Authors' second response for Transient Attracting Profiles in the Great Pacific Garbage Patch

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Preface

We thank the referees for their careful review and helpful comments on our revised manuscript. In the following, we provide a detailed point-by-point response to all referee comments from the second review iteration and specify all changes made to the revised manuscript. Our response to a referee comment is structured in three steps: (1) **comment** from the referee, (2) author's *reply* and (3) author's *changes* in the manuscript. In addition, we provide a marked-up manuscript showing the changes made to the last version of the manuscript using the latexdiff command. Unless otherwise stated, this marked-up manuscript is the reference for line numbers in the following replies.

1 Replies to referee 1 (report 2)

Statement by the referee

I find the revised paper improved but still have some follow-up questions on all my original comments.

1.1 Mesoscale vs. submesoscale

I am still confused about the authors' overall take on this question. The authors seem to admit that 1) the statistics of TRAPS in a submesoscale-resolving flow (let's term these submesoscale TRAPS) is likely to be different than that of mesoscale TRAPS, and that 2) submesoscale TRAPS will likely influence the movement of floating objects over short timescales (say, a day or less). However, they also claim that 3) it is the mesoscale TRAPS that are most important for the purposes of cleanup operations (on spatial scales of 1-10 km, i.e., in the submesoscale range). I am having a hard time reconciling (3) with (1) and (2), as well as finding support for (3) without actually computing TRAPS in a submesoscale-resolving flow and looking at their statistics and behavior of drifters in their vicinity. I am not implying that the authors necessarily compute submesoscale TRAPS (although they could do it, for example, in a numerical model) and their statistics, but at least they should further clarify their overall view on the importance and interaction

of mesoscale and submesoscale features, and their importance for cleanup applications.

reply

We appreciate the comment and acknowledge that this point needs further clarification. We do not claim that (3) mesoscale TRAPs are more important for cleanup operations than submesoscale TRAPs. In lines 513 - 542 of the previous manuscript version, we dedicate two paragraphs to the topic of mesoscale vs. submesoscale TRAPs. Contrary to point (3), we emphasise in lines 519 - 520 of the previous manuscript version that "TRAPs computed from submesoscale velocities [...] are crucial to an application of the concept during offshore cleanups.". In lines 530 - 531 of the previous manuscript version, we further explain that surveys about TRAPs computed from SWOT measurements "can further improve the applicability of TRAPs to offshore cleanups". This statement implies that we do not expect mesoscale TRAPs to be the best predictor for cleanup operations. However, unless comparable research about submesoscale TRAPs becomes available, we can only recommend mesoscale TRAPs derived from satellite altimetry as an additional tool for the cleanup community. We describe a potential application of mesoscale TRAPs where we explicitly state in lines 538 - 541 of the previous manuscript version that "The large-scale navigation along mesoscale TRAPs could then be complemented by [...] the detection of [...] attracting flow features on the small scales [...] ". In lines 541 - 542 of the previous manuscript version, we communicate the need for more research about the relation between mesoscale and submesoscale TRAPs. These examples disprove point (3). However, we acknowledge that we should explain our view more explicitly throughout the introduction and the conclusion of the new manuscript version. We think both mesoscale and submesoscale TRAPs are important for detecting debris hotspots. We note that computing submesoscale TRAPs from numerical models would go beyond the scope of our study and be better placed in a follow-up project.

We will also emphasise our point in lines 521 - 525 of the previous manuscript version that large-scale strain generates/intensifies submesoscale fronts and, therefore, mesoscale TRAPs could be useful as a proxy for intensified submesoscale features while at the same time supplying these submesoscales with material.

