CLIMADA MANUAL

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Obtain the full package from https://github.com/davidnbresch/climada

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Uncertainty and risk of climate change: from probabilistic damage calculation to the economics of climate adaptation – shaping climate resilient development[1]. The open-source and open-access tool.

Instead of an Introduction: Preamble

Climate adaptation is an urgent priority for the custodians of national and local economies, such as finance ministers and mayors. Such decision-makers ask:

- What is the potential climate-related damage to our economies and societies over the coming decades?
- How much of that damage can we avert, with what measures?
- What investment will be required to fund those measures – and will the benefits of that investment outweigh the costs?

The economics of climate adaptation methodology as implemented in climada provides decision-makers with a fact base to answering these questions in a systematic way. It enables them to understand the impact of climate on their economies – and identify actions to minimize that impact at the lowest cost to society. Hence it allows decision-makers to integrate adaptation with economic development and sustainable growth. In essence, we provide a methodology to pro-actively manage total climate risk. Using state-of-the-art probabilistic modeling, 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. We then build a portfolio of adaptation measures, assessing the damage aversion potential and cost-benefit ratio for each measure. The adaptation cost curve illustrates that a balanced portfolio of prevention, intervention and insurance measures allows to pro-actively managing total climate risk.

climada consists of the core module, providing the user with the key functionality to perform an economics of climate adaptation assessment. Additional modules implement global coverage (automatic asset generation), a series of hazards (tropical cyclone, surge, rain, European winter storms, … and even earthquake and meteorites) and further functionality, such as Google Earth access, animations…

climada runs on both **MATLAB** (version 7[2] and higher, all tested with version 9) and **GNU Octave** (version 3.8.0 and higher, see https://www.gnu.org/software/octave). Some modules might not have been thoroughly tested using Octave, but core climada works without limitations (in order to read Excel, Octave's io package has to be installed, see section "Notes on Octave" below). All climada is available on GitHub[3].

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[1] See lecture course at the Swiss Federal Institute of Technology (ETH): http://www.iac.ethz.ch/edu/courses/master/modules/climate-risk.html

[2] see e.g. ch.mathworks.com/products/matlab and e.g. introduction for engineers http://www.cse.cuhk.edu.hk/~cslui/CSCI1050/book.pdf

[3] Either use Clone to desktop in Git or install git first, then clone any repository by first creating an empty folder (e.g. `mkdir climada`), then `cd climada`, then (note that the last `.` is part of the command) `git clone https://github.com/davidnbresch/climada .` See also `climada_git_pull`

