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The Editors
Earth System Science Data

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Dear Dr. Prasad Gogineni,

Please find attached the revised version of the manuscript essd-2021-128 entitled:

Towards a regional high-resolution bathymetry of the North West Shelf of Australia based on Sentinel-2 satellite images, 3D seismic surveys and historical datasets.

By Ulysse Lebrec, Victorien Paumard, Michael O'Leary and Simon C. Lang.

All comments and issues raised by the reviewers were addressed including updates to the text and figures. Our response to individual comments and how we addressed them is detailed below.

All authors have approved the updated manuscript and have agreed to its submission.

We look forward to hearing back from you.

Yours sincerely,

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Comments from Referee 1.

Digital Elevation Model (DEM) vs Bathymetry

Throughout the manuscript there seems to be alternating use of the concept of a digital elevation model/elevation and a bathymetry model/depth. Initial description in line 63 describes a DEM, but most figures and discussion thereafter refer to bathymetry/depth. This leads to thing being mixed up (e.g. Figures 4, 9 and 11) where images use depth/bathymetry and the profile charts use elevation. Sticking with just bathymetry/depth I think would help with consistency and interpretation. I would also specify the datum in each figure (MSL).

We agree that the alternating use of bathymetry/ depth and DEM can be confusing. We have used 'bathymetry/ depth' consistently in the revised manuscript apart from the compilation that remains in 'elevation' given that it includes onshore SRTM data.

The concept of Extinction depth

I think the work would benefit from a better discussion around the use of the concept of Extinction depth. Firstly, a description of what this concept physically means, and how this relates to similar concepts such as Optical Depth used by other satellite derived bathymetry methods would be helpful to the non-remote sensing reader. References around these concepts and statements (e.g line 340) should be included.

Optical depth and depth of extinction refer to the same concept: the maximum depth at which the SDB is valid. It appears that authors generating SDB using the physical approach are often using the term optical depth whereas authors using the empirical method are mostly using the term depth of extinction. Physically, this means that the change in satellite images reflectance cannot be related to the water depth beyond a certain depth. We did the following modification to the text (see line 367, with track changes):

The resulting averaged values were then plotted against the depth measurements from the calibration points. This revealed a linear correlation between the band ratio values and the calibration depths, up to a certain depth which is referred to as the depth of extinction. The depth of extinction (sensu International Hydrographic Organization and Intergovernmental Oceanographic Commission (2019)) *corresponds to the depth beyond which changes in the satellite image reflectance can no longer reflect changes in depths, and effectively indicates the maximum depth of validity of the method. The depth of extinction* is different for each satellite image and *varies depending on environmental factors such as the met-ocean conditions and the turbidity of the water.*

Second, a bit more clarity around the target coefficient of correlation (line 344), how this is decided, and if it is the same for each image (why/why not) is needed.

The script tries to find the depth of extinction with a minimum r2 of 0.95, if it does not work, it tries again with 0.90 etc. We included the following clarification to the text (see line 373, with track changes):

To allow batch processing satellites images, the determination of the depth of extinction was automated via python scripts and the use of a threshold coefficient of correlation (Fig. 7): a linear regression was calculated using all data points; if its coefficient of correlation r2 was higher than ~~a specific threshold~~ 0.95, the regression was validated, else it was recalculated using all depths, minus one meter. This maximum depth boundary corresponds to the theorical depth of extinction being tested

(Fig. 7). The process was repeated until the target coefficient of correlation was achieved or a minimum depth of extinction of 15 m was reached. ~~Similarly, if the targeted coefficient cannot be reached, the threshold is iteratively lowered.~~ In such instance, the target coefficient of correlation was iteratively lowered by 0.05 and the process presented in Figure 7 (i.e., the iterative lowering of the theorical depth of extinction being tested) was repeated all over again and so forth until a target coefficient of correlation was validated. Ultimately each satellite image was associated to a depth of extinction and a coefficient of correlation.

