Authors' replies to
"Comment on essd-2022-111
Anonymous Referee #2"

Referee comment on "Sea surface height anomaly and geostrophic current velocity from altimetry measurements over the Arctic Ocean (2011–2020)" by Francesca Doglioni et al., Earth Syst. Sci. Data Discuss., https://doi.org/10.5194/essd-2022-111-RC2, 2022

In this work, the authors assess a new Arctic-wide gridded dataset of sea surface height and geostrophic velocity at monthly resolution during the period 2011 to 2020. This dataset was generated using Cryosat-2 observations from two products (RADS and AWI). The authors describe how the gridded altimetry-derived variables are produced and show results from comparisons against available in situ measurements (moorings) and an independent state-of-the-art data (altimetry). The seasonal cycle emerging from the final monthly maps is finally discussed.

Overall the paper is certainly of interest to the Arctic community. There is a need to have a unified data set for the ice-covered region and for the ice-free region that is validated properly. The authors provide a description of RADS and AWI products as well as how the two products are made consistent and homogenous before gridding. The new gridded data set is validated, but only in the Fram Strait and Laptev Sea.

We are grateful to the reviewer for the constructive comments, which helped to improve the manuscript and the validation of our gridded product. We thank you also for your positive statement on the value of the publication of our manuscript and dataset, once the validation is reinforced. Please find here few general remarks on the revision, and further below our elaboration on each comment.

In order to provide more evidence on the quality of the altimeter data used as source data and of our final gridded product, we added two pieces of analysis. First, we gave an overview on the statistics for the AWI and RADS along-track datasets and the merged dataset, furthermore including the latter in the file deposited by PANGAEA. Then, in order to extend the assessment of our gridded product to the western Arctic, we included comparisons with data from the Beaufort Gyre Observing System moorings, part of the Beaufort Gyre Exploration Program (BGEP[1], hereafter used as acronym for the moorings) and from two moorings in the central and eastern Chukchi Sea. We explored the possibility to compare to further data in the Chukchi Sea and Bering Strait but these time series were either too close to the coast to find good comparison points in the altimetry maps, or too short to have significant comparison, or very difficult to get at all.

We also revised our processing of in-situ data to evaluate possible errors deriving from it. We evaluated the reliability of our sea surface height from in-situ data in Fram Strait by comparing these data to continuous hydrographic profiles (for the steric height) and to a nearby bottom pressure recorder (for the bottom pressure equivalent height). We came to the conclusion that most of the variability is resolved, therefore we did not exclude these data from the validation. Detailed documentation is given below. We also found, though, a mistake in the computation of monthly means of in-situ data. When this was corrected, correlations between altimetry and in-situ sea surface height improved, with the greatest improvement in the Fram Strait. Finally, we adjusted the averaging depth of in-situ velocity data in order to exclude the surface Ekman layer, with negligible impact on the results.

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1) Overall the paper is well written with a clear rationale. My feeling is that the processing and validation part is rather limited. Altimeter data retrieval in the ice-covered region is very challenging due to presence of ice that perturbs radar echoes. It is stated that AWI product takes care using a customized processing. The reader expects more convincing analyses of RADS and AWI before their merging, with some statistics about their quality in the whole Arctic area. Authors only show one profile at certain date (Figure 3) that cannot be representative of a ten year period.

Within the ice-covered regions, we retrieve the sea level from leads (openings in the ice cover, cracks). Because of their flat surface compared to sea ice, the received radar echo power is dominated by the reflections from open water, even if it covers just a small area within the satellite footprint. Therefore, the perturbation by sea ice is rather limited (Ricker et al., 2014).

However, we agree that providing an overview on the statistics relative to the AWI and RADS datasets can help the reader to evaluate the quality of the final product. For this reason, we added panels in Fig 3 to visualise average 2011-2020 statistics, namely the spatial distribution of monthly standard deviation and number of observations for AWI and RADS (separated into summer and winter seasons) and for the merged dataset. These maps are commented in ll. 308-315. Furthermore, we included the merged along track dataset, as processed in this work, in the final data file deposited in PANGAEA (Doglioni et al., 2021)

2) I have also a remark about the velocity geostrophic computation at the surface. It is well known altimetry data are noisy and the accuracy of the slope estimate from along-track SLA is strongly impacted. It might dominate the errors in estimating ocean currents because a simple finite-difference of the along-track SLA acts as a high-pass filter. This effect can be mitigated, see Liu, Y., Weisberg, R.H., Vignudelli, S., Roblou, L. and Merz, C.R., 2012. Comparison of the X-TRACK altimetry estimated currents with moored ADCP and HF radar observations on the West Florida Shelf. Advances in Space Research, 50(8), pp.1085-1098.