Contents

A visual primer

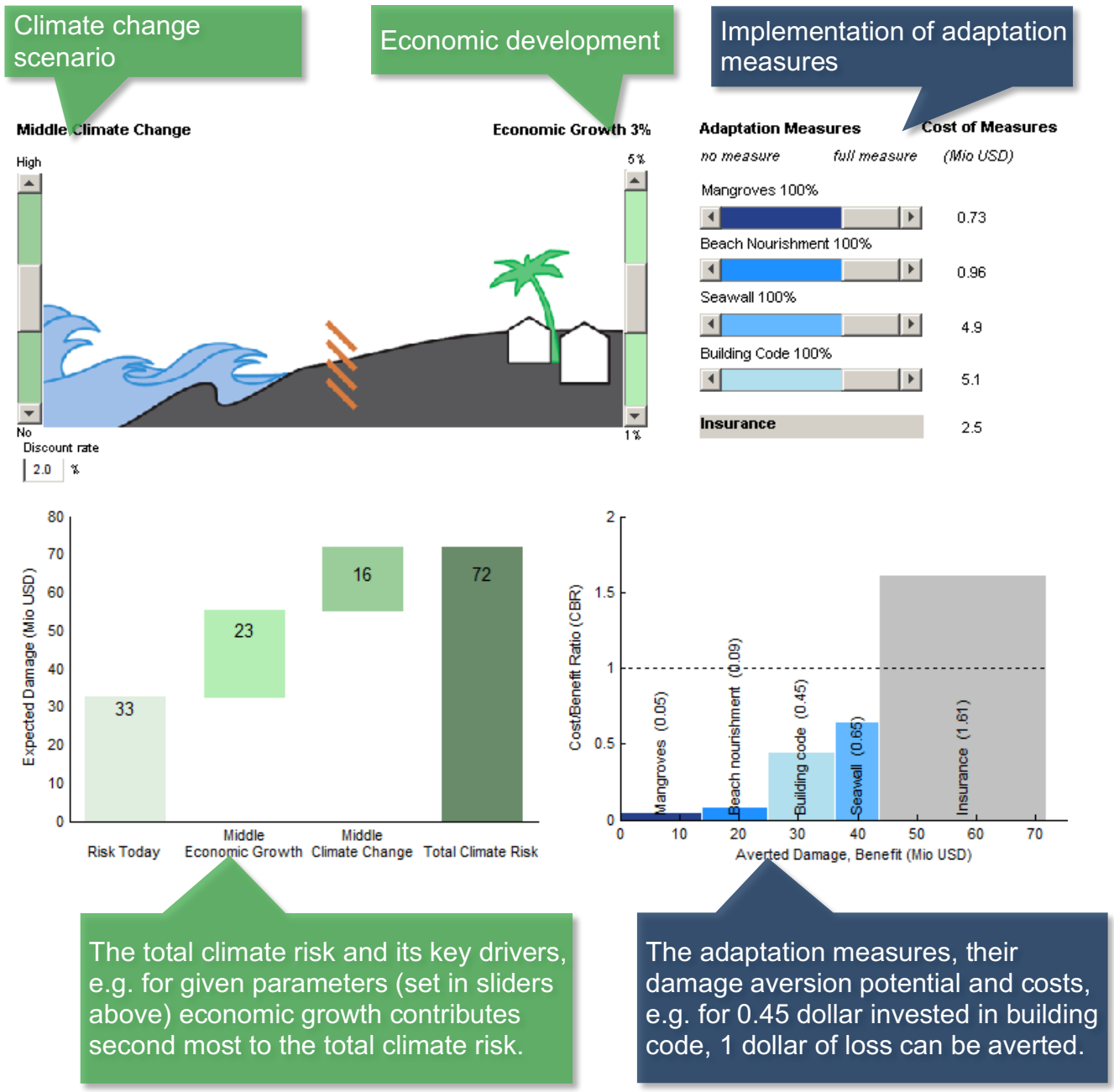


Figure: The demonstration code `climada_demo`[4] implements the concept of total climate risk and cost-effective adaptation in an interactive way: The user can experiment with key relevant factors (sliders, top) and instantly observe the effect – both on risk (measured by expected damage, graph on the left) and the basket of adaptation measures (shown as adaptation cost curve, graph on the right). The user can also edit the underlying input data[5] and hence experiment further.

The simple call `climada` runs the core automatically and prompts for user input.

[4] This GUI runs properly under MATLAB, see `climada_demo_step_by_step` for Octave for he time being, as Octave does not yet support all GUI features.
[5] Just edit the file ../climada/data/entities/demo_today.xls, then select Re-init from the GUI's file menu.

A brief introduction to the concepts behind climada

Instead of studying this now, the user might also jump to the step-by-step introduction below and later come back.

Risk is the combination of the probability [or likelihood] of a consequence and its magnitude, i.e. risk = probability x severity. Or, to be more specific:

risk = hazard x exposure x vulnerability
= (probability x intensity) x exposure x vulnerability
\……severity……../

where both the probability of occurrence and the (physical) intensity are part of the hazard (sometimes named peril) and the 'product' of intensity, exposure and vulnerability constitutes the severity. The product symbol 'x' does not stand for a simple multiplication, but in fact a convolution of the respective distributions. Instead of providing the general framework here, one can easily think of severity thus being of the following form

severity = F(intensity,value,vulnerability)

where F is often of the form F = value * f(intensity),
where f(intensity) is the damage function which parametrizes vulnerability

Note that value is the asset value of the exposure, intensity the hazard intensity at the exposure location and the * a simple multiplication. Note that assets do not necessarily need to be monetary assets and value hence not necessarily a monetary value, think about exposed people. In this simple form, vulnerability is given as a function f of intensity (and asset class/type). See Appendix "climada, the inner workings" below for details.

Any risk model hence attempts to quantify these elements in a way most appropriate for the specific purpose. Depending on purpose, the level of detail in quantification of any element will thus vary. For the geographical representation, think e.g. of a local flood model at very high resolution of a few decameters compared to a global earthquake model at e.g. 10 km resolution. For the vulnerability resolution, think e.g. of a general description of building damage to an earthquake as a simple function of modified Mercally intensity[6] compared to a detailed damage curve depending on flood height in meters, building construction, number of floors, basements… and usage (also called occupancy).

Probabilistic damage model

A model is nothing more than a simplified representation of reality. Natural hazard models use the virtual world of computers in an attempt to simulate natural catastrophe damage expected in reality. The quantification of natural catastrophe risk depends on three basic elements (or sets of data), upon which the damage model operates. They are:

- Hazard (sometimes also called peril): Where, how often and with what intensity do events occur? A hazard (event) set is usually generated once and stored for subsequent calls (resulting in massive speedup). A hazard event

[6] Please note that a sophisticated earthquake model can indeed be built on MMI... see e.g. https://github.com/davidnbresch/climada_module_earthquake_volcano

set comprises just many single events, i.e. one ‘footprint’ for each event. Think of a single event footprint as for example a georeferenced distribution (or simply a map) of windspeed.

- Assets (also referred to as value distribution or portfolio of exposed assets or simply exposure): Where are the various types of potentially affected objects located and what is their value? Think of the assets as for example a georeferenced distribution (or simply a map) of houses, represented by their replacement values – or of people, represented by their number at any given location.
- Damage function (sometimes referred to as vulnerability or vulnerability curve): What is the extent of damage at a given event intensity? A damage function is just a simple function of the hazard intensity, but there can be many damage functions for all kinds of assets (and obviously for different hazards).