Filtering images in the stack and deriving the correlation coefficient

In section 5.3.4 a process is described that essentially filters images that have outlier 'temporal effects' present (as illustrated in Figure 9). There does need to be more clarity in lines 379-383 around how a correlation coefficent threshold for each image is determined. Is there a lower threshold for an image near a river mouth with a regular sediment plume. If so, doesn't that still make that data less reliable?

The threshold was defined based on the authors judgement to find the best balance between the number of images included in the stack and their accuracy. For example, south west of Dampier all images have r2 values in excess of 0.9 whereas offshore DeGrey the highest r2 is of 0.8. This indeed suggests that the SDB generated in front of a river mouth is less reliable. The effect of a regular sediment plume is however minimised by the error model used to correct the SDB. See next comment for included modifications.

I think the authors also need to discuss/acknowledge how this process relates to the error correction process described in 5.3.3. As the error correction already corrects the bathymetry based on a surface error model in comparison to the calibration points, if you are then looking at a correlation model based on this corrected bathymetry, the process is at risk of becoming circular and less valid. For example, it seems that in a turbid estuary, the error model process would do its best to correct the underestimated bathy values (in a regional surface sense) back to the calibration points. Running a correlation then for image QA/QC on these already corrected outputs needs a bit more justification I think.

The coefficient of correlations used here are the ones obtained from the derivation of the initial bathymetry presented in section 5.3.2 and which are therefore calculated before the error model correction. We are not calculating any coefficient of correlation on corrected images as this would provide meaningless values and basically be, as described by the reviewer, a circular self-correlation.

We performed the following modification to the manuscript (see line 421-427, with track changes):

For each tile, a minimum coefficient of correlation between the predicted depths and the calibration points was determined and images with a coefficient below that threshold were discarded. Coefficients of correlation values used here to determine if an image should or should not be included in the stack were the values calculated during the derivation of the initial bathymetry, before the application of any types of correction, to avoid circular correlations. The threshold varied from one tile to another to reflect their respective specificities: tiles located in front of a delta, where the seabed is rapidly changing, have overall lower coefficient of correlation values than areas with no sediment supply. In that regard it was not possible to establish a firm rule and the threshold was subsequently determined for each tile by the authors to obtain the best ratio between the number of images integrated in the stack and their respective coefficient of correlation. On average, the threshold was set at 85%. In total, 222 images from 26 tiles met their respective selection criteria.

Use of pixel based Standard Deviation layer

The inclusion of a pixel based standard deviation layer in the data product is a very useful tool, and I think should be used more in the manuscript, as it is only mentioned as an afterthought in line 418 and Section 8. Already in Figure 9(c), we can see the expected increased variance in the single image solutions as depth increases. Showing an image illustrating this based on the standard deviation layer would be very informative. Likewise, an image figure would help illustrate how a higher variance of the product would be expected in dynamic and/or turbid estuaries, helping to back up statement such as line 443.

In my opinion, this SD layer is as useful in terms of the user assessing the accuracy of the SDB product as the validation to the LADS data. To add further value to the statement on mean SD in line 419, I would suggest extracting a graph/table that shows the mean SD for pixels based on depth intervals (ie. Model depth SD for pixels 0-2m, 2-5m, 5-10m etc etc). This would be extremely helpful to the end user.

Agree, interestingly one could use the STD layer to assess bedform mobility. We added the following figure and table. Overall, the standard deviation increases:

- With depth.
- In areas with potential mobile bedforms including near river mouths and tidal channels.
- In areas with high tidal range (the standard deviation increases eastward along with the tidal range. The only exception is a tile which includes an insufficient number of images in the stack to generate meaningful metrics due to the high turbidity of the area.
- In turbid/ muddy areas.
- Potentially where major change of seabed type occurs (i.e., sea grass meadows).

