. 341: figure referencing: Fig. 8 instead of Fig. 6?

Indeed. Corrected.

l. 344: repetition: 'Staircases are absent under the deepest eddy (about 12° E)', already said in the following sentence (l. 345)

Corrected. The paragraph has been reworded.

l. 397: interface/step starts around 1250 m and ends near 1300 m. To avoid confusion in the wording, you may choose another term than interface if you depict a region encompassing mixed layers and steps.

We have modified the text to indicate the average depth of the interfaces for the selected stations we have chosen to display.

l. 427: unit: 'µm' instead of 'm'

Corrected.

l. 491: 'stronger than' instead of stronger that'

Corrected.

l. 510: extra dot..

Corrected.

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