These three building blocks are combined in the process of estimating event damage as follows:

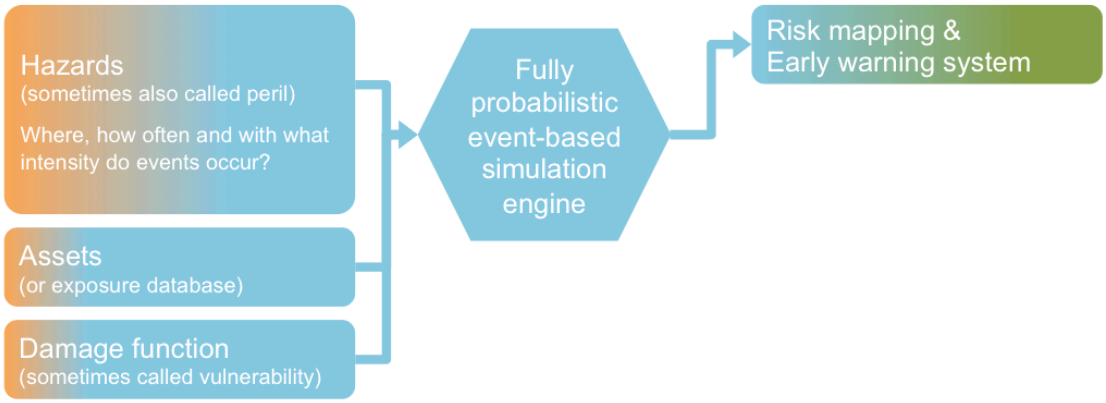


Fig: The basic three building blocks (hazard, assets and damage function). Main result is risk quantification (here subsumed as risk mapping), but the same system can also be (operationally) used to provide early warnings in terms of impact quantities, if fed with a particular (forecasted) single hazard event (such as a wind field of a storm or an shake map of an earthquake).

This approach may generally be applied to all forms of natural hazard, whether storm, flood, earthquake … or any other type of peril.

The simplest way to assess the damage is to simulate an individual natural catastrophe scenario. This is known as “deterministic” or “scenario-based” modeling. Such models often refer back to major historical damage events, applying these to the assets that exist now (“as-if analysis”). The disadvantage of this method is that, whilst it allows a single, extreme, individual event damage to be assessed, it fails to take account of all the other events that might occur. It is not possible to calculate an expected annual damage for a portfolio of assets on the basis of single event damage, and any prediction as to the occurrence frequency of the model scenario will remain very uncertain.

Today, in an attempt to avoid these problems, so-called “probabilistic” models (i.e. a fully probabilistic simulation engine) are being used to assess hazards such as storms and floods. Rather than simply analyzing one event, the computer is programmed to function as a sort of time-lapse film camera, simulating all the possible events that could unfold within a sufficiently long period of time (thousands or tens of thousands of years). This type of model produces a “representative” list of event damages (i.e. a list that accurately reflects the risk). From this list it is possible

to understand the relationship between damage potential and occurrence frequency, and hence the cost of average and extreme damage burdens.

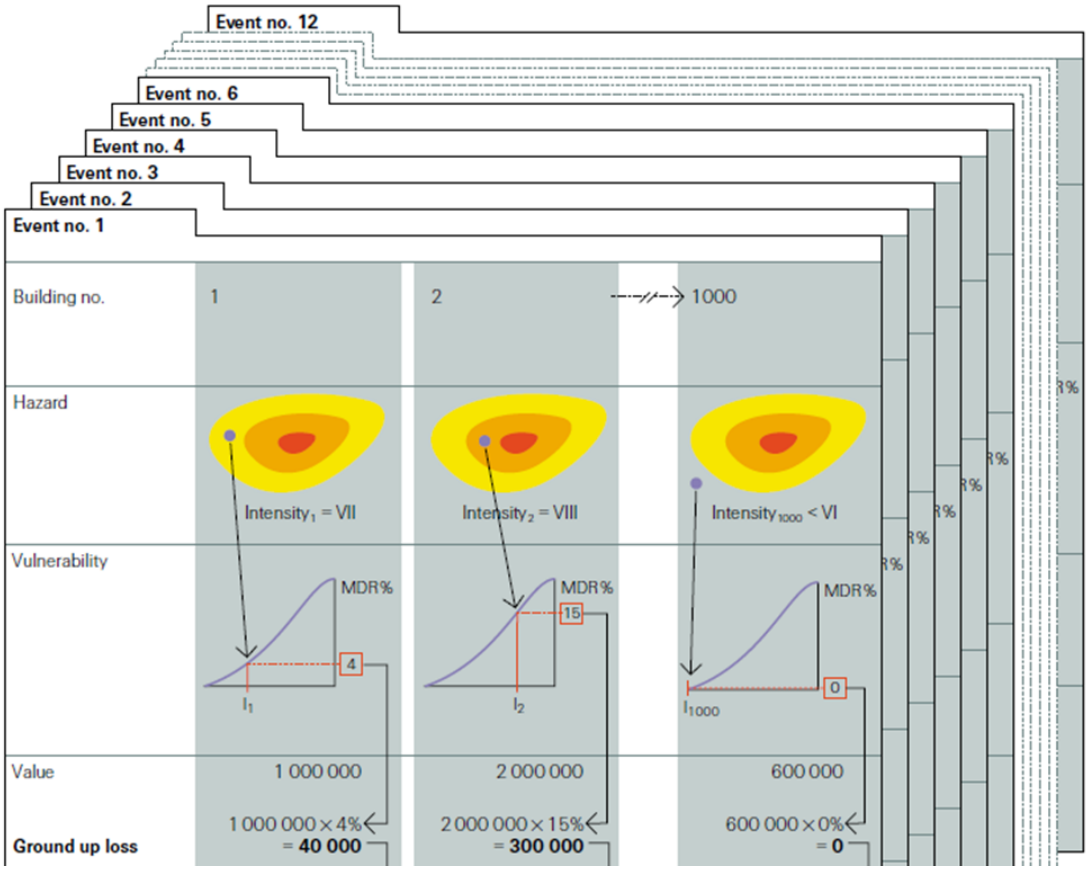


Figure: Using risk assessment tools to calculate event damage. Let's assume a hypothetical portfolio containing 1000 assets (buildings). For the sake of simplicity, let us assume that the risk assessment tool only contains 12 potential events over a projected period of 200 years. The following calculations would be performed:

- The hazard module generates the expected intensity (VII) for event no.1 at asset (building) location no.1.
- The damage function (called vulnerability in the figure) corresponding to the asset provides us with the mean damage ratio (MDR[7]) for given hazard intensity (4 stands for 4% of the asset's value)
- The damage is calculated by multiplying the MDR and the value of the asset (1'000'000), resulting in a (ground up) damage (called loss in the figure) of 40'000.
- Above steps are performed on all 1'000 assets in the portfolio. The sum of all damages produces the total damage from event no.1, i.e. event damage no1.
- All above steps are then repeated for the other (11) events in the event set.
- Upon completion of all these stages in the modeling process, a list of all event damage is produced, upon which damage statistics can be derived (average damage, max damage…).

See mentioned lecture course[8] or e.g. the Swiss Re publication[9] "Natural catastrophes and reinsurance", which covers the methodology in detail.

[7] Please note that climada uses MDR=MDD*PAA, where Mean damage degree (MDD) and percentage of affected assets (PAA) allow to deal with local deductibles in a more appropriate form than a simple Mean damage ration (MDR) model could do, since one does, due to the PAA, know how many assets are affected, hence deductible application is more specific.
[8] http://www.iac.ethz.ch/edu/courses/master/modules/climate-risk.html
[9] http://media.swissre.com/documents/Nat_Cat_reins_en.pdf

Adaptation cost curve

While the assessment of cost and damage aversion potential of any adaptation measure can be quite demanding, climada provides a consistent approach to do so. The tool provides a common yet flexible framework to appraise a basked of adaptation options (sometimes also referred to as resilience measures). Each option can be specified to act on any component of the model (hazard, assets and damage function) – or even a combination thereof.

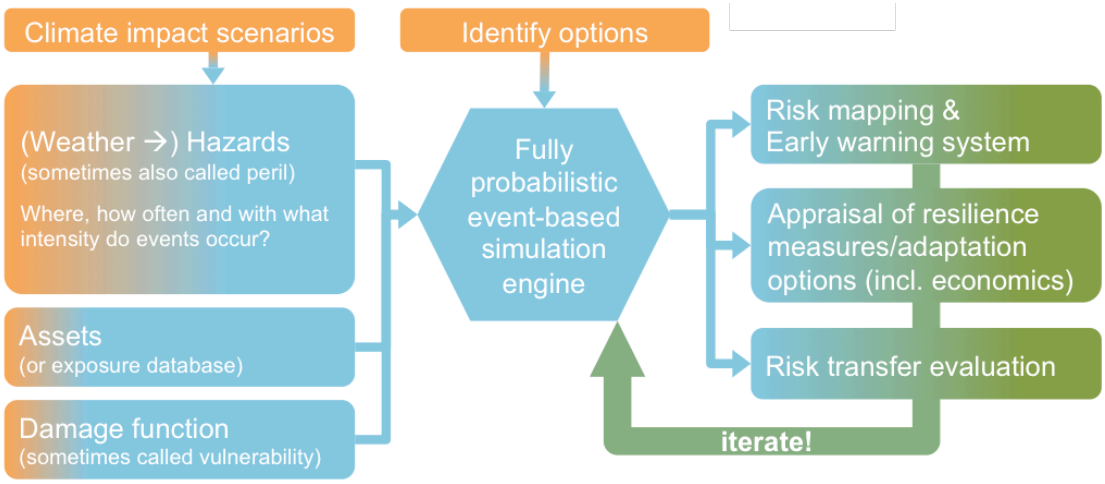


Fig: The climada model, including inputs such as different climate scenarios (which change the hazard component, which itself can be understood as being built on weather events) as well as adaptation options, plus additional outputs such as appraisal of resilience measures or adaptation options. Note the emphasis on iterative approach in options appraisal (see main text, too).

The specific potential damage aversion comes with a certain degree of uncertainty, even for measures for which extensive research exists – for example, for building codes to fix roofs against hurricane winds. Hence we strongly propose an *iterative* approach, i.e. to re-run climada with a range of parameters in order to converge to a consistent evaluation.

The assembled cost curve shows – from left to right – the range of measures from most cost-efficient to least cost-efficient. The results should thus be used to start discussions on the different measures and the opportunity to avert expected damage, rather than be read as recommendations to implement certain measures.