It should be noted that the standard deviation is however very sensible to the number of images included in the stack. Areas where only a few images were included in the stack tend to show lower standard deviation values which does necessarily means that they are more accurate. The text was updated as follow (see line 471-475, with track changes):

The standard deviation appears to increase with depth (Fig. 12, Table 2) but also in areas with strong current, water turbidity, tidal range and potentially where major change of seabed type occurs (e.g., seagrass meadows), effectively highlighting areas that have changed significantly through the time interval included in the final stack. This suggests that the standard deviation layer could be used to better understand seabed conditions and could potentially, for example, help identifying mobile bedforms.

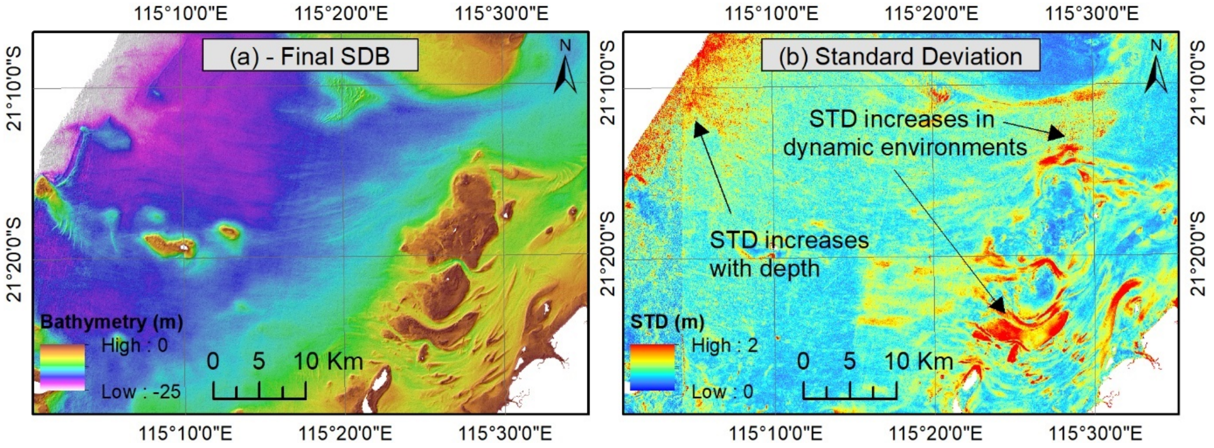

Figure 1 Illustration of the standard deviation grid (b) generated with the final SDB bathymetry (a). The grid illustrates the spatial variability of the final SDB grid accuracy. The standard deviation increases (and hence the accuracy of the bathymetry decreases) with depth as well as in dynamic environment where the seabed changed through the sensing period such as tidal passes (b).

Table 1 Mean standard deviation per depth range.

Depth range (m)	0 - 5	5 - 10	10 - 15	15 - 20	20 - 25	25 - 30
Mean standard deviation (m)	0.90	1.04	1.11	1.23	1.18	1.53

Technical Corrections

Line 49 *– Please explain 'indirect' datasets, the meaning is not particularly clear.*

As per suggestion from Robin Beaman, we changed it to 'multi-source'

Figure 6 *– In description, it should be made clearer that the Australian Bathymetry and Topography refers to the Regional Data in panels b and c.*

Figure label was modified to AusBathyTopo.

Lines 288, 323 and elsewhere *– Including the band centre wavelengths for the Sentinel 2 bands described would be helpful.*

We included it in section 5.2.1 (data selection, see line 337 with track changes).

Lines 305 – 312 *– A rewording and perhaps further explanation I think would help to explain what is meant by abnormal values and the rational for avoiding them (ie. Dry season in the North?)*

Abnormal values refer to pixel values from the input satellite images that are affected by seasonal environmental factors (e.g., water turbidity increases during wet season) and may therefore not be representative of the water depth. We clarified this point in the text (see line 332, with track changes). The rational for avoiding them is explained the next paragraph.

