climada module **Barisal demo (storm surge)** 14 Dec 2014

https://github.com/davidnbresch/climada_module_barisal_demo
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Makes use of the following climada modules:
https://github.com/davidnbresch/climada_module_tc_surge
https://github.com/davidnbresch/climada_module_etopo
https://github.com/davidnbresch/climada_module_tc_hazard_advanced
https://github.com/davidnbresch/climada_module_country_risk
and https://github.com/davidnbresch/climada_module_GDP_entity

This document covers storm surge. See also the tropical cyclone wind part of the documentation. The present document does provide the reader with a short basic introduction to climada and covers the specifics of the surge module's application to the city of Barisal in Bangladesh.

Introduction

As one of the largest river deltas in the world, the onset of climate change has severe implications for Bangladesh. With an average land elevation of less than 10m, and most of the coastal regions being at sea level, Bangladesh is extremely susceptible to flooding in the rainy season. In fact, nearly 80% of the total Bangladeshi land area consists of flood plains. Then, given the poverty, illiteracy and high population density[1], it is not so surprising that Bangladesh was considered the nation most vulnerable to the impacts of climate change by the National Geographic[2].

Situated at the heart of the Kirtankhola River Delta, the city of Barisal is especially exposed to the risk of natural disaster. The ICLEI[3] identified saline water intrusion, disruption of sanitation systems and water supply, and siltation of natural canals as major issues faced by Barisal.

The Economics of Climate Adaptation methodology[1], as implemented in climada, aims to give a better, quantitative understanding of the threat posed by climate change. Ultimately, this fact base should help in decision-making with regard to implementing adaptation measures, improving Barisal's resilience.

Modeling Concept

Using state-of-the-art probabilistic modelling, we estimate the expected economic damage as a measure of risk today, the incremental increase from economic growth and the further incremental increase due to climate change. A portfolio of adaptation measures is then built, assessing the damage aversion potential and cost-benefit ratio for each measure. Finally, the adaptation cost curve illustrates that a balanced portfolio of prevention, intervention and insurance measures allows to pro-actively managing total climate risk.

The climada model is constructed from the analysis of four key components:

- the natural hazard;
- the assets at risk;
- the susceptibility of these assets to the natural hazard (damage function); and
- the impact of prevention, intervention and insurance measures.

While climada is versatile with regard to the different types of natural hazards considered and has a global scope, this document will outline each of these concepts, with particular reference to

[1] See www.swissre.com/rethinking/climate_and_natural_disaster_risk/shaping_climate_resilient_development.html

storm surge in Barisal. To run this simulation, execute the `tc_surge_Barisal` function. Note, throughout this document, references will be made to end notes explicitly stating the syntax of key functions explained in the text. See their documentation in climada for more detail.

Storm surge hazard

Starting from the historical tropical cyclone tracks, probabilistic tracks are generated using a directed random walk[2]. This entails first analysing the distribution of the initial, and change in, wind speed of the original tracks. Then, a probabilistic storm is initiated at a random starting location in the vicinity of the original storm. At each subsequent time step, the probabilistic storm follows a pseudo-random path, its direction randomly varied about the direction of the original storm. This probabilistic hazard set is then used to generate the so-called hazard event set for both tropical cyclone wind as well as storm surge hazard, as illustrated in Figure 1.