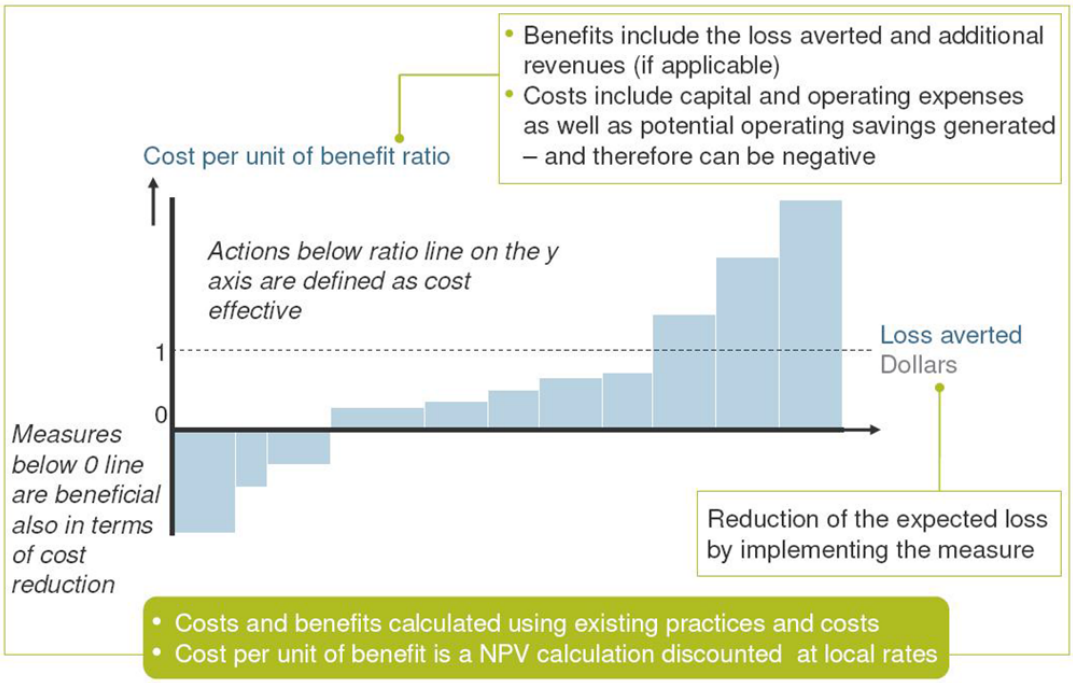


Figure: The width of each bar in a cost curve represents the cumulative potential of that measure to reduce total expected damage up to 2030 for a given scenario. The height of each bar represents the ratio between costs and benefits for that measure. Whether or not this ratio is attractive to a decision maker depends on many factors, including risk appetite. After considering the other – including non-economic – impacts and benefits related to implementing a measure, a risk-neutral decision maker would select measures based on a sense of how much protection they offer and at what cost. The advantage of calculating cost-benefit ratios for all measures is that doing so allows decision-makers to compare measures using a single simple metric.

In a recipe form, the adaptation cost curve is constructed as follows (repeat for each measure)

1. Calculate present value (PV) of costs of measure [e.g. Excel, outside of climada]
2. Risk today: import today's assets and damage functions (input via Excel) and expose them to present hazard (part of climada)
   2.1. climada calculates annual expected damage with no measures
   2.2. climada calculates annual expected damage with measure applied
   → difference 2.1) minus 2.2) shows benefit of measure today
3. Future risk (e.g. year 2030): import future assets and damage functions (input via Excel, damage functions likely to be unchanged) and expose them to future hazard (part of climada)
   3.1. climada calculates annual expected damage with no measures
   3.2. climada calculates annual expected damage with measure applied
   → difference 3.1) minus 3.2) shows future benefit of measure
4. climada discounts benefits --> horizontal axis of adaptation cost curve
5. climada calculates the cost benefit ratio → vertical axis of adaptation cost curve

A note on decision-making

While the climada tool does provide decision-makers with that a fact base, it does by no means pre-empt any decision or constitute an adaptation strategy by itself. The adaptation cost curve shall by no means be interpreted as a 'recipe' to be implemented 'from left to right'. Many more elements need to be considered in order to take a decision, not least to contextualize model results.

