Reply to referee #1 of

"GEST: A multi-scale dynamics-based reconstruction of global ocean surface current"

Authors: Guiyu Wang et al.

June 19, 2023

(RC: referee comments | AC: authors comments)

RC: This paper presents a methodology to reconstruct ocean surface currents optimally combining different components of the ocean surface circulation : geostrophic, Ekman, tidal and wave-induced currents. Scientifically this work is sound, as it aims at providing a global surface currents product which can account locally for significant processes which could be missed relying only on a single/few of the aforementioned surface circulation components. I therefore recommend this paper for publication after considering the following major and minor issues.

AC: We highly appreciate your valuable comments and professional advice. Taking into consideration your suggestions and requests, we have made a substantial revision. Please find the specific details outlined below.

Responses to General Comments:

RC: Firstly, the metrics for evaluating the goodness of the data are mostly based on direct comparison with in-situ measured currents (drifting buoys), while the authors, already at the abstract level, mention the importance of both "high precision" and "fine resolution". I think inserting additional analyses (e.g. spectral analyses based on Fast-Fourier-Transform) to evaluate the effective resolution of the GEST data set could strengthen the manuscript (at least for the analyses presented in section 4.2);

AC: We added the results of the FFT-based spectral analyses to illustrate the effective resolving capabilities of our GEST data set. The results indicate a dominate signal scale of approximately 250 km and an equal minimum spatial scales of 10-50 km for GEST and GlobCurrent products under the same spatial resolution, which are both significantly better than the minimum spatial scales of 100-600 km for OSCAR product with 1° resolution. Specifically, figure A shows the wavenumber-power spectral density within the North Pacific Ocean (20°N-30°N，160°E-170°W) and the North Atlantic Ocean (30°N-50°N, 50°W-30°W). Figure B and figure C exhibit the latitudinal distribution of maximum and peak spectral wavenumbers of GlobCurrent (green dotted line), OSCAR current (blue dotted line), and GEST current (red dotted line) across each 5° band. The maximum wavenumber indicates the smallest spatial scale at which the product can be resolved, while the peak spectral wavenumber represents the dominant signal scale within the product. Besides the capacity for spatial resolution, GEST current also shows lower reconstruction errors through accuracy verification.

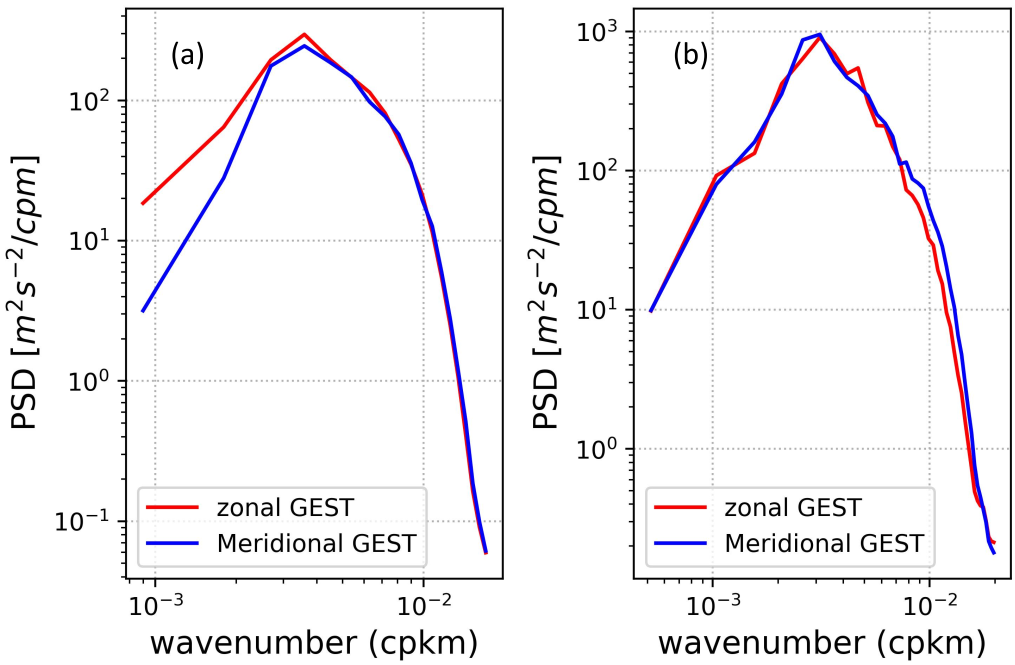


Figure A: The GEST wavenumber-power spectral density (PSD) within the (a) North Pacific Ocean (20°N-30°N， 160°E-170°W), and (b) the North Atlantic Ocean (30°N-50°N, 50°W-30°W).