[2] See code `climada_tc_random_walk`

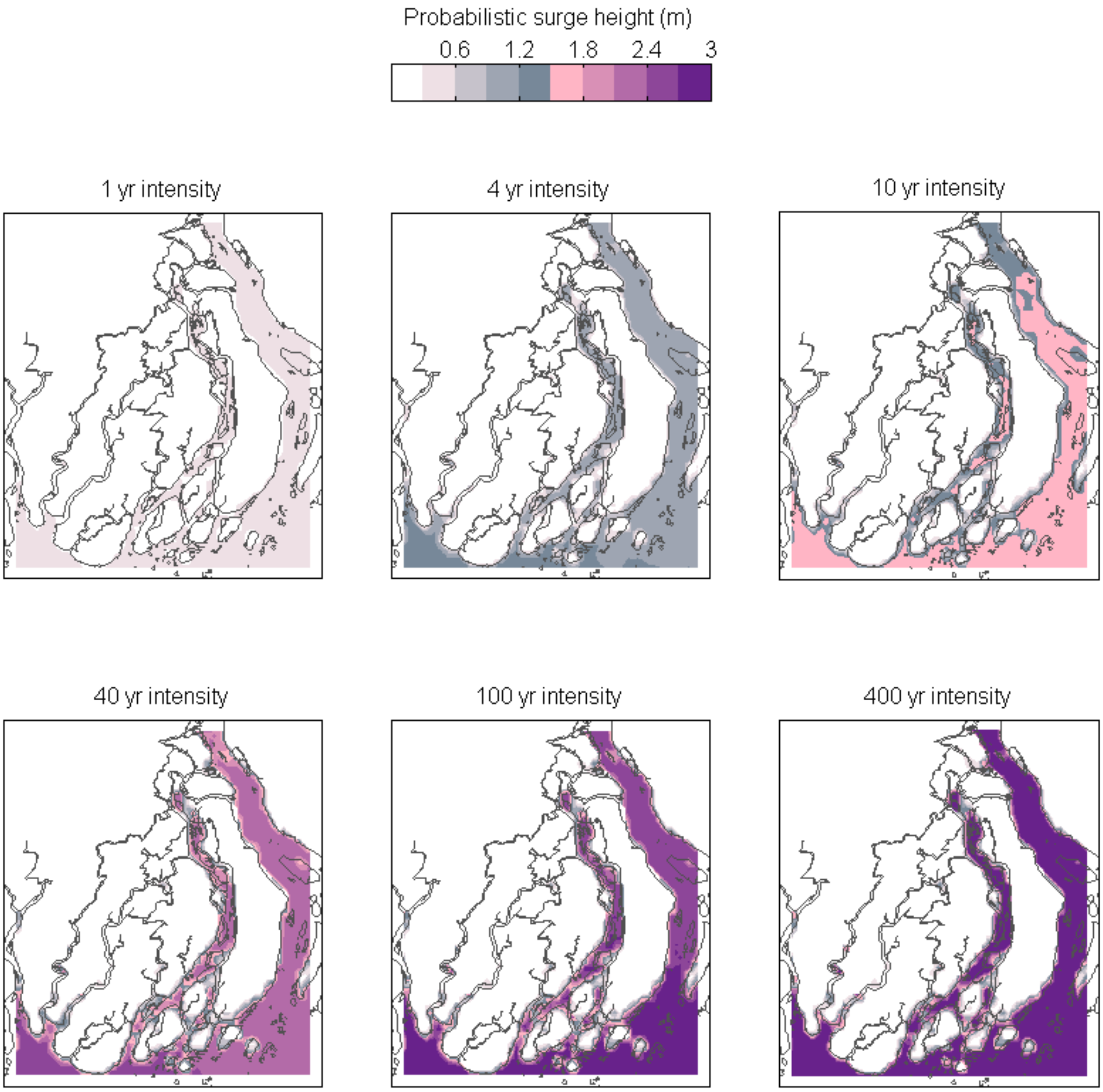

Figure: The max intensity expected for different return periods, as computed from the probabilistic hazard set. In the model, this figure is generated by calling `climada_hazard_stats(hazard)`.

In addition to the meteorological information, the locations at which storm intensity [m/s] and surge height [m] will be evaluated needs to be defined – these locations are called centroids[3]. The centroids structure defines the locations at which the hazard intensity is calculated. Wind footprints for each cyclone track are determined from the maximum wind speed through implementation of the Holland wind field[4], leading to a spatial distribution of intensities[5].

