Impacts from Hurricane Sandy on New York City in alternative climate-driven event storylines

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= Response to the reviewers =

Reviewer #1:

The paper has successfully addressed the issue of estimating the consequences of high-impact-low-frequency events. The research applied a combination of profound models to generate multiple scenarios of global warming, sea level rise, and storm tracks, as well as simulate corresponding flood events. The adoption of multiple stochastic process-based models greatly reduced the inherent uncertainty and arbitrariness of the Storyline Approach. Furthermore, the study managed to include and compare the factors of climate change and internal variability. This further contributes to the understanding of major driving force of high-impact events in the future. With mostly positive feedbacks and pleasant learning experience, there are some minor comments for the current manuscript.

We would like to genuinely thank the reviewer for their constructive review of our manuscript. In this document we respond to these comments and highlight the modification in the revised text.

1. Climate scenario constructions. The paper in general well explained how the researchers employed spectral nudging to recreate climate events under various climate conditions. However,

    a. What is the necessity of creating a pre-industrial (PI) climate scenario, instead of building a climate change scenario warmer than 2 degree?

Thank you for the comment. We agree that exploring warmer scenarios can be beneficial for the analysis of global warming impacts. However, the generation of these scenarios by spectrally nudging GCMs to reanalysis data and then changing the boundary conditions can be quite complex and time consuming. Therefore, the data used in the paper comes from an already existing dataset (van Garderen, 2021) and was not developed for this study. The dataset has the same 3 climate scenarios used in this study (PI, PD and 2C). The idea for these scenarios is that with the pre-industrial simulation we understand the changes we are already experiencing, and putting those in a climate change context for a near future situation of 2C.

We added to the limitations paragraph at the discussion section the following:

Line 304: "Our warmest storyline is based on SST and GHG projections of a 2◦C above pre-industrial levels scenario, but due to indirect aerosol influence, the actual temperature increase is 1.55◦C, making it a conservative estimation of the climate-change signal (van Garderen and Mindlin, 2022). Warmer climate scenarios can provide extra insight on the effects of global warming on storms, as seen in Yates (2014) where the strongest precipitation increases occurred for the +4C scenario."

b. More reflection is recommended on the validity of these reconstructed tracks. As the authors pointed out in Figure 2 and line 221, the simulated storm tracks did not well represent the MSLP, highest wind speed, or the variation in flood volume, though they in fact have rather successfully reproduced the situation when the storm hits NYC. Such discrepancies should be better discussed.

Thank you for the comment, this is indeed an interesting point of discussion. The peak in the TC activity over the Caribbean between 24 and 26 depicted by the observation is missed by the spectrally nudged storylines. But it is also missed by the other two modern and widely used reanalysis datasets (ERA5 and MERRA-2), and by the historical spectrally nudged simulations (ECHAM_SN), as shown in figure A3. When compared to these datasets, the spectrally nudged storylines perform similarly over the study area.

According to Hodges et al. (2017), reanalysis products tend to underestimate the peaks in both maximum wind speeds and minimum MSLP (mean sea level pressure). This is likely a consequence of not high enough model resolution and dependence on parameterized processes used in the reanalysis. They also mention that modern reanalysis products show an improvement in reproducing TCs, such as demonstrated with MERRA-2.

Ref: Hodges, Kevin, Alison Cobb, and Pier Luigi Vidale. "How well are tropical cyclones represented in reanalysis datasets?" Journal of Climate 30.14 (2017): 5243-5264.