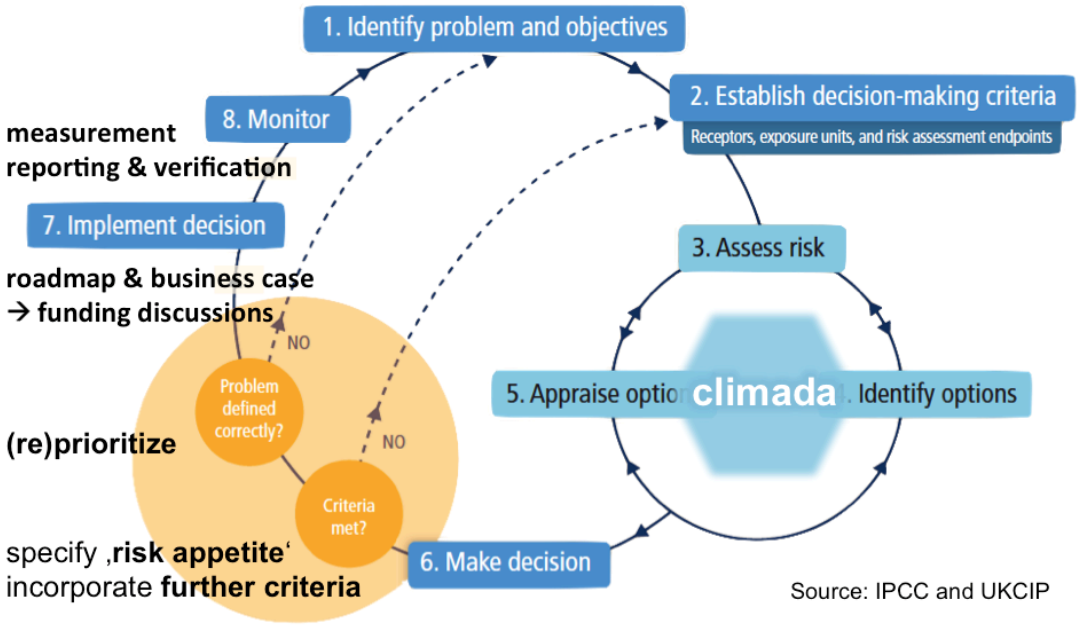


Fig: The decision-making context around climada. Note the necessary steps that precede any application of climada – and even more so the steps that build on the modeling results.

Please refer to the descriptions of Economics of Climate Adaptation (ECA) methodology[10], which emphasizes mentioned context and provides a structured approach to provide decision makers with a comprehensive fact base.

Please note that a comprehensive Economics of Climate Adaptation (ECA) guidebook for practitioners[11] has recently been published. It describes the project setup, the full planning cycle for an adaptation study and puts a lot of emphasis on the stakeholder engagement. The ECA Guidebook is designed to accompany any climate change adaptation assessment using the open-source ECA methodology and its associated climada tool. The ECA Guidebook is particularly helpful in cases which require an integrated approach towards the development, planning and financing of specific adaptation measures.

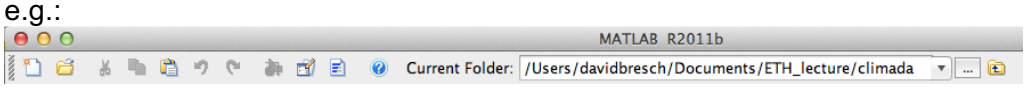
[10] http://media.swissre.com/documents/rethinking_shaping_climate_resilent_development_en.pdf
[11] https://www.kfw-entwicklungsbank.de/PDF/Download-Center/Materialien/2016_No6_Guidebook_Economics-of-Climate-Adaptation_EN.pdf

Getting started

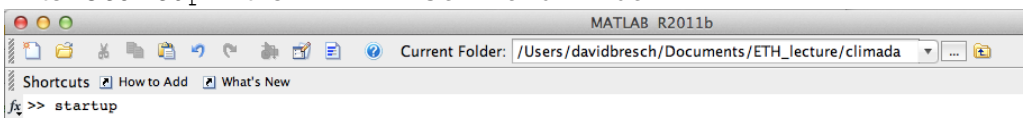
Local installation

Get the climada core module from GitHub[12], i.e. go to https://github.com/davidnbresch/climada and either just click on the Download ZIP button or on Clone in Desktop.

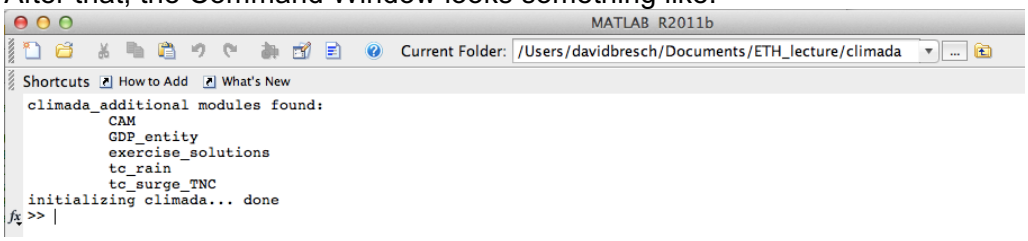
- Set the MATLAB[13] Current Folder to climada[14] (use the ... button to browse), e.g.:



- Enter `startup` in the MATLAB Command Window:



and press Enter (or Return). This initializes climada, sets some variables (e.g. the location of the data folder[15]) and detects any additional modules[16].
After that, the Command Window looks something like:



It's ok if there are no further modules shown, as long as `... done` appears.

- Start by just invoking the climada demonstration by entering `climada_demo` in the MATLAB Command Window[17], which is also the best way to test whether climada works properly – you should see something as shown above as a visual primer (see above) and be able to play with the sliders.
  In Octave, use `climada_demo_step_by_step`, instead, as Octave does not support guide (the interactive climada GUI has been built with).
  In case you run climada on a remote machine (e.g. a cluster, if no window system), test it by entering the following three commands:

```
entity=climada_entity_load('USA_UnitedStates_Florida_entity');
hazard=climada_hazard_load('USA_UnitedStates_Florida_atl_TC');
EDS=climada_EDS_calc(entity,hazard)
```

  EDS then contains the event damage set and the variable `EDS.ED` should contain a value close to 2.3824e+09 (i.e. simulated annual expected tropical cyclone damage to Florida amounts to USD 2.4 billion).