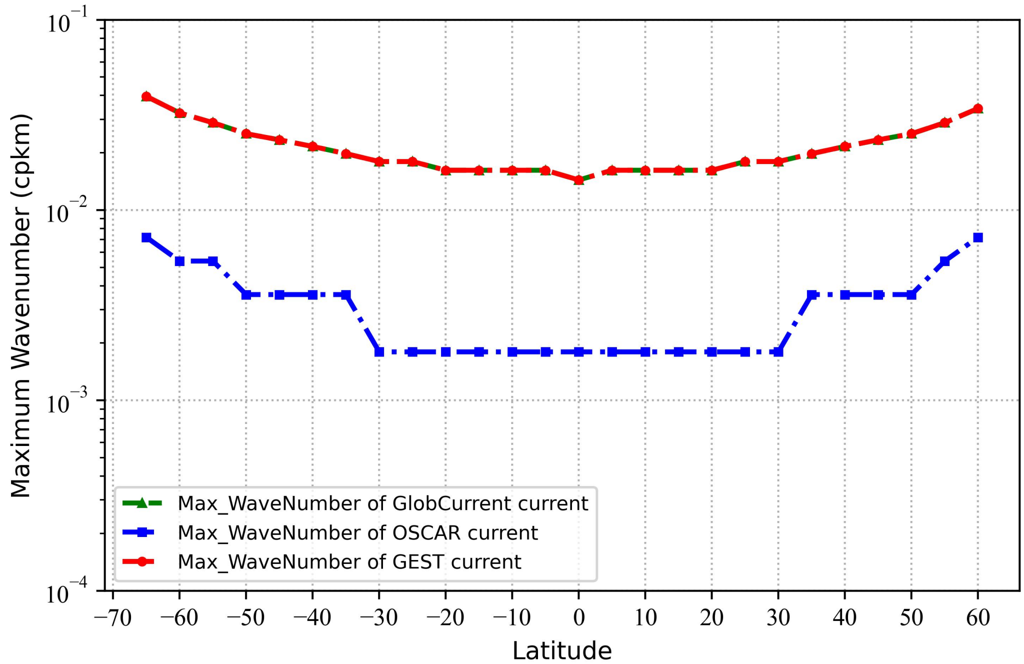


Figure B: The maximum wavenumbers of GlobCurrent (green dotted line), OSCAR current (blue dotted line), and GEST current (red dotted line), by latitude bands.

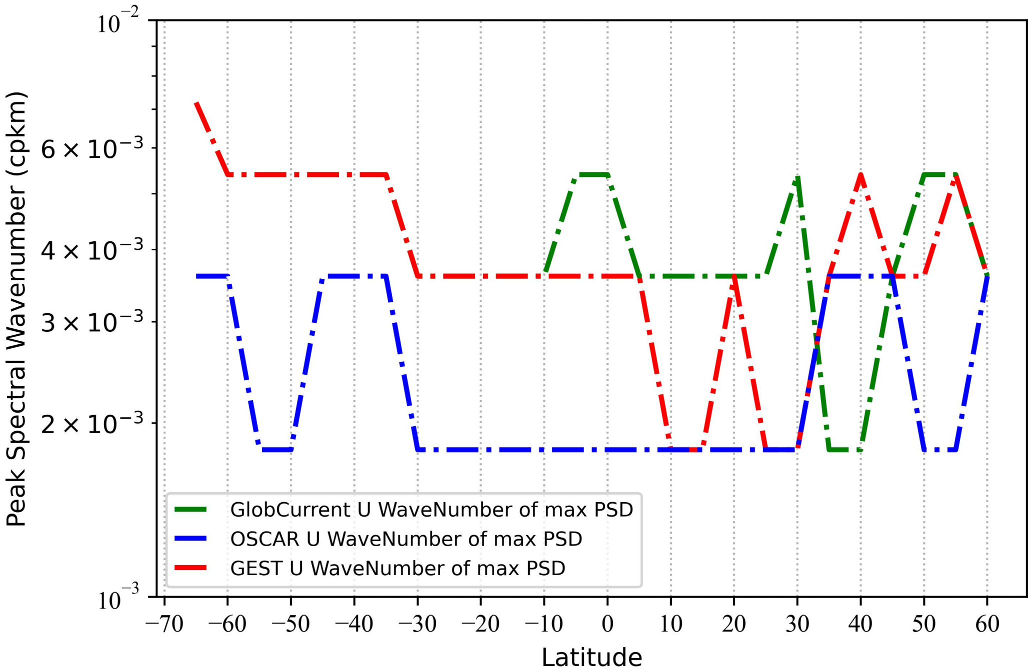


Figure C: The zonal peak spectral wavenumbers for GlobCurrent (green dotted line), OSCAR current (blue dotted line), and GEST current (red dotted line), by latitude bands.

RC: While reading the results, I was concerned by the statistical significance of some of them. As an example, I may provide the specific case reported in figure 14 a. The RMSEs of the different datasets under evaluation are often few tenths of cm/s apart from each other. I was wondering if it is possible to add an information on the confidence level of the different RMSE computation (e.g. via bootstrap analysis). I think it could help readers understand when the GEST RMSE value is confirming the higher accuracy compared to other available surface currents datasets:

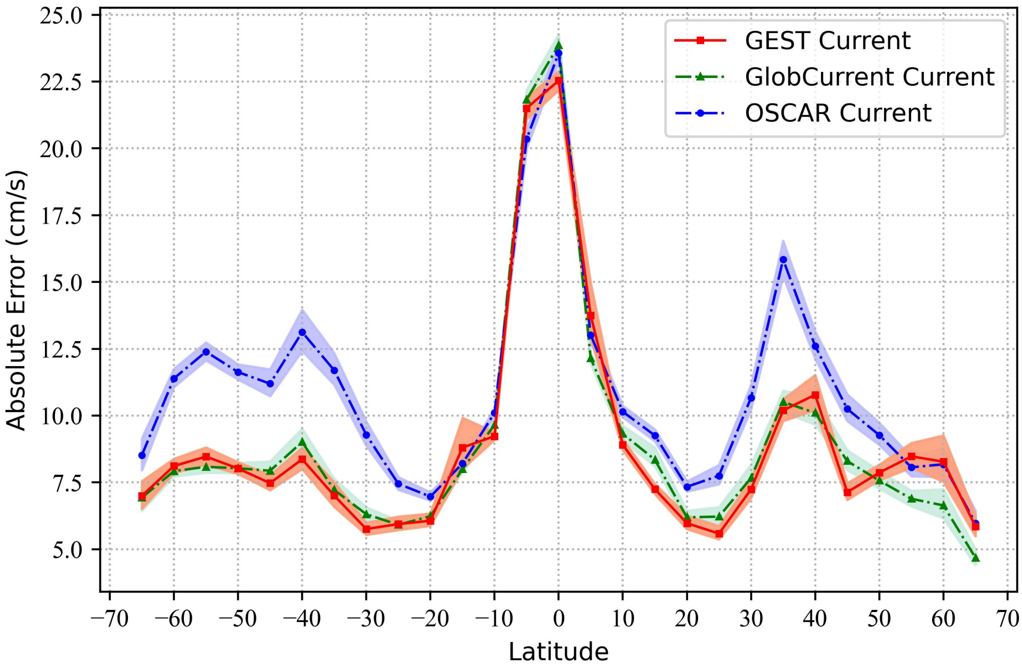


Figure D: The absolute error of OSCAR current (blue line), the GlobCurrent (green line), the GEST current (red line), by latitude bands. The shaded red, green, and blue areas indicates the 95% confidence interval for the absolute error.

AC: In accordance with your suggestion, we performed the bootstrap analysis to calculate the absolute error within the 95% confidence interval, represented by the color lines with shading in the above figure D. It is evident that the accuracy of the three products remains consistent within the equatorward regions of 20°S-15°N. Our GEST product has the highest accuracy in latitudes ranging from 20° to 50° in southern hemisphere and 10° to 40° in northern hemisphere by compared to the other two products. Additionally, its accuracy in higher latitude regions is comparable to that of GlobCurrent. Notably, the OSCAR current product exhibited the least accurate performance across nearly all latitudes.

RC: I struggled a bit to understand why the Authors wish to provide a data set with 1°x1° degrees spatial resolution. It was not that clear to me for which purposes/applications it was meant for. Could the Authors please explain?

AC: Among the four flow fields (geostrophic, Ekman, tidal currents, and Stokes drift) involved in the reconstruction, Ekman current has the lowest 1° spatial resolution after the local applicability analysis, and we initially attempted to reconstruct the flow field with its spatial resolution. However, the results are not very satisfactory. This 1 ° resolution data set can be considered as an interim product in the flow field reconstruction process, and also a contrast example of the effect of resolution on flow field reconstruction.

Responses to Specific Comments:

RC: I would recommend to further clarify section 3. I honestly struggled a bit to understand that section 3 presents the building blocks of the GEST product. Inserting few lines explaining this concept would be beneficial for the paper;

AC: We have added a further explanation for section 3 in the revised manuscript as below (line 142-147).

Revised: "Before ocean current reconstruction, four flow fields were temporally and spatially matched to drifter observations, and a series of data preprocessing and analyses were carried out. Then, the global correlation distribution of different flow fields with drifters was calculated. After that, the global reconstruction sub-models based on different ocean current combinations were constructed and validated, separately, to choose the best performing model in each 3° grid, which is finally used to reconstruct the sea surface current."

RC: I think the introduction is lacking part of the effort that has been done to reconstruct surface currents from tracers observations. I thus encourage the authors to consider few additional literature items (e.g. Bowen et al. 2002, Gonzalez-Haro et al. 2014, Liu et al. 2017, Rio and Santoleri 2018 and references therein) and insert few lines in the introduction;

AC: These papers have been added to the reference list of our manuscript, and the description in the introduction section is as follows (line 50-54).

Revised: "...In addition, high-resolution Sea Surface Temperature (SST) products and Ocean Color (OC) images have also contributed to improving the accuracy of reconstructed ocean currents with methodologies from Maximum Cross Correlation technique and surface quasi-geostrophic theory. (Bowen et al., 2002; González-Haro andIsern-Fontanet, 2014; Liu et al., 2017; Rio and Santoleri, 2018). ..."

RC: In the manuscript, there are some images (see e.g. figs. 1,3,5) where you claim you are presenting information on 1°x1° boxes. It seems to me the information has somehow been further smoothed spatially. Could the Authors please clarify the reasons behind this choice or, at least, clarify that directly in the text?

AC: These diagrams were automatically interpolated before, and they have been updated as below.