[3] See further below for climada_nightlight_entity which creates both the assets as well as the centroids rewquired. But please note that in essecne, any set of geolocations can be used as centroids.
[4] Holland, G. J., 1980: An analytic model of the wind and pressure profiles in hurricanes. Monthly Weather Review, 108, 1212-1218.
[5] See `climada_tc_hazard_set`

Results from the National Hurricane Centre's SLOSH model[4] indicate that, accurate to within 15%, the storm surge height is can be computed from a storm's wind speed through a linear relationship. Following this method, a hazard set for storm surge is generated from the tropical cyclone intensities, taking into account high-resolution bathymetry data to determine the absolute surge height at each centroid[6].

Asset Distribution

While for a specific application, the spatial distribution of assets will likely stem from different sources, climada provides a unique approach. The assets distribution is inferred from the distribution of night lights[7] and stored in the so-called entity structure[8], which contains information on asset values at centroids (i.e. locations) specified by the pixels of the night light image. The resulting entity is pictured in Figure 2. In order to assess the damage done to each asset, they must be encoded to the nearest centroid at which the hazard intensity has been computed[9]. In the particular case of storm surge, we are concerned with hazard intensities (surge height) relative to ground elevation; it is thus necessary to encode assets to the nearest on-land hazard centroid.

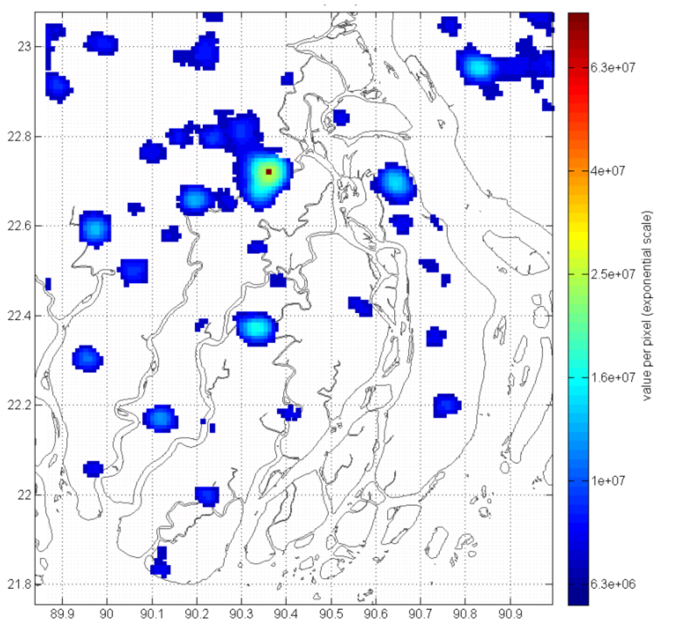

Figure: Distribution of assets in the Barisal Division, derived from high-resolution night-lights. The total asset value in Barisal as calculated is USD 19 billion. Figure created by `climada_entity_plot(entity)`

In addition to the asset information, the entity structure further stores damage functions, adaptation measures, and discount rates.

Damage Functions

Given the asset distribution and hazard footprint, the damage done to each asset may be determined through a damage curve. This involves two components: the percentage of assets affected (PAA) and the mean damage degree (MDD). In the case of storm surge, the PAA is a convex function of surge height (measured in meters), while the mean damage degree takes the shape of a Gaussian cumulative distribution function, also of surge height (see Figure).

[6] See climada module tc_surge (https://github.com/davidnbresch/climada_module_tc_surge) and especially `tc_surge_hazard_create`

[7] See the climada modules https://github.com/davidnbresch/climada_module_country_risk and https://github.com/davidnbresch/climada_module_GDP_entity and their documentation, i.e. https://github.com/davidnbresch/climada_module_country_risk/blob/master/docs/climada_module_country_risk.pdf and https://github.com/davidnbresch/climada_module_GDP_entity/blob/master/docs/climada_module_GDP_entity.pdf

[8] Such an entity structure can be either generated in MATLAB (see e.g. `climada_nightlight_entity` (module country_risk) or `climada_create_GDP_entity` (module GDP_entity), or imported from an Excel file, see core climada's ../data/entities/ USFL_MiamiDadeBrowardPalmBeach_today.xls)