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[12] About GitHub, recommended reading (especially chapters 1, 2 and 3): http://git-scm.com/book/en/v2 and directly to the pdf: https://progit2.s3.amazonaws.com/en/2015-02-21-5277c/progit-en.346.pdf
[13] Same procedure in Octave, see also „Notes on Octave" below.
[14] Usually the folder you downloaded or cloned to from GitHub.
[15] The global variable `climada_global` (a struct) contains all these variables. See the code climada_init_vars.m which sets all these variables. Make sure you never issue a `clear all` command, as this would also delete `climada_global` and hence climada would not find it's stuff anymore.
[16] A climada_advanced module extends the functionality of climada and allows users to further develop climada without risking to change the core code. See further below for some examples of modules. Just run **`climada_git_clone`** to obtain and install most modules fully automatically.
[17] From now on, just type any command in `Courier` in the MATAB Command Window, as we will not state this each time again.

- Note that the command `climada` allows you to run the essentials in one go, i.e. to import assets and hazard event sets, to show a few plots for checks, to run all calculations and to produce the final adaptation cost curve[18].
- Further note that `climada('TEST_CLIMADA')` tests the full climada (very similar to `climada_demo_step_by_step`), that `climada('DEMO')` invokes the demo GUI (same as `climada_demo`) and
- `climada('TC')` invokes the interactive GUI to calculate the ensemble-prediction damage for a specific tropical cyclone (automatically accesses the web to find latest tracks etc.).

While the standard climada setup contains the data folder within climada, it is highly recommended to create a folder named climada_data parallel to climada to allow for your local climada data NOT being synched (only the folder ../climada/data within core climada gets synched). Just run `climada_git_clone`, which installs most modules and sets up such a local climada_data folder. This way, any data used in climada beyond the default files will not be synchronised. Your directory tree shall then look like

```
{parent_dir}/climada          % contains core climada, usually no edits in there
{parent_dir}/climada_data     % contains your data
```

Make sure at the start, the folder {parent_dir}/climada_data (your local data folder) does at least contain the contents of {parent_dir}/climada/data (the sub-folder within core climada). If you run `climada_git_clone`, this has been taken care of.

In case you do not want to (or cannot, on some systems) run `climada_git_clone`, install modules yourself (skip this, if you are new to climada and come back to thism later). In order to grant core climada access to additional modules (see https://github.com/davidnbresch?tab=repositories and the section on climada modules further below), create a folder 'climada_modules' on the same level as the core climada folder to store any additional modules. This way, climada sources all modules' code upon startup. Your directory tree shall then look like

```
{parent_dir}/climada          % contains core climada, usually no edits in there
{parent_dir}/climada_data     % contains your data
{parent_dir}/climada_modules  % contains additional modules
```

Again, see the code `climada_git_clone` to automatically clone all modules and `climada_git_pull` to automatically update all installed modules[19].

[18] On subsequent calls, the routine suggest last inputs - and if the first file selection is the same as on previous call, even asks to re-run with previous call's inputs without asking for each file's confirmation. It further checks for the entity file to have been edited since last call. If not, it does not ask for plotting assets and damagefunctions again.

[19] Proper working of these two routines depend on your operating environment (it issues system commands to your system's git). On latest MATLAB version, it looks as if one could use its own git (not implemented) and for Octave, it depends again on how it is set up (access to system commands).

Process on one page

To cut the whole story short, climada (inter alia) produces an adaptation cost curve, as shown in the lower right part of the visual primer (and many more nice things). The following steps are required in order to come up with a climate adaptation cost curve

1. Generate a hazard event set[20]
    a. Generate a hazard event set for today's climate
        i. Obtain historical events
        ii. Produce the probabilistic events
        iii. Store intensities at centroids
    b. Repeat above steps for future hazard
    (climate change impact scenarios, e.g. for 2030)

2. Import a list of assets and corresponding damage functions[21]
    (the so-called entity)
    a. Read the list of today's assets
        i. Encode to centroids (to the nearest point where hazard information is available, up to a distance threshold[22])
        ii. Read the damage functions and make sure they correspond to assets
    b. Repeat above steps for future assets (e.g. 2030)

3. Import the list of adaptation measures
    (also stored into the entity structure)
    a. Read the list of measures

4. Calculate the damages and benefits of measures
    a. Calculate the damages[23] for the list of today's assets, today's hazard event set and the list of measures[24]
    b. Repeat the previous step for future assets but still today's hazard and the list of measures
    c. Finally, repeat the first step (a.) again now for future assets, the climate change scenarios and the list of measures. Note that for this step, you need to create the hazard event set for the climate change scenarios (e.g. 2030)

5. Display the results – e.g. in the form of an adaptation cost curve.

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[20] Provided for basic tropical cyclones by core climada and climada module for other (and refined) hazards (see further below).

[21] Sometimes also referred to as ‚vulnerability curves' of just ‚vulnerabilities'. See lecture material for proper definitions.