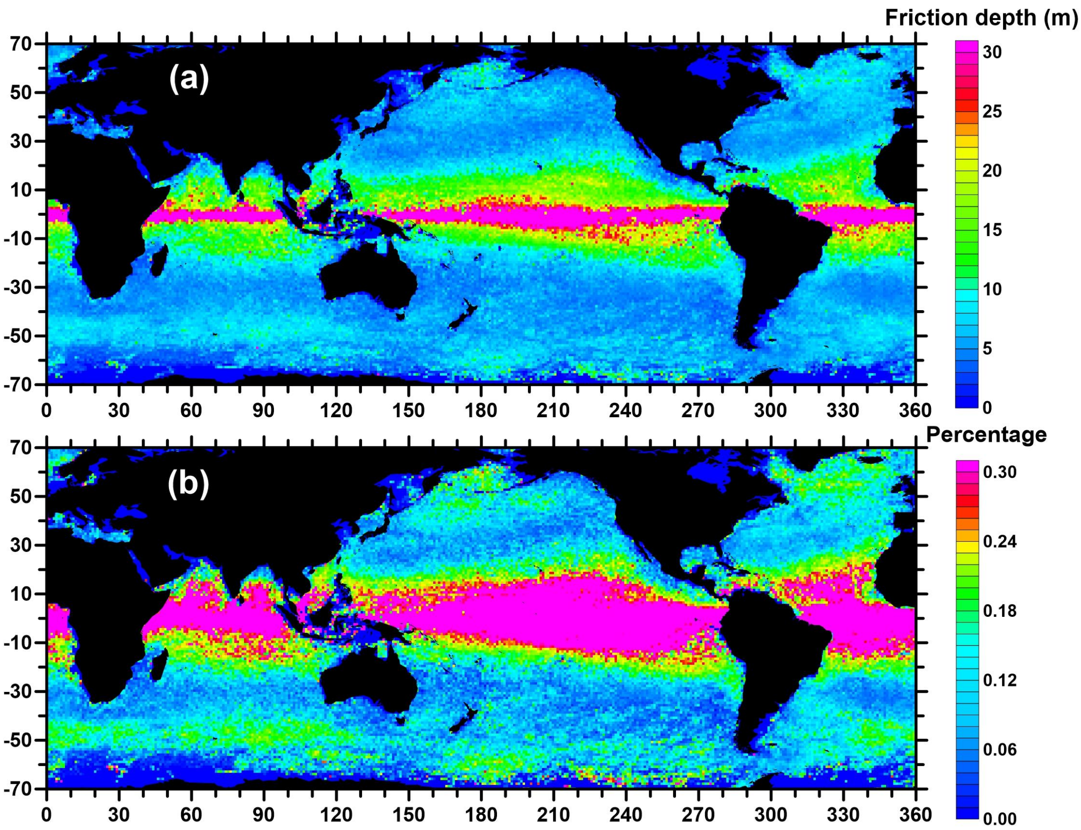


Figure 3: (a) Global mean distribution of the friction depth per 1° × 1°. (b) Proportion of friction depth up to 15 m in drifter observations.

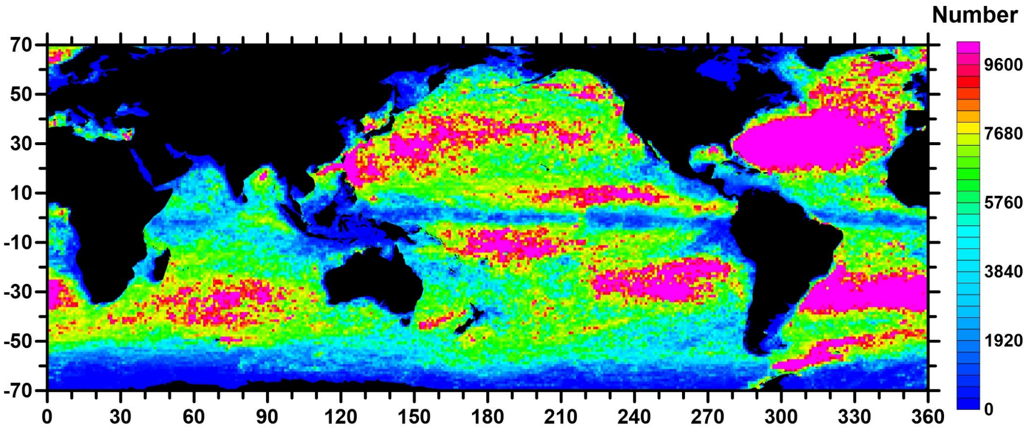


Figure 1: Spatial distribution for the drifter observations per 1° × 1° from 1999 to 2019.