[9] See `climada_assets_encode_centroids`

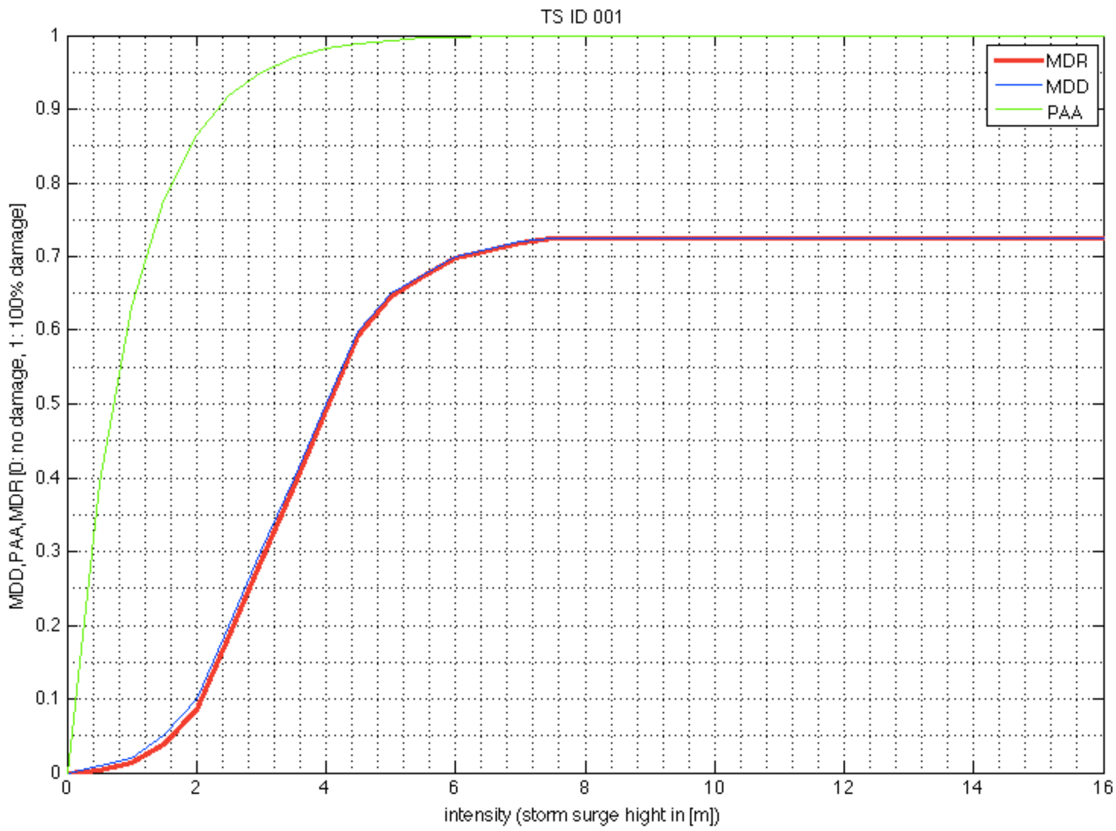

Figure: The storm surge damage function. Figure created by `climada_damagefunctions_plot(entity)`

Assignment of specific damage functions to each asset, dependent on factors such as e.g. building quality is supported, but for the sake of brevity, we provide here one single curve. For any particular hazard intensity, the damage done to an asset is calculated as the product of the asset's value, PAA and MDD. By calculating the damage done to every asset for each event, the event damage set (EDS) can ultimately be constructed[10].

Preliminary Results

As a first validity test of the Barisal storm surge simulation, we consider the most severe storm Bangladesh has seen in recent years: Cyclone Sidr. Sidr struck in November of 2007, with peak sustained winds of 260 km/h, this Category 5 tropical cyclone resulted in of the worst natural disasters in the country. The storm left more than 3000 dead, and caused total damage estimated at USD 1.7 billion. The districts of Barguna and Patuakhali, in the Barisal division, suffered the worst, reporting 423 and 385 deaths respectively[5], largely due to storm surge reaching heights greater than 5m. By January the following year, the World Health Organisation reported thousands of people suffering from diarrhea, pneumonia, skin disease and typhoid fever in the aftermath of the storm[6].

