Replies to referee 2: Transient Attracting Profiles in the Great Pacific Garbage Patch

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We thank the referee for their careful summary of our research project and for their helpful comments on our paper.

Summary by the referee

This manuscript applies the theory of Transient Attracting Profiles (TRAPs, defined as regions of strong attraction identified from the instantaneous velocity field) to identify regions of attraction in the Great Pacific Garbage Patch. Using a 20-year long dataset, the authors track TRAPs through time, identifying regions in the garbage patch that exhibit large numbers of TRAP trajectories, regions that exhibit the longest-lived TRAP trajectories, and regions with the highest average attraction rates. They correlate the location of TRAPs to the edges of mesoscale eddies, identifying a typical quadrupole pattern of eddies around a given TRAP. They also show that drifters are typically attracted to TRAPs, with shorter retention times on average compared to TRAP lifetimes.

Overall, the manuscript provides a novel analysis and is a nice contribution to the field. Below I provide some major and minor comments that I think would help to improve the manuscript.

Major comments:

1 Temporal continuity of TRAPs

The most important issue to address is the temporal continuity of TRAPs. TRAPs by definition, are features that arise in the instantaneous velocity field, and the Serra et al. (2020) paper describes TRAPs as *'short-term attractors'*, and that *'TRAPs necessarily persist over short times'*, with an example of a TRAP existing for several hours. They used a high-spatial resolution HF Radar dataset, along with a high-resolution MIT-MSEAS forecast model with hourly output. Their focus was, of course, on the timescale of hours due to the search and rescue nature of their paper.

Lifetimes of TRAPs in this manuscript are in the timescale of days to almost a year long, and it's not clear to me how spatially proximate detections of TRAPs at consecutive timesteps necessarily determine that these TRAPs are the same object. TRAPs are, by definition, instantaneous features that *'necessarily persist over short times'* (Serra et al. (2020)). They could emerge, persist for hours, and later die, all within a day.

Can the authors provide more evidence on why TRAPs can be tracked on timescales of days (and months), when they may not exist for more than, as I understand, a few hours? Could successive TRAP identifications simply be older TRAPs decaying and newer TRAPs emerging? The comparison with drifter-TRAP pairs shows typical retention times of just a few days, with the largest retention time being 46 days, far shorter than the longest lifetime of a tracked TRAP. As it stands, I don't think there is enough in the manuscript to make that connection, and additional justification is needed.

reply

We appreciate the comment and agree that this is an important aspect that needs clarification. The theory behind TRAPs guarantees their existence for short periods but says nothing about their existence at larger timescales. When Serra et al. (2020) mention that TRAPs 'necessarily persist over short times' they are not implying they cannot persist for longer periods. Serra et al. (2020) chose a period of 6 hours, which is a reasonable choice for a "short" timescale (relative to typical oceanic timescales), and, importantly, a critical timescale for search and rescue operations. However, the lifespan of a TRAP depends on the oceanic structures that give rise to the hyperbolic-type Lagrangian motion that TRAPs are designed to identify. Indeed, Serra and Haller (2016) show different types of OECSs, including TRAPs, computed from altimetry data, that last at least six days. In our paper, we show that TRAPs are closely related to vorticity patterns in general, and eddy-like features in particular. Thus, we do not find it surprising that mesoscale TRAPs would have lifetimes comparable to those mesoscale features, typically measured in months and not days.

We note that our drifter-TRAP pair results are observations of the hyperbolic-type Lagrangian motion induced by TRAPs, and therefore a confirmation of the persistence of TRAPs over periods considerably longer than a few hours. We know from our drifter-TRAP statistics that, over about a week, drifters are attracted normally to a TRAP, to then accelerate and leave the TRAP in a tangential direction. Given that the drifter and altimetry datasets are independent oceanic observations, we have shown that TRAPs often persist for at least a week. However, due to the relatively quick transport time of a drifter in the vicinity of a TRAP, it should be expected that a TRAP's lifetime can be considerably longer than a week. Hence, the fact that we observe small drifter retention times is not at odds with long TRAP lifetimes. Importantly, we note that the behavior of drifters in the vicinity of TRAPs that are forming or decaying is clearly distinct from the hyperbolic behavior that is observed in drifters when TRAPs neither form nor decay. Thus, the trajectories of drifters in the vicinity of TRAPs proves that we are following the same TRAP and that we are not following different TRAPs that form and decay quickly at similar locations.

An independent example of satellite-observed TRAPs that persist for at least a week while inducing independently-observed tracer deformation can be found in Duran et al. (2021).

We will address the temporal continuity of TRAPs with a new paragraph in the Introduction between the ones starting in line 85 and line 91:

> Since altimetry can be seen as a filter for the ocean circulation that separates out all small-scale, short-term features of the flow, our study is naturally embedded in the low-frequency circulation. This motivates us to locate TRAPs within the mesoscale eddy field by comparing our dataset to corresponding records of mesoscale eddy detections. We investigate how these coherent structures relate in order to advance our understanding of strain between eddies and how it can be utilised to predict debris transport.
>
> Serra et al. (2020) mention that TRAPs 'necessarily persist over short times' with examples of TRAPs existing for several hours and attracting nearby objects within two to three hours. These time scales of persistence and impact are derived from TRAPs that are computed from submesoscale velocity fields with a high tempo-spatial resolution. But the concept is in principle scale-invariant and can be applied to velocity data of any resolution. TRAP characteristics will depend on the velocity data which is used for their computation and therefore, the lifetime and impact of TRAPs will be relative to the time scales of the oceanic structures that give rise to the hyperbolic-type Lagrangian motion that TRAPs identify. This is why Duran et al. (2021) find persistent TRAPs that predict transport patterns eight days in advance. They compute TRAPs from mesoscale surface velocities with daily frequency and consequently study these structures at larger scales than Serra et al. (2020). With our choice of altimetry data, we follow Duran et al. (2021) and expect mesoscale TRAPs to exist and impact on time scales comparable to those of mesoscale flow features. Indeed, some examples from altimetry data in Serra and Haller (2016) show that different types of OECSs, including the attracting hyperbolic type studied here, can last for at least six days.
>
> TRAPs that persist over several days will then highlight permanent features of the flow where we might find large-scale confluence of material. The detection of persistent TRAPs can therefore help to point cleanup operations in