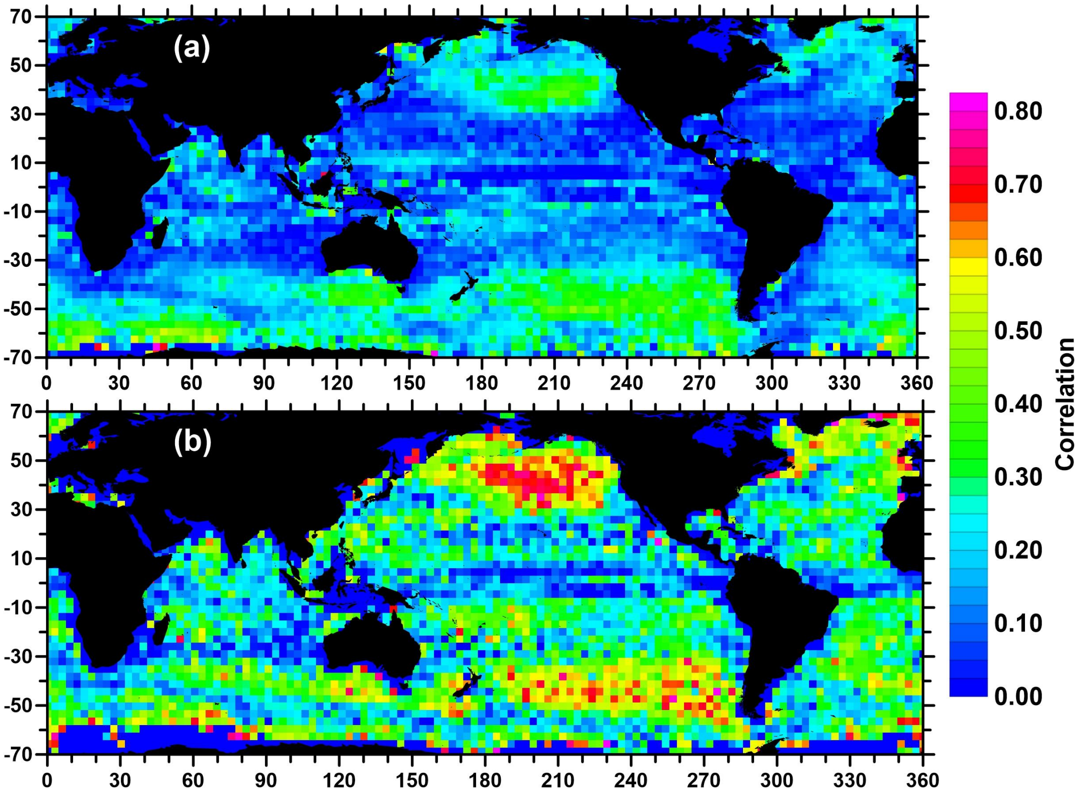


Figure 5: The correlation between Ekman currents and drifter observations per 3° grid (a) before and (b) after depth validation.

RC: A doubt is still related to figure 14 a/c/d: on average, it seems that the overall RMSE of GEST and Globcurrent datasets are equivalent in the latitudinal bands 30-50N and 40-60S, In particular, it seems that GEST and Globcurrent products show alternating better performances in the 30-50N band and equivalent performances in 40-60S band. Such areas are dominated by major current systems, thus relevant for assessing the quality of a surface current product. Could the authors please try to explain further such behaviour? I think it would be useful for users, in order to understand which data set should be used for a specific study area/application;

AC: We think the phenomenon that the RMSE of the GEST and Globcurrent products show alternating better performances in the region you mentioned may be related to the smaller amounts of drifter observations at middle latitudes that can be seen in figure 3 (b), leading to a lack of model reconstruction accuracy. Furthermore, the GlobCurrent data set assimilates drifter observations in the calculation of Ekman current, and we guess that it may results in an improved reconstruction accuracy in the westerly zone (30° N-50° N and 40° S-60° S) where Ekman current has high correlation with drifter observations.

RC: Line 152-153: this sentence is unclear to me. Which data set does not constitute a full independent validation for your reference field? Which reference field are the Authors referring to?

AC: We mean that previous studies have assimilated drifter observations to derive the ocean current product, while we have not used this method and have achieved similar accuracy, thus demonstrating the independence and strength of our algorithm.

RC: Line 159: What do you mean exactly with " Ekman layer reaches the position of the drogued drifters position of the drogue drifters"? Are you referring to the vertical position of the drogue? If so, please specify;

AC: Yes, "the position of the drogued drifters" refers to the vertical position of the drogue (i.e. 15m). We have specified it in the revised manuscript (line 184-185).

Revised: "A verification is necessary that the mixing depth of the Ekman layer reaches the vertical position of the drogue (i.e. 15 m)."

RC: Line 186: although one might guess what the Authors mean by "ocean components" I don't think it is appropriate to mention that one can compare "ocean components and drifter observations. I'd ask the Authors to rephrase the sentence;

AC: The corrections made are as follows (line 194-196).

Revised: " With the deepening of Ekman depth h_e, the correlation between ocean current velocities with different scales and drifter velocities shows a trend of increase and then decrease, ..."

RC: Figure 6: The legend should clearly mention what the Authors mean by the blue and red curves. Also, it seems the "Attenuation of experience" and theoretical formula are not precisely mentioned in the manuscript. This makes It hard to intercompare the figure with the findings reported in the text. Could the Authors please further clarify?

AC: The "empirical percentage method" and the "theoretical method" are further specified, as follows (line 205-217). In addition, we have also modified figure 6: Taking as an example in figure 6 (a), the Y-axis represents the correlation between geostrophic+ Ekman+Stokes zonal velocity and drifter zonal velocity, while the X-axis are the decay scale of Stokes drift using different decay methods (red curve: theoretical decay method (upper X-axis); blue curve: empirical decay method (lower X-axis)).