Cyclone Sidr

From the historical track data for cyclone Sidr, the climada storm surge module is capable of reconstructing the storm surge heights at any point. The maximum storm surge height calculated by the model is 8.4 metres and the reported height exceeding 5m is well reproduced by the model. The model is run with standard parameters, hence fine tuning the climada storm surge model by considering local specificities in the Bay of Bengal will further increase the accuracy.

[10] See the core function `climada_EDS_calc(entity,hazard)`

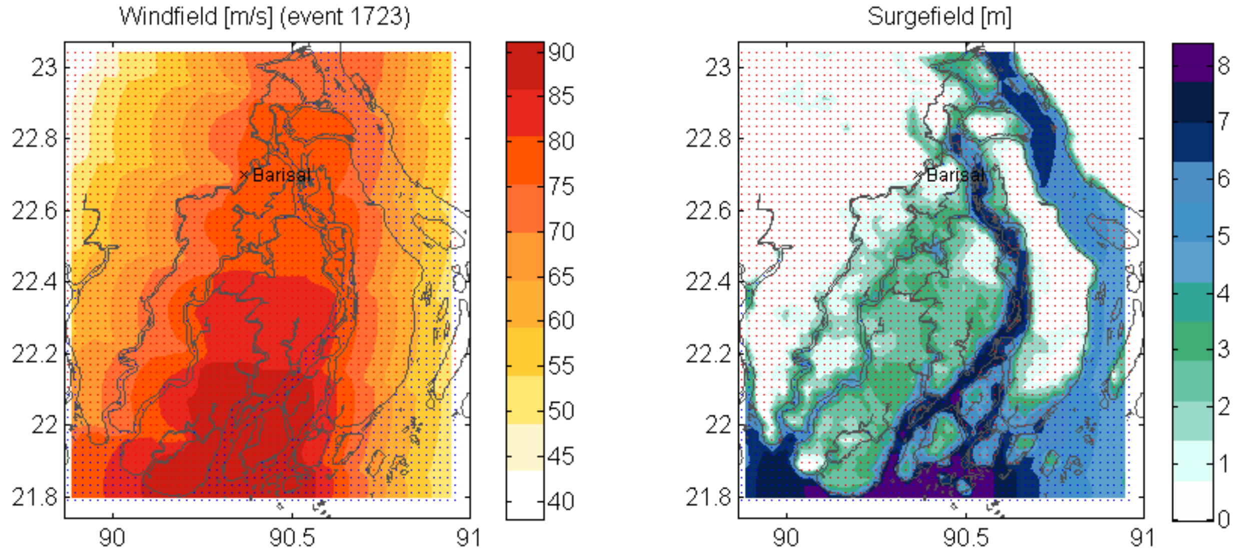

Figure: Contour plots showing the windfield intensity on the left, and the storm surge height on the right, for the Barisal Division. Note the steps in the windfield vertically along the frame, these are artifacts of the finite temporal resolution[11]. The y and x axis indicate the degrees latitude and longitude respectively.

Event Damage

While it is difficult to determine the breakdown of the multitude of causes of the total USD 1.7 billion in losses resulting from cyclone Sidr, it may quickly be noted that the damages computed by the simulation are in line with those reported. For the entire country, the model predicts damages totaling USD 780m attributed to storm surge. Given that this figure does not include the damage done by the cyclone's winds, we conclude that the model is already capable of generating a reasonably accurate, quantitative fact base for understanding storm surge. Further adjustments of the damage function parameters, as well as incorporating more detailed knowledge about the asset base, will surely improve the model's accuracy.

[11] This could be removed by interpolating to more than 1h tforward time step, but given other substantial uncertainties (e.g. in damage functions), such a refinement only makes sense (i tat all) once other drivers of final result uncertainty have been assessed.