the right direction which motivates us to design a tracking algorithm that follows TRAPs through space and time. We are the first to track these Eulerian flow features, to determine their lifetimes and to describe their propagation through the domain. We further combine these findings with observations of surface drifters to investigate the TRAP properties that are relevant for an offshore cleanup in the Great Pacific Garbage Patch. However, the findings we make also have the potential to facilitate maritime search operations in other contexts and regions.

Our study shows from large datasets that TRAPs persist over periods considerably longer than the short period mathematically guaranteed to exist. We therefore propose to add the following lines to the paragraph starting in line 440 so that this result can be explicitly stated:

There are obvious limits to the application of this mesoscale permitting dataset. The effective resolution in space and time can be expected to be greater than the 0.25° latitude-longitude grid and the daily frequency. We observe the effects of this in animations where TRAPs reappear after a one-day gap. At such a gap, our tracking algorithm defines a new trajectory and therefore TRAP lifetimes might be underestimated. Similarly, detection gaps affect the identification of drifter-TRAP pairs, leading to an underestimation of retention times. Nevertheless, we find a remarkable consistency between Duran et al. (2021) and our study. They find persistent mesoscale TRAPs that predict the spread of surface oil at least eight days in advance and confirm our finding of retention times of $\varphi = (5.3 \pm 3.8)$ days for hyperbolic drifter motion. The agreement between their study and ours, as well as the overall similar behaviour we observe for drogued and undrogued drifters, further underlines the concept's robustness against differences in tracer properties.

Our results for drifter-TRAP pairs are observations of the hyperbolic-type Lagrangian motion induced by TRAPs, and therefore a confirmation of the persistence of TRAPs over periods considerably longer than a few hours, which is the lifetime of a TRAP that is mathematically guaranteed to exist. We know from our drifter-TRAP statistics that, over about a week, drifters are attracted normally to a TRAP to then accelerate and leave the TRAP in a tangential direction. Given that the drifter and altimetry datasets are independent oceanic observations, these statistics show that TRAPs often persist for at least a week. Importantly, we note that the behaviour of drifters in the vicinity of forming or decaying TRAPs is distinct from the hyperbolic behaviour observed near TRAPs that are neither forming nor decaying. This shows that we are following the same TRAP and not following different TRAPs that quickly form and decay at locations that coincide with the path of propagating eddies. Due to the relatively short transport time of a drifter in the vicinity of a TRAP, it is expected that a TRAP's lifetime can be considerably longer than a week. Indeed, the persistent relation between TRAPs and mesoscale vorticity structures that we report, including the similarity in their propagation speed, suggests that the lifetimes of mesoscale TRAPs are often related to the lifetime of long-lived mesoscale structures. Duran et al. (2021) present another example of the temporal continuity of TRAPs and their influence on hyperbolic tracer deformation, again from independent observations. The hyperbolic nature of this latter deformation pattern is established in Olascoaga and Haller (2012) and Duran et al. (2018).

2 Additional mathematical rigour

Section 2.1 Transient Attracting Profiles. This section would benefit from a more thorough description of the theory of TRAPs. In particular, additional rigour in the mathematics is required to make the method more readable to users. As I understand, $s_i = s_i(\boldsymbol{x},t)$ are, in fact, eigenvalue fields, and $e_i = e_i(\boldsymbol{x},t)$ are eigenvector fields. The manuscript then describes e_1-lines and e_2-lines, along with local minima of s_1 and local maxima of s_2 , which from the current description of s_i and e_i don't make sense. This section (and later sections) would benefit from more careful notation and rigour.

reply

We acknowledge that our mathematical description of the concept requires more clarification. We propose to edit the description starting in line 107 as follows:

Serra et al. (2020) derive TRAPs from the instantaneous strain field of the ocean surface using snapshots of the two-dimensional surface velocity field $\boldsymbol{u}(\boldsymbol{x},t)$. The symmetric part of the velocity gradient represents the time-dependent strain tensor $\mathbf{S}(\boldsymbol{x},t) = \frac{1}{2}(\boldsymbol{\nabla u}(\boldsymbol{x},t) + [\boldsymbol{\nabla u}(\boldsymbol{x},t)]^\top)$ with the eigenvalue fields $s_i(\boldsymbol{x},t)$ and eigenvector fields $\boldsymbol{e}_i(\boldsymbol{x},t)$. $\mathbf{S}$, s_i and $\boldsymbol{e}_i$ denote the respective quantities at a fixed position $\boldsymbol{x}_0$ and time t_0 and we apply the notation for the diagonal form of $\mathbf{S}$ from Serra and Haller (2016):

$$\mathbf{S}\boldsymbol{e}_i = s_i\boldsymbol{e}_i, \quad |\boldsymbol{e}_i| = 1, \quad i = 1,2; \quad s_1 \leq s_2, \quad \boldsymbol{e}_2 = \mathbf{R}\boldsymbol{e}_1, \quad \mathbf{R} := \begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix} \tag{1}$$

