Tropical cyclone **rain**, part of climada module **tropical cyclone** 24 Dec 2015

Formerly until 20151224 a module https://github.com/davidnbresch/climada_module_tc_rain
david.bresch@gmail.com

This climada module allows to generate the precipitation fields accompanying a tropical cyclone - the torrential rain (TR) hazard event set.

Simply read the header in **`climada_tr_hazard_set`**, all other code implements subroutines.

A good demonstration of the application of the module can be found in `centroids_generate_hazard_sets` of the module country risk[1].

Table of Contents

Theoretical Background 2
Generate the Rain Sum Footprint 3
Collect the Damages and Benefits of Measures of different hazards 7

[1] https://github.com/davidnbresch/climada_module_country_risk

Theoretical Background

Main source: Tuleya et at., 2006: Evaluation of GFDL and Simple Statistical Model Rainfall Forecasts for U.S. Landfalling Tropical Storms.

The symmetric rainfall field can be computed after Tuleya et al., 2006 who developed a simple rainfall climatology and persistence model (R-CLIPER). Rainfall rates are calculated as a function of storm intensity and radius. The accumulated rainfall rate along the storm track can then be derived by integrating the rainfall rate along the storm track, give the intensity.

R-CLIPER:

The radial structure of the TRMM profiles suggests that the following equation could be used to represent the TRMM rain rates (TRR) as a function of radius and maximum wind (V):

$$\mathrm{TRR}(r, V) = T_0 + (T_m - T_0)(r/r_m) \quad r < r_m \quad \text{(3a)}$$

and

$$\mathrm{TRR}(r, V) = T_m \exp[-(r - r_m)/r_e] \quad r \geq r_m, \quad \text{(3b)}$$

where T_0 is the rain rate at $r = 0$ and T_m is the maximum rain rate at $r = r_m$. In Eq. (3), TRR varies linearly with radius from $r = 0$ to $r = r_m$, and then decays exponentially for $r \geq r_m$ starting from T_m. Equation (3) has four parameters (T_0, T_m, r_m, and r_e). From a least squares fit of the TRMM radial profiles in Fig. 6, it was found that the dependence on storm intensity could be accounted for by making these four parameters linear functions of the storm intensity as follows:

$$T_0 = a_1 + b_1 U, \quad \text{(4a)}$$

$$T_m = a_2 + b_2 U, \quad \text{(4b)}$$

$$r_m = a_3 + b_3 U, \quad \text{(4c)}$$

and

$$r_e = a_4 + b_4 U, \quad \text{(4d)}$$

where U is the normalized maximum wind given by

$$U = 1 + (V_m - 35)/33 \quad \text{(5)}$$

and V_m is the maximum wind speed in knots. Table 2 lists the a_1–a_4 and b_1–b_4 that were obtained from the fit of Eqs. (4) and (5) to the TRMM rainfall profiles, assuming that the maximum winds of the three profiles in Fig. 6 are 45, 80, and 115 kt. The units of the coefficients were chosen to give the rain rate in units of inches per day. Equations (3)–(5) provide an excellent represen-

TABLE 2. The constants from the fit of the TRMM rainfall rates as a function of radius and storm maximum wind for the R-CLIPER model. The bottom four rows are the bias-corrected constants used by the NHC in the operational version.

	Intercepts	Slopes
Preliminary	$a_1 = -2.11$ in. day^{-1}	$b_1 = 3.63$ in. day^{-1}
	$a_2 = -2.73$ in. day^{-1}	$b_2 = 4.24$ in. day^{-1}
	$a_3 = 69.1$ km	$b_3 = -8.49$ km
	$a_4 = 215$ km	$b_4 = -35.8$ km
NHC	$a_1 = -1.10$ in. day^{-1}	$b_1 = 3.96$ in. day^{-1}
	$a_2 = -1.60$ in. day^{-1}	$b_2 = 4.80$ in. day^{-1}
	$a_3 = 64.5$ km	$b_3 = -13.0$ km
	$a_4 = 150$ km	$b_4 = -16.0$ km

