Biogeosciences Discuss.,
https://doi.org/10.5194/bg-2017-506-AC2, 2018
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Biogeosciences Discussions

Interactive comment on "Understanding Mn-nodule distribution and related deep-sea mining impacts using AUV-based hydroacoustic sensing and optical observations" *by* Anne Peukert et al.

Anne Peukert et al.

tschoening@geomar.de

Received and published: 21 February 2018

Reviewer 2: The authors of this study should present information on the mean nodule size . . . Authors Comment: Considering the potential inaccuracy of nodule detection and separation of the image analysis tool, the application of quantiles on the size distribution allows a more accurate interpretation of the data (Peukert, 2016). Therefore, a mean size value would not be appropriate here. An explanation was added to the Appendix (see DC). Document Changes: Interpretation of Mn-nodule size results Considering the probable error in correctly detecting nodules by the image-analyzing tool,

the application of quantiles of the size distribution allows a better interpretation of the data. It is suggested not to use size values of the smallest and largest 1 % of the quantile calculation, due to the above mentioned error source. The graph in figure 1 illustrates the quantiles of the calculated sizes of two images, which clearly differ from each other. The graph correctly displays a size difference between both images, indicating larger nodules for image #29302. This shows that the tool can be reasonably applied to calculate the nodule size. The best differentiation however exists for the 50% - 75% quantile. Towards larger and smaller size values the curves approach each other which points towards the detection of similar - non nodule - features in both images. Therefore, the median values are considered to best represent nodule size differences between images/areas. Since truly correct nodule identification by the tool cannot be ensured for this quantile, size values should not be seen and used as absolute values, but rather indicators of changes between areas that are compared.

R2: Moreover, Kuhn & Rathke (2017) showed in their study that a good correlation can be established between coverage data from box corer stations and image analysis for small-sized nodules [. . .].The authors of this study [. . .] should provide information if they have found a similar correlation. [. . .]In the presented manuscript there is no information about precision and accuracy of the image analysis approach but this information is necessary and must be included. AC: Indeed it would have been nice to correlate box-core data with image data. Unfortunately, we do not have corresponding image and box-core information. To do this properly, the seafloor photographs from before the sampling would be required, exactly knowing where the box-corer will take the sample. Alternatively, the AUV could have made a photo survey before and after the sampling. We do not have such data and thus cannot accommodate the request of the reviewer.

R2: [. . .] Even if I doubt the absolute number of 12.5 % nodule coverage as the threshold value. . . AC: The 12.5% Mn nodule coverage is of course not an absolute value, as it has been discussed several times. The calculated coverage results are in a range be-

tween 7-24%. However, the majority of 99% is between 8 and 17 %. Values below and above are outliers and can be considered as inaccuracy of the automatic nodule detection by "unusual" objects in the image (like tracks or a fish for example). 12.5% was set as a threshold, since it is the median and mean of this majority and is the highest occurring coverage amount (Figure 1, this comment section). Furthermore, applying this threshold, the difference in Mn nodule coverage follows bathymetric structures (especially in A2); of course, the differences in Mn nodule coverage are very low (and probably not relevant for resource assessment, which is not the goal of this study) but so are the morphological undulations within the studied area. To make this clearer, an explanation of the threshold value was added to the text (see DC, p.12, line 17ff.). DC: Based on the automated image analyses, the majority of the seafloor shows nodule coverage values between 8% and 17% (Figure 5A). Values below and above this range (<1%) are to neglect, since they are caused by "unusual" objects (like tracks or organisms) in the images. In the following examinations the threshold between 'low' and 'high' Mn-nodule coverage is set at 12.5%; which is the analyzed mean coverage value of the considered range. In the eastern A2 sub-area a greater proportion of higher coverage values (13-16%) can be observed.

R2: However, more real ground truth data from box corer stations would be necessary to verify the threshold value. AC: That is true and would be part of further investigations, as mentioned above. The following sentence has been changed to mention this: section 4.1. p.24, line 4-5 DC: For absolute accurate resource assessments and verification of the results, detailed sampling based on this study would need to follow.

