We would like to thank both reviewers for providing further suggestions and comments on the manuscript. Following both reviews, we have revised the manuscript in several ways.

In the following, we respond (blue font) more in detail to every single referee comment (black font). Line references are related to the revised manuscript unless otherwise stated. Underlined text indicates changes within sentences/paragraphs.

Report #1 by Anonymous referee #1

The changes made to the manuscript “Human displacements from tropical cyclone Idai attributable to climate change” have improved the paper structure and coherence substantially. There are still several open issues that need to be addressed to make the manuscript acceptable for publication:

1. Thank you for adding a sentence to the abstract. Might it be possible to quantify the effect of wind intensification compared to sea-level rise?

The isolated effects of wind intensification is twice that of SLR (median assumption). We have changed the sentence accordingly:

Line 27: “The isolated effect of wind speed intensification is double that of sea level rise.”

2. Figure 3: In the extended text describing the figure on section is missing that is referenced in the response to one of my comments:

“Overall, it is observable that depth differences are higher in less populated parts, especially in Beira, suggesting that a counterfactual Idai of lower intensity leads to only neglectable changes in displacement. Nonetheless, already small differences in flood depth can cause inundation to drop below the critical flood depths, as shown for the west bank of the Pungwe River. In the next section, we turn to this topic in a numerical way by comparing the number of affected people and displacements between factual and counterfactual simulations.”

Should this be added to the lines following line 436?

Thank you for noticing this. We modified this paragraph in the final version of the last revised manuscript, but did not update the response letter accordingly. We apologize for the inconvenience. Following up on your comment below, we have now extended the paragraph to address this topic more in depth.

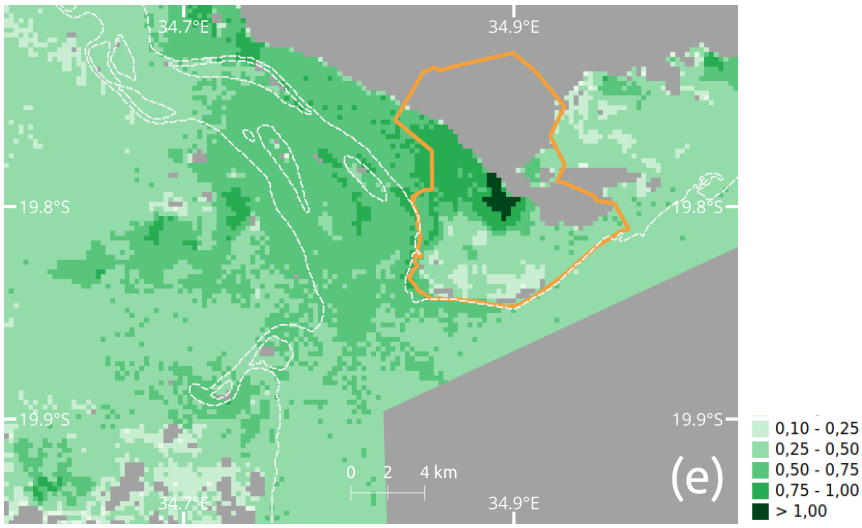
Also, I was wondering whether the differences in flood depths in less populated parts might be related to the DEM data as these surface models are known to overestimate elevations in densely populated locations due to the fact that the first reflected signal is registered by the satellite, thereby resulting in lower flood depths in dense urban settings?

Thank you, this is a valid point. When we say that the "differences in flood depths" are higher in less populated than in more populated parts, we refer to the differences between factual and counterfactual simulations. Since both simulations use the same DEM, we would assume that any urban-rural biases in the DEM are consistent between the factual and counterfactual simulations. In the most recent revised version of the manuscript, we have improved the formulation to be clear about the kind of comparison that we refer to. Nonetheless, your suggestion about the cause of the flood depth differences is justified and we address this point now as well:

Line 446-452: “In contrast, differences in simulated flood depth are more pronounced (Figure 3e). Counterfactual flood depths are up to 80 cm lower than factual flood depth in some parts of the southern city center. The highest difference in flood depth, of up to 140 cm, is found between the northern and southern population centers of Beira. Flood depth differences outside of Beira are rather low, however, Figure 3c and 3d show that absolute flood depths drop below the critical flood depth of 100 cm over great parts around the west bank of the Pungwe River inflow. Overall, it is observable that depth differences (between factual and counterfactual simulations) are higher in less populated parts, especially in Beira. This could partly result from the fact that digital elevation models tend to overestimate elevation in dense urban settings (Shen et al., 2019), thereby underestimating flood depth and potentially also differences in flood depth between different scenarios, however, this is hard to ascertain given the available data. Nonetheless, local variations in simulated flood depth should be interpreted with care.”

Furthermore, as Fig. 3e shows the difference between 3c and 3d, might it be useful to use a different color scale for depicting these differences?

We agree and have changed the color, as shown below.



3. “AER” (l. 583) is mentioned, but not defined in the manuscript. Are those the remote sensing

Data?

Thank you for pointing to this. Atmospheric and Environmental Research (AER) is the provider of the satellite imagery. We have opted to refer to this product in the mentioned section by its name “FloodScan”, as done in previous sections, instead of using “AER”.

Lines 608-618: “Similarly, no suitable validation data for the coastal flood simulations is available. According to the FloodScan description (Atmospheric and Environmental Research & African Risk Capacity, 2022), the used products “depict large scale, inland river flooding well but are less likely to depict flooding in smaller floodplains and near coastlines”. We have hence opted to not choose the FloodScan product as the sole coastal flood hazard estimate nor as validation dataset for the flood extent from our coastal flood model. A flood risk screening for Beira (van Berchum et al., 2020) showed that simulated flood extent for a 10-year rainfall event plus a 10-year coastal surge event covers most parts of the Central and Munhava city districts of Beira (South-Eastern city districts). In contrast, the FloodScan product shows only little flooding in this area, while it is assumed that flooding by TC Idai exceeded an average recurrence interval of 10 years.”

4. L. 611: the sensitivity of results to the choice of population data should be elaborated here, particularly considering the two studies that are referenced along with this statement: which aspects may affect exposure results?

Thank you for highlighting this. We now discuss some drawbacks related to the GHS-POP dataset in the manuscript:

Lines 638-648: “Additionally, our analysis may be sensitive to the choice of population dataset (Archila Bustos et al., 2020; Leyk et al., 2019), which may lead to uncertainties regarding our estimated exposure. One of the main error sources for population datasets is related to the areal interpolation methods to disaggregate the population data (Archila Bustos et al., 2020). GHS-POP distributes population only within built-up areas, which has the downside that non-residential areas are simulated as populated as well (Freire et al., 2016). In fact, a comparison with satellite imagery reveals that some areas in Beira are populated which are most likely only commercial or industrial sites. On the other hand, not all settlements are captured by GHS-POP, most likely due to their building type. Nonetheless, GHS-POP is still one of most accurate datasets in estimating and modeling the known population (Archila Bustos et al., 2020), especially in urban contexts (Leyk et a., 2019) as in the case for Beira.”

5. L 699-700: the authors allude to changes in population and urbanization in driving future risk. This statement would profit from more specific context, supported by population and urbanization projections for the country under different scenarios (e.g. SSPs), particularly as the authors refer to these scenarios in the preceding lines.

Thank you for this suggestion, we have added the following sentence:

Lines 746-751: “Even though these increases may vary between basins, an enhanced displacement risk due to Idai-like TCs needs to be accounted for in the next decades, especially if future changes in exposure due to population growth and urbanization are considered. Under both SSPs 1 and 5, the population of Mozambique is projected to increase by approximately 8 million, and its urbanization level from about 40% to over 70%, just over the next 30 years (Riahi et al. 2017).”

6. My biggest concern are still the uncertainties inherent in this study, stemming from the data as well as the modeling approach and assumptions. Although the authors have done a great job in discussing these uncertainties, I am unsure about the confidence in these findings. Is it really possible to attribute these migrants to climate change? The authors state rather specific numbers which may give a false sense of accuracy, e.g. 2.7-3.2 %. Furthermore, these uncertainties should be stated clearly and discussed explicitly in the abstract as well as the Discussion and conclusion section.