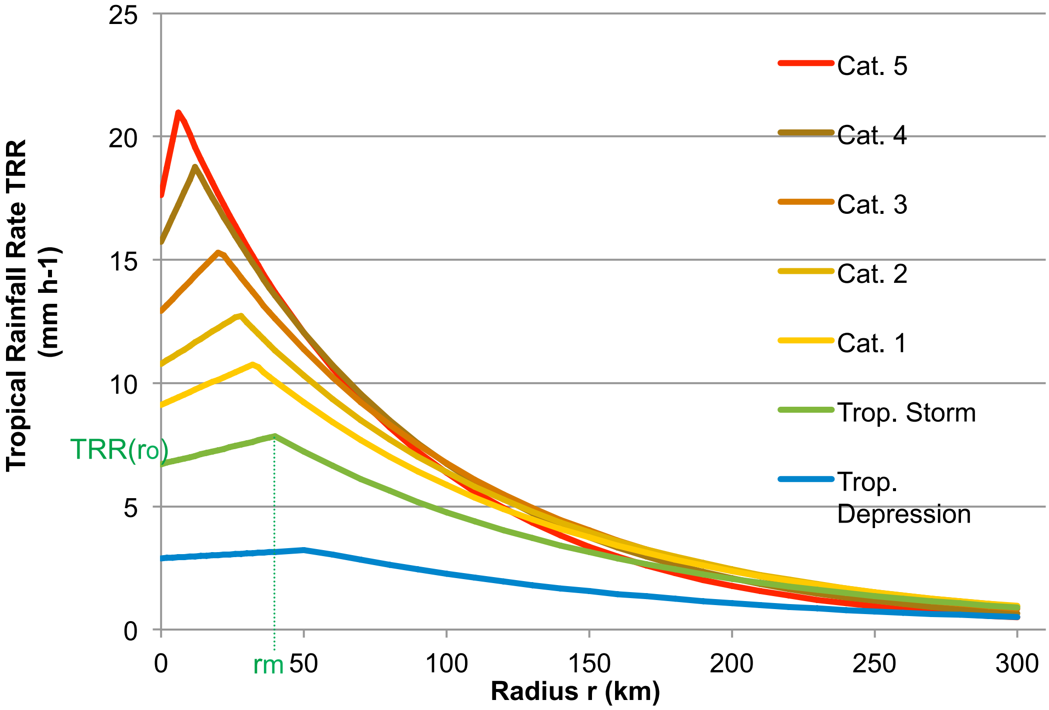

Figure: R-CLIPER radial rainfall rates profiles based on the Saffir-Simpson Hurricane wind speeds. Rainfall rates increase linearly between r = 0 and r = rm, which is the maximum rainfall rate, and decay exponentially with r>rm.

More variables that influence the distribution and amount of precipitation:

- Forward Speed
- Curvature
- Vertical Wind Shear: Precipitation Pattern Asymmetries
- Topography: Orographic Enhancement on windward hillside
- Interaction with Frontal Boundaries/Upper Level Troughs

Generate the Rain Sum Footprint

Generate rain sum field resulting from single track of tropical cyclone. The function computes rain rates for every hour and accumulates rain fall for every storm, based on R-CLIPER (symmetric rain field). Results saved in `res.rainsum` as total rain fall in mm per storm.

