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Reply on RC1

Kytt MacManus et al.

Author comment on "Estimating population and urban areas at risk of coastal hazards, 1990–2015: how data choices matter" by Kytt MacManus et al., Earth Syst. Sci. Data Discuss., https://doi.org/10.5194/essd-2021-165-AC2, 2021

We thank the referee for their helpful remarks, and have addressed them below inline. Our responses begin with "A:", we have marked each referee question with "Q:" in order to enhance readability.

This is a good and timely paper which I have enjoyed reviewing. It aims to address the wide range of estimates of coastal population presented in the literature and understand why these arise. Hence, it defines the uncertainties of population estimates in the coastal zone, and equally defining what we do know about the problem. It builds on a large body of work by the authors and many others, and cites a comprehensive literature. In particular, it considers many of the difficulties of working with broad-scale coastal data and the authors show great knowledge and deep thinking about these problems, including practical recommendations for taking this work forward. The results emphasises that growing concentrations of people occur in the low-elevation coastal zone, often in urban locations and the coastal zone is more urban than the global average. This has important implications for coastal policy and management as well as sea-level rise and its impacts and risks.

I have the following queries:

Q: What is the purpose of defining the Low Elevation Coastal Zone (LECZ)? As far as I understand to define the broad areas and population threatened by sea-level rise. So the main goal is to define the exposure to sea-level rise (following IPCC) or the receptors following the SPRC (source-pathway-receptor-consequence) framework (http://www.floodsite.net/html/faq2.htm). Hence we are defining the areas that might be affected by sea-level rise. Am I understanding the goal correctly? It would be good if this purpose was explicitly defined.

A: You are correct that our goal is to identify the broad areas in which populations are, or will be if they settle there, at a heightened risk of exposure to hazards arising from sea level rise, more extreme weather events and other climate-related environmental changes. The SPRC framework is very apt, with its attention to Sources (e.g. sea level rise and more extreme weather events), Pathways (e.g. storm surges and related flooding), Receptors (e.g. people and their built environments) and Consequences (e.g. damage to human health and wealth). On the one hand, the use of 5 or 10 meter bands of elevation, with coastal contiguity, creates a very crude approximation of areas where the Sources and Pathways of coastal hazards are more evident. There are no risk thresholds empirically associated with these particular elevations, and lower elevation is only a rough indicator of higher risk - many other physical factors influence risk, and must be taken into account in modelling flood risk, for example. On the other hand, we use the LECZs as they are relatively transparent conceptually and comparable internationally, and we are concerned that smaller size bands are incommensurate with the level of uncertainty in the spatial distribution of population (see answer to 3 below). For the purposes of a global-scale analysis, a common landward limit must be established. As we aim to understand population, along an urban continuum, living at risk of coastal hazards, to be useful in evidence-based policy frameworks, we explicitly opt for an inclusive range. In response to this comment, we have changed the text, and particularly the first paragraph of the introduction, to explicitly state the purpose of delineating the LECZ, using some of the concepts and language from the SPRC framework. We hope to use and cite this framework more fully in a companion paper, more focused on the policy dimensions.

Q: This raises questions about how to appropriately define the landward limit of the LECZ. For example, in the TanDEM-X elevation model the treatment of the raised roadways in the analysis reduces the area of the LECZ. But this misses the point of defining exposure as the lower areas landward of the roadways would still be threatened by sea-level rise. In effect, the analysis is treating the elevated areas as defences, when measuring exposure should be based on elevation only and not consider defences. This raise the key point that the treatment of the landward boundary of the LECZ could be rigorous and this should be discussed in more detail.

A: This is an important point. Indeed, the TanDEM-X model has been shown to produce high accuracies, but in those accuracies also captures features of the landscape as barriers which may or may not actually function that way. Elevated roadways most usually include culverts which provide connectivity and would in essence put those low-lying areas along the roadways at risk. To evaluate these issues globally will require significant resources and especially local knowledge, beyond the scope of this study. However, it is important work which should be done to improve the accuracy of exposure estimation for SLR. We have added emphasis to the conclusion on this point.

Q: Can anything be said about land area and populations situated below mean sea level (0 m)? Globally there are many millions of people in this situation – but how many?