Line 325 *– Please elaborate on what is meant by speckles (ie pixel based glint, signal/noise artefacts)*

Pixel based glint. Such filtering is recommended by the IHO cookbook. We updated the sentence accordingly (see line 353, with track changes).

Figure 8 *– I think 'seismic' may meant to be 'satellite'*

Indeed.

Line 376 *– Perhaps 'statistical analysis' instead of 'statistics'*

Ok.

Figure 9 *– Would benefit from inclusion of the true colour image of this example to visually show the temporal artefacts concept the author is trying to highlight.*

We added another 'row' to the figure with three insets from true colour images illustrating each of the three points (ships, clouds, turbid water, Fig. 2; Fig. 9 in revised manuscript).

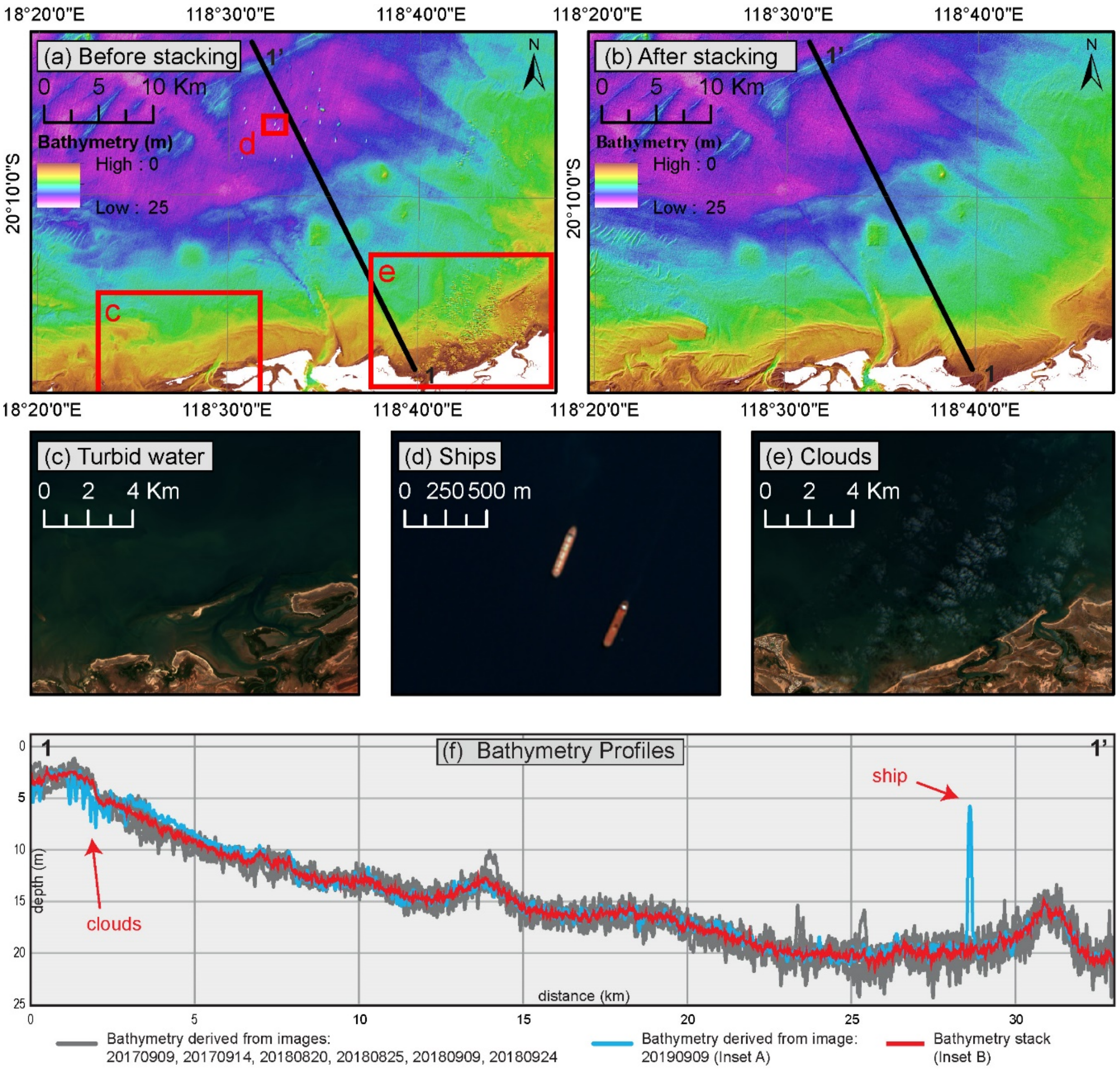

Figure 2. Updated Fig. 9 (cf revised manuscript)

Line 433 *- use of ‘constrained’ rather than ‘tied’ perhaps*

Ok.

Comments from referee 2:

Our understanding is that the two main comments are as follow:

Include the LADS LiDAR data in the compilation

The LADS LiDAR dataset was made available to us under Creative Commons licensing CC BY-NC-SA which forbids any commercial use of the data. Any remix or transformation of the data should also carry the same licence. On the other hand, AusSeabed data portal, used to share the compilation, is based on Creative Commons licensing CC BY hence allowing commercial use.

Our understanding is that we are therefore not allowed to include the LADS LiDAR dataset in the compilation as this would breach the LADS LiDAR dataset CC BY-NC-SA licence.

Reprocess the seismic derived bathymetry to include refined velocity models

In the absence of site-specific sound velocity profiles, we made the decision to use a constant value to convert seismic-derived bathymetry from the time to the depth domain instead of using more refined approaches such as polynomial equations. The value of 1500 m/s was retained by averaging the sound velocity values that were sometimes specified in the navigation file headers of the seismic surveys. Importantly, this conversion was only performed for the reflection-derived bathymetry. In the case of navigation-derived bathymetry, the input data was already in depth and, most of the time, velocities were not available at all, hence forbidding back calibration. Reflection-derived bathymetry includes 26 surveys with an average depth of circa -750 m.