Equal time steps of one hour (interpolation of longitude, latitude, maximum sustained wind speed, minimum pressure).

```
[res,tc_track,centroids] = climada_tc_rainfield(tc_track,...
      centroids,equal_timestep,silent_mode,check_plot)
```

Analog to climada_tc_windfield, the rain field code makes use of climada_nonspheric_distance_m and climada_RCLIPER

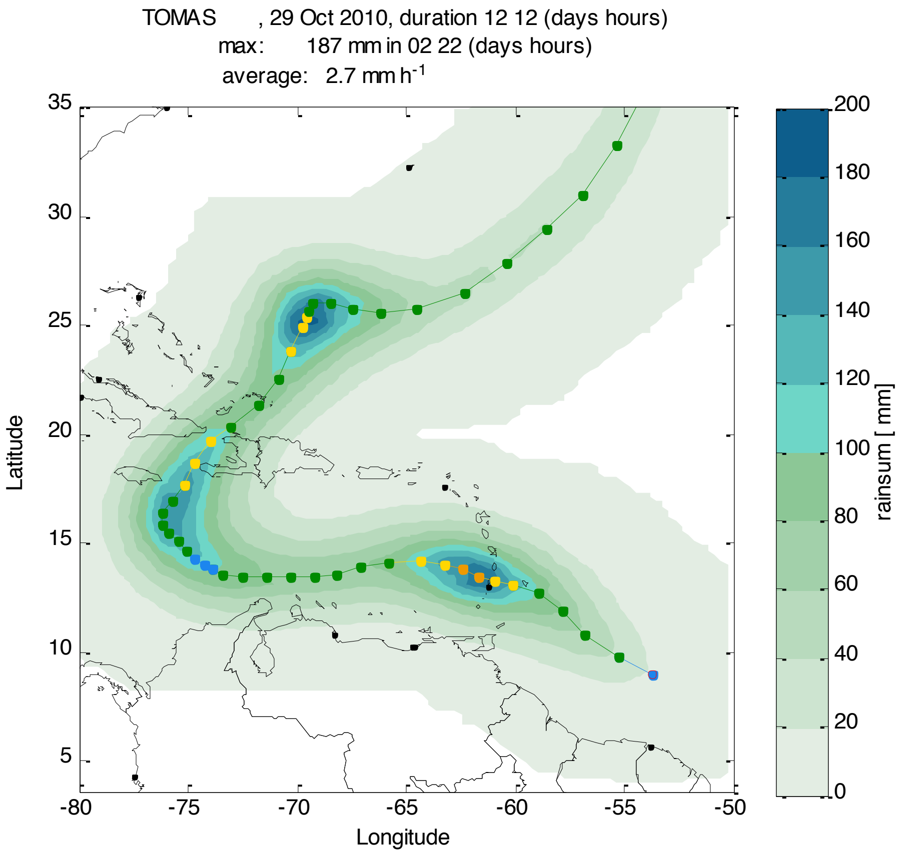

Figure: Rainfall sum footprint.

Calculate Rain Rate for Each Node of Specific Tc Track Based on Symmetric Rain Field R-CLIPER

```
rainrate = climada_RCLIPER (fmaxwind_kn,inreach,Radius_km)
```

Given the windspeed (kn) at a specific node calculate the rain rate at all centroids according to RCLIPER (symmetric rainfield).

The radial structure of the TRMM profiles suggests that the following equation could be used to represent the TRMM rain rates (TRR) as a function of radius and maximum wind (V):

$$\mathrm{TRR}(r, V) = T_0 + (T_m - T_0)(r/r_m) \quad r < r_m \tag{3a}$$

and

$$\mathrm{TRR}(r, V) = T_m \exp[-(r - r_m)/r_e] \quad r \geq r_m, \tag{3b}$$

from: R-CLIPER (Tuleya et at., 2006: Evaluation of GFDL and Simple Statistical Model Rainfall Forecasts for U.S. Landfalling Tropical Storms).