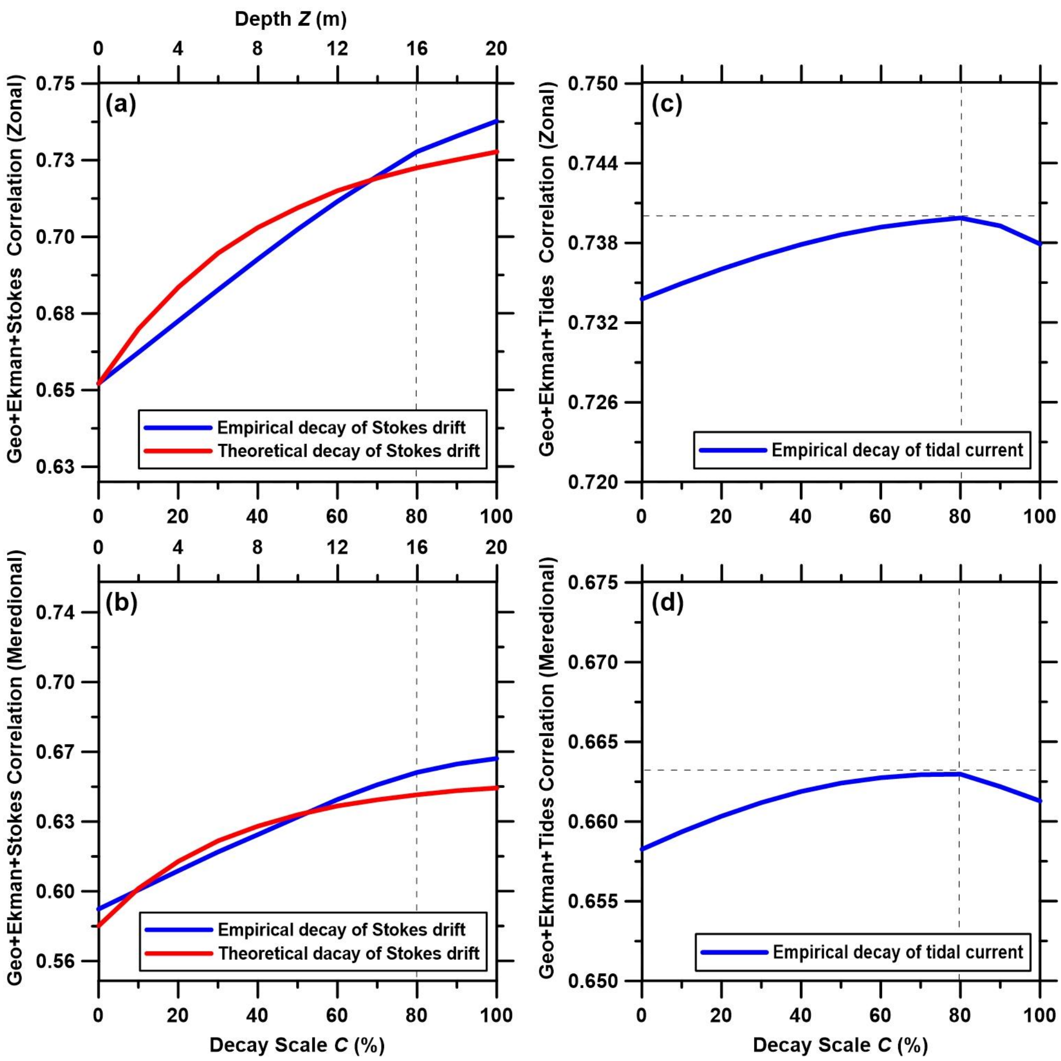


Figure 6: The zonal (top row) and meridional (bottom row) correlation of vector combinations of (a)-(b) geostrophic, Ekman currents, and Stokes drift, and (c)-(d) geostrophic, Ekman, and tidal currents, by theoretical decay method (red line) and empirical decay method (blue line). The upper x-axis represents decay depth Z of the theoretical decay method for Stokes drift, and the lower represents the percentage decay scale C of the empirical decay method for Stokes drift and tides.

Revised: "The reanalysis Stokes drift and tidal currents u_0 cover 0 m vertically and need to be attenuated, respectively, by the empirical decay method given in Eq. (4a), which is related to a decay scale c,

$$u = u_0\ (1 - c\%), \tag{4a}$$

$$u_s = u_{s0} \exp\ (2kz). \tag{4b}$$

Additionally, there is a theoretical decay equation for Stokes drift that can be expressed in Eq. (4b), where u_{s0} denotes the surface Stokes drift, z is the profile derived from a monochromatic wave with wavenumber *k* and wavelength $\lambda=2\pi/k$ (Kukulka and Harcourt, 2017)."

RC: Line 203: reading the text it is not simple to understand what the Authors mean by "theoretical formula". Is this equation 4? Please specify and, in addition, I would provide more details for the "empirical percentage method", in order to help readers not familiar with that;

AC: We have corrected the descriptions, please check the responses to the above comment.

RC: Line 224: "Geostrophic currents act as the primary mechanism that form the ocean surface current field". I do not think it is appropriate to mention that the Geostrophic Currents are a mechanism that generate the ocean current field. I would rather say that they are a component of the total marine currents field;

AC: We have revised the sentence as below (line: 242-244).

Revised: "Geostrophic current is a major component of the ocean surface current field, and the Pearson correlation coefficient can reach nearly 0.98 in the regions with strong and persistent currents along the western boundary."

RC: Line 254: recalling what I mentioned in the "major comments" section. I would ask if the Authors could check whether this 0.3 cm/s RMS difference is significant or not;

AC: Following your suggestion we have added bootstrap analysis, which has been further described in the "general comments" section. In fact, the average observed velocity of the flow field is about 12.28 cm/s and the mean RMSE is approximately 2 orders of magnitude smaller than the true value, so the mean RMSE of 0.3cm/s is a small error. However, it is worth pointing out that we do not assimilate drifter observations in the reconstruction of ocean current, so the results are more independent and scientific.

RC: Table 1: I would ask the Authors to apply a minor change to the Table: please add the name of each sub-region, in order to help the readers locating the different sub-regions in a global map;

AC: Corrected. The updated table is as follows.