You mentioned in your comments the ‘CSIRO software SVP builder’ that can generate synthetic SVP profiles using climatology data anywhere around Australia. After enquiring about it, it appears to be an earlier version of the Doris software https://www.doris-svp.org/ which is published by IFREMER and SHOM and uses climatology data from the World Ocean Atlas 2013 (https://climatedataguide.ucar.edu/climate-data/world-ocean-atlas-2013-woa13). To the best of our knowledge this is the only tool available to generate such synthetic profiles.

We generated a few profiles within the area of interest to compare the differences between the resulting values with the constant 1500 m/s used in the manuscript. It should be noted that the tool returns more depth/velocity pairs in shallow waters (i.e., the vertical interval between two velocity points increases with depth). We therefore filtered the synthetic profile values to obtain meaningful averages. The resulting average velocities per depth interval is presented in Table 1. This comparison indicates that for most intervals the difference is below 0.5%.

The software does not provide quantifiable uncertainties for neither the climatology data used as input nor for the computation of the velocities themselves, it is therefore not possible to fully assess by what extent the synthetic profiles would actually improve the results.

Additionally, the difference in velocities should be looked at in the context of seismic surveys vertical resolution. For the most part, seismic surveys are acquired with a vertical sampling rate of 2 to 4 ms and frequencies comprised between 40-150 hertz (MBES surveys use frequencies 1000s of times higher). Moreover, as presented in the manuscript, morphologies from the reflection derived bathymetry exhibit increasing vertical distortion in shallow waters, overwriting by an order of magnitude any offset related to the sound velocity model.

In light of the above, we believe that there are not enough elements to support a reprocessing of the reflection derived bathymetry using synthetic sound velocity profiles. The uncertainties associated with sound velocity profiles are covered by the current data limitation sections and data accuracy tables.