In the new manuscript version, we will highlight one additional motivation for computing TRAPs from mesoscale-permitting satellite observations, which has not been communicated clearly within previous versions: TRAPs can predict material aggregation. At the mesoscale and daily frequency, TRAPs computed from near-real-time observations of the flow, such as altimetry measurements, should be able to indicate where drifting objects will aggregate within a few days.

changes

We address these points with the changes made in the following lines:

1. mesoscale and submesoscale TRAPs: 84 - 85, 91 - 96, 615 - 619, 621 - 622, 650 - 652

2. large-scale strain and submesoscale features: 629, 631 - 633

3. prediction of aggregation: 75 - 80, 91 - 96, 615 - 619, 642 - 644, 663 row 1 of Table B1

1.2 Parameter choices

1.2.1 1 degree

The authors admit that the 1-degree criterion is not necessary and can be dropped in future studies. If so, it might be better to just drop it in this study and do the analysis without it. It is not a requirement for publication, just a suggestion. Instead of the 1 deg criterion, they suggest using a 30% strength criterion for defining the lengths of TRAP lines. I understand that this criterion has been used in prior work, but the choice of 30% still seems arbitrary to me – why not 25 or 35%? I am suggesting that the authors more clearly acknowledge that TRAP algorithm has several subjective parameter choices

reply

We appreciate the comment, and we refine our statement about TRAP lengths. It will explain why we keep the 1° limit on TRAP length. As a consequence of this statement, we refrain from recomputing our dataset for different TRAP lengths unless required for publication since it will barely generate new insights for our study purposes:

We truncate TRAP curves wherever the attraction rate along the curve falls below 30 % of the attraction at the respective core. Such a cutoff criterion makes sense physically because the attraction of nearby parcels becomes negligible as distance increases away from the core. Without cutoff, TRAPs can become indefinitely long and merge with nearby structures, which makes them hard to distinguish. In addition, their converging ends put wrong emphasis on regions between TRAP cores where the attraction rate is comparably low. Moving away from a TRAP core, the local eigenvectors $\boldsymbol{e}_2$ also start pointing in arbitrary directions and are no longer representative of the TRAP. The attraction strength criterion does not necessarily prevent such an excessive integration of the eigenvectors. To obtain an accurate TRAP that indicates hyperbolic flow, one has to define an upper limit for TRAP length in addition to the cutoff by attraction strength, see Fig. S1 in the Supplementary Material for details.

The TRAPs algorithm (Serra, 2020) provides default values of 1° for the maximum arclength of a TRAP and 30 % for the attraction strength cutoff. Together, both parameters determine the length of a TRAP curve and must be set thoughtfully before computation. With the mesoscale velocity data we use, the preset values provide a clear saddle-type representation of TRAPs. Also, a maximal arclength of 1° limits each TRAP branch to a maximal arclength of 0.5°, which roughly corresponds to the average radius $\overline{r}_e$ of mesoscale eddies in our domain. We consult an eddy census product by AVISO+ et al. (2022) and derive an average eddy radius and its standard deviation of $\overline{r}_e \approx (53 \pm 20)$ km. We expect TRAPs to highlight strain between mesoscale eddies, and therefore, it is helpful to study TRAPs and eddies on comparable length scales. For these reasons, we keep the preset parameter values. However, this choice does not affect our main diagnostics, and future studies should adjust these settings according to the applied velocity data. Modified TRAP lengths do not change our analysis since our statistics refer to the position and attraction of the TRAP *core*.

changes

We implement such a statement with the changes made in lines 170 - 189 and 191 - 193.

1.2.2 75 km radius

I appreciate the additional statistics on the distance of drifters to the nearest TRAP and the explanation that this is 1.5 times the eddy radius, but it doesn't fully address my question about why one should care more about the statistics of drifters within 75 km from TRAPS and not, say, within 50 or 25 km?

reply

We refine our statement on the 75 km search radius. When defining the search zone, our main question was *'Up to what distance can we observe hyperbolic drifter motion around a TRAP?'*. We wanted to maximise the search zone in order to capture *all* surrounding hyperbolic drifter motion, regardless of whether it occurs within a distance of, e.g., 25 km or 70 km to a TRAP. We aimed to record as many hyperbolic drifter trajectories as possible since they occur within an abundance of motion patterns, and we needed a large dataset to develop robust statistics.