`climada_tc_rainrate_field_animation`: Calculate the Rain Rate Fields for a Single Track and Display as Animation

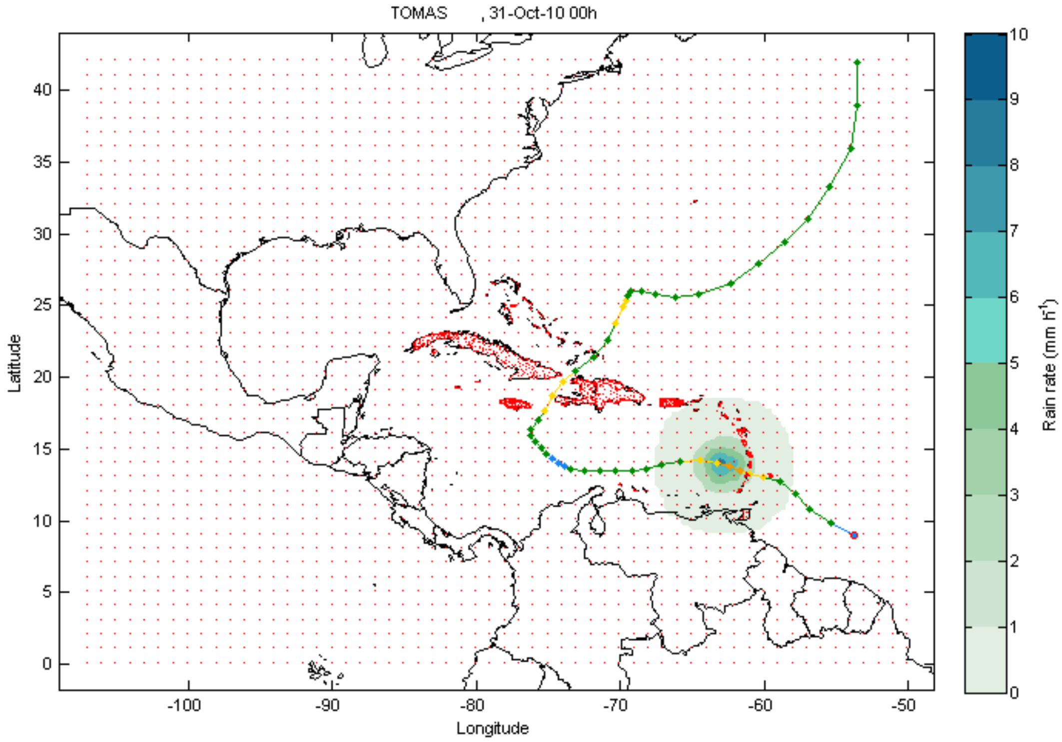

Figure: Rain rate field for the highest probabilistic storm, see *`climada_tc_rainrate_field_animation`*

`climada_tc_rainsum_field_animation`: Calculate the rain sum fields for a single track and display as animation