The deformation of any fluid's surface element A is determined by the local strain rates s_i which specify the rates of stretching $(s_i > 0)$ or compression $(s_i < 0)$ of A along the principle axes indicated by the local eigenvectors $\boldsymbol{e}_i$, see Olbers et al. (2012) for details. Due to the condition $s_1 \leq s_2$, the local eigenvector $\boldsymbol{e}_1$ describes the direction of minimal and $\boldsymbol{e}_2$ the direction of maximal stretching for a non-uniform deformation. The compression and stretching of surface elements translates into the attraction and repulsion of material and negative local minima of $s_1(\boldsymbol{x},t)$ therefore describe the most attracting regions of the flow, maximising attraction normal to $\boldsymbol{e}_2$ at the respective position. For incompressible conditions, $s_1 = -s_2$ further holds and local minima of $s_1(\boldsymbol{x},t)$ simultaneously indicate local maxima of $s_2(\boldsymbol{x},t)$. The strongest attraction and strongest repulsion then occur at the same position and in orthogonal directions.

TRAPs indicate the most attracting regions of the flow as they start at negative local minima of the $s_1(\boldsymbol{x},t)$ strain field and extend tangent to the local eigenvectors $\boldsymbol{e}_2$ until the strain rate s_1 along the tangent ceases to be monotonically increasing. Consequently, TRAPs contain one minimum value of $s_1(\boldsymbol{x},t)$, i.e. the point of strongest attraction perpendicular towards the TRAP. The position of this local minimum is called the TRAP *core* which represents an objective saddle-type stagnation point of the unsteady flow (Serra and Haller, 2016). The TRAP itself, as it is at every point tangent to the unit eigenvectors $\boldsymbol{e}_2$ describes the direction of maximal stretching and will in the following also be referred to as TRAP *curve*.

We will also differentiate more carefully between field quantities $\mathbf{S}(\boldsymbol{x},t)$, $s_i(\boldsymbol{x},t)$ and $\boldsymbol{e}_i(\boldsymbol{x},t)$ and local quantities $\mathbf{S}$, s_i and $\boldsymbol{e}_i$ throughout the rest of the manuscript:

line 128: underlying $s_1(\boldsymbol{x},t)$ strain field

line 130: of the $s_1(\boldsymbol{x},t)$ field

caption Fig. 2: the colourmap indicates the $s_1(\boldsymbol{x},t)$ strain field

row 3 Table B1: while other structures like e.g. $s_1(\boldsymbol{x},t)$ minima

3 Spatial analysis of TRAP trajectories

Section 3.1 Spatial distribution of TRAPs. I like the spatial analysis, however I think it is hampered by the same problem that spatial analyses using Lagrangian approaches have. Specifically, that trajectories of TRAPs (like Lagrangian particles) that start outside of the domain and later enter the domain (or TRAPs that start in the domain and shortly exit the domain), will be undersampled throughout their true lifetimes, and necessarily have shorter lifetimes (on average) than those that start and remain in the domain throughout their entire lifetimes. Given the size of the domain, the timescales of the largest TRAP lifetimes, and the 20-year duration of the dataset, can the authors comment on any bias this might have on the analysis?

reply

We acknowledge that this effect occurs within our tracking procedure. We also consider it important to clarify any bias on our lifetime statistics since our analysis depends on TRAP lifetime. We propose to address this topic in the paragraph starting line 152 as follows:

> Our tracking algorithm runs on the full TRAPs record and finds spatially proximate detections at consecutive timestamps which can be identified as one single feature of the flow. The only free parameter ϵ defines the size of the search area around a current TRAP to look for a detection in the next snapshot and is set to $\epsilon = 0.25°$, see Kunz (2024) for more details. The algorithm assigns a unique label to each TRAP trajectory and its associated instances and it derives metrics like e.g. the lifetime Λ of TRAPs and their age τ at a particular snapshot. The programme only captures the time spent *inside* the study domain and period and therefore gives rise to potential bias in the lifetime estimation of TRAPs that reach beyond the tempo-spatial limits of the domain. However, we find that only 5.4% of all TRAP trajectories are adjacent to these limits and might not entirely occur within the study domain, but our conclusions and particularly the TRAP lifetime distributions don't change if those biased trajectories are excluded, see Section 3 in the Supplementary Material where we analyse this in detail. With the trajectory estimation, we can now derive the zonal and meridional translation speeds c_x and c_y for every instance of a TRAP trajectory. Therefore we choose all TRAPs that persist for at least three days and average the forward and backward shifted velocity at a current timestamp. The forward/backward shifted velocity is the distance to its succeeding/preceding position divided by the time lapsed between both instances, respectively. This way we deliberately create no velocities at the start and end of a trajectory and do not gain propagation speeds for trajectories of two days lifetime. In turn, we obtain translation speeds of individual TRAP instances which we consider more accurate than taking the full distance travelled by a TRAP and dividing it by the respective lifetime.

Then we will include the following explanation together with Fig. 1 and Table 1 as a new Section 3 in the Supplementary Material:

> In Section 2 of the Supplementary Material and in the documentation of our tracking algorithm (Kunz, 2024), we define the search area around a TRAP to look for future detections by a box reaching $\pm\epsilon$ in zonal and meridional

direction around the position of the current TRAP core. There, we also motivate our choice of $\epsilon = 0.25°$ and we use this parameter in Kunz (2024) to define a smaller ϵ-domain with the new boundaries displaced by ϵ from the original domain boundaries. The boundaries of the ϵ-domain are exclusive.