R2: I also wonder if there are any correlations between AUV-based backscatter data (such as BS intensity) and nodule coverage? AC: Unfortunately, the BS data of the area analyzed in this study were not usable due to technical errors. The data from other areas though look very promising. These are part of other studies, which are currently in preparation.

R2: Another approach would be to analyze the nodule coverage and the hydroacous-

tic data based on artificial neural networks or on random forest. Did the authors try these approaches? AC: This approach is part of other studies and was not pursued here. As mentioned above, the data used for this study were "data of opportunity" and not acquired to perform statistically correct machine learning approaches aiming at extrapolation of nodule coverage / resource assessments.

R2: What the manuscript generally lacks is real ground-truth data for Mn nodule coverage which can only be obtained from sampling with box corers. Is there any such information from the working area, e.g. from other cruises? I know that the BGR has carried out several expeditions to this area within their exploration campaign. AC: As already mentioned above, box core sampling would be the next step based on these results for verification. This would require highly detailed sampling at exactly the same area analyzed here. In the publication of Kuhn et al. (2016), the box core stations are too far away (at least 500m) and also the BGR BC stations are located within this area, are too far away (Figure 2, this reviewer section). Thus, this data cannot be used as ground truth validation of our results. However, two tracks of visual observations, which were also carried out from BGR, match more or less the AUV photo track of this area and provide similar observations (Peukert, 2016).

Specific Comments Abstract R2: First sentence: Optical imaging data are no real ground truth data. If they could be linked with nodule coverage/abundance from box corer stations of this area, then one could speak of "ground-truth data". Otherwise, the authors should change this sentence removing the word "ground-truth". AC: "Ground-truth" here means the visually from the AUV images detectable nodule coverage on the sediment surface, not the absolute coverage including the buried nodules. The term "ground-truth" seems reasonable to us for this study. Nodule coverage vs. nodule abundance

R2: The authors sometimes use the term "nodule abundance" and sometimes "nodule coverage". There is a significant difference between both: abundance means the mass of nodules per area (e.g., in kg/m^2) and coverage means the seafloor areal fraction

covered by nodules in %. From image analysis only the coverage can be detected and this is what the authors mean in their manuscript (e.g. refer to Fig. 5). Therefore, the authors should only use the term "nodule coverage" in the manuscript. AC: Thank you for this remark. We changed this throughout the text.

R2: [. . .] To my understanding this discrepancy is the main reason for the poor correlation coefficients and it may be caused by the observation that nodules are covered by sediments to a variable degree. But in images only the part of the nodules not covered by sediments can be analyzed and this may lead to a significant underestimation in both coverage and size of nodules as we can see it in the data presented in this manuscript. AC: We are aware of the discrepancy between the visually detectable sediment surface and the "real" nodule coverage on the seafloor which is discussed in the paper (e.g. p.17, line 2ff. or p. 18, lines 27-29). The results of Kuhn & Rathke (2017) regarding the accuracy is taken into account and mentioned in the text (section 4.1, p.24, l.4), see DC). This study aimed to show possible correlations between morphology on different scales and small-scale relative (not absolute!) changes in nodule coverage; such small scale-changes of course require very detailed sampling which needs to be taken out to verify the results as a next step. However, as mentioned in the paper, for habitat mapping purposes, nodules are considered as a hard substrate habitat where only the unburied part of the nodules on the sediment surface is relevant, making the visual mapping technique a very useful tool (p. 2, line 8-9, p. 17, line 4-6). DC: Photographs only provide information of the sediment surface and thus will not be able to detect buried/sediment-covered Mn-nodules (Sharma and Kodagali, 1993; Sharma et al., 2010, 2013), resulting in an underestimation of the absolute Mn nodule coverage (Kuhn and Rathke, 2017).