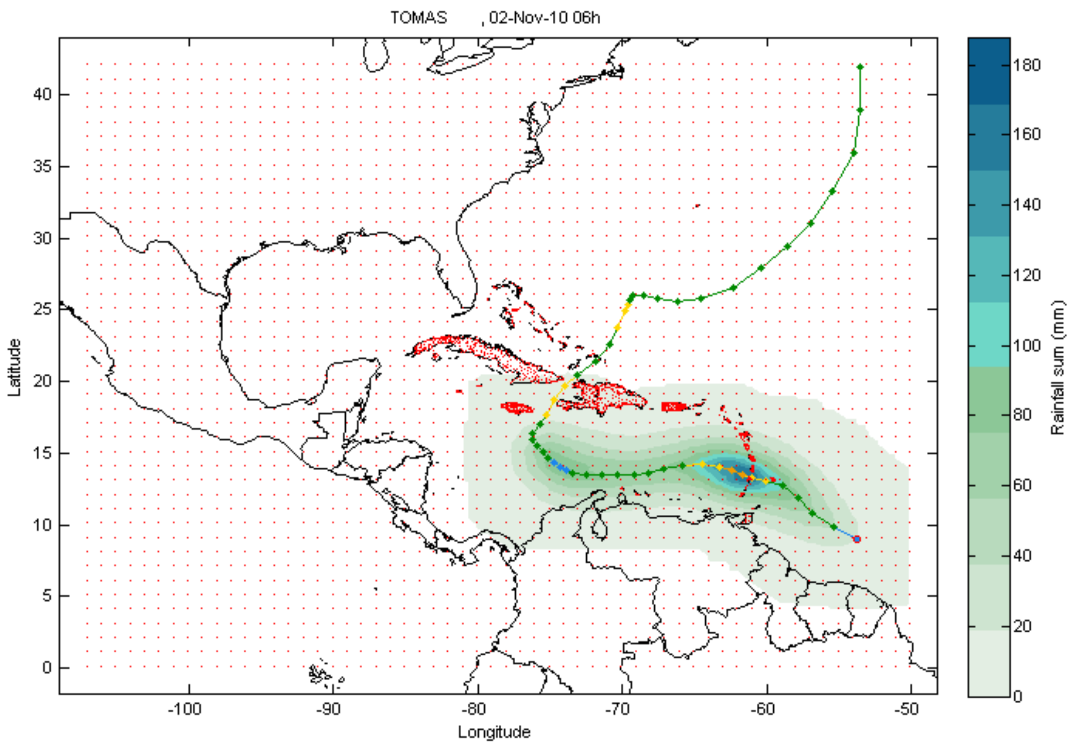

Figure: Rainfall sum field, see climada_tc_rainsum_field_animation

`climada_tc_hazard_rain`: Generate the Rain Hazard Set (i.e. All Rain Sum Footprints). It needs `climada_tc_rainfield`, `climada_nonspheric_distance_m` and `climada_RCLIPER`.

Analyze Statistics; Plot Rain Sum for Specific Return Periods at all Centroids for Historical Data Set, Probabilistic Data Set or Climate Change Scenario

`climada_hazard_stats`: Plot rain sum based historical, probabilistic or climate change data, for requested return periods at all centroids.

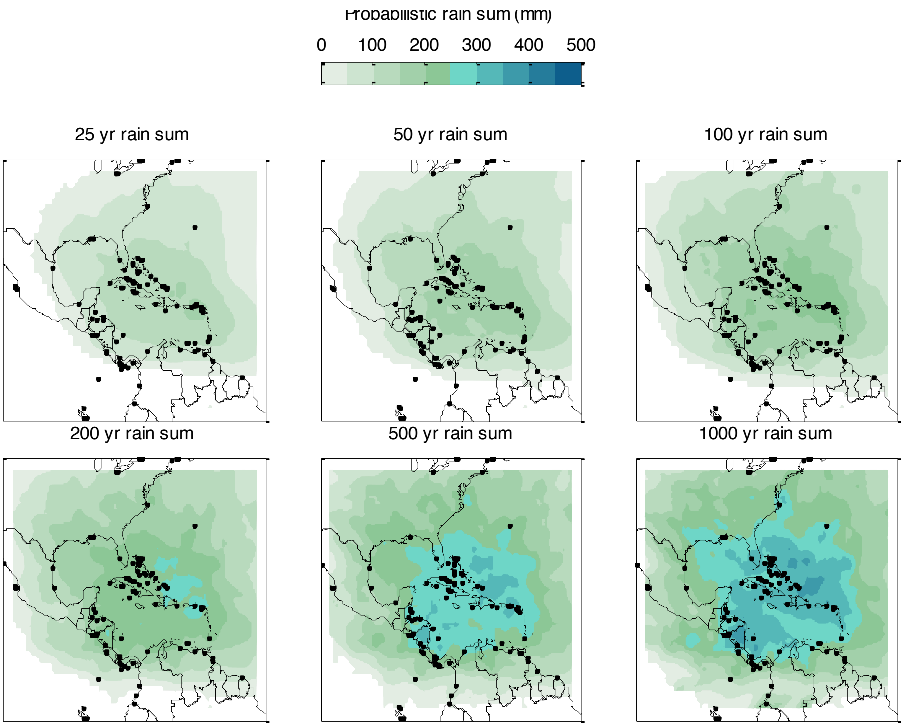

Figure: Rain sum maps for specific return periods, see `climada_hazard_stats`

Plot Waterfall Figure for Today's Damage and Future's Damage Including Economic Growth and Climate Change Separately for one or two hazards