When a TRAP core is located outside the ϵ-domain, its past/future position within the search box may be on or beyond the boundaries of the original study domain - but we do not detect TRAPs there. As a consequence, TRAP trajectories that reach beyond the ϵ-domain at least once have the potential to be shortened because they might originate from outside the domain or continue there. Their lifetime would then be underestimated. But lifetimes can also be overestimated beyond the ϵ-domain due to a wrong association of two close trajectories for which additional data is hidden behind the boundaries of the study domain. The algorithm corrects to some extent for the second case, see *bias circles* in Kunz (2024), while it is agnostic to the first case. Because the second case presupposes the first one, we expect that lifetimes are generally underestimated for detections beyond the ϵ-domain.

A similar boundary error may occur at the temporal limits of our dataset. TRAP trajectories that start on the first or end on the last day of our record might have existed before or might continue to exist after the study period, respectively.

To estimate the bias that might result from these boundary effects, we filter the TRAPs record for trajectories that reach outside the ϵ-domain or that occur on the first or the last snapshot of our record. We find that 5.4% of all TRAP trajectories fulfil one of these conditions and are therefore susceptible to a spurious lifetime estimation (with 5.2 percentage points being attributed to the spatial limits only). We flag these trajectories as potential bias and define four groups of trajectories:

1. the *biased* dataset, i.e. the original TRAPs record
2. the *bias* subset of trajectories with potentially spurious lifetime estimation
3. the *debiased* subset which only consists of trajectories that stay within the tempo-spatial limits of the experiment, i.e. the biased set excluding the bias set
4. the *corrected* dataset with lifetimes increased by 13 days for all trajectories that are part of the bias subset, 13 days is one standard deviation of the lifetime distribution within the debiased set

In Fig. 1 we present the distribution of TRAP lifetime Λ within each of these groups. It illustrates that the bias potentially introduced by the tempo-spatial limits of the experiment, i.e. trajectories entering or leaving the domain and period, is negligible since the biased and debiased lifetime distributions in panel (a) as well as the biased and corrected distributions in panel (b) almost perfectly coincide. In panel (b), we try to compensate for lifetime underestimation by simply increasing spurious lifetimes by one standard deviation of the debiased distribution.

In Table 1 we compare a few statistics for the biased, the debiased and the corrected datasets. The subtle differences between the subsets confirm that these boundary effects are negligible and that the 5.4% potentially spurious lifetime estimations do not affect the main findings of our paper. We note that our approach here is conservative and therefore will produce false positives which require an individual examination. Future studies might however try to further reduce the impact of these boundary effects by e.g. choosing a larger domain.

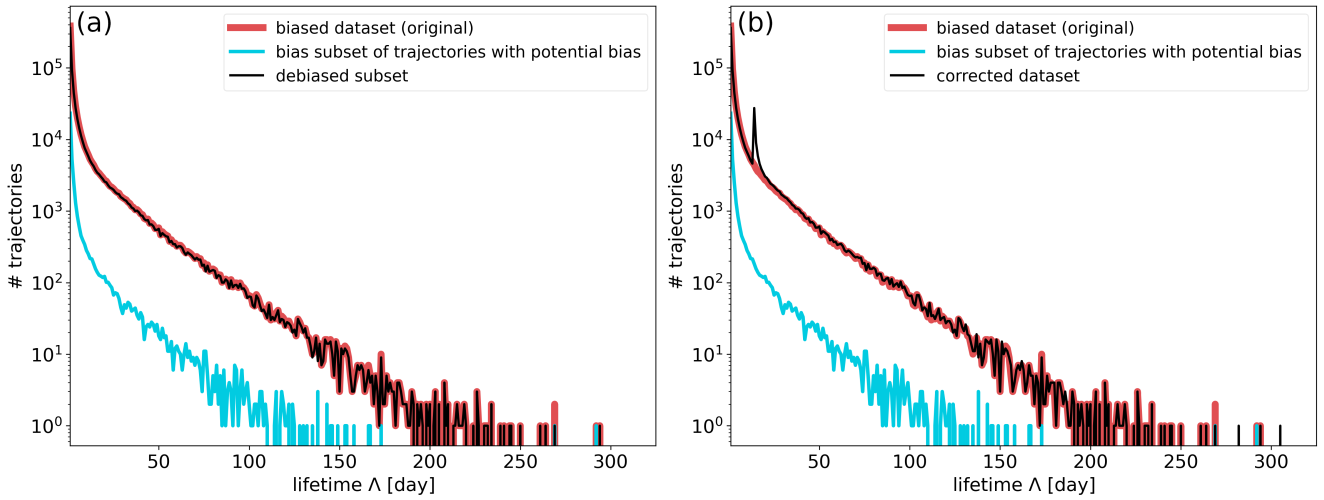

Figure 1. Distribution of TRAP lifetime Λ within different subsets of the TRAPs record. (a) The red line indicates the distribution within the *biased* dataset, i.e. the original TRAPs record as shown in Fig. 5 of the manuscript, the blue line represents the distribution of the *bias* subset and the black line indicates the *debiased* subset. (b) as (a) but with the black line indicating the distribution for the *corrected* dataset.

