Response to Referee #2

RC2*: Analysis of tracer advection, particularly analysis of the Lagrangian trajectories, is of much importance. This paper investigate tracers' trajectories in terms of spatial pattern, relation to ENSO, statistical properties and the role of fractional Brownian motion. The topic is somewhat interesting, but some fundamental flaws, in terms of methodology and interpretation, are seen in this manuscript and important additional calculations or evaluations are needed.*

AC2: We are grateful for the detailed and thoughtful comments by the referee and the time and efforts the referee has devoted to our paper.

We fully understand and agree that in our presentation there is lack of discussion why the fractional Brownian motion model is useful. In the revised version we insert our related remarks. See also Author Comment 1 (Responses to Referee #1), since he/she formulated similar questions.

RC2*: Major comments:*

The key points of this study are: interannual variability of advection is related to ENSO, and well reproduce the statistical properties of the tracers' trajectories with a fractional Brownian motion model. It is well known that the oceanic advection is associated with ENSO cycle and there are actually numerous previous studies have examined the relationship between oceanic advection and ENSO in very details and on multi time scales. So, to me, the most important point of this paper the latter, i.e., the interpretation of the observed statistical properties of the tracers' trajectories using the fractional Brownian motion model. The authors examined the tracers' trajectories which are 1°, 2°, 4°, and 8° west of the starting position, claim that "the westward moving tracers can be mapped into a simple 1D stochastic process" and "numerical simulations of the fractional Brownian motion model that it is able to well reproduce the observed statistical properties of the tracers' trajectories". However, this may not correct. The advection of sea water particles is influenced by not only molecular-scale processes, but also small scale, mesoscale to large scale processes that related to geophysical fluid dynamics. Although the molecular-scale processes and even small scale processes may be stochastic, the geophysical fluid dynamical processes are not stochastic, whose major component is linear. One of the difference between the two kinds of processes is in the spatiotemporal scales. Because the spatial scale of mesoscale to large scale processes is much greater than 8 degrees and the time scale of large scale processes is longer than order of 100 days, the conclusions of the present paper is very misleading to the oceanography community. So, the authors may extend the range of tracers' trajectories in investigating the role of fractional Brownian motion in the observed trajectories.

The writing of this manuscript needs further improvement, including the logic structure and grammar.

AC2:

To be specific, we neither claim nor believe that "*the advection of sea water* *particles is influenced by ... only molecular scale processes*". Our simulations of the motion of tracer particles are the solutions of deterministic equations of motion, where only the time and position dependent meso-scale surface velocity of the ocean currents enter. Hence our tracer particles are advected by this motion, and there is no diffusion on the molecular scales in our simulations. Due to the time step of the integrator (5 minutes), in each update step the particles make jumps of the order of 1 - 100 m. Our simulated tracers have a velocity of the order of 10 km/day, which is much faster than any molecular scale diffusion process.

However, the fluctuations of the velocity fields in time and space cause the tracers to perform quite irregular motion (Fig. 1). Despite some overall westward drift which is particularly strong in La Niña years, the motion is not ballistic. This means that the distance of a particle from its origin does not grow linearly in time. Our intention is to model these irregularities of the particles' motions in a statistical way. Our analysis shows that the particle motion represents an anomalous diffusion process. More specifically, fractional Brownian motion is the most suitable model which is well able to reproduce essential statistical properties of the spreading of the tracer particles, without the need to know details of the velocity fields. Instead, we have only two parameters, the Hurst exponent H and the value of the generalised diffusion constant k_H, which are sufficient to reproduce the spreading of, e.g., pollutants on spatial scales from 10 to 10000 km and on temporal scales from 2-365 days. So our model is not a physical model for the molecular diffusion process, but a data driven effective description of the motion on meso-scales.

A more detailed comment on the temporal and spatial scales evidently is in order: We study the mean squared displacement of the particles up to distances of 10000 km, and on times up to one year (Fig. 8), where the fractional Brownian motion model reproduces well the observed anomalous diffusion on the whole range of scales. However, the nontrivial scaling of the MSD alone is not enough to identify fractional Brownian motion as the correct model among several other anomalous diffusion processes, so that we perform in addition the study of the first passage times. In this specific aspect, indeed, we restricted ourselves to distances of at most 900 km and 100 days. The reason for this is that in many years (one shown in Fig. 1), a large fraction of the particles does not cross the 8-degree-distance from the place where they have been released. This means that the number of particles which contribute to the first passage time distribution becomes the smaller the larger the distance, and already for 16 degrees we do not have any more a good statistical sampling of the probability density.

We will amend the revised manuscript along these lines, as well as we will, in response to referee 1, explain why such a stochastic model is useful and which insights we have gained by this approach.

We are most grateful also for the listing of many detailed comments, which we will all address in the revised version. Here we comment only on those which contain a scientific issue.

***RC2**: Minor comments:*
What does "advection strength" mean? The definition should be specified here What kind of data or "numerical experiments" used? It's needed to replace equatorial with "tropical" since the domain in this paper beyond the equatorial region obviously.

AC2: We will amend the abstract accordingly.