Since a quadrupole represents the average flow around mesoscale TRAPs, we assume that the position and size of surrounding mesoscale eddies determine the limit to which we can observe hyperbolic drifter motion. AVISO+ et al. (2022) find an average radius of $\overline{r}_e \approx 53\ \mathrm{km}$ for mesoscale eddies in our domain, and we use it in Fig. 1 to sketch an idealised quadrupole situation. We show that within a search radius of $r_s = \sqrt{2}\overline{r}_e$, we can capture the eddy regions that constitute the hyperbolic flow around a TRAP. Smaller radii r_s will also allow the detection of hyperbolic drifter motion. However, they will not provide a complete picture up to the centre of an eddy, and they may not suffice for larger eddies, for eddies that are less adjacent than illustrated here, or for TRAPs that are up to 25 km off their estimated position due to the coarse resolution of our velocity data. For these reasons, we apply a search radius of $r_s = \sqrt{2}\overline{r}_e = \sqrt{2} \cdot 53\ \mathrm{km} \approx 75\ \mathrm{km}$. We acknowledge that Fig. 1 only illustrates an idealised situation and that r_s is constant for all TRAPs. Nevertheless, the agreement between the observed hyperbolic drifter motion around mature TRAPs and this scaling of a quadrupole confirms our approach.

The statistics for drifter-TRAP distances additionally support our choice for r_s since the vast majority of drifter positions is within a radius of 75 km. Drifter detections beyond this limit do not provide more insights than the ones shown in Fig. 10 of the manuscript. Instead, we observe a significant increase in the number of one-day pairings for the 14 % of drifter days beyond this radius. For these reasons, we set $r_s = 75\ \mathrm{km}$ for our analysis. We will present such a refined statement in the new version of the manuscript.

changes

We address this with the changes made in lines 273 - 277 and 283 - 302.

We complement this by inserting Fig.1 as the new Fig. S4 in the Supplementary Material. The figure number of all subsequent figures in the Supplementary Material will shift by 1, and we correct the respective references in the new version of the manuscript.

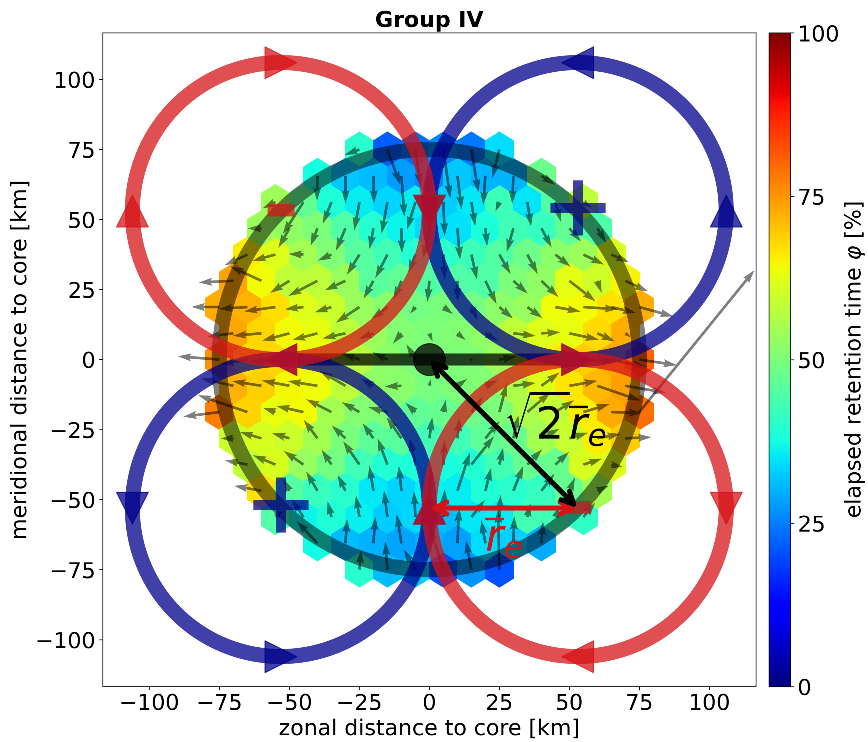

Figure 1. Drifter motion around TRAPs and eddies. We embed Fig. 10d of the article in a scheme of four idealised mesoscale eddies. Blue and red circles represent cyclonic and anticyclonic mesoscale eddies, respectively, with a radius equal to the mean radius $\bar{r}_e \approx 53$ km that we find for mesoscale eddies in our domain, using eddy detections from AVISO+ et al. (2022). $\bar{r}_e$ determines the search radius $r_s = \sqrt{2}\bar{r}_e$ of our drifter-TRAP pair algorithm. A transparent TRAP in the middle represents a generic profile, the black circle draws the limits of the drifter search zone around it. The rotation of the idealised eddies aligns with the hyperbolic drifter motion we observe around mature TRAPs.