Table 1. Comparison between TRAP lifetime statistics from the biased (original), the debiased and the corrected datasets. Trajectories that might enter and/or leave the study domain and/or period represent the potential bias. Mean values are given together with one standard deviation σ.

position in manuscript	metric	biased dataset	debiased dataset	corrected dataset
line 266	average TRAP lifetime $\overline{\Lambda}$	(5.66 ± 12.38) days	(5.74 ± 12.48) days	(6.36 ± 12.65) days
line 268	share of long-living TRAP trajectories with $\Lambda > 30$ days	4.3 %	4.4 %	4.5 %
line 268	share of TRAP instances associated with long-living TRAP trajectories with $\Lambda > 30$ days	40.5 %	40.8 %	41.1 %
line 253	mean attraction strength $\overline{s}_1$ of instances associated with long-living TRAPs with $\Lambda > 30$ days	(-0.283 ± 0.111) s^{-1}	(-0.281 ± 0.108) s^{-1}	(-0.283 ± 0.111) s^{-1}
line 253	mean attraction strength $\overline{s}_1$ of instances associated with 'short'-living TRAPs with $\Lambda \leq 30$ days	(-0.198 ± 0.087) s^{-1}	(-0.197 ± 0.084) s^{-1}	(-0.197 ± 0.085) s^{-1}

Minor comments:

1. **Overall, the manuscript would benefit from additional editing, for language and grammar, as some parts of the manuscript are a little hard to follow.**

   Our replies to referee 1 and referee 2 involve many editions to the original manuscript. Therefore, we will check the revised manuscript for correct spelling, grammar and language and apply necessary corrections before submitting the revised manuscript for peer-review completion and potential final publication in OS.

2. **The abstract contains notation ($\overline{\Lambda}$, and $\overline{\varphi}$) which are somewhat confusing if not explained, I would stick to more plain language.**

   We will apply the following editions:

   line 14: on average lasts for six days

   line 15: TRAPs with lifetimes greater than 30 days

   line 18: a streamlined bypass takes on average five days

3. **Throughout the manuscript, the authors describe 'attractive regions' in the flow. To be consistent with typical dynamical systems literature, these should be described as 'attracting regions', 'attractors', or 'regions of high attraction'.**

   We will apply the following editions:

   line 7: the most attracting regions of the flow

   line 8: TRAPs are the attracting form of

   line 26: indicate the most attracting regions of the flow

   line 61: it allows to detect the most attracting regions of the flow

   line 62: TRAPs are the attracting form of

   line 116: describe the most attracting regions of the flow

   line 201: highlight the most attracting regions

   But we propose to remain with the following terms:

   line 11: about the persistence and attractive properties

   line 75: since the persistence and attractive properties

   line 241: the most attractive TRAP

   line 355: for increasingly attractive TRAPs

4. **Line 73, the authors mention 'inevitable errors'. Can they expand on what these errors are? Inevitable in the sense of those that Serra et al. (2020) mention with numerical integration schemes, or other errors?**

We mean inevitable errors in the sense of those described in Serra et al. (2020) and propose to replace the respective phrase starting line 70 as follows:

> Moreover, Serra and Haller (2016), Serra et al. (2020) and Duran et al. (2021) argue that TRAPs are more robust to moderate errors in the underlying velocity field while trajectory-based methods are susceptible to error accumulation during the velocity integration, see Table B1 for more details and benefits of the TRAPs method.

5. **In Section 2.2-2.6, the authors use a maximal arclength of 1°, a search area of ϵ = 0.25° (which corresponds to the model resolution), and a maximal drifter-TRAP pair distance of 75km. These choices seem a little arbitrary, can the authors comment on why they chose these parameters? Could one, for instance, choose a drifter-TRAP pair distance that is related to the TRAP attraction rate? Weak TRAPs may not influence debris 75km away, but strong TRAPs can?**

1° TRAP length and 75 km search radius

We have received similar comments from referee 1. For a statement on the 1° maximal arclength and the 75 km search radius, we would like to point referee 2 to *Section 2: Parameter choices* in our response to referee 1. The idea to dynamically relate the search distance for drifter-TRAP pairs to the TRAP attraction rate is similar to the other referee's suggestion of defining a 'basin of influence' around a TRAP. We also discuss this point in our reply to referee 1.

choice of ϵ

We already motivate our choice of $\epsilon = 0.25°$ in the documentation of our tracking algorithm (Kunz, 2024). We now also include a new section in the Supplementary Material where the choice is motivated and explained in detail. We added in line 153ff of the paper:

> The only free parameter ϵ defines the size of the search area around a current TRAP to look for a detection in the next snapshot and is set to $\epsilon = 0.25°$. A larger value for the algorithm creates 'jumps' from a current to an unrealistically far future TRAP detection and overestimates trajectory lengths, see Section 2 in the Supplementary Material for a detailed explanation and motivation of this choice.

And we will include the following description as new Section 2 in the Supplementary Material:

> We define the search area around a TRAP to look for future detections by a box reaching $\pm\epsilon$ in zonal and meridional direction around the position of the current TRAP core. We have tested the tracking algorithm for different values of ϵ and find that the distribution of TRAP lifetimes Λ broadens with increasing ϵ until it remains practically constant for $\epsilon \geq 0.75°$. The longest TRAP lifetime Λ_{max} likewise plateaus for $\epsilon \geq 0.75°$. Table 2 lists the tested values of ϵ together with the respective value of Λ_{max}. The broadening of the lifetime

distribution from $\epsilon = 0.1°$ to $\epsilon = 0.75°$ occurs because small values of ϵ will lead to underestimated while large values of ϵ to overestimated TRAP trajectory lengths. In the first case, the search box is too small to capture the future position of a TRAP while in the last case, the algorithm creates 'jumps' from a current to an unrealistically far future TRAP detection. To choose a sensible ϵ-value from this range, we can derive the highest possible absolute TRAP propagation speed $c_{max}(\epsilon)$ in each realisation and compare it to propagation speeds of mesoscale eddies, as e.g. given in Abernathey and Haller (2018); Chelton et al. (2011), because we expect a relation between these mesoscale flow features.