Table 1. Verified RMSE (cm/s) based on Sub-GE/ Sub-GES/ Sub-GET/ Sub-GEST models

Reconstruction Model	55° E-70° E 10° S-5° N Southwest Maldives	Longitude and Latitude 80° E-100° E 45° S-60° S Southwest Australia	103° E-113° E 3° N-19° N Eastern Malaysia	125° E-142° E 22° N-37° N Southern Kyushu Island
Sub-GE	22.0333	9.1091	12.3418	11.7525

Sub-GES	20.9319	9.2731	11.9773	11.9136
Sub-GET	23.3724	9.2368	12.4657	11.3579
Sub-GEST	20.6216	9.3872	12.0061	11.4845

Reconstruction Model	Longitude and Latitude			
	156° E-173° E 10° S-10° N Southwest Marshall Islands	175° E-195° E 40° S-55° S Southeast New Zealand	228° E-240° E 9° S-21° S Western Peru	260° E-290° E 18° N-28° N Gulf of Mexico
Sub-GE	16.9963	7.1911	6.5527	7.9553
Sub-GES	16.4886	7.3135	6.5541	8.0693
Sub-GET	17.0196	7.2609	6.5225	7.6361
Sub-GEST	16.5005	7.3945	6.5184	7.8609

RC: Lines 266-271: would it make sense/be possible for the Authors to add a global map that emphasizes the choice of the different sub-models combinations used for the global reconstruction?

AC: A global distribution of the zonal optimal sub-models combinations in Spring can be seen in below figure E, and has been added in the revised manuscript in section 3.5.

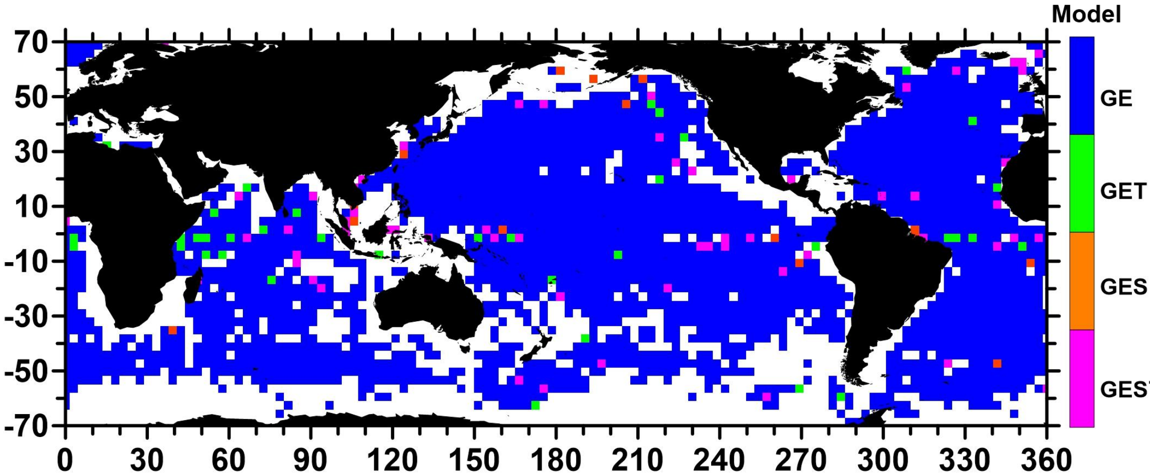
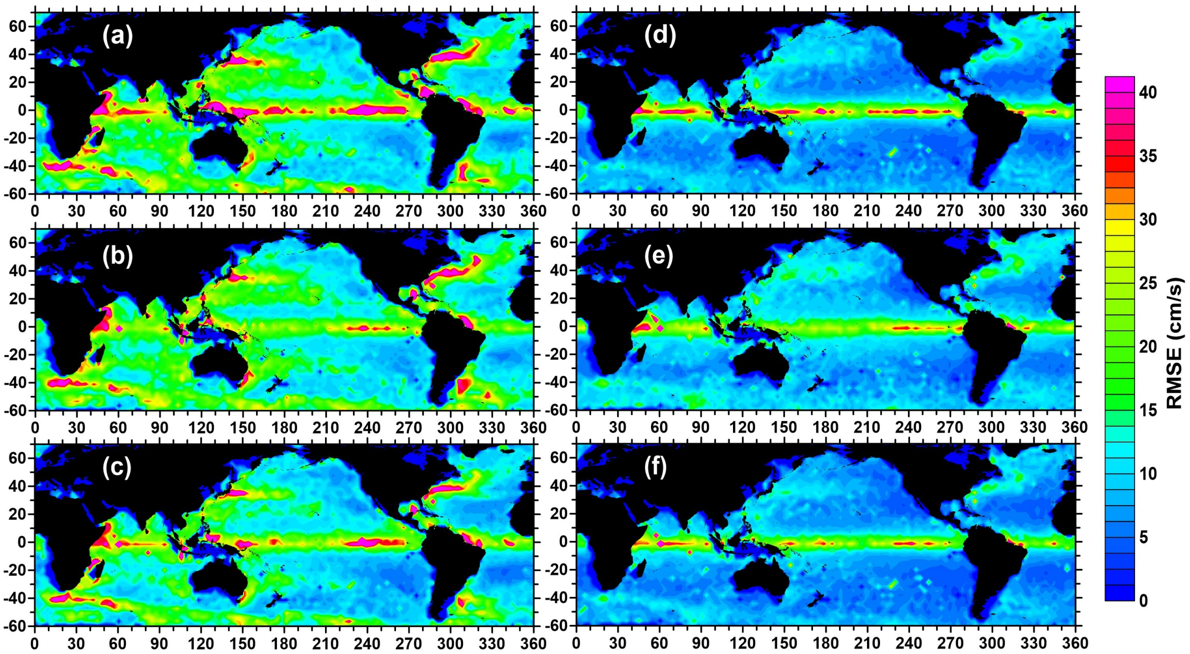


Figure E: The global distribution of the zonal optimal sub-models combinations in Spring.