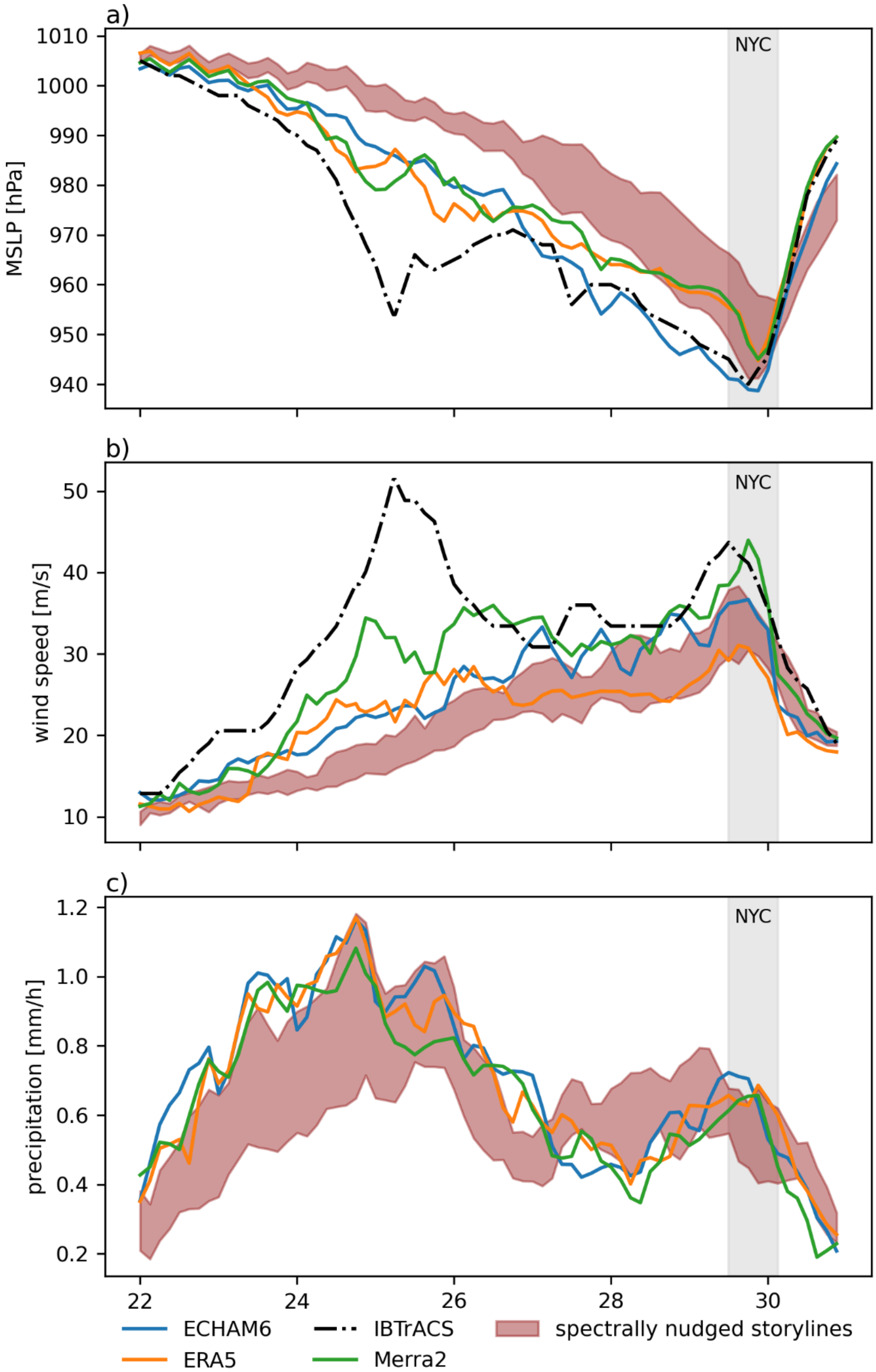
Therefore, the discrepancies seen are not particular to the spectrally nudged storylines, but true to all models, and likely due to their limitations in simulating TC peak activities. Conversely, we see that the spectrally nudged storylines perform similarly to the best reanalysis products currently available. When combined to the evidence shown that the results are approximate to the observations over the region of NYC (our study area), we believe the spectrally nudged storylines can be used for the purposes of our study.

Based on this discussion, we added to the XX(discussion/results?)XX section:

Line 193: "Meteorological features match the observed event well in the region of interest, with some minor underrepresentation of the maximum wind speed (Figure 2b-c)"

Line 296: "The simulated storms underrepresent the maximum wind speed and minimum MSLP during the TCs peak over the Caribbean and to a lesser extent during landfall. Similar discrepancies are seen for the other reanalyses tested, indicating the data is within the same range of performance of other reanalyses and models. Peak TC activity is often underrepresented in reanalyses due to limited model resolution and dependence on parametrised processes (Hodges et al., 2017)."

In addition, we also added to Figure A3 the range of the spectrally nudged storylines for a better comparison with the reanalyses:



2. Vulnerability of CI to different water levels. It is well understandable that precise estimation of the fully continuous vulnerability curve of various CI is nowhere to find. Therefore it is a common approach to use a discrete and qualitative impact function. However, it remains quite confusing to me how the authors in Section 3.5 managed to give a quantify the change of impacts. I assume the authors actually assigned a percentage of damage to each level of exposure defined in the paragraph between line 172 and 175. It may be more clear to give this numerical relationship.