`climada_waterfall_graph_advanced`: Include one or two hazard (3 EDS per hazards). The EDS files get sorted (according to hazard type and EDS size automatically)

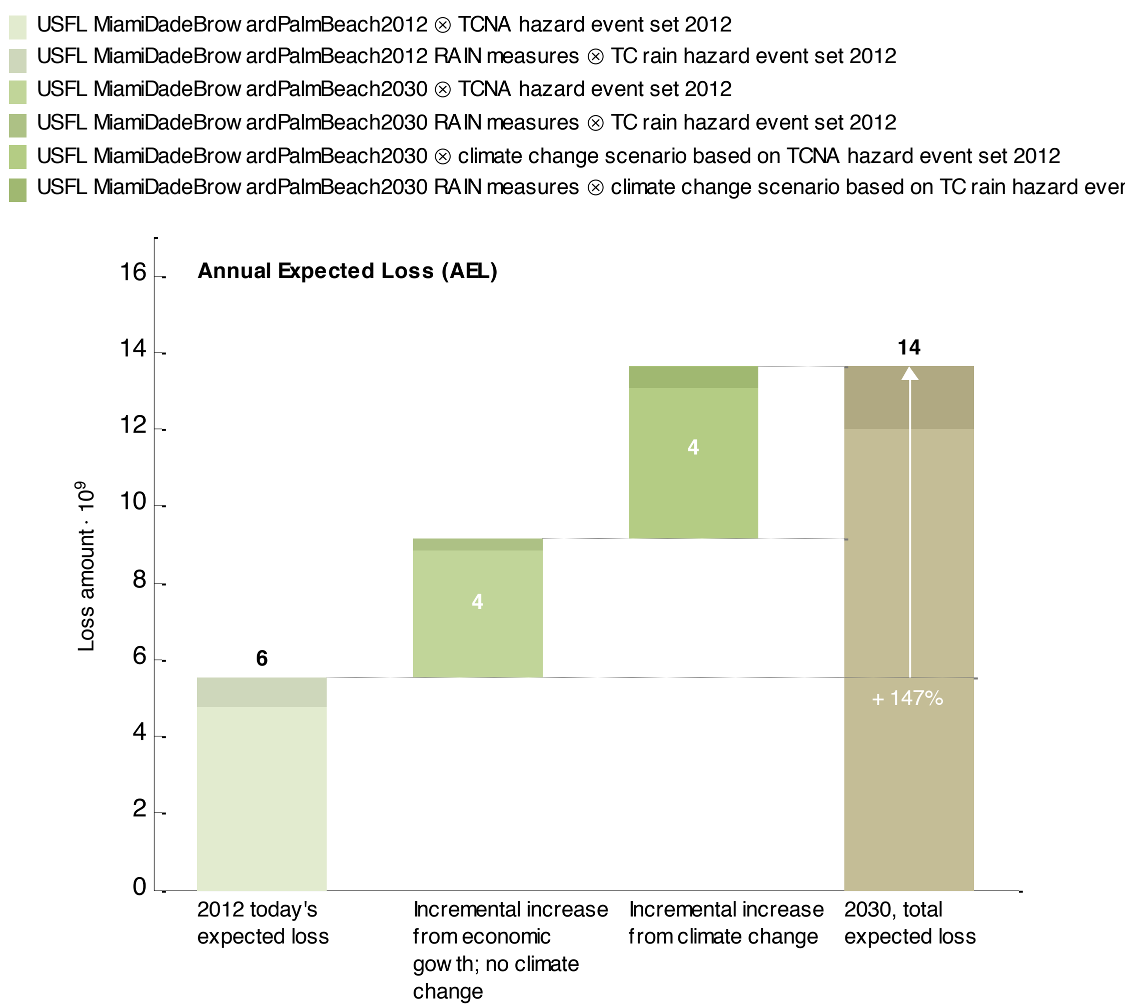

Figure: waterfall plot for the hazard rain and wind. See climada_waterfall_graph_advanced-