We certainly agree that the use of site-specific sound velocity profiles should become part of the best practice to produce reflection seismic-derived bathymetry. However, we think that the actual accuracy gain from the inclusion of synthetic sound velocity profiles should be further assessed and that such task extends beyond the scope of this paper.

Table 2 Comparison of average velocities from Doris with a constant value of 1500 m/s

Depth Interval (m)	0-250	0-500	0-750	0-1000	0-1500	0-2000
Avg Velocity (Doris) m/s	1526.37	1512.74	1505.2	1500.86	1496.58	1495.1
% difference with 1500 m/s	1.72	0.84	0.34	0.05	0.23	0.32

Additional comments.

we have included below additional questions raised in the PDF document. Comments and text editing suggestions that are not specifically mentioned hereafter are regarded as “accepted” and were included in the revised manuscript.

Line 57 – Change ‘shelf’ to ‘Shelf’. But it is not really full bathymetry coverage of the NWS – only the southern or western part of the NWS (as per your description in Line 30).

The combination of this dataset with the compilation produced over the Northern Territory by the reviewer results in a full coverage of the NWS. As stated in the text, it is the combination of both compilations that provide a full coverage of the NWS.

Line 126. Could you incorporate 4.1.2 with 4.1.

While we agree that in this specific case having a sub section for data source is a bit superfluous, the idea was to have the same section breakdown for each datatype.

Line 131. How did you deal with noise < 150 m?

Whenever possible we used navigation-derived bathymetry instead of reflection-derived bathymetry as this issue is specific to reflection-derived bathymetry. However, in some areas, navigation data was either not available or not dense enough to generate a grid. In such case we included the reflection-derived bathymetry because we consider that, while the relative elevation of a given seabed feature compared to another one might be inaccurate, the actual morphology is still valid and adds value compared to the Australian Bathymetry and Topography grid. The bottom line is that we dealt with the noise by choosing which survey to include in the compilation, but we did not apply any specific correction to filter that noise as we could not find an accurate method to precisely quantify it. This is explained in section 4.5.

Line 394. How were small water bodies automatically removed?

We first generated a raster domain shapefile (a shapefile delineating the boundaries of a raster) where each feature – in this case polygons – corresponds to an individual water body. We then filtered the shapefile to only keep the polygon corresponding to the main water body and used it to clip the bathymetry, effectively resulting in the removal of all disconnected water bodies. We added clarification in the text (see line 441-445, with track changes).

Line 406 What do you mean by mesh of 500 m?

A grid (fishnet) of points separated by 500 m along the X and Y axis. We added a clarification in the text (see line 457, with track changes).

Line 429 – I think you are looking at the wrong IHO publication. You want S-44 Edition 6.0 0: https://iho.int/en/standards-and-specifications Your error values would likely conform to Order 2 of Table 1, and this is worth quoting in the text.

The document cited in the text https://iho.int/uploads/user/pubs/standards/s-57/S-57_e3.1_Supp3_Jun14_EN.pdf refers to Zone Of Confidence (see p 17). We have however followed the reviewer suggestion to use S-44 instead as the point remains the same (see line 486, with track changes).

Line 463 Sensing tool what is that?

We are referring to the different types of bathymetry (e.g., seismic vs satellite vs MBES). We rephrased the sentence to use 'source data metadata' instead (see line 532, with track changes).

Data availability. Error when loading shapefile and use of the term 'bathymetry domain'.

The shapefile is pretty heavy (1.9Gb). Given that by default Arcmap/catalogue only has 2Gb of ram this can easily make the software crash.

The term domain refers to the coverage of the datasets included in the compilation. We believe the reviewer used the term lineage in its own compilation. The term 'domain' corresponds to the name of the ArcGIS geoprocessing tool used to generate the file and is, to the best of our knowledge, commonly used in GIS.