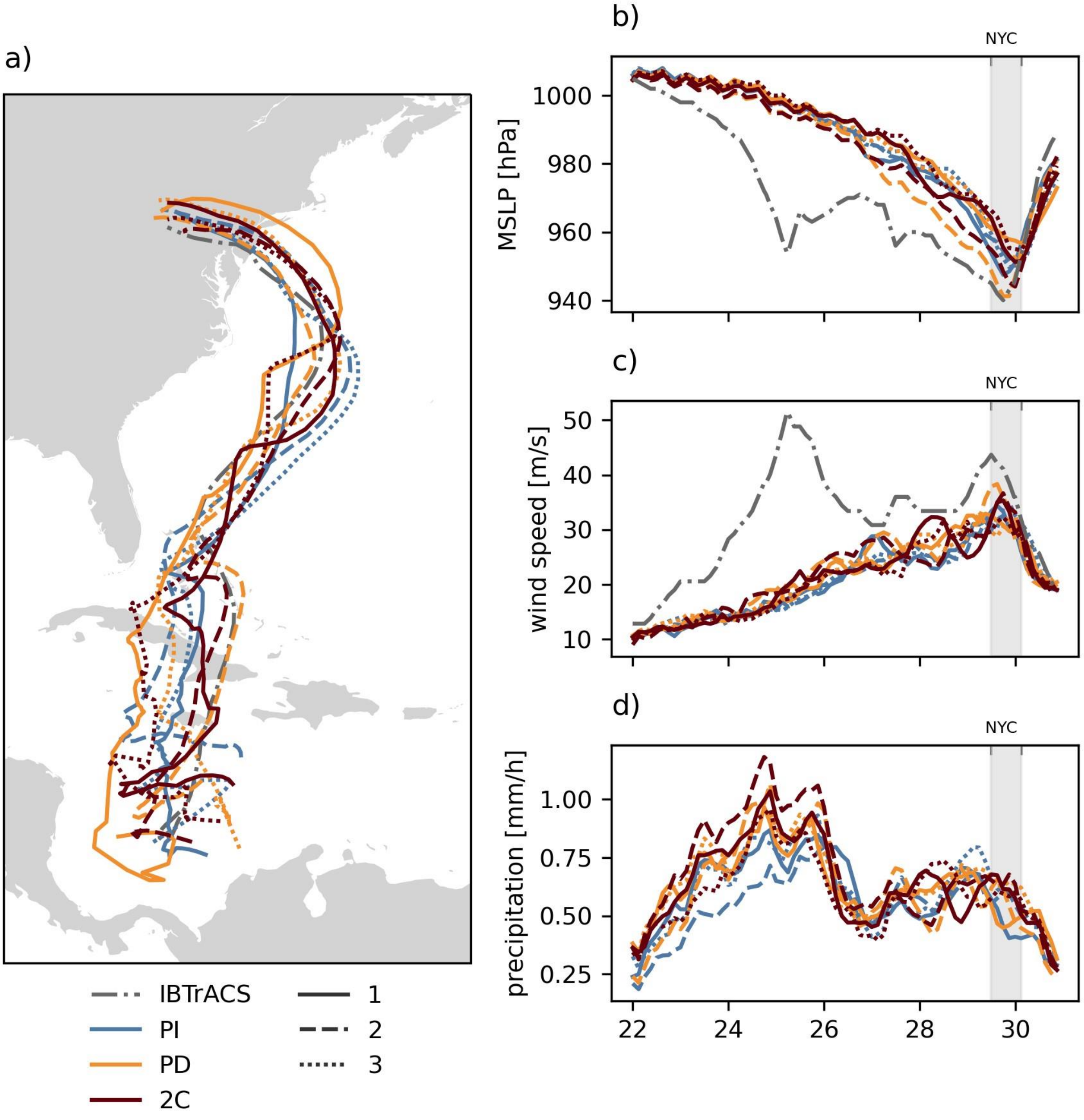
Thank you for the comment. As the reviewer has already pointed out, we adopt a discrete and qualitative approach in separating the water levels because we are analysing multiple CI systems. However, we do not assign percentages of damage to each level of exposure in posterior step. The changes in impacts shown in Section 3.5 and illustrated by Figure 6 a) and b) are the changes in the number of exposed assets for each water level category between the different scenarios in the study. The changes in Figure 6 c) and d) are the differences in water level (m) for the same CI assets between the different scenarios.

We believe the text could be better explained, so we rewrote parts of the methods section to improve the clarity of our approach:

Line 180: "Different CI assets may exhibit varying responses to distinct flood levels. Unfortunately, comprehensive information regarding the vulnerability of CI assets to specific flood levels is limited (Zio, 2016) and, in particularly, the cost of reconstruction and replacement of CI assets is not available for New York City. Inspired by Koks et al. (2019), we adopt a discrete and qualitative approach by dividing water levels in three categories: low (0.15m-0.5m), medium (0.5m-1m), and high (>1m). This approach allows to quantify the number of exposed assets in each water level category and how it changes under different scenarios, identifying hotspots of impacts, without trying to assign specific monetary value."

3. Results presenting. Figure 2 on Page 8 could probably have been polished, such that the simulated results of MSLP, wind speed and precipitation in NYC could be highlighted.

Thank you for the suggestion! We agree that having a better indication of the period that the storm is on the study area Is beneficial for the paper. Therefore, we have updated the figure as follows:



a)
b)
c)
d)
NYC
MSLP [hPa]
1000
980
960
940
wind speed [m/s]
50
40
30
20
10
precipitation [mm/h]
1.00
0.75
0.50
0.25
22
24
26
28
30
IBTrACS
PI
PD
2C
1
2
3