A: Any population living below 0m and contiguous to seacoast is included in the <5m zone -- in particular, for population living below 0m (and contiguous to seacoast) we rounded up to zero. We changed the two instances of 0-5m in the paper to <5m make this clearer. But as we caution readers to not use finer increments of LECZ zones (e.g. 0-1, 1-2, etc…) because of RMSE, we do not estimate the population below 0m in this analysis. This would be a good subject for further research with local, high-resolution data (such as LIDAR), understanding the role of seawalls and other physical barriers (which may not be captured in all of the elevation data sets), and high resolution population/settlement data.

Q: Subsidence is affecting many coastal cities causing large losses of elevation which is relevant to these methods (e.g. Kaneko & Toyota, 2011). There is some discussion of subsidence but this could be expanded, especially for coastal cities.

A: We've added references to literature (including Kaneko and Toyota) on the theme of subsidence at several points in the manuscript. In the first paragraph of the introduction we have noted the importance of subsidence, in deltas and in cities, and mentioned that identifying urbanisation as a process in LECZs is important not just because it represents increasing concentrations of cities (and helps explain why LECZs are still growing relatively rapidly), but is also likely to contribute to subsidence and hence relative sea level rise (as calculated by Nicholls et al., 2021). We have also commented on subsidence at several other points, though we cannot address it using the global elevation data sets, which are employed in this paper. We hope to explore these issues further in a companion paper on urbanisation and deltas, though even there we are not intending to quantify the impacts of subsidence, or for that matter vertical accretion and bounce-back. The references we have added are:

Nicholls et al. 2021 https://www.nature.com/articles/s41558-021-00993-z.pdf

Erkens, G., Bucx, T., Dam, R., de Lange, G., and Lambert, J.: Sinking coastal cities, Proc. IAHS, 372, 189–198, https://doi.org/10.5194/piahs-372-189-2015, 2015.

Syvitski, J., Kettner, A., Overeem, I. et al. Sinking deltas due to human activities. Nature Geosci 2, 681–686 (2009). https://doi.org/10.1038/ngeo629

Tessler, Z.D., Vörösmarty, C.J., Grossberg, M., Gladkova, I., Aizenman, H., Syvitski, J.P. and Foufoula-Georgiou, E., 2015. Profiling risk and sustainability in coastal deltas of the world. Science, 349(6248), pp.638-643. (this is where our delta data come from FYI)

Kaneko, S. & Toyota, T. (2011). Long-Term Urbanization and Land Subsidence in M. Taniguchi, editor, Asian Megacities: An Indicators System Approach. Groundwater and Subsurface Environments: Human Impacts in Asian Coastal Cities. 249-270. 10.1007/978-4-431-53904-9_13.

Zoccarato, C., Minderhoud, P.S.J. & Teatini, P. The role of sedimentation and natural compaction in a prograding delta: insights from the mega Mekong delta, Vietnam. Sci Rep 8, 11437 (2018). https://doi.org/10.1038/s41598-018-29734-7

Q: What about the new paper by Hooijer and Vernimmen (2021) on coastal elevation and population? (https://www.nature.com/articles/s41467-021-23810-9)

A: Hooijer and Vernimmen's (2021) interesting paper (published while this paper was under review), for the first time, creates a global LIDAR-based layer (GLL_DTM_v1) delimiting coastal areas up to 10m. Importantly, it appears to have greater confidence in the <5m range than the STRM-based measures used in our study (attaining 68% confidence for areas <2m using a Digital Terrain Model (DTM) derived from ICESAT 2) whereas Gesch shows the same confidence for only the most accurate DEMs at < 5m. We have not conducted a thorough sensitivity analysis using these data, but here are some considerations that we or others who would like to do so should take into account: (1) The spatial resolution of GLL_DTM_v1 is nominally 5km whereas all four LECZ layers used in our study are standardized to 250m; coarse resolution differences may be susceptible to the modifiable areal unit problem (MAUP), for instance in coastal cities where coarse pixels may capture city centers with high population density. (2) While we have not done a thorough review of the GLL_DTM_v1 layer, the grid appears sparse in coastal areas where we would expect coverage as shown in the image below (notable high-flood, very low-elevation areas of the NYC area are omitted by the absence of any blue shade below). (3) They use GPW for population estimation. As we show in our paper, it may not be the most suitable source of population data in certain countries where input population geographies are low resolution, (since it uses a uniform allocation approach to disaggregate population.) Using multiple population datasets, as there are many options now, would be better in order to give a range of possible estimates.