Pit Structures R2: The occurrence of pit structures may not only be restricted to larger depressions as stated on page 8, line 12, but could also be controlled by E-W trending linear structures as Fig. 4C may suggest. AC: Yes, they could be controlled by E-W trending linear structures, however the AUV-mapped area does not allow the statement

that E-W structures are more important than 'negative BPI' in general.

R2: A pit structure was sampled during SO140 with a box corer (station 107KG). There were no nodules on the sediment surface but two nodule layers at greater sediment depth (16 and 32 cm below surface; Kuhn et al., 2015). This contradicts the interpretation of the authors of this study of how larger nodules in the pit structure could have formed (page 18, line 20/21). [. . .] AC: We believe the reviewer considered larger structures in the SO140 cruise than the pits in focus of this study: "sizes from several tens of meters to 150m in diameter with a maximum depth of 4m" (p.8,line 11). However, at this point the reviewer mixes this study's "depressions" which are proposed to contain higher nodule coverages with this study's "pits", where no nodules can be seen at the sediment surface. We argue that nodules could be buried here (p.27, line 4-5, see edited manuscript), which is in agreement with your findings.

R2: [. . .]BGR data suggest that larger nodules have a larger diagenetic fraction and thus should have grown faster. A larger diagenetic fraction, however, is only possible at sites with higher sedimentation rates and/or higher TOC content. A slightly higher sedimentation rate in areas of higher nodule coverage is also discussed by the authors of this study further down in the manuscript (page 18, line 30/31). Moreover, the pit structures are interpreted as sites of higher sedimentation rates (page 18, lines 35ff.). Why should other depressional sites behave differently in terms of the sedimentation regime? AC: We distinguish between "depressions" and "pits", which occur within wider depressions (section 3.1, p. 12, line 9-11). In section 4.2.2. where the lack of Mn nodule coverages in these structures are discussed, we changed the text so the difference becomes more prominent (see DC). DC: p. 26, line 29ff (see edited manuscript): Rather special for the presented data set are the pronounced pit structures, observed throughout the AUV-mapped area with very little to no Mn-nodules observed at the sediment surface, which is in contradiction to the wider depressions, where higher Mn-nodule coverage was observed.

AC: Our interpretation is that only in the pits the sedimentation rate is too high for

nodules to appear at the sediment surface (because they were buried, p.18, lines 32-34), which is in agreement with the reviewer's above mentioned findings. The pits are likely to be younger structures; nodules have formed within the depressions first. The collapse forming the pits occurred later. The nodules within the pits were then buried by sediments following the gravity to the deepest point and accumulating there. We added the interpretation of pits being marine karsts and the associated reference to the interpretations (see DC). DC: p. 27, lines 5-7 (edited manuscript): The formation process of the pits is unclear, but could be karst structures, as proposed by Kuhn et al. (2017), which are younger than the Mn nodule formation and which would point towards Mn-nodule burial within the pits.

R2: At sites with stronger bottom currents, e.g. at sites where the near-bottom currents are channelized, nodules do have a higher hydrogenetic content and they are generally smaller and occur in higher numbers (BGR data, e.g. Rühlemann et al., 2012). AC: What kind of morphological changes would be needed to increase bottom currents, what would be the size of the morphological change? Do we talk about kilometer-, 100m- or meter-scale? This 'scaling issue' makes these results hard to compare with previous studies, which dealt with coarser scales, than this one.

R2: The discussion on the pit structures on page 19, lines 1-13 is wrong. During cruise SO240 one such pit was sampled with box corer and gravity corer. Pore water chemistry was not different from other sampling sites outside the pits (Kuhn et al., 2015). Moreover, heat flow measurements over such pit structures did not show any temperature anomalies. [. . .] AC: As mentioned above, we believe the reviewer did not sample a structure in a comparable size in the mentioned cruise. Moreover, it is hard to precisely sample exactly within the pits of such size, especially if the high resolution bathymetry is not available. Small-scale bathymetry and nodule coverage

R2: Figure 4b indicates that there is a steeper slope in sub-area A2 whereas this area is characterized by higher nodule coverage compared to sub-area A1 (Fig. 5B). This is contradictory to the statement given at page 8, line 26-27. AC: The trouble is that

that ship- and AUV-obtained bathymetry show different correlations. Therefore, it is not possible to apply one statement to different scales. This is one of the main findings of this study and is discussed in section 4.2.4. p.19.