ϵ defines the maximal distance which can be tracked between a current and a future TRAP position. This distance limit ranges between ϵ in purely zonal or meridional direction and $\sqrt{2}\epsilon$ in purely northwest, southwest, southeast or northeast direction, i.e. into each corner of the box. The upper threshold for the absolute TRAP propagation speed $c_{max}(\epsilon)$ consequently depends on direction and ranges between $c^{+}_{max}(\epsilon)$ in purely zonal or meridional direction and $c^{\times}_{max}(\epsilon)$ in purely northeast, northwest, southwest or southeast direction. Practically, the algorithm allows higher propagation speeds towards intercardinal directions. The limits of this range can be approximated as follows:

$$c^{+}_{max}(\epsilon) \approx \frac{111120\ \mathrm{m}}{1\ \text{degree arclength}} \cdot \frac{\epsilon}{86400\ \mathrm{s}}$$

$$c^{\times}_{max}(\epsilon) = \sqrt{2} \cdot c^{+}_{max}(\epsilon)$$

A future version of the algorithm should use a search circle to remove this sensitivity to direction. Table 2 presents the values of c^{+}_{max} and $c^{\times}_{max}$ for each test run. Propagation speeds of mesoscale eddies typically range below $0.2\ \mathrm{m\ s^{-1}}$ and even less for the latitudes that we study (Abernathey and Haller, 2018; Chelton et al., 2011). Therefore it seemed reasonable to discard test runs with $\epsilon \geq 0.5°$ because they certainly include TRAPs with propagation speeds above $0.32\ \mathrm{m\ s^{-1}}$ which is revealed by the increase of Λ_{max} when switching from $\epsilon = 0.25°$ to $\epsilon = 0.5°$. On the other hand, $\epsilon = 0.1°$ could be too restrictive on TRAP propagation speeds because mesoscale features might, even if rarely, move with speeds above $0.13\ \mathrm{m\ s^{-1}}$. Moreover, $\epsilon = 0.1°$ is below the technical resolution of our velocity data. For these reasons, we considered $\epsilon = 0.25°$ as a reasonable choice for the analysis.

Table 2. Values of the search box parameter ϵ for which the tracking algorithm has been tested together with the longest TRAP lifetime measured Λ_{max} and upper threshold for absolute TRAP propagation speed c_{max}.

ϵ [degree arclength]	0.10	0.25	0.50	0.75	1.00	1.25	1.50
Λ_{max} [day]	197	294	302	321	321	321	321
c^{+}_{max} [$\mathrm{m\ s^{-1}}$]	0,13	0,32	0,64	0.97	1,29	1,60	1,93
$c^{\times}_{max}$ [$\mathrm{m\ s^{-1}}$]	0,18	0,46	0,91	1.36	1,82	2,27	2,73

After the tracking procedure, we computed the zonal and meridional propagation speed of individual TRAP detections which allows us to compare the distribution of absolute TRAP translation speeds c with the estimated thresholds c_{max}^{+} and $c_{max}^{\times}$ from Table 2 and to evaluate our choice of $\epsilon = 0.25°$. We further measured the surface geostrophic + Ekman current velocity at the position of every TRAP core which provides an additional distribution of flow velocities around these features. In Fig. 2 we show these two distributions of absolute TRAP and absolute surface velocities.

First, we see a clear difference between both distributions which indicates that TRAPs are not advected by the flow. TRAP propagation speeds are generally smaller than geostrophic + Ekman currents. Next, we see that a choice of $\epsilon = 0.1°$ would have caused an underestimation of TRAP trajectories since the respective limits of $c_{max}^{+}(0.1°)$ and $c_{max}^{\times}(0.1°)$ would cut-off the smooth tail of the distribution of TRAP propagation speeds. This is different for the choice of $\epsilon = 0.25°$ where most of the tail is preserved by $c_{max}^{+}(0.25°)$ and the distribution ends well before $c_{max}^{\times}(0.25°)$. It suggests that the search box is large enough to capture the majority of TRAP propagation speeds, i.e. future TRAP positions, in any direction. And it is small enough to prevent 'jumps' to unrealistically far future TRAP detections, in intercardinal directions, that would artificially extend the distribution up to the limit of $c_{max}^{\times}(0.25°)$. Since the highest measured TRAP translation speed lies clearly within the range between $c_{max}^{+}(0.25°)$ and $c_{max}^{\times}(0.25°)$, we expect the optimal value of ϵ within this range. Future studies could fine-tune this parameter using a search circle instead of a box. Optimising ϵ for TRAPs at different scales would be another valuable contribution since it makes the algorithm applicable to different kinds of velocity sources.

