Revised version, 7 February, 2021

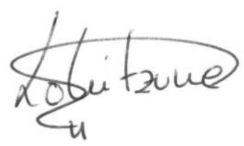
Dear Editor,

We would like to express our sincere appreciation to the reviewers and the Editor for their interest, patience and deep analysis of our manuscript, entitled “A new Lagrangian based short term prediction methodology for HF radar currents”. We would also like to thank the comments and suggestions they have proposed. The paper has been revised and carefully modified following those suggestions. They have undoubtedly helped to improve the quality of this manuscript.

Our individualized response to the first revision of Reviewer #1 and the second revision of Reviewer #2 can be found below (the location of the main changes in the text is also indicated).

Hoping the manuscript fulfils now the quality requirements of Ocean Science Journal, I look forward to hearing from you at your earliest convenience.

Yours sincerely,



Lohitzune Solabarrieta

Reviewer #1

We thank the effort made by the Referee in reviewing our Manuscript (hereinafter Ms.) entitled ***"A new Lagrangian based short term prediction methodology for HF radar currents"***. Taking in consideration the comments of the reviewers, we wanted to make a deep review to present an improved version of the Ms. We have updated the replies for the revision done by the Reviewer #1, accordingly to this new version of the Ms.

We deeply think that thanks to your comments the new version of the Ms. has improved significantly. The paper has been revised and carefully modified following your advices and comments. In the following, you can find the answers to your queries (revision received on 12-Mar-2020) as well as the changes performed in the new version.

Reviewer #1 Comments & Replies

The manuscript describes the application of the method of analogues to the prediction of Lagrangian trajectories computed from HFR.

Lagrangian trajectories are computed from an historical data set providing surface currents from HFR systems. The catalogue of these Lagrangian trajectories is the basis to be compared to any new data set, from present HFR surface currents. Then the future time evolution of the analogue provides the forecast for the present case.

The best analogue is selected in 2 steps. First the difference between the centroid of the 25 trajectories (the 48-h or the end position, is not clear) of each hour of the catalogue is compared with the centroid of the target field. Only the analogues resulting in a difference lower than 10km are selected. Then a Lagrangian error (\epsilon_ANL) is defined as the sum of the mean separation distance between trajectories computed from the catalogue fields and those computed from the target field, at 4 different times (6, 12, 24, 36 hours of advection). This error is in km^2. The field having the lowest error is selected and will provide the analogue forecast.

<u>Comments:</u>

#Q1. Why do we need the first step? I suppose that if \delta_cg is bigger than 10km, then the error is high? Is it for computational issues?

#R1. As the reviewer states this step decreases significantly the computational time. This issue has been explicitly stated in the Ms. (line 212-225).

"To increase the efficiency of this process, the search was done in two steps…"

#Q2. To assess the performance of the method, an equivalent Lagrangian error is computed. I'm not sure that the definitions of the errors (\epsilon_STP and \epsilon_PRS) (line 303-304 308-309) are correct. I think that the authors compute the forecast so next 48 hours instead of last 48 hours. Otherwise, I really misunderstood completely the method, which is possible, according to my numerous questions. For example, on Figure 3, I do not understand why the blue dots are the same in a) and c) (or (b) and (d)). The end points of a) shouldn't be the start points of c)? Either (a) is a backward trajectory plot, and (c) a forward plot, or again I'm missing some fundamental explanation.

#R2. The referee is right. ε_{STP} and ε_{PRS} are computed for forecast trajectories to compare them with realized/true trajectories, this was an unfortunate mistake in the captions. A schema of the process has also been included in the manuscript (Figure 4) to clarify the methodology. Errors have been redefined and the whole section has been rewritten. Errors are now defined in the new Ms (lines 256-277) as:

"To assess the performance of the methodology, we computed forecasted trajectories based on persistence of currents (hereinafter 'persistence fields' X_{PRS}). To obtain simulated trajectories using persistence currents, the particles are advected during 48 hours using a constant (frozen) velocity field (given by the current velocity field, or target field, V(tf)) during the 48 hours of simulation: V(x,y,tf +T)= V(x,y,tf), where tf = current time and T={1 : 48h}.
The mean drift of the truth forecasted trajectories, XTRU, is also computed for each simulation period (the mean drift is computed averaging over all the particle trajectory length during 48 hours).
The Lagrangian errors between the truth trajectories X_{TRU} and the L-STP trajectories X_{STP} were also computed as:

$$\varepsilon_{STP} = \sqrt{\frac{1}{T}\sum_{j=1}^{T}\left(\delta_{STP}(t_i)\right)^2} = \sqrt{\frac{1}{T}\sum_{j=1}^{T}\left(\frac{1}{N}\sum_{j=1}^{N}\left(X_{TRU}^{j}(t_i) - X_{STP}^{j}(t_i)\right)\right)^2}\,, \qquad (3)$$

where δ_{STP} is the mean separation distance between truth and the L-STP trajectories for t= t : t+48 (following 48 hours from the study time). To compare with persistence, we also compute the Lagrangian error between the truth trajectories XTRU and the trajectories derived from the persistence field XPRS,

$$\varepsilon_{PRS} = \sqrt{\frac{1}{T}\sum_{j=1}^{T}\left(\delta_{PRS}(t_i)\right)^2} = \sqrt{\frac{1}{T}\sum_{j=1}^{T}\left(\frac{1}{N}\sum_{j=1}^{N}\left(X_{TRU}^{j}(t_i) - X_{PRS}^{j}(t_i)\right)\right)^2}\,, \qquad (4)$$

where δ_{PRS} is the mean separation distance between truth maps of trajectories, X_{TRU}, and maps of trajectories from persistent velocity fields, X_{PRS}, for t= t:t+48 (following 48 hours from the study time)".

Regarding Figure 3 (now Figure 2), the blue dots are the same in all the subplots; those are the points where we initialize our simulations for 48 hours. They need to have the same starting point to be able to make comparisons between them.

#Q3. So, let's assume that the authors were mistaken, and that the performance is evaluated by computing the error on the next 48 hours (forecast), by comparing the original field with the analogue forecast. Another forecast is used for comparison, based on a persistent field (constant velocity field for the future). The time series and spatial distribution of the errors have then been analyzed for 2 regions (Bay of Biscay & Black sea).

#R3. As pointed in our reply for your previous paragraph, your assumption is right and the performance is evaluated computing the error on the next 48 hours, as this will be the case in real time. And it has been analyzed for 2 regions (Bay of Biscay and Red Sea).

#Q4. Figure 4 shows the time series of the errors ANL, STP and PRS. The black dots over the timeline shows the times the STP error is higher than PRS according to the caption, the other way around in the text (line 328)! At this point I was thinking to give up the reading, too many errors, to complicate to decrypt the manuscript. But let's go on. . .. PRS method seems better during winter period, since high persistent structures are present. The correlation between ANL-STP is 0.46 and ANL-PRS is 0.05. How significant are both values? Are the authors happy with the 0.46 value? Does it mean something for the methodology?

#R4. In Figure 5 (formerly 4), the black crosses over the timeline in the x-axis shows the dates when $\varepsilon_{STP} > \varepsilon_{PRS}$, as indicated in the caption. It has been corrected in the text (line 314-315).

"Black dots over the timeline in Figure 5 show the times when ε_{STP} is higher than the ε_{PRS}, which occurs 12% of the time. "

Regarding the correlation values for ε_{ANL} - ε_{STP} and for ε_{ANL} - ε_{PRS}, as we are comparing the errors of the past with the errors in the future (from the L-STP), we agree that the 0.46 value is low but we find it as significant. We point these values in the description of Figure 5 in the manuscript, just to show that even for persistent periods ε_{STP} is higher than ε_{PRS}, ε_{PRS} it is not correlated at all with the ε_{ANL} , while ε_{STP} shows bigger correlation, as expected.

#Q5. Then the analysis is done by plotting errors (STP, PRS) or separation distances versus error_ANL comparisons are shown and discussed. Here my question is how reliable are the results in terms of the dynamics. The error values are enormous, hundreds of km^2, considering the domain size (~1.5°*1.5° according to Fig1), and the correlation coefficients quite low (maximum of 0.56 according to Table 2). Maybe a visual and qualitative comparison between the eulerian fields (the winner analogue, its forecast vs the target fields) could give an idea of the performance of the method. The values alone are not enough in my sense to validate the methodology.