R2: The interpretation of the distribution of the nodule coverage presented in Fig. 7 is based on these weak correlations. How does the predicted low coverage from Fig. 7 correspond with the coverage data from the AUV photo survey? Please provide a scatter plot with nodule coverage from image analyses (x-axis) and nodule coverage from the combination of hydro-acoustic data (y-axis). AC: This links to the Machine Learning approach, which was not done in this study. Sediment plume settling

R2: Page 13, line 30: How was the threshold of 8% nodule coverage as complete blanketing defined? Why not 0%? AC: 8% was the minimum value, because the algorithm sometimes misinterprets shadows as nodules (no area with 0% nodule coverage).

R2: Discussion about particles size in a sediment cloud (page 20/21): The assumption of Stoke's law to describe the sinking behavior of the plume particles is incorrect. Flocculation occurs at large-scale as experimental and modelling results from the JPIO project "Mining Impacts" have shown (pers. comm. A. Vink). AC: This is written in the text (p.20, line 30/31). Flocculation could also lead to increased friction lowering the sinking velocities, as discussed in p. 20, line 31

R2: Thus, the particles sizes should be much larger than 29 μm on average and the sinking velocities should be rather between 0.5 and 3 m/s. These higher sinking velocities may require a plume height greater than 1.6 m. . .? AC: 29 μm is the median particle size in the area, disregarding flocculation (p.20, line 26-27). This scenario and the simple application of Stokes Law was just used to highlight the difficulty in estimating the distribution of a mining-induced sediment cloud, since several factors, such as flocculation / aggregation have to be taken into account and it is hard to make a statement on how such massive sediment plumes will behave in a real mining scenario and what difference these factors make. Nevertheless, the calculated plume height created

by the EBS in the experiment is approximately 0.96 to 1.6m (p.20, line 30) in agreement with measured ADCP data (p.20, lines 32-35). Regarding "sinking velocities should be rather between 0.5 and 3 m/s": How did the reviewer get these values? Mn nodule growth (page 18-19)

R2: The work of von Stackelberg & Beiersdorf (1991) describes the influence of different parameters on the Mn nodule growth. This work should be taken into account by the authors. AC: The mentioned work has been taken into account and was cited (p. 17, line 20).

R2: The citation of Mewes et al. (2014) on page 18/19 may not be correct. Mewes et al. (2014) describe that at sites with medium to large-sized nodules a smaller percentage of clay particles have been found in the surface sediments. This may be due to increased activity of near-bottom currents which has removed part of the clay particles. The remaining sediment may have contained a relatively higher proportion of mobilizable Mn which was then available for Mn nodule formation. AC: "[. . .]higher sedimentation rate in a low current regime would also mean a higher accumulation of clay size particles, which are proposed to hinder nodule growth Mewes et al. (2014)." To our understanding this means the same in reversion? However, "hinder" has been changed to "not favorable for" (p.29, line1).

Technical Corrections R2: Mixing of abundance and coverage throughout the manuscript. Please correct - see above. AC: Has been corrected.

R2: Always use the term "ferromanganese nodules" in the text starting with a small letter except at the beginning of sentences. AC: Mn-nodule was introduced as an abbreviation for ferromanganese nodule in p.2 line 5. It was changed from a capital letter to starting with a small letter, as suggested.

R2: Pay attention to the correct statement of references, e.g., always use parenthesis within a sentence (cf. page 2, line 7 and at many other lines in the text). AC: Has been changed.

R2: Page 1, line 18: mining operations (no -). AC: Has been corrected.