1.3 Implications for cleanup

If a drifter is equally likely to be found near a TRAP as within an eddy, and assuming that statistics of drifters is similar to that for floating debris, then I don't see why one should preferentially look for debris near TRAPS (rather than in the eddies) and concentrate the cleanup efforts there.

reply

We acknowledge that our description in lines 478 - 486 of the previous manuscript version raises this question. We clarify our view in the following statement, which we will communicate more clearly within the new manuscript. We will only mention Fig. S6, former Fig. S5, to illustrate the low number of drifters and as a motivation for future research:

In our study domain, the average surface area within a mesoscale eddy is $\overline{A}_e \approx 8361\ \mathrm{km}^2$, as derived from eddy detections by AVISO+ et al. (2022). Even if mesoscale eddies accumulate floating material in their interior, there is no preferential region within that area expediting debris collection. For a similar area, however, TRAPs maximise normal attraction of nearby trajectories, which then move tangentially to a TRAP. Surrounding material will move towards the TRAP, aggregate and then move along the TRAP towards its ends. Because the circulation aggregates material from *both* sides of a TRAP into a smaller subarea, we expect the density of debris along a TRAP, i.e. the number of debris per unit area, to be considerably greater than in its periphery. Eventually, the hyperbolic flow would convey this aggregated debris into a strategically placed cleanup system. For these reasons, navigating a cleanup system along mesoscale TRAPs could be more productive than navigating it through mesoscale eddies.

We demonstrate this aggregation with Fig. 10d of the manuscript, where the hyperbolic flow transports drifters into a smaller subarea. As illustrated in these rotated scenes, there are two pathways for searching debris, i.e. the western and eastern branches of the TRAP, each supplied with material from the north and south. However, we can only show this effect using a composite of many drifter trajectories in Fig. 10d. Individual examples of a TRAP attracting multiple drifters are rare due to the low number of drifters in the domain. Fig. 3b presents one of the few observations with two drifters. Although the number of drifters allows us to show the impact of TRAPs on individual, nearby drifters, it is insufficient to quantify the likelihood of drifters aggregating around mesoscale TRAPs and other regions of the flow, such as mesoscale eddies. We illustrate this deficiency with a time series for the number of daily drifter positions spent around TRAPs and within mesoscale eddies in Fig. S6, former Fig. S5, of the Supplementary Material. The high standard deviations for respective drifter counts result from the low number of drifters and prevent an accurate comparison. We leave the time series as a motivation for future studies. Prospective research could investigate the likelihood of aggregation using a significantly higher number of drifters or suitable measurements of debris concentrations, which are being collected during current missions.

changes

We address this with the changes made in lines 552 - 581.

2 Replies to referee 2 (report 1)

Statement by the referee

The authors have done a good job at responding to earlier comments, however, I feel the manuscript requires more polish regarding the sentence structure and grammar. I am happy to recommend the manuscript for publication provided additional editing for grammar and sentence structure is completed, and a few comments on word choice are addressed. I provide a *non-exhaustive* list of my concerns below. I feel an exhaustive list of my concerns is unhelpful, rather, I suggest the authors go through the manuscript thoroughly to polish the presentation quality.

2.1 Minor editorial comments

1. **Line 6 – "we here take ..." to "here, we take ..." (and on line 59).**

   reply

   We appreciate the comment and change the wording accordingly.

   changes

   Respective changes are made in lines 6 and 61.

2. **Line 21 – "... and can benefit even more offshore operations, ...", this is a little ambiguous. Do you mean to say that offshore operations are benefitted by a better understanding of TRAPs? Or, that a more (in the numerical sense) offshore operations are benefitted?**

   reply

   We mean "more" in the numerical sense of "more offshore applications in addition to ocean cleanups". We change the wording accordingly.

   changes

   Respective changes are made in lines 22 - 23.