RC: Figure 11/Line 290: I sincerely struggled a bit in understanding the meaning of synthetic vector/optimal vector. Could the Authors please further explain or harmonize the nomenclature of the variables?

AC: The "synthetic vector" means the synthesis of zonal and meridional components (i.e. $\sqrt{u^2 + v^2}$), while "optimal vector synthesis" is a flow field reconstruction model, which can choose the optimal vector synthesis combination of flow fields. The latter is the same as the optimal regression model and aims to select the best combination of flow fields. We have revised the caption of figure 11.



Revised: "Figure 11: The RMSE of the 1° reconstructed field of (a) zonal vector u, (b) meridional vector v, and (c) synthetic vector $\sqrt{u^2 + v^2}$, with the optimal combination of the regression model, and the 0.25° reconstructed field of (d) zonal vector u, (e) meridional vector v, and (f) synthetic vector $\sqrt{u^2 + v^2}$, with the optimal combination of vector synthesis model."

Responses to Technical Comments:

RC: Line 78: Maybe I would say " and the Globcurrent project products";

AC: We have corrected it as below (line 81-83).

Revised: "This global daily product covers the period of 2013-2019, with a 0.25° spatial resolution, and is compared with the OSCAR and the GlobCurrent project products."

RC: Line 108-110 (and elsewhere if necessary): Please remove the acronym CMEMS , keep Copernicus Marine Service instead;

AC: Corrected.

RC: Line 201: "wavenumber k and wavelength ?" It seems this sentence is unfinished. Could the Authors please double check?

AC: We have added a detailed description of the wavelength (line 215-217).

Revised: "Additionally, there is a theoretical decay equation for Stokes drift that can be expressed in Eq. (4b), where us_0 denotes the surface Stokes drift, z is the profile derived from a monochromatic wave with wavenumber k and wavelength $\lambda=2\pi/k$ (Kukulka and Harcourt, 2017)."

RC: Figure 9: I would add x and y axes labels as Longitude and Latitude while It is redundant to repeat RMSE (cm/s) for each of the four sub-figures;

AC: We have corrected it, and please see figure 9.

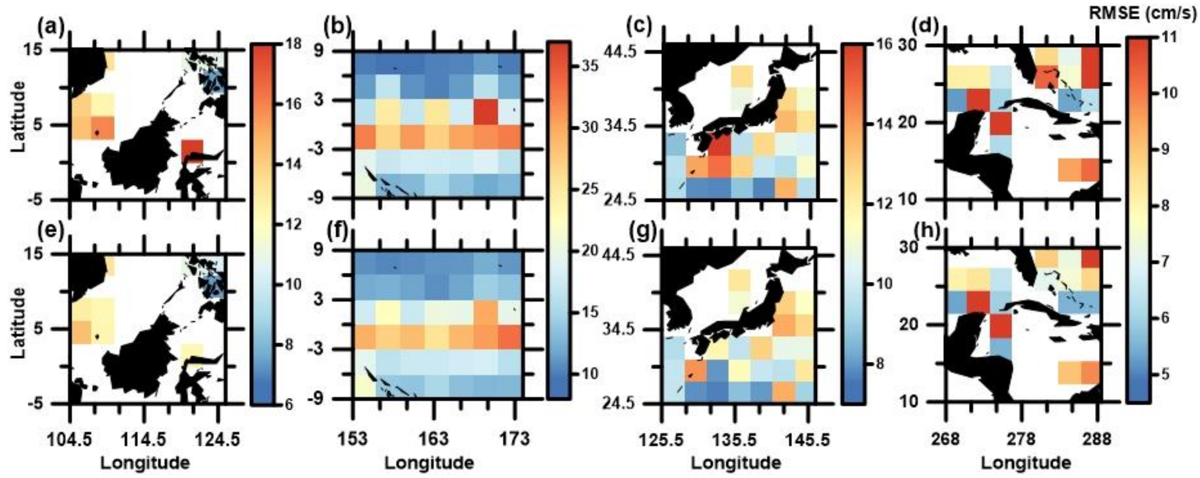


Figure 9: RMSE of (a)-(d) Sub-GE, (e)-(f) Sub-GES, and (g)-(h) Sub-GET models.

RC: "The OSCAR near-surface current with a grid size of 1°on a 5 days basis use the quasilinear, quasi-steady sea surface momentum equations and improve the equatorial algorithm by fitting…" should be modified as follows: "The OSCAR near-surface currents product, with a grid size of 1° on a 5 days basis, uses the quasi-linear, quasi-steady sea surface momentum equations and improves the equatorial algorithm by fitting…"

AC: It has been corrected as follows (line 323-325).

Revised: "The OSCAR near-surface current product, with a grid size of 1° on a 5 days basis, uses the quasilinear, quasi-steady sea surface momentum equations and improves the equatorial algorithm by fitting 12 orthogonal polynomials (Johnson et al., 2007)."