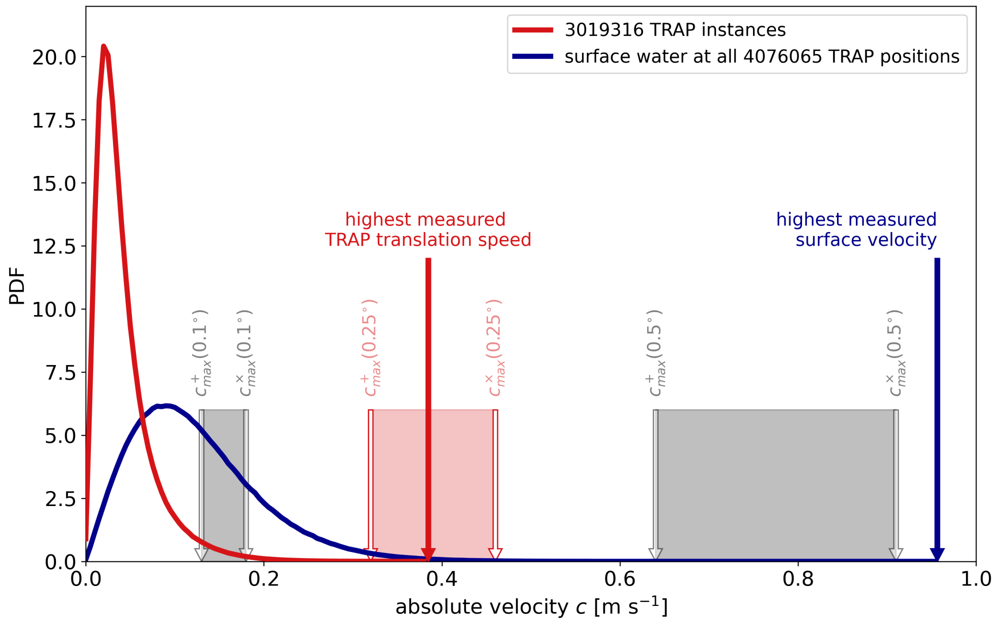

Figure 2. Distribution of absolute TRAP and surface water velocities. The red line illustrates the distribution of all measured absolute TRAP translation speeds c. The blue line presents the distribution of absolute geostrophic + Ekmann current surface velocities measured at *all* TRAP positions. Filled arrows indicate the maximum value of each distribution, empty arrows the upper thresholds $c^{+}_{max}(\epsilon)$ and $c^{\times}_{max}(\epsilon)$ of absolute TRAP propagation speed, displayed for three values of the search box parameter ϵ. The shaded bands illustrate the range between these upper thresholds which results from the dependence of $c_{max}(\epsilon)$ on direction due to the geometry of the search box.

6. **The authors use a 0.25° spatial resolution velocity dataset, which is quite coarse for operational purposes. Would the authors expect similar results (and similar statistics) when using a higher resolution velocity field (e.g. 0.1° eddy-resolving, or even higher submesoscale resolving velocity fields more commonly used for operational purposes)?**

   We acknowledge that in the manuscript, we should highlight that different statistics can be expected for TRAPs computed from submesoscale velocities. We have received similar comments from referee 1 and we would like to point referee 2 to *Section 1: Mesoscale velocity data* in our response to referee 1. There we propose important editions to the manuscript.

7. **In the discussion around Figure 4, can the authors give further explanation for why the locations of the strongest average attraction rate, number of TRAP trajectories, and largest average TRAP lifetimes don't correlate well? Could this be hampered by the major point above (point 3)?**

   We acknowledge that this result requires more explanation. We propose to complement line 261 as follows:

   > We summarise that TRAP trajectories are very abundant but only remain for a few days around the eddy desert while they become less abundant but more persistent towards the equator and the eastern boundary. It suggests that the underlying oceanic structures that create TRAPs show different characteristics for these two regions. Our observations are therefore consistent with the sparse occurrence of weak mesoscale eddies in the eddy desert around the northern domain boundary (Chelton et al., 2011) and with the generation of energetic mesoscale eddies around the CALUS and the NHRC (Pegliasco et al., 2015; Lindo-Atichati et al., 2020), which eventually propagate through the southeastern part of the domain.

   The different spatial distributions we see in Fig. 4 of the manuscript do not effect from TRAPs that enter or leave the domain. We have demonstrated in point 3 that the 5.4% potentially spurious trajectories do not affect the main findings of our paper and therefore are not expected to have a visible impact on our spatial histograms. Moreover, panel (a) in Fig. 4 cannot be affected by this problem since it is based on TRAP instances. Panel (c) can neither be affected because it counts the number of TRAP trajectories which would remain constant for a truncation of trajectories at the domain boundaries. If panel (c) was hampered by the underestimation of lifetimes for entering or leaving TRAPs, we should see some signal of high average TRAP lifetimes $\overline{\Lambda}$ around the northeast-southwest diagonal of the domain since TRAPs are propagating westward and towards the equator. $\overline{\Lambda}$ would then decrease on both sides of this diagonal, but we do not observe such a pattern.

8. **On lines 425-426, the authors say the computations of OECSs and TRAPs are 'instantaneous'. Do the authors mean these computations are on 'instantaneous datasets'?**

   We appreciate the comment and will change line 424ff to:

   > Serra and Haller (2016) introduce elliptic OECSs which can be derived from singularities of $\mathbf{S}(\boldsymbol{x}, t)$ and build a complement to the strain-dominated regions uncovered by TRAPs, with the additional benefit of both methods being applicable to Eulerian snapshots of velocity.

9. **The paragraph on line 428 describes a debate in the community on whether mesoscale eddies accumulate and transport material, whether the transport by an eddy is largely outside of the eddy core, and whether objective methods exist that identify the periphery of an eddy. This discussion point is missing some references, and would be further enhanced with comments on the following articles which describe the transport by both the eddy core and the periphery of an eddy core:**

Early et al. (2011) (using relative vorticity in an idealised flow),
Froyland et al. (2015) (using finite-time coherent sets from a transfer operator),
Denes et al. (2022) (using finite-time coherent sets from a dynamic Laplace operator).

We appreciate the suggestion of these articles and will include respective comments in the paragraph starting line 428 as follows (note that the subsequent paragraph lines 434ff will also be modified as described in *Section 3: Drifter retention* of our reply to referee 1):

> There is an ongoing debate on whether mesoscale eddies accumulate and transport floating material. van Sebille et al. (2020) discuss confirming examples such as Brach et al. (2018), Budyansky et al. (2015) and Dong et al. (2014). Early et al. (2011) use the zero contour of relative vorticity to define eddy boundaries in an idealised flow. They show how an anticyclonic eddy core perfectly transports floats and tracers over large distances but they also explain why fluid from the outside cannot be entrained by the core. The authors illustrate that the ring of fluid around an eddy core both entrains and sheds fluid from and into the environment and can disperse material over different scales. Abernathey and Haller (2018), however, argue that transport by coherent eddies is negligible and that material transport is caused by stirring and filamentation at the periphery of strictly coherent eddies, rather than by the coherent motion within eddy cores. They emphasise the need for objective methods to identify such peripheral regions. Froyland et al. (2015) demonstrate such an objective approach using finite-time coherent sets from a transfer operator which minimises mass loss from eddy boundaries. They are able to track the long-term decay of an observed Agulhas ring and to estimate the proportion of surface water that has leaked from this coherent structure. Using their theory, Denes et al. (2022) derive finite-time coherent sets from a dynamic Laplace operator and estimate the material transport that is provided by the periphery of a modelled Agulhas ring. They show that the quasi-coherent outer ring of this eddy significantly contributes to the entrainment and retention of fluid. TRAPs are intrinsic to these peripheral regions and the concept should facilitate further understanding of these processes.