3. **Line 37 – "that exhibit" to "which exhibit" since it's a non-restrictive sentence.**

   reply

   We agree and change the wording accordingly. We will search for similar examples of incorrectly used relative clauses throughout the manuscript and correct them accordingly.

changes

Respective changes are made in lines 38, 97, 306, 314, 353 and 611.

4. **Line 39 – “at [a] global scale”.**

reply

We agree and change the wording accordingly.

changes

Respective changes are made in line 40.

5. **Line 40 – “has been” to “have been” since “experiments” is plural.**

reply

We agree and change the wording accordingly. We will search for similar examples of incorrect conjugations throughout the manuscript and correct them accordingly.

changes

Respective changes are made in line 41, 57, 403, 429 and 454.

6. **Line 48 – “. . . , which eventually allow to derive . . . ” to “from which . . . can be derived”.**

reply

We agree and change the wording accordingly.

changes

Respective changes are made in lines 49 - 50.

7. **Line 61 – “ … provides answers to this since it …” is unclear. Is ‘it’ refereeing to the “concept of [TRAPs]” or simply the “[TRAPs]”?**

reply

Here, "it" refers to the concept since its numerus is singular and the numerus of TRAPs is plural. We prefer to keep this version of line 61 in the previous manuscript version but we acknowledge that this is a delicate wording. Our idea is that "TRAPs *detect* to most attractive regions of the flow" whereas "the concept *allows to detect* the most attractive regions of the flow". Following this logic, we have to correct a similar expression in line 7 of the abstract. There, we replace "it" by "TRAPs". We prefer this over using "allow to" a second time after a first instance in line 2.

changes

Respective changes are made in line 7.

8. **Line 64 – “the ocean surface” to “a two-dimensional surface, such as the ocean surface,” since, as I understand, TRAPs are not confined to just the ocean surface, but could be computed at depth or along a density surface.**

reply

We agree and change the wording accordingly.

changes

Respective changes are made in line 66.

9. **Line 71 – “more” can be removed as no direct comparison on robustness is being made.**

reply

We agree and change the wording accordingly.

changes

Respective changes are made in line 74.

10. **Line 79 (and elsewhere) – “geostrophic + Ekman current velocities”, I would refrain from using “+” in a sentence like this, rather, “the combined near-surface geostrophic and Ekman current velocities”.**

reply

We agree and change the wording accordingly for all instances of "geostrophic + Ekman".

changes

Respective changes are made in lines 44 (caption of Fig. 1), 88, 157 - 158, 162 (caption of Fig. 2) and 200.

11. **Line 85 – I'm not sure I understand what you mean by "altimetry acts like a filter". This can be clearer.**

reply

We mean that conventional altimetry measurements of the ocean surface filter out all small-scale, short-term features of the flow. We clarify the explanation accordingly.

changes

Respective changes are made in lines 100 - 101.

12. **Line 87 – "We investigate how these coherent structures relate", unless you define a coherent structure, I would refrain from calling TRAPs "coherent", not to conflate with the typical Lagrangian coherent structures. Additionally, "relate" to what? Perhaps "We investigate the relation between TRAPs and mesoscale eddies in order to. . . "?**

reply

We acknowledge the comment and apply the suggested formulation. We note that within the manuscript, there are three more instances of the term "coherent structure", two of them being part of the term "Objective Eulerian Coherent Structure" (TRAPs). The third instance of "coherent structure" appears in our discussion about TRAPs and mesoscale eddies where we use it as a synonym for an Agulhas ring. We replace this instance by "coherent eddy" so as not to create the need to define a coherent structure.

changes

Respective changes are made in lines 103 and 547.