In short, we are pleased to see GLL_DTM_v1 data in the mix of data that can be used to construct LECZs and hope that we and others will evaluate its usages, and make suggestions for its improvement in future research. (Recall, the estimates in our research here represent more than a decade of improvements in all three domains -- elevation, population, urban measurement, so the authors of this complementary data can hope for the same.)

The population estimates below 2m in Fig 3 of Hooijer and Vernimmen are not inconsistent with our estimates of population below 5m, but comparison of the two data sets and estimation strategies would be required to understand how consistent they really are. (Estimates up to 10m +MSL in their paper are not given in the paper and would need to be in order to compare fully.) Like our study, they find that a large share of the global exposure is in (tropical areas of) Asia.

We have made reference to this new paper, in several key locations in our manuscript.

I have the following minor queries:

A: Thank you for these comments. We have addressed them with small edits, as appropriate.

Q: Line 22 -- McGranahan et al., 2007b here and through the manuscript – why 2007b – we haven't seen 2007a yet?

A: This has been corrected throughout.

Q: Line 40 -- Oppenheimer and Hinkel, 2019 – should be Oppenheimer et al, 2019

A: This has been corrected.

Q: Line 238 – Table 2 – why is this not structured as the text – population datasets appear in a different order – harmonization of order makes for an easier read.

A: Text edited to incorporate this feedback.

Q: Line 449 – Figure 4 – hard to read -- needs to be reproduced at a larger font size.

A: We have included the figure as a full page.

Q: Line 480 – no global standards for coastlines – a very good point that all those working on coastal data at broad scales appreciate but is often not explicit to the user.

A: We've introduced this issue a bit more to call attention to it.

Q: Line 652 – the change from 1990 to 2015 is 200,000 to 400,000 people? – this seems far too small a global change over 25 years – 0.25% to 0.49% is about 20 to 40 million people in 2015 alone – this needs to be corrected.

A: Thank you for identifying this typo, we have corrected it.

Q: Line 677 – English of the sentence – change "the land area is about 40% more in CoastalDEM ≤5m LECZ than in the others" to "the land area ≤5m LECZ is about 40% more in CoastalDEM than in the others"

A: Thank you, edited to this effect.

Q: Line 685 – Figure 10 and the caption does not make sense to me – the main text needs to be taken into the caption so it can be read standalone --– does not show all of China and the caption should say this.

A: Thank you, we have clarified the caption text.

Q: Line 801 "under 5" – units are needed

A: Added units.

Q: Line 1025 – what about rapid subsidence of coastal cities? Similar issue to deltas.

A: Thank you for calling this out. Indeed, coastal cities in addition to deltas face issues of subsidence. We have modified the text and added some relevant citations, including the one by Kaneko and Toyota that you have suggested (thank you for that).

Q: Line 1048 – "4.2 Can these data be used to observe changes over time?" – again what about subsidence in deltas and cities which is quite rapid in some populated locations?

A: We do not observe change over time in the elevation measures used to construct the LECZ and therefore our estimates cannot address changes in population exposures in deltaic and coastal urban areas due to subsidence. The underlying population or urban proxy data sets do represent different points in time, and thus with time-varying LECZs, we could contribute to the understanding of changes in exposures in areas experiencing differential subsidence. (Without independent measures of subsidence, however, we could not ascribe changes in exposure to subsidence versus other factors.) We appreciate the importance of this issue and have noted it in the text in this section on change over time and the conclusions to reflect this.

Q: Line 1224-1225 – McGranahan et al 2007a or 2007b?

A: This has been corrected.

Q: Line 1238 – mention that CoastDEM uses population in the elevation model?

A: Added.

Q: Line 1333-1342 – is coastal city subsidence an additional issue here??

A: Yes, thank you for drawing our attention to this important issue. We've added to this section to indicate as much.

Literature cited: There is a very large and good literature cited. However, I note many of the references are missing journals – such as Balk (2009) – there seem to be other cases. A thorough review of the references to make sure that they are all correct and complete is essential.

A: This has been corrected.

References

Hooijer, A., Vernimmen, R. (2021) Global LiDAR land elevation data reveal greatest sea-level rise vulnerability in the tropics. Nat Commun 12, 3592. https://doi.org/10.1038/s41467-021-23810-9

Kaneko, S. & Toyota, T. (2011). Long-Term Urbanization and Land Subsidence in M. Taniguchi, editor, Asian Megacities: An Indicators System Approach. Groundwater and

Subsurface Environments: Human Impacts in Asian Coastal Cities. 249-270. 10.1007/978-4-431-53904-9_13.