TECHNICAL APPENDIX: VALUING THE FLOOD RISK REDUCTION BENEFITS OF FLORIDA'S MANGROVES

1. Overview

The methodology for estimating the risk reduction benefits of mangroves follows a series of steps that are standard practice in catastrophe risk and coastal engineering assessments, and is also outlined as the recommended methodology for national valuations of natural capital by the World Bank (Beck & Lange, 2016). Using these steps, we estimate surge-related flood damages for two scenarios: i) With Mangroves, and; ii) Without Mangroves. The difference in damages between these scenarios at a given location represents the flood reduction impacts of mangroves at that location.

For estimating annual flood damages, we develop a set of 100 hypothetical storms that are representative of the full set of possible storms for the region (Section 3). For each storm we estimate surge-related flooding and damages for the two scenarios.

For the reconstruction of a surge event based on Hurricane Irma, we use observational data on Hurricane Irma's storm parameters including storm track, location, forward movement, central pressure and wind-fields.

2. Methodology

First, we estimate the offshore hurricane conditions that drive nearshore water levels and inland flooding using a parametric wind-field model. The wind field is based on the modification of a parametric wind-field model (Loridan et al., 2015; Willoughby et al., 2006) and is calibrated using historical observed wind speeds.

Next, we use a 2-D hydrodynamic coastal flood model (hereafter, 'RMS surge model') to simulate the propagation of storm surge from ocean to land and the resulting inland flood extents and heights. The flood model, described in detail and validated for Hurricane Sandy in Narayan et al., (2017), is based on the Danish Hydraulic Institute (DHI) Mike21 model, a finite volume hydrodynamic model which solves the 2D shallow water equations on an unstructured grid (Danish Hydraulic Institute, 2016a). The model is forced by the wind field and air pressure over the domain and by the tides at the open-sea boundaries. The model extends from the offshore continental shelf up to inland elevations which are well above the highest possible extent of flooding by storm surge. Tidal boundary forcings are from DHI's Global Tidal Model. With these boundary conditions, the RMS surge model is used to simulate the propagation of tides and storm surge from the continental shelf onto land during individual storm events. The model's mesh resolution is variable in space, with elements as small as 150m close to shore and in areas of high exposure, and larger elements in deeper areas with more uniform flow. The bathymetry for the model comes from Jeppesen Marine's C-MAP Professional+ digital nautical charts, a global navigational-quality vector chart database, extracted using DHI MIKE C-MAP software (Danish Hydraulic Institute, 2016b) and land elevation is from the U.S. Geological Survey National Elevation Dataset.

Then, we estimate the effect of mangroves on this surge-related flooding by running the surge model for two scenarios: i) With Mangroves, and; ii) Without Mangroves. In the surge model, mangroves are represented as a land cover-based Manning's friction coefficient of 0.1 (or Manning's n of 10). Land use data, used to calculate the spatial extent of this friction coefficient, is taken from the U.S. Geological Survey National Land Cover Dataset (USGS NLCD) (Arcement Jr and Schneider, 1989; Multi-Resolution Land Characteristics Consortium (MRLC), 2011). Additional data on mangrove extent is obtained from Florida Fish and Wildlife (FFWCC, 2019). In the 'Without Mangroves' scenario all mangrove forests in Florida are re-classified as open water with all other conditions and parameters unchanged. This approach allows us to isolate the influence of mangrove presence on flood extents and therefore on flood damages.

Finally, we translate these flood extents and heights into avoided economic damages to properties, using a loss model coupled to data on property exposure ('RMS loss model'), for both mangrove scenarios. We also use public population datasets to estimate the number of people within flooded areas and the number of people affected by the presence of mangroves. The difference between these flood footprints and damage values represents the risk reduction benefits of mangroves. To estimate mangrove benefits using the loss model we first interpolate the peak surge heights from the flood model onto a variable resolution grid with a maximum resolution of 100m X 100m in areas with the highest concentration of properties, and a minimum resolution of 5km X 5km for the least densely populated areas. The RMS loss model then applies flood damage functions to all exposed assets in the property exposure database to estimate the total economic loss due to flooding. These damage functions describe the possible distribution of damage to a structure based on the flood height and the structure's characteristics, such as the construction type, its occupancy, its height, the year it was built, and whether it has any additional protective features. The damage functions were derived from observations of flood related damage compiled and developed by RMS, and were calibrated with proprietary data on historic flood insurance claims and structure types. Wave-induced damages are also included in the flood damage functions for locations known to be affected by storm waves. All losses are estimated in terms of 2018 US$. The property exposure database is a proprietary asset exposure database compiled by RMS. The maps of spatial variation in flood heights and losses are aggregated using hexagonal units of uniform area (10 km2) for clarity and ease of viewing. All analyses use ArcGIS v10.4.1 and RStudio v1.01.136 software.