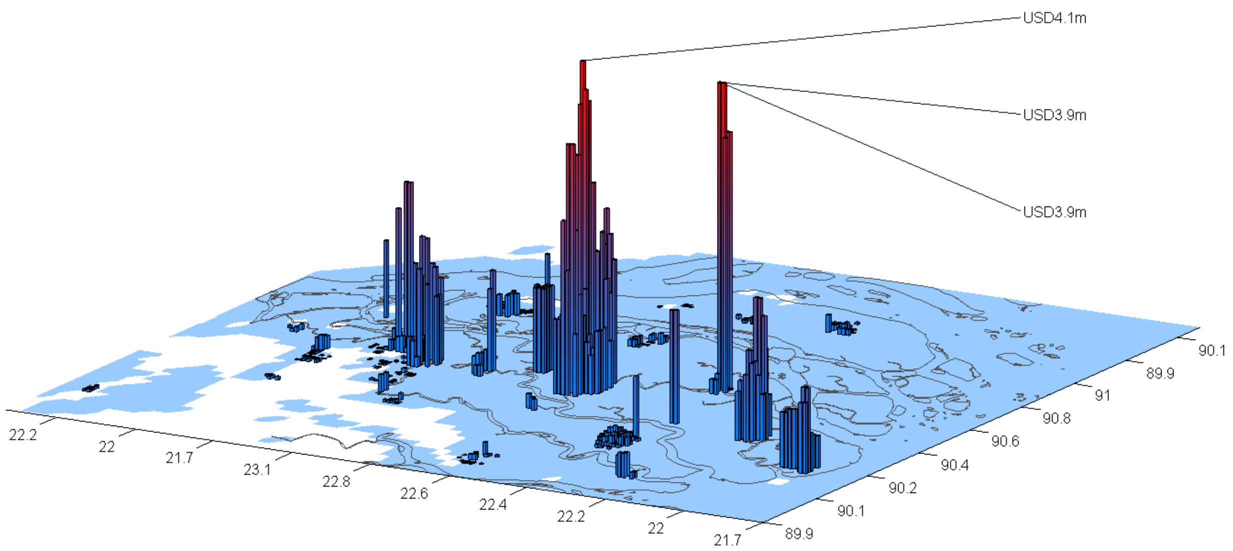

Figure: The event damage for cyclone Sidr, as simulated by the model, the three assets suffering the largest damage are labeled. The spikes indicate the damage done to assets at their respective locations, whereas the blue surface illustrates the areas that were flooded as a result of Sidr's surge. Total losses due to storm surge during this event amount to USD 280 million in the Barisal Division. This graphic may be plotted using `climada_plot_EDS_3d`.

Conclusion

As it stands, the Barisal storm surge model is capable of generating a physically sound storm surge hazard set, which, in conjunction with a high resolution asset distribution for Barisal, leads to a reasonable reproduction of the cyclone Sidr event from 2007.

References

[1] A. K. Denissen, "Climate Change & its Impacts on Bangladesh", 03/04/2012, http://www.ncdo.nl/artikel/climate-change-its-impacts-bangladesh (retrieved 09/12/2014)
[2] D. Braun, "Bangladesh, India Most Threatened by Climate Change, Risk Study Finds". *National Geographic*, 20/10/2010.
[3] M Rahman, S. Tiwari, "Urban vulnerability assessment in South Asia: the example of Bangladesh", *4th Global Forum on Urban Resilience & Adaptation*, 02/07/2013
[4] Xu, Liming. "A simple coastline storm surge model based on pre-run SLOSH outputs." In *29th Conference on Hurricanes and Tropical Meteorology*. 2010.
[5] WAGA, "Bangladesh cyclone toll rises to 1,723", 17/11/2007
[6] World Health Organization, "Public Health Situation in 9 Districts: (Since 27 December 2007 to 15 January 2008)", 15/01/2008
[7] Mazda, Y.; Kobashi, D. and Okada, S. (2005) "Tidal-Scale Hydrodynamics within Mangrove Swamps" *Wetlands Ecology and Management* 13(6): pp. 647-655