3 Second revision on English language

In response to referee 2 and in addition to our first revision on spelling, grammar, sentence structure and word choice, we thoroughly went through the manuscript and applied minor revisions to further improve these aspects. We also applied minor revisions to meet the quality standards of OS. We call these minor revisions because they aim to enhance the easiness of reading and understanding our paper without changing the meaning of the original content. Some of these revisions imply a rewording of sentences or rearranging of paragraphs. Since we apply a large number of minor changes throughout the entire manuscript, we only list the most important ones for brevity:

1. We rearrange paragraphs by moving lines 189 - 191 and 193 to lines 166 - 168.
2. We adapt the tense to the narrative in line 251.
3. We move "however" from line 305 to line 306 to put the emphasis on our research.
4. We rewrite a cumbersome sentence in lines 334 - 336.
5. We clarify that the distributions in Fig.4 are spatial distributions with 2000-2019 being the reference period in line 355 (caption of Fig. 4).
6. In line 371, we clarify that we make this conclusion based on the previous paragraph, not only based on the previous sentence.
7. We clarify that water parcels within coherent eddies rotate *within* and not *about* closed transport barriers in line 394.
8. We correct a preposition and specify that we mean *coherent* eddies in line 536.
9. We remove a contestable and redundant expression in line 539.
10. We correct the symbol for the mean retention time of hyperbolic drifter motion in line 589.
11. We remove the term "first-order" in line 610 since it incorrectly expresses that our velocity data would be a first-order choice compared to other mesoscale observations.
12. In order to avoid repetitions, we shorten lines 634 - 639 and move them to 622 - 625.

4 Other revisions to be mentioned for disclosure

changes

In the previous versions, multiple references within one referencing command had no specific order. We now follow the OS requirements and, in such cases, order references by date. This causes the reference changes made in lines 44 (caption of Fig. 1), 47 - 48, 318, 353 and 525 - 526.

changes

We insert "of the study domain" in the caption of Fig. 1 in line 44 to clarify to what the term "boundaries" refers.

changes

We acknowledge that our previous descriptions of the vorticity curves $\zeta(\alpha)$, the removal of the average background vorticity from each curve, and the usage of the normalised vorticity curves $\hat{\zeta}(\alpha)$ were somewhat confusing about when and for what purpose these are computed. An average background vorticity is removed from each vorticity curve $\zeta(\alpha)$ for the detection of vorticity patterns. We use normalised vorticity curves $\hat{\zeta}(\alpha)$ only for visualisation purposes. We clarify this and correct wrong variables with the changes made in lines 255 - 258, 406 - 409, 411 (caption Fig. 6), 419, 425 (caption Fig. 7) and 456 (caption Fig. 8).

changes

We insert "observed" in the caption of Fig. 3 in line 259 to clarify that we are demonstrating real observations of drifter movement in the ocean. We complete this by indicating the source for these observations a few lines later within the caption.

changes

The pair algorithm works from a drifter's perspective, but we show results that refer to the TRAP core. In lines 273, 274 and 277, we clarify why this is possible.

changes

One might actually create statistics from drifter-TRAP pairs that last for one day. However, we cannot derive any statistics from them that are useful for our study purposes. We clarify this by inserting "useful" in line 301.

changes

In line 375, we clarify that the article does not provide the mentioned histogram of the mean eddy contour speeds U.

changes

The changes in lines 476, 481 and 499 arise from changing internal labels within the latex version of the manuscript. However, these table and figure numbers are already correct within the previous manuscript versions.

changes

We remove the term "however" in line 542 because the statement by Abernathey and Haller (2018) is actually consistent with the results by Early et al. (2011).

changes

In line 677 we now mention the identification number of the funding DFG project. In lines 678 - 679, we now also thank the handling editor for reviewing the new version of the manuscript.

References

Abernathey, R. and Haller, G.: Transport by Lagrangian Vortices in the Eastern Pacific, Journal of Physical Oceanography, 48, 667–685, https://doi.org/10.1175/JPO-D-17-0102.1, 2018.

AVISO+, CNES, SSALTO/DUACS, and IMEDEA: The altimetric Mesoscale Eddy Trajectories Atlas 3.2 Delayed-Time (META3.2 DT) Allsat Version, AVISO+ [dataset], https://doi.org/10.24400/527896/a01-2022.005.220209, 2022.

Early, J. J., Samelson, R. M., and Chelton, D. B.: The Evolution and Propagation of Quasigeostrophic Ocean Eddies, Journal of Physical Oceanography, 41, 1535–1555, https://doi.org/10.1175/2011JPO4601.1, 2011.

Serra, M.: Compute Transient Attracting Profiles (TRAPs), GitHub [code], https://github.com/MattiaSerra/TRAPs, 2020.