***RC2**: Lines 50-51: Explain how did AVISO calculate geostrophic currents in the equatorial region.*

AC2: Geostrophic balance does not hold at the equator, but the altimetry data can still be used to infer velocities there, albeit with less confidence. The AVISO data set implements the method of Lagerloef et al. (1999) between ±5°. The basic balance underlying this method is the y-derivative of the meridional geostrophic balance at the equator. The Lagerloef et al. method is essentially a way of matching this regime with the geostrophic regime away from the equator. The method has been validated with drifter data and has been demonstrated to capture the major features and variability of the equatorial circulation.

***RC2**: Figure 1: How did you choose these representative trajectories?*

AC2: If we had drawn the paths of all trajectories, they would superimpose each other to some red blot. We therefore picked a sub-set of 20 of the initial positions with regular spacing along the vertical line from 15°N to 15°S as those where we draw the full path in red. If we had chosen another sub-set, the individual paths would be different, but the qualitative behaviour of showing many turns and deviations from the westward motion or even looping around would be the same.

***RC2**: Figures 3-6: (1) It seems that the 99 % confidence interval is shown in plenty of grey lines? Why? (2) It should be specified in the captions what a positive time lag means.*

AC2: As explained in the Section "Data and methods", confidence intervals are estimated from a test set of 10,000 Fourier surrogate time series of the second signal, and obtained the cross-correlations between the basic signal and each surrogate. We dropped the lowest 50 and highest 50 values (defined by the cross-correlation value at the maximum/minimum time lag of the original result). The remaining 9900 cross-correlation functions are plotted individually by grey lines.

***RC2**: Section 3.2: I am confused what your purpose of section 3.2 is.*

AC2: As its title suggests, here we analyse the cross-correlations between the ONI and SOI and the advection indices. The later is a global characterisation of the advection intensity or advection strength.

***RC2**: Figure 6: The relationship between ONI and SOI is well known. Figure 6 is not necessary and should be removed.*

Ac2: We did not find any similar cross-correlation plot with well defined 99 % confidence interval. Also this figure validate our code of computing the time lagged correlations.

***RC2**: Line 174: what does "distance" mean?*

AC2: The "distance" is here the length in km of the projections of the starting point of a tracer trajectory (i.e., at 110°W) onto the equator and of the endpoint after time t. This includes the approximation that particles which move south or north of the equator have travelled in reality a shorter distance than those on the equator when their endpoints are on the same longitude, but this inaccuracy is small and cannot be well resolved, if the particles' starting and ending points are at different latitudes.

***RC2**: Lines 176-177: The definition does not show an average. The authors may modulate the formula.*

AC2: We did it.

***RC2**: Line 192: need to show the four positions in Fig.1*

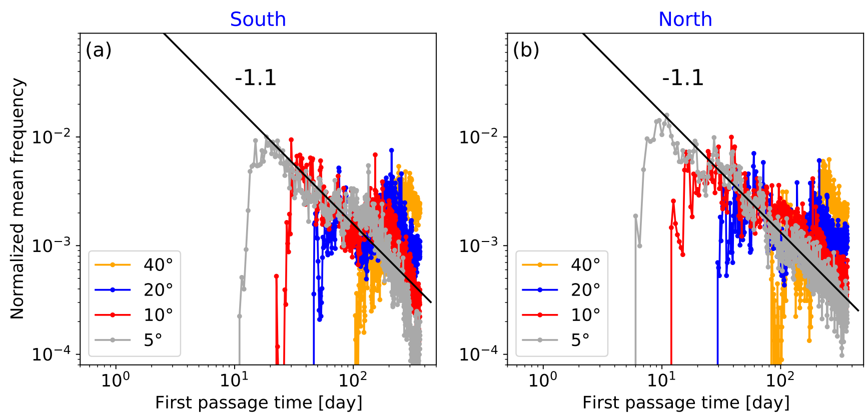
AC2: We do not think that four meridional (vertical in this map projection) lines can help something. The longitudes and latitudes are clearly shown in the maps.

***RC2**:Figure 7: why did you choose 1-8 degrees? How about longer distances?*

AC2: As explained above in the Response to the Major comments, for large distances the statistics breaks down, see ACfigure 1. Specifically, there are several years when the longitude of 150°W is crossed by only a few parcels, see also Fig. 1a in the manuscript. Note however, that while FPT statistics is sensitive to the dilution of tracers (the same number of parcels cover larger and larger area), the scaling behaviour holds for much larger distances and time intervals clearly illustrated by Figs. 8 and 9 in the manuscript.

***RC2**:Lines 235-236: what are the "two phenomena"?*

AC2: The two phenomena are the mean drift, seen by the mean of the particle distribution, i.e., their average distance from the point where they were released, plus the random motion of the individual paths around this mean value.



ACfigure 1: Normalised first passage time distributions for large distances from the line of release at 110°W, see legends. **(a)** Southern section; **(b)** northern section.

So in summary, we see that the presentation of our material has to be improved, which we will do in the revised version. We are grateful to the referee for showing us where our article cannot be properly understood and where it was even misleading an expert reader. We hope that our responses will have helped putting our results into the right context.

We present a model which is valid on spatial scales up to several thousands of km and on time scales of up to 1 year. We believe that such a model which does not rely on the detailed knowledge of the velocity fields over space and time but only on two parameters, can be most useful to model and to forecast the spreading of advected tracers in the ocean. At the same time, it gives insights into the complex fluctuations of oceanic transport.