We thank you for sharing your concerns. We agree that there are several sources of uncertainty related to our study, which must be clearly stated and discussed. In the last revision, we have extended our discussion of uncertainties and modeling assumptions, which now spans eight paragraphs in the Discussion and Conclusions section and, from our perspective, covers all the relevant points; we are glad to hear that you approve of this extended discussion. Nevertheless, we should indeed have highlighted these uncertainties even more. Following your suggestion, we have added a statement about the uncertainties to the Abstract, which also puts into perspective the numbers resulting from our main model estimates and thereby hopefully avoiding a sense of false accuracy; and we have added further statements and explanations in the “Discussion and Conclusion” section; see below.

Regarding the attribution approach: We should have made clear that we do not attribute displacement of individual persons to climate change; this is virtually impossible due to the manifold drivers which shape the vulnerability or even trigger the displacement outcome on an individual level. Our approach amounts to statistically attributing a total number of displaced persons to climate change, similar to e.g. the attribution of TC-related total economic damages (Strauss et al., 2021). In this way, we provide insight into the overall order of impact of global warming on coastal flooding and related displacements. With respect to the challenges of our approach, it is a reasonable advice to put our numbers directly into context of the related uncertainties.

Abstract:

Lines 16-32: “Extreme weather events, such as tropical cyclones, often trigger population displacement. The frequency and intensity of tropical cyclones is affected by anthropogenic climate change. However, the effect of historical climate change on displacement risk has so far not been quantified. Here, we show how displacement can be partially attributed to climate change, using the example of the 2019 tropical cyclone Idai in Mozambique. We estimate the population exposed to high water levels following Idai’s landfall, using a combination of a 2D

hydrodynamical storm surge model and a flood depth estimation algorithm to determine inland flood depths from remote sensing images, for factual (climate change) and counterfactual (no climate change) mean sea level and maximum wind speed conditions. Our main estimates indicate that climate change has increased displacement risk from this event by approximately 12,600 - 14,900 additional displaced persons, corresponding to about 2.7 to 3.2% of the observed displacements. The isolated effect of wind speed intensification is double that of sea level rise. These results are subject to important uncertainties related to both data and modeling assumptions, and we perform multiple sensitivity experiments to assess the range of uncertainty where possible. Besides highlighting the significant effects on humanitarian conditions already imparted by climate change, our study provides a blueprint for event-based displacement attribution."

First paragraph of the Discussion and conclusions:

Lines 561-575: "Our modeling study of TC Idai suggests that climate change may have induced between 12,600 (2.7%; lowest estimate under the no tide assumption) and 14,900 (3.2%; highest estimate under the maximum tide assumption) additional displacements from this one event. This is primarily due to the intensification of TC wind speed inducing a more powerful storm surge; and to a lesser extent due to sea level rise providing a higher baseline for the storm surge. We also show that the sensitivity of the results to the choice of TC intensification is approximately in the same range as for the tide assumption. We note that our attribution statements are, as commonly in the climate (impacts) attribution literature, purely statistical; that is, we do not make any claims about whether or to what extent any individual person may have been displaced because of climate change. Our methodology and results are subject to a variety of limitations and uncertainties, primarily related to the models (coastal, fluvial, DEM) and underlying datasets (population, displacement). Additional sources of uncertainty are the counterfactual input quantities (SLR, wind speed intensification), impact flood levels, and tide assumption, for which we perform sensitivity analyses."