10. **The manuscript suggests that the TRAP approach is useful to marine debris cleanup operators, but the analysis is mostly statistical, analysing a large set of TRAP trajectories. A nice-to-have would be a description of how operators may use the TRAP approach in their cleanup operations.**

11. **The manuscript would benefit from more discussion around the potential applications of the TRAP-tracking approach, mentioned in the very last line of the manuscript (lines 470-471). The current main application mentioned is marine pollution cleanup, but a broader description of the applications (by expanding the very last line of the conclusion) may benefit a broader audience.**

We will address both questions 10 and 11 with this updated final paragraph starting line 463ff:

> Our results can already support offshore cleanup operations since they reveal which TRAPs are most likely to indicate the large-scale confluence of drifting objects. Operators should search for long-living TRAPs that are at an advanced stage of their life cycle. These TRAPs streamline floating objects into hyperbolic pathways. Such a streamlined bypass involves a short but strong attraction which could be exploited to *filter* the flow around a TRAP. The state-of-the-art cleanup system which operates in the Great Pacific Garbage Patch tows a two-kilometres-long surface barrier behind two vessels (The Ocean Cleanup, 2023). The system could move along TRAPs in order to act like a filter on the through-flowing water. Apparently, the scales of this system will better correspond to TRAPs computed from submesoscale observations and therefore, more research is needed to characterise TRAPs at different scales. But if enhanced submesoscale clustering can be confirmed around mesoscale TRAPs, the latter will point operations in the right direction. Moreover, this research is not limited to the subject of marine debris and various offshore applications can benefit from the detection and tracking of these hyperbolic structures. For instance, authorities might use TRAPs to mitigate sargassum transport towards ports and coastal areas where beaching events cause limited accessibility. Oceanographers can apply the TRAPs concept to optimise drifter deployments in case drifter trajectories should separate fast or remain within a specific region. If mesoscale TRAPs can indicate clustering at the submesoscale, we can expect elevated levels of organic compounds around these structures. This might help biologists to monitor and protect the foraging of pelagic species. Moreover, TRAPs make it possible to estimate oil transport at the ocean surface and might be considered in the emergency response to oil spills. Finally, and importantly, a better understanding of TRAPs will help to establish their use in the essential search and rescue operations that are constantly carried out at sea.

A couple of spelling issues:

1. **Line 153, ‘programme’ should be ‘program’.**
2. **Line 164, ‘Mesoscalle’ should be ‘Mesoscale’.**
3. **Line 265, ‘view’ should be ‘few’.**
4. **Line 304, ‘frequenlty’ should be ‘frequently’.**
5. **Line 436, ‘approx.’ can just be ‘approximately’.**

We appreciate the advice and will correct the spelling issues 2 - 5 in the manuscript. The first issue arises from the fact that we write in British English.

4 Other revisions to be mentioned for disclosure

We want to correct an unfortunate word choice in line 384:

> The situation appears rather chaotic with no specific motion pattern to detect.

Chaotic here is probably not a good choice because in the literature of trajectories and hyperbolic motion it has a specific meaning, a meaning that happens to be opposite to what we wish to convey. We propose to change this to:

> The situation appears rather disorganised with no specific motion pattern to detect.

We want to correct a typo in line 358 to keep it consistent with other numbers using a comma instead of a dot:

> We identify 33.878 drifter-TRAP pairs ...

We propose to change this to:

> We identify 33,878 drifter-TRAP pairs . . .

We will correct another unfortunate word choice in the paragraph starting line 358:

> We identify 33,878 drifter-TRAP pairs with retention times of $\varphi > 1$ day. These pairs cover 73% of all drifter days and exhibit a mean retention time of $\overline{\varphi} \approx (4.8 \pm 3.7)$ days which reflects the transient impact of TRAPs, i.e. drifters are ~~accumulated~~ attracted and dispersed again within a few days.

We will edit the the short summary in the manuscript as follows:

> TRansient Attracting Profiles (TRAPs) indicate the most attracting regions of the flow and have the potential to facilitate offshore cleanup operations in the Great Pacific Garbage Patch. We study the characteristics of TRAPs and the prospects for predicting debris transport from a mesoscale permitting dataset. Our findings provide an advanced understanding of TRAPs in this particular region and demonstrate the importance of TRAP lifetime estimations to an operational application. Our TRAPs tracking algorithm complements the recently published TRAPs concept and prepares its use with high-resolution observations from the SWOT mission. Our findings may also benefit research in other fields like e.g. optimal drifter deployment, sargassum removal, the identification of foraging hotspots or search and rescue.

And we apply the same corrections for the version on the article page:

> TRansient Attracting Profiles (TRAPs) indicate the most attracting regions of the flow and have the potential to facilitate offshore cleanups in the Great Pacific Garbage Patch. We study the characteristics of TRAPs and the prospects for predicting debris transport from a mesoscale permitting dataset. Our findings show the relevance of TRAP lifetime estimations to an operational application and our TRAPs tracking algorithm may benefit even more challenges that are related to the search at sea.

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