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Discussions

# *Interactive comment on* "High accuracy coastal flood mapping for Norway using LiDAR data" *by* Kristian Breili et al.

**Kristian Breili et al.**

kristian.breili@kartverket.no

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**Note: All line and figure numbers refer to submitted manuscript**

This paper is an effective study of sea-level rise and coastal flooding exposure in Norway based on a high-quality DEM. It exhibits a sound, straightforward approach that uses many of the best practices that have been established for these types of coastal assessments. The paper documents well the data, methods used, and results, and the tables and figures effectively support the material in the text. Overall, the Discussion section is very good, especially the factors affecting uncertainty and the accuracy of the DEM.

**Author comment:** Many thanks for your review which has improved the



quality of our manuscript.

The results could be improved by attaching confidence levels to the estimates of impacted area and objects. This would entail not just describing the accuracy of the DEM (and the associated datum conversions), but applying that cumulative vertical uncertainty to characterize the confidence of the results (see Gesch, 2013 and Gesch, 2018 for details on how this is done). All the needed information is already available with the comprehensive DEM accuracy assessment that has been done and all the other uncertainty information that is listed in Table 7. I am not saying that this needs to be done for this paper to be accepted, as I believe the results as currently presented are useful, but adding confidence information could be done in future related work (perhaps as the remaining 20% of the country is worked on and national results are revised and added to), and the authors could add this idea of characterizing the confidence of the results to the Discussion/Conclusions sections.

**Author comment:** This is definitely something we will address in future work.

**Added to discussion (Section 4.1):** "Future work should look at how these uncertainties can be incorporated into our mapping and web tool (Gesch, 2013, 2018; Cooper and Chen, 2013; Cooper et al., 2013)."

(See also reply to comment to line 334)

Comment on lines 207-216 (discussion of Smola) in section 3.1, and Figures 13 and 14 that it refers to: The area affected is important, but without knowing the total area of each of the ten municipalities (assuming there's variability in the areas) it's hard to see which ones are affected the most. So you could also show the affected area as a percent of the total area of each municipality as a way to rank the municipalities.

**Author comment:** Thank you for this nice suggestion. The updates of Figure 11 and 12 (Figure 9 in revised manuscript) include the percentage affected total area of each municipality. Please see new figures in supplementary document.

**Added at line 216:** ”Taking into account the municipalities total area, Smøla is the tenth and ninth most affected municipality by a 200 year storm at present and for 2090, respectively.”

**Added at line 317:** ”When considering flooded land area as a percentage of the total municipality area (lower panels of Figure 9), we find that six of the ten municipalities with the highest percentages are located on the west coast.”

Line 3 (abstract): What about isostatic rebound? I see it is mentioned in lines 24-28 as being important, so may want to also mention it here

**Added to abstract:** ”...and land uplift due to glacial isostatic adjustment”

Line 50: Suggest ”potential consequences” here

**Author comment:** Ok, ”potential” added

Line 81: It is good that the DEM used has high accuracy (0.26 m RMSE) so that these 1 m intervals can be effectively mapped at high confidence

**Author comment:** Yes, this point is mentioned in line 154. We have added a reference to Gesch (2018).

Line 110: Given the accuracy of the DEM used in this study (0.26 m RMSE), each of these will be mapped with a different level of confidence. 0.40 m is closer to the inherent noise level of the DEM, so will be mapped with less confidence than 0.82 m. For further information see Gesch, 2018.



**Author comment:** This is an important remark.

**Text added to Section 4.1, line 347:** ”Given the accuracy of the DEM used in this study (0.26 m RMSE), each water level will be mapped with a different level of confidence because the lower levels are close to the inherent noise level of the DEM.”

Line 172: Although these disconnected low-lying areas can be important to account for too, especially for storm surge flooding that may overtop the barriers because of waves, or rising groundwater due to sea-level rise. Some studies have mapped and reported these areas separately. See Rotzoll and Fletcher, 2012; Copper et al., 2013; Copper et al., 2015).

**Author comment:** Thank you for making us aware of this. We have decided not to comment on this in the text because this will not be a significant problem for our coastal service due to the generally steep topography of Norway.