[22] For the threshold, see the parameter `climada_global.max_encoding_distance_m` in `climada_init_vars`, the encoding distance in meters. One theoretically could interpolate between points where the hazard intensity is defined (in fact, technically trivial), but in order for the code to be general, the user shall in such a case provide a higher resolution hazard set, as the interpolation depends on the kind of hazard – and the performance would drop substantially if the interpolation is repeated each time a damage is calculated. Note that for the full use of climada (adaptation options appraisal), the full damage calculations are easily run hundreds of times. Hence it is much faster to provide the hazard at the appropriate resolution. climada does not make any assumption beyond what is provided. As we otherwise would lure the user into providing suboptimal inputs and 'hope' for climada to fix it ;-)

[23] In essence, we calculate $damage_{j,k}=value_k * f(intensity_{j,k})$, where $value_k$ ist he value of asset k and $intensity_{j,k}$ the hazard intensity of event j at location of asset k. f denotes the damage function, i.e. the relation between the hazard intensity and the resulting damage (as a fraction of the asset value). See "climada, the inner workings" further below for some more details on the damage calculation

[24] climada quantifies the damage reduction benefit of each measure by comparing the damage with the measure in place tot he (default) run with no measures in place. This is obviously done on the full event damage set (EDS), i.e. event by event.

Excel interface to climada

The hazard module is usually provided by climada developers or advanced users (it will be described in the next section “From tropical cyclone hazard generation to the adaptation cost curve”, see also the description of the climada modules further below). It forms an integral part of climada and can be developed for almost any hazard (wind, flood, surge, landslides...).

The assets, the damage functions as well as the list (and costs) of adaptation measures are defined in an Excel file which is imported into climada (for advanced users, it is possible to import this information from any source and to modify free within MATLAB, of course). This Excel file is referred to as ‘entity’. climada provides several outputs, among them the adaptation cost curve (as a graphic in almost any format). Obviously, any number calculated by climada can be exported, too.

To start with, the key interface to climada is an Excel file[25], with three main tabs, named ‘assets’, ‘damagefunctions’ and ‘measures’. To familiarize, one might briefly read this section, then inspect the template (../data/entities/entity_template.xlsx), and (if familiar with MATLAB, otherwise proceed first to “From tropical cyclone hazard generation to the adaptation cost curve”), run
`entity=climada_entity_read('entity_template','TCNA_today_small');`
and inspect the content of entity in MATLAB (each field is briefly described in the header section of `climada_entity_read`, too).

But first now for the contents of the entity:

The tab '**assets**' lists all exposed assets by location (*Latitude*/*Longitude*) and *Value*. Please note that values do not necessarily need to be monetary values. E.g. in case the number of exposed people is stated in the *Value* column, climada does calculate the number of affected people (you will obviously use a damagefunction which relates to people in this case). You can specify the unit of the Values in an additional column labelled *Value_unit*, where you specify the unit for each Value entry, such as ‘USD’ or ‘people’ (best to start with only one value unit per Excel file, mixed use for advanced users only). The column *DamageFunID* relates each asset to its corresponding damage function (which is provided in tab damagefunctions).

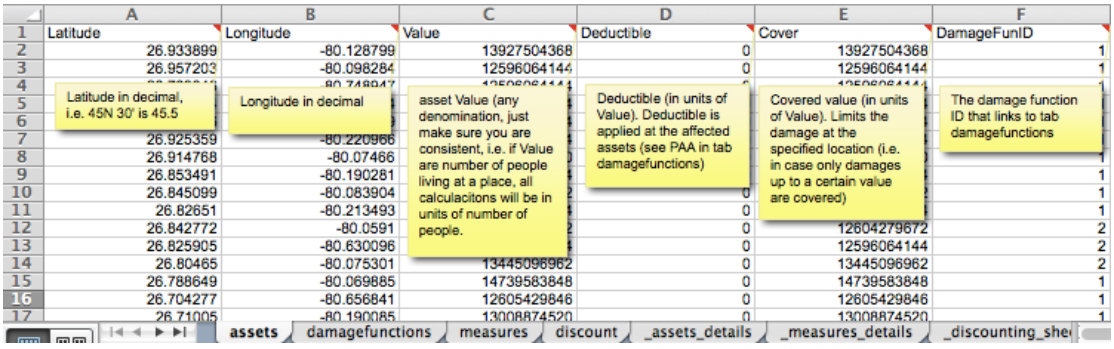


Figure: the assets tab, see ../data/entities/entity_template.xls and display the comment for each field of the header rows (only key columns showed here). **Mandatory are only Latitude, Longitude, Value and DamageFunID** (if not provided, Deductible is set to zero and Cover is set to Value).

[25] Since the content of the Excel file is imported (using `climada_entity_read`) into MATLAB, any other source can be used to define the content of the `entity` structure of climada, too. In order to understand the `entity` structure, it’s in fact easiest to import the file ../data/entities/entity_template.xls using `entity=climada_entity_read` and to inspect the resulting `entity` structure.

Note for advanced users: In addition to the columns visible in above figure (the essential ones, so to say), one can add a column labelled *Category_ID* which allows later to select results based on a single or a group of categories (see `climada_viewer`[26]). The column does contain just integer values i.e. 1 for category one which might e.g. be 'Residential House' and 2 for category 'Commercial Building'. Such names can be defined in the tab *names* (see the Excel template). Further, there can be a column *Region_ID*, which allows to group assets into regions (if one runs a large set of assets, for example, same rules as for Category_ID apply).

The tab '**damagefunctions**' contains the relationship between the hazard intensity (e.g. wind speed in m/s or storm surge height in meters) and the percentage of affected assets (*PAA*) as well as the mean damage degree (*MDD*). What's called a damage function in climada is elsewhere often also referred to as 'vulnerability