3. Subsampled storm event set for annual flood damages in Collier County

The event set used in the study on changes in Average Annual Losses (AALs) in Collier County was obtained by sampling 100 storm events from a larger event set containing 3,966 synthetic storm events affecting Collier County. This full event set was taken from the RMS 2018 North Atlantic Hurricane model, which was also used and described in Narayan (2017). The events in this synthetic set are generated using a large-scale North Atlantic statistical tropical cyclone track model which involves randomly sampling historical cyclone data, following the approach described in Hall & Jewson (2007) and Jewson & Hall (2008), to create a set of storms which are physically realistic and which are considered to span the range of all possible events which could occur (Hall & Jewson, 2008; Risk Management Solutions, 2015). The 3,966 events considered in this study represent the subset of storms generated by the track model which impact Collier County, Florida. Each of these events has an assigned frequency, which has been calibrated to match the observed frequency of storms in the county for the period AD 1900–2011. This approach follows a catastrophe modelling methodology widely used in the insurance sector (Grossi & Kunreuther, 2005).

This set was subsampled to obtain 100 representative events, which could be rerun for the no-mangrove scenario. This sampling was carried out by calculating an economic loss from storm surge for each event using the RMS Industry Exposure Database for Collier County, splitting the full set into 100 classes, and selecting the event in each class whose total loss contribution (i.e. loss multiplied by the sum of the rates of the class's events) is closest to the class's total AAL contribution. The event's new rate in the subsampled set is taken to be equal to the sum of all event rates in its class. The 100 events selected are therefore the best representatives of their respective classes in terms of their contribution to the Collier County storm surge AAL.

The subsampled event set was found to very closely approximate the full event set in terms of Collier County AAL, with an AAL error of +0.045%, and a standard deviation error of only +0.008%, meaning that biases in both the AAL and variance around it are negligible. In order to ascertain potential biases at the lower end of the Exceedance Probability curve – the part which we are most interested in for this study, given that mangroves are expected to have most impact on high-frequency, lower-magnitude events – we also used the XSAAL metric, in particular by calculating the inverse XSAAL (which we define as AAL - XSAAL, i.e. the contribution to the total AAL from events whose Return Period [RP] is lower than a specified level). The inverse XSAAL errors for various RPs are given in Table 1. This table shows that events whose RP is < 100 years account for 56% of the total AAL and events whose RP is < 100K years account for 99.999% of the AAL. The errors within this band in the subsampled set we use in this study are low: +0.122% for RP 100 and +0.071% for RP 100K.

SI Table 1: Comparison of AAL values of the limited event set used in this study with the full storm event set for Collier County

Return Period (yrs)	InvXSAAL Error (*this study – full set*)	Relative Event Contribution to AAL (*i.e.* $InvXSAAL_{FullSet} / AAL_{FullSet}$)
100	+0.071%	56%
1K	+0.057%	92%
10K	-0.247%	99%
100K	+0.122%	>99.999%

4. Storm Event Based on Hurricane Irma

We estimate mangrove benefits for risk reduction from a single catastrophic event using a simulation based on Hurricane Irma in 2017. To simulate surge-related flooding from this event, we use observational data from Hurricane Irma on track, forward movement, wind-fields and air pressure to define the offshore boundary conditions for the 2-D surge model described here in Section 2. The resulting flood footprints (extents and heights) are used as inputs to the loss model described in Section 2. We note that this event is not an official RMS reconstruction of Hurricane Irma.

5. References

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