Second last paragraph of the Discussion and conclusions:

Lines 720-726: "Framing the risk of tropical cyclones in the context of climate change in an event-specific rather than a probabilistic manner also allows us to assign absolute numbers of attributable displacements, which raises risk awareness in a more tangible way. Even though these numbers include substantial and important uncertainties related to the models, datasets and counterfactual assumptions, as discussed above, they provide an informative quantitative indication of the additional risk posed by climate change to communities affected by one of the worst natural disasters in recent history. "

Report #2 by Anonymous referee #2

Overview

This study aims to model and identify the 'excess' population displacement triggered by tropical cyclone Idai that can be attributed to climate change. By utilising a 'storyline approach' the study compares actual recorded displacement against estimated levels of displacement derived from counterfactual scenarios of mean sea level and maximum wind conditions without contributions of climate change. The conclusion of the study is that the impact of climate change has increased displacement risk by between 3.1 to 3.5%, corresponding to 16,000 – 17,000 displaced people.

The approach and results are interesting and of value in exploring the impact of climate change on environmental shocks and stressors, and the resulting affect this will have on patterns of human mobility.

The revisions that have taken place since the first review have significantly strengthened the paper. The assumptions on which the modelling approach is based are clearly outlined. The results of the study are much more clearly elucidated, alongside the limitations of results. This contextualises the author's use of a 'storyline approach' as opposed to, for example, a probabilistic approach and highlights the utility of this framing in terms of raising awareness of potential risks.

This is now a good paper and worthy of publication. This recommendation is made both in terms of the results themselves and the blueprint that it offers for future studies. As the authors highlight, the use of counterfactuals and 'storyline' approaches have potential in event-based displacement attribution.

A few minor textual changes and edits are suggested below, including an update of a hyperlink.

Astract

26 "corresponding to about 2.7 to 3.2%." Can these percentages be clarified? I presume they are of recorded / estimated actual displacees.

Yes, this is correct, the percentages relate to the number of observed displacements. We have revised the sentence:

Lines 24-27: "Our main estimates indicate that climate change has increased displacement risk from this event by approximately 12,600 - 14,900 additional displaced persons, corresponding to about 2.7 to 3.2% of the observed displacements."

1 Introduction

32 missing space 'TCs pose'

Done, thank you.

45 Suggest breaking sentence to improve clarity: '… very intense TCs (category 4-5 on the Saffir-Simpson scale). This is…'

We have revised the sentence as following:

Lines 47-51: "At the same time, global climate change is expected to alter TC characteristics, resulting in an increase in overall TC intensity (maximum wind speed and precipitation) and hence in the frequency of very intense TCs (category 4-5 on the Saffir-Simpson scale) (Knutson et al., 2020). Primarily, this is the result of an increase in potential intensity due to warmer sea surface temperatures (SST) (Emanuel, 2005, 2013, 1987)."

2 Methods

2.1 Counterfactuals

143 Mean sea level rise is expressed here in centimeters ('23cm') whereas later in the paragraph the IPCC rates are expressed in mm yr-1. Using millimeters in this instance (230mm, for example) is suggested.

Done, thank you.

Lines 144-145: "Total global mean sea level has risen by approximately 230 mm since the turn of the 20th century (Church and White, 2011)"

2.3 Inland Flood Depth Estimation

304 The location of the source code referenced has changed and the link should be updated to

https://github.com/NRCan/RICorDE/tree/main.

Indeed, the location has changed. We have replaced it with your suggestion. Thank you.

2.5 Displacements

342-347 This is a useful detail of the limitations of GIDD information

357-362 Again useful section which acknowledges the complexity of driver of displacement which helps place the results of this paper in context.

Thank you, we are glad to hear this.

398-399 & 401 There is an inconsistency between 'flood depth threshold' and 'flood-depth threshold', where the latter is preferred.

Thank you for pointing this out, we have changed the text and tables accordingly, and are now using only “flood-depth threshold”.

4 Discussions and conclusions

545-549 This is a clear exposition of the findings.

562 Additional space ‘ideally coupled’

Done, thank you.

674 onwards Useful framing of the ‘storyline approach’ in terms of its potential role in raising awareness of risks

697 Hyphen required in ‘Idai-like’

The expression already contains a hyphen:

Lines 746-749: “Even though these increases may vary between basins, an enhanced displacement risk due to Idai-like TCs needs to be accounted for in the next decades, especially if future changes in exposure due to population growth and urbanization are considered.”