R2: Page 2, line 21: 12 km^2 AC: Has been corrected.

R2: Page 6, line 8/30: data citation is missing AC: Has been added.

R2: Page 14, line 7: it must read East instead of West AC: It is correct as it is. Three different things are named here.

R2: Page 15, line 3: it must read west-facing slope AC: No, the purple shadings indicate east-facing slopes.

R2: Page 21, line 36-39: Something is wrong with the grammar AC: These lines are not present? Do you mean another page?

R2: Table A1: AUV MB (Fig. 4, not Fig. 2) AC: Has been corrected.

R2: Table A2: What is the difference between mineable ridges and ridges, flat depression and depression, mineable deep depression and deep depression? Table A3: How are the different classes (mineable versus un-mineable) defined? AC: Thank you for the remark. The following explanation was added to the Figure captions: DC: p.6, line 3 and p.9, line3: The terms "minable" and "unminable" are defined by slope threshold ("minable": slope <= 3°; "unminable": slope >3°).

R2: Table A6: Why is BPI440st used in this table and not BPI50st? AC: BPI440st seemed more reasonable for an overview description of the AUV-mapped area, which is why it was used for Fig. 4. BPI50st was used for the small-scale analysis because this BPI-scale detects the single pit structures. Table A6 summarizes the statistics for the descriptive derivatives of the AUV-mapped area, displayed in Figure 4.

R2: Page 29, 1st reference: year is missing. AC: Reference year is not missing in our document?

Cited References Kuhn, T., Rathke, M. (2017). Report on visual data acquisition in the field and interpretation for SMnN. Deliverable D1.31 of the EU-Project Blue Mining.

www.bluemining.eu/downloads. BGR Hannover, 34 pp. Peukert, Anne. 2016. "Correlation of ship- and AUV-based multibeam and side scan sonar analyses with visual AUV- and ROV-based data: Studies for Mn-nodule density quantification and mining-related environmental impact assessments." unpublished MSc. Thesis MSc. Thesis, Institute of Geosciences, Christian-Albrechts-Universität zu Kiel.

Interactive comment on Biogeosciences Discuss., https://doi.org/10.5194/bg-2017-506, 2017.

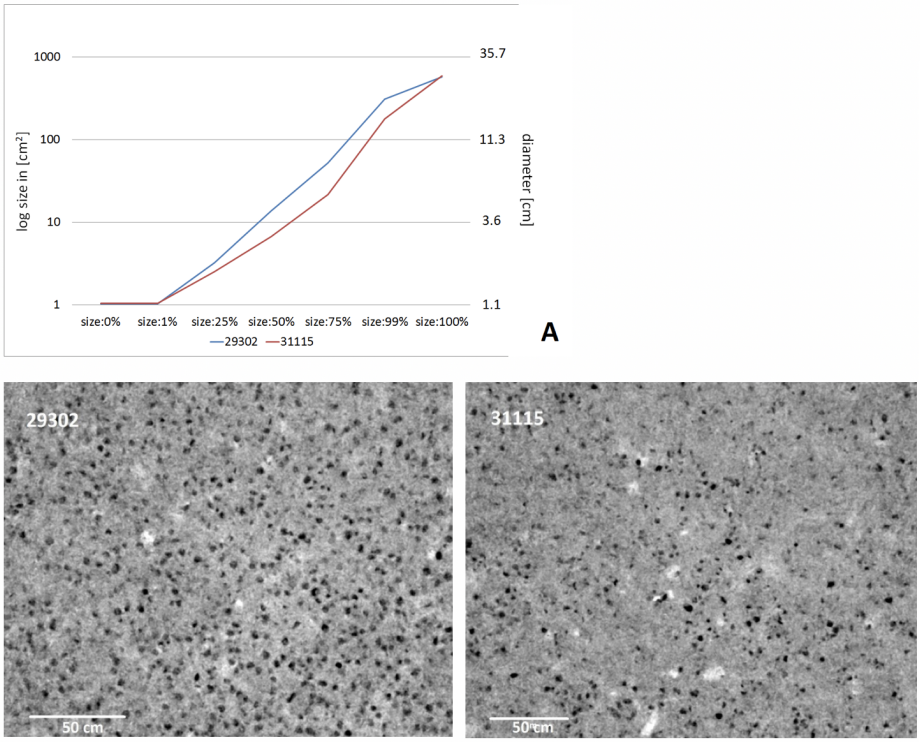

Fig. 1.