R5. Note that errors have been redefined in Section 2.2. As explained in our previous Reply, the fact that the maximum correlation values between past ε_{ANL} and future ε_{STP} or ε_{PRS} is 0.56 does not mean that the method is not providing good forecast. The comparison has been done to compare the forecast against past ε_{ANL} values, as well as to provide a warning on the use of Persistence or L-STP as forecast.

Figures 8 and 9 (former 7 and 8) show the performance of the methodology. The separation distances obtained are similar or even better than previously published and validated results.

#Q6. Maybe this method is worthwhile to be further investigated, but I would recommend to go through a major review, making the method clearer, making a methodological analysis in parallel to a physical explanation. The methodology should also be more detailed. Results should be better presented to be convincing. The analogue method was developed mainly for meteorological dynamics, which have very different time and spatial scales. Moreover, the application of this method to Lagrangian motion which very often exhibits chaotic behavior, even in regular and simple Eulerian flows, is questionable. A sub region may have analogues in one period, and a distant region another period. The authors may consider to work on sub region, and with a higher number of trajectories.

#R6. We totally agree with the Referee. The Ms. has been fully revisited and specifically and following your advice, the definition of the errors corrected. We have also added a figure to make a more detailed and clearer description of the methodology. We think that one of the advantages of the presented methodology is that it is simple, easily applicable in real time and immediately updated, as new data will become available. All these points have been detailed in the new Ms. The use of a large number of trajectories was widely discussed by the coauthors and tested during the development of the methodology. A higher number of trajectories increased computational time while the improvement of the methodology was not appreciable.

Regarding the sub regions it was also investigated during the tests. We tried to decompose analogue finding, not only for different periods, but also for different regions. Finally, we discarded this approach, since one of the main goals of the methodology is to provide a fast, reliable real time forecast. However, since we also agree in that this is a very good suggestion, we have included this point as a future work.

Also consider that analogue detection based on full area analogues implies the search in a space that considers all the simultaneous spatial variability, rather than local details, but as the analogue used for forecasting contains small scale and local features, the smallest scale features can be understood and the fingerprint of the bigger scale match.

Specific comments:

#Q7. Once the Error is defined (eq.1) no need to repeat it (eq.2 & 3), since the difference between the errors is not the equation, but the field used to compute the trajectories and the separation distance.

#R7. We totally agree. A completely new section 2.2., unifies the definitions.

#Q8. Not sure either that the definition of the time interval in line 293 is correct. Maybe the authors wanted to write v(ti)=v(tf), ti=[tf tf+48] ?

#R8. Yes, it has now been modified.

#Q9. Please find better definitions, and schematize the method. Instead of realized you may use truth, as for the twin experiments in data assimilation?

#R9. Thank you for your comment (see R#3, #4 and new Figure 4). "Realized" has been replaced by "truth" through the whole manuscript.

#Q10. The authors say that the method has been applied to the eulerian field with unsatisfying results (no improvement compared to other methods). Can the authors suggest some explanations for this?

#R10. Hourly HF Radar surface current fields for both study areas have more than 1000 nodes in their respective footprint areas. And each of those nodes has longitudinal and latitudinal velocity values. Moreover, the variability associated with those hourly fields is really high and we usually have to filter the data to make long time analysis of the surface currents. By contrast, Lagrangian trajectories are robust against errors in the velocity field data and against the dynamics of unresolved scales, since the averaging effect is produced by integrating over trajectories which extend in time and space, that tends to cancel random-like errors. Furthermore, we consider that it is better to deal directly with trajectories since our goal is to minimize the separation distances between the truth and simulated trajectories. This fact, together with a lower variability associated with the Lagrangian fields, could be the reason for the better behavior of the analogue methodology with the Lagrangian fields.

#Q11. How the trajectories are computed is not explained, since the readers may not know the CODAR package. Are they purely advected? Is there any diffusion term?.

#R11. In the Matlab package used in this paper, particles are considered infinitesimal and neutrally buoyant and are advected using the HF radar hourly fields without any diffusion term. It has been included in the text (line 286).

#Q12. What is the physical significance of the error (thousand of kilometers)? - What is the distance between initial points?