We agree that in general the computation of ocean currents from along-track data is impacted by the noise in the observations. In our case, this was most true for the AWI data in the ice-covered regions because they were originally provided at high frequency sampling (20 Hz), not smoothed. For this reason, in our procedure we do smooth and subsample the AWI data along the satellite tracks before using them (see ll. 247-248). As an addition, we mention now in the text (ll. 248-250) that smoothing is beneficial to reduce noise in the computation of geostrophic velocity as well.

In our work however, we compute geostrophic velocity from the interpolated maps of sea surface height, which consist in a two-dimensional, smoothed reconstruction of the fields from along track data. In this case, the error in the ocean currents is rather dominated by residual sub-monthly variability between neighbouring tracks, that is aliased into spatial variability when mapping monthly data (see appendix C). This is addressed in our work by (1) using up-to-date corrections for tides and the response to wind and atmospheric pressure and (2) interpolating the along-track data weekly and averaging four subsequent weekly fields (see explanation in section 4.3.2).

3) Also, the direct comparison of the altimeter-derived geostrophic current velocities with the mooring real current velocities does not account for a wind-driven Ekman velocity component. Why ? is the wind contribution supposed negligible ?

Previous studies indicate that in the Arctic Ocean the Ekman layer extends approximately down to a depth of 20 m (e.g., Hunkins 1966; McPhee 1992; Cole et al. 2014; Peterson et al. 2017). In our previous manuscript version, we were already excluding data from the upper 10 m at the Laptev Sea continental slope. In the Fram Strait comparison, we used data from 75 m depth in order to avoid discontinuities in the timeseries when Current Meters were substituted with ADCPs in the later part of the time series. In order to account for the above comment, we adjusted the averaging depth at the Laptev Sea continental slope to the range 20-50 m, and included a comment about the averaging depth in ll. 200-2001. This change, however, did not lead any to significant changes in our results.

4) Having said that, I think the paper deserves publication after the authors reinforce the statistics of the two data sources (AWI and RADS) that are used to generate the new data set. If possible I also recommend to extend the validation to other sites in order to provide the reader with a more complete picture about the accuracy of the altimeter-derived sea level and velocities against in situ measurements.

Following your advice, we integrated Fig. 3 to provide an overview on the average monthly statistics of the AWI and RADS datasets and the merged dataset, and commented the results therein. This addition supported our confidence in the quality of the input data and the consistency between the AWI and RADS sub-datasets.

Furthermore, we substantially extended our assessment of altimetry-derived sea surface height and geostrophic velocity fields to the western Arctic by comparing to additional mooring data in the Beaufort Sea and Chukchi Sea and hydrographic profiles in the Amerasian and Eurasian basins (see additions in sections 3, 5.2.1 and 6.2).

Regarding the assessment of sea surface height, first, we compared our sea surface height product to time series of the sum of steric height and bottom pressure equivalent height measured at the BGEP moorings A and D in the Canadian basin. Then, we compared our monthly fields to monthly estimates of the sum of steric height from in-situ hydrographic profiles, distributed in the deep basins, and bottom pressure equivalent height from GRACE. Geostrophic velocity was further compared to near-surface velocity from the BGEP moorings A, B and D and moorings S1 and S3 in the Chukchi Sea. In agreement with the comparisons previously done in the Eurasian Arctic, the additional comparisons show that, while there is reasonable agreement between our product and in-situ data at seasonal and longer time scales, significant differences are observed at monthly time scales.

We believe that these comparisons to data in western Arctic, in addition to the ones we conducted with mooring data at three locations in Fram Strait and the Eurasian Arctic (i.e., Arctic Cape and Laptev Sea; see Fig 9), provide an overview of the capability of our satellite product to reproduce in-situ measured variability for a large portion of the Arctic. Despite differences in the resolution and the nature of in-situ and remote sensing measurements, our gridded sea surface height significantly correlates with mooring data from the ice-covered Arctic and its boundaries, showing correlation coefficients ranging between 0.5 and 0.9. Furthermore, our work entails also the generation and assessment of geostrophic velocity, which now includes comparison with data from nineteen moorings and a discussion of its realism in the spatial and temporal patterns in regions of different dynamical regimes.

References:

[1]Beaufort Gyre Exploration Projgram: https://www2.whoi.edu/site/beaufortgyre/

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