Line 230: ”region’s”

**Author comment:** OK, corrected

Line 275: This sound like a key finding from this study

**Text added to Conclusions at line 457:** ”Notably, we also find that the numbers of affected objects for a 20 year storm-surge return height in 2090 will exceed the numbers for the 1000 year storm-surge at present. Indicating that an increasing number of objects will be at risk of more frequent flooding.”

Line 304: This, of course, assumes that no protective structures are build (seawals, levees, etc.)

**Text changed to:** "In this scenario, more than 1700 km$^2$, 263,000 buildings, and 6800 km of roads would be permanently flooded if no adaptive measures are taken."

Line 334: But the uncertainties could be accounted for. See: Gesch, 2013; Gesch 2018; Cooper and Chen, 2013; Cooper et al., 2013.

**Author comment:** This is a preliminary assessment of the uncertainties - the purpose of which is to indicate that the uncertainties are generally smaller than the projected sea-level rise. Also, to give the reader an idea of the different uncertainties involved in the mapping method. There are also smaller errors associated with the different vertical datums and transformations that have not been assessed for the entire coast.

We agree that it would be very useful to show confidence intervals. However, we have not come so far in our work that we at present can build that into our mapping.

**Added to end of Section 4.1:** "In summary, a preliminary assessment indicates that the elevation model (RMSE 0.26 m) is the largest source of uncertainty in our mapping method. There are also smaller errors associated with different vertical datums and transformations between datums that have not been assessed for the entire coast. However, we believe that the sum of these mapping errors are generally smaller than the projected sea-level rise, which gives us confidence in our results. Future work should look at how these uncertainties can be incorporated into our mapping and web tool (Gesch, 2013, 2018; Cooper and Chen, 2013; Cooper et al., 2013)."

Line 370: The correct name is "National Geodetic Survey".

**Author comment:** Ok, corrected.

Figure 1: These numbers are meters, right? It should indicate that.



**Text added to caption:** "For all figures the unit is meter."

**Other corrections applied by the authors**

Table 1: The sub category is changed from "Private" to "Private industry" for "factories, workshops, storage halls, power plants, and transformers".

Table 5: Horizontal lines added between each category

Figure 3 has been improved. The new version is clearer and easier to interpret.

In the revised manuscript, we have replaced Figure 11 and 12 by Figure 9, 10, and 11 that separately show the affected land areas, buildings, and roads for a 200-year storm surge at present and for 2090. This allows each theme to be visualized in larger figures.

Line 52: objects of impact -> objects at risk

Line 72: line break added

Line 129: Reference updated from Nicholls and Cazenave (2010) to Bamber et al. (2018).

Line 179: correcting typos: ...the object's height is used determines whether...

Line 194 changed to: "Furthermore, the maps and numbers presented in Se havnivå i kart will be regularly updated as new knowledge and data (e.g. new elevation data, better understanding of vertical datums, error corrections) becomes available."

Line 203 changed to: "...the three types of coastlines (strandflat, glaciofluvial deltas, and soft moraine coast)..."

Change at line 313: ”The municipalities with the largest land areas that are at risk of flooding are located in the middle of Norway (between Trondheim and Lofoten Tromsø) and in the outer part of Oslofjorden.”

Added at line 314: ...evident by the upper left...

Line 383: solid bedrock -> exposed bedrock

## References

Bamber, J. L., Westaway, R. M., Marzeion, B., and Wouters, B.: The land ice contribution to sea level during the satellite era, Environ. Res. Lett., 13, 063 008, https://doi.org/10.1088/1748-9326/aac2f0, 2018.

Cooper, H. M. and Chen, Q.: Incorporating uncertainty of future sea-level rise estimates into vulnerability assessment: a case study in Kahului, Maui, Clim. Change, 121, 635–647, https://doi.org/10.1007/s10584-013-0987-x, 2013.

Cooper, H. M., Fletcher, C. H., Chen, Q., and Barbee, M. M.: Sea-level rise vulnerability mapping for adaptation decisions using LiDAR DEMs, Prog. Phys. Geogr., 37, 745–766, https://doi.org/10.1177/0309133313496835, 2013.

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Please also note the supplement to this comment:
https://www.nat-hazards-earth-syst-sci-discuss.net/nhess-2019-217/nhess-2019-217-AC2-supplement.pdf

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