#R12. The physical significance is the sum of the mean square separation kilometers at 6, 12, 24, 36 and 48 hours. It gives an approximation on how big the separation distance is between the truth and simulated trajectories. The distance between the initial points is different for both systems:

δ_Lat=0.225 and δ_Lon=0.35 for the BoB

δ_Lat=0.1 and δ_Lon 0.15 for the Red Sea

The initial locations and the trajectories to be distributed around the study area is more important than the separation distance of the initial particles.

Reviewer #2

We thank the effort made by the Referee in reviewing for second time our Manuscript (hereinafter Ms.) entitled ***"A new Lagrangian based short term prediction methodology for HF radar currents*****.** Taking in consideration all the comments of the reviewer (both in revision 1 and revision 2), we made a deeper review, to present an improved version of the Ms.

We deeply think that thanks to all your comments, this new version of the Ms. has improved significantly. The paper has been revised and carefully modified following your advices and comments. In the following, you can find the answers to your queries as well as the changes performed in the new version.

Reviewer #2 Comments & Replies

The new version of the paper by Solabarrieta et al. is overall satisfying but I am still unconvinced by the following concerns:

#Q.a) L250: why are values different from those at lines 221 and 225.

#R.a: It was a typo error. The frequency is mentioned correctly in the new version of the Ms.

#Q.b) L282-284: still puzzled by the fact that the authors want to mention the Eulerian attempt. In order to show that the Lagrangian results are better than the Eulerian ones, as argued in their response, authors should clearly explain and provide details on how the analogue for the surface Eulerian velocity is found and at least report quantitative metrics for the comparison.

#R.b: We agree with referee that a clearer explanation was needed. We have chosen the Lagrangian approach because it has been shown that errors in the velocity field and missing inter-grid dynamics effects are reduced in the Lagrangian computations (see Hernandez-Carrasco et al., 2011, Hernandez-Carrasco et al., 2018). Accordingly, this paragraph has been rewritten in the manuscript (lines 112-114) as:

"The method is based on Lagrangian computations since they have proven to be robust against errors in the velocity field data and against the dynamics of unresolved scales, since the averaging effect produced by integrating over trajectories which extend in time and space, tends to cancel random-like errors (Hernandez-Carrasco et al., 2011,Hernandez-Carrasco et al., 2018, Sayol et al., 2014). Consequently, they are robust in identifying dynamical flow structures.

For the sake of clarity, and in order to focus only on the new approach we have removed in the new version of the Ms. all comparison with the Eulerian approaches. This is a very relevant issue that deserves a detailed analysis in a new work.

#Q.c) L330: As the method runs in a very short time it should not be a problem to explore its sensitivity to the number of virtual trajectories used. Looking at Figure 1, we still have plenty of gridpoints. what if we use 100 or 50 or less (like 12) virtual particles? How do results change?

#R.c: The number of particle trajectories is chosen based on a compromise between the maximum area covered for the trajectories and a reasonable computational cost for operational purposes. We find that the optimal number of particle trajectories, with an affordable operational processing time, was 25. This is indicated in the new Ms., in the lines 290-291. The spatial distribution of the virtual trajectories aims to cover the whole study area. The optimal number of particle trajectories, with an operational processing time was 25, as indicate in the new Ms., in the lines 290-291.

Using more than 25 virtual trajectories, the improvement in the results was not appreciable but the processing time increased substantially. This is why we found that N=25 was the optimal number.

#Q.d) L348: why is epsilon calculated as the sum of squared difference every 6h? do results change if difference are calculated at every hour?

#R.d: The results were not differing too much when calculating Ɛ every hour or every 6h. But the computation time was much shorter, and this is why we decided to use values every 6 hours.

#Q.e) L574: why is 0.39 meaningful? where is this value?

#R.e: The correct value is 0.37 (from table 2) and it has been corrected in the new Ms.

There is no correlation between ε_{ANL} (used to find the analogue in the catalogue) and $\delta_{\_PRS}$ (distance between real and PRS simulated trajectories); while there is higher correlation between ε_{ANL} and $\delta_{\_STP}$, especially after 12 hours of simulation (R2 (ε_{ANL} vs $\delta_{\_STP}$) increases rapidly after 12 hours, from 0.37 to 0.54) as indicated in table 2. This has been clarified in the text (lines 392-401).