Collect the Damages and Benefits of Measures of different hazards

```
Impacts_collected=climada_collect_measures_impact(impact1,impact2)
```

This function sums up the benefits (damage averted) and costs[2] of shared measures (i.e. measures with the exact same name). WARNING: It is assumed that the two hazards are insured separately, therefore make sure to not use the same name for both hazards e.g. risk_transfer_rain and risk_transfer_wind. If one insurance covers both hazards sum up the losses of both hazards, apply the risk transfer and calculate the NPV of the benefits and the premium.

After collection of impacts, use `climada_adaptation_cost_curve(impacts_collected)` as usual to plot the adaptation cost curve.

[2] takes higher costs if costs not the same.

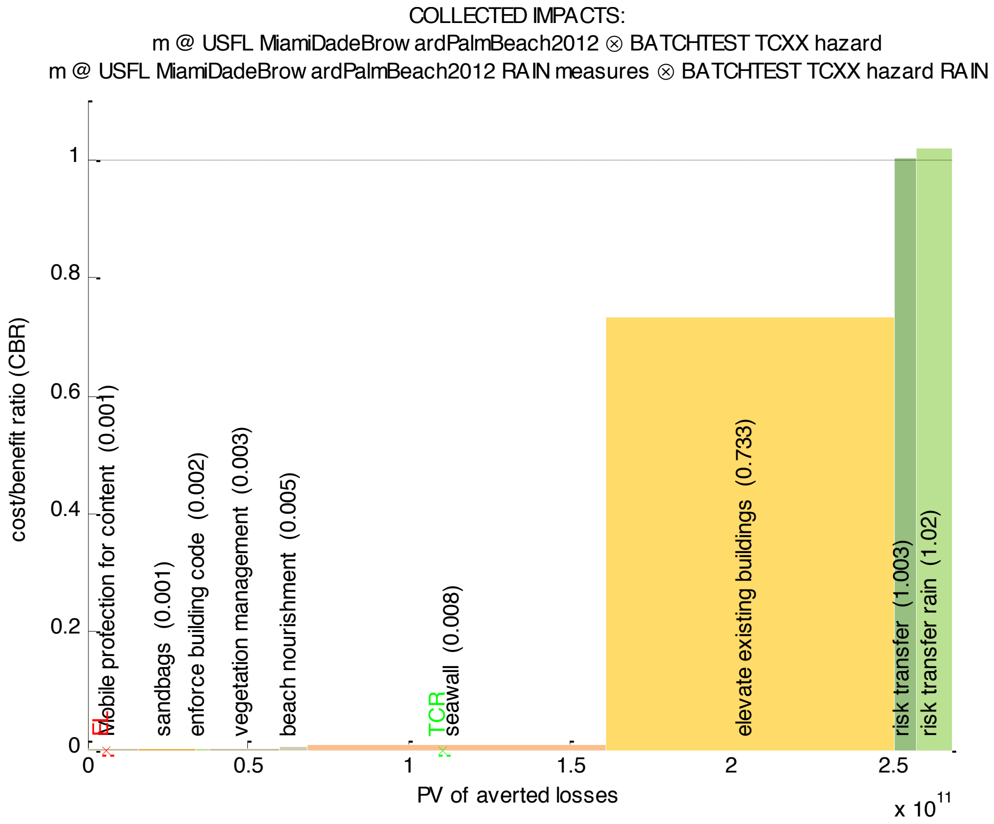

Figure: Cost curve of collected impacts.