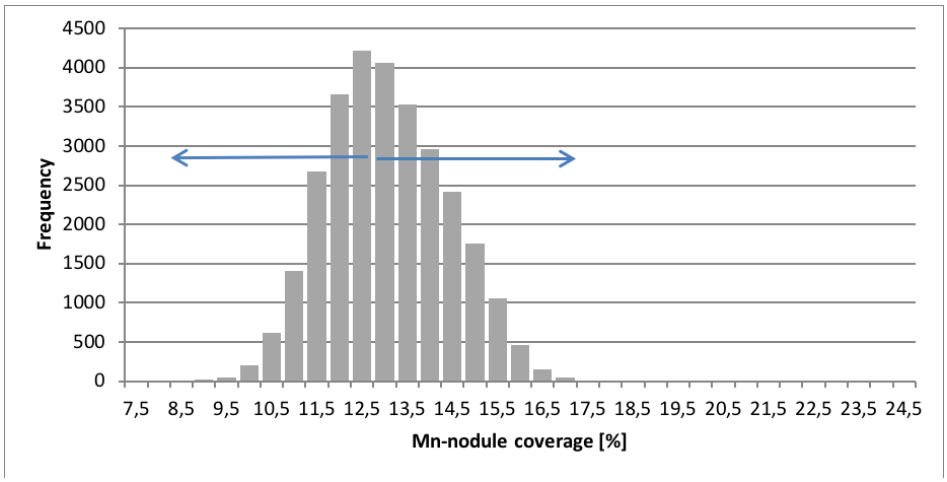
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Frequency
7,5 8,5 9,5 10,5 11,5 12,5 13,5 14,5 15,5 16,5 17,5 18,5 19,5 20,5 21,5 22,5 23,5 24,5
Mn-nodule coverage [%]

Fig. 2.

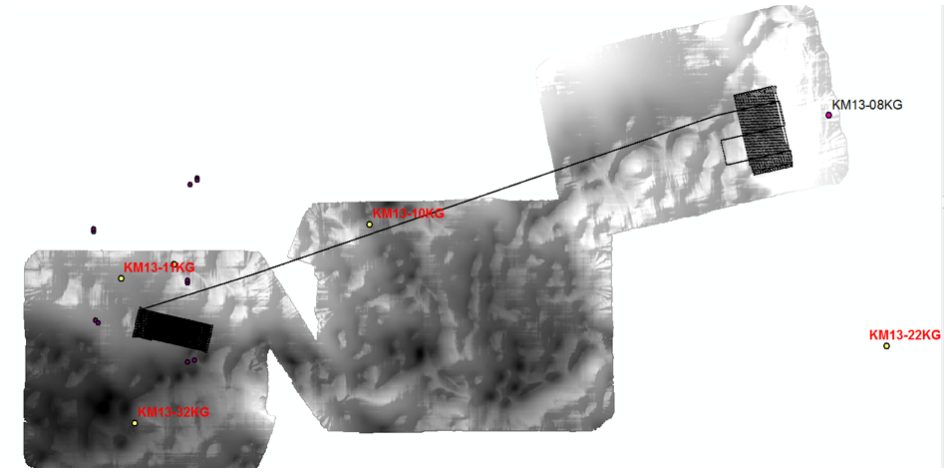
KM13-08KG
KM13-10KG
KM13-19KG
KM13-22KG
KM13-32KG

Fig. 3.