#Q.f) L670: where is shown that the cross point is at 714 km2?

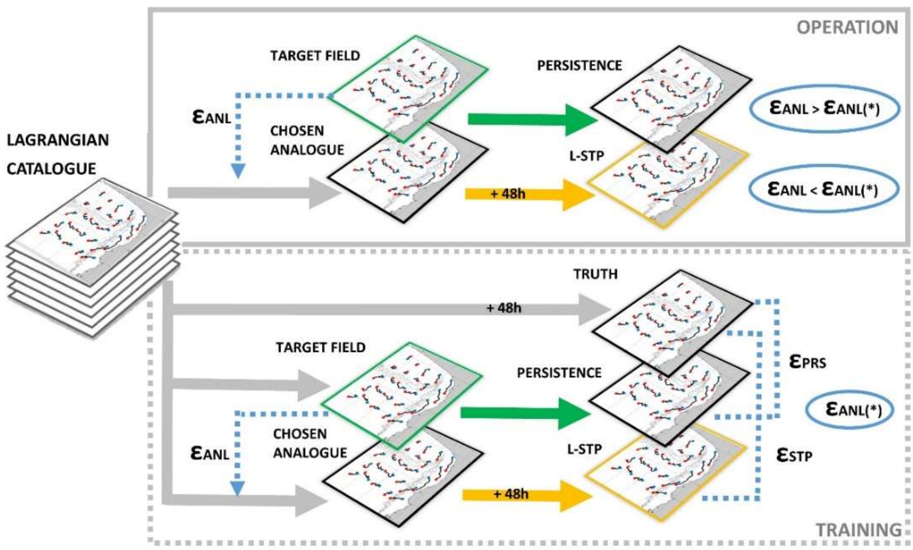
This value has been removed from the Ms, mainly because the errors have been redefined and a $\varepsilon_{ANL(*)}$ (directly related with the cross point) has been introduced for a better understanding of the methodology.

#Q.g) Overall discussion: I must admit that this part remains poor. Still not able to grasp why HF radars are less able to resolve persistent feature wrt the PRS method. Why is the PRS method less affected if the persistent structures do no take place at the same positions as the authors are saying in their response? A clear reference to an example where both method are used for one of these structures is really needed. Authors are also not showing GDOP maps which could help the discussion and the interpretation of the results.

Since temporal resolution of HF-Radars is hourly, they capture well all scales of interest above hours. This includes persistent currents. The comparison in the discussion is made between the STP system based on radars in front of a prediction made with persistence (in an abuse of language since persistence here means that the prediction for the next hour is simply the velocity measured in the last observation). At this point we remark that persistence is defined in the Eulerian frame and not in the Lagragian one which is the one that the present method works. This means that any (small) difference in one of each velocity component could lead to a different trajectory although velocities are persistent. This paragraph has been rewritten/completed in the manuscript in order to clarify and provide more dynamical insight of the presented results.

g) Figure 4: I must confess that I find this figure more confusing than inspiring. It is not really understandable, very wordy and it is not clear what the different lines are referring to.

#R.g: We agree on this comment too. This is why we have generated a new figure to replace the old one and help to the new schematic summary of the methodology, included in 2.2 Lagrangian analogues. We hope that you will find it clear now.



Typos:

1) L73: correct infrastructure

   It has been corrected in the new Ms.

2) L76: correct existing

   It has been corrected in the new Ms.

3) L148: correct ITS

   The sentence has been rewritten in the new Ms.

4) L240: remove one THE

   It has been corrected in the new Ms.

5) L331: missing parenthesis

   The sentence has been rewritten in the new Ms.

6) L400: here and throughout the manuscript, should not be 'TRUE' and not 'TRUTH' trajectories?

   We have preferred to maintain "Truth" throughout the manuscript, as suggested by the reviewer #1 and agreed by the native English speaker coauthors of this Ms.

7) L489 and L494: slightly change notion here as we delta_t you refer to two different errors

   δ_{ANL}, δ_{STP} and δ_{PRS} have been included to clarify the equations.

8) L530: correct LAST

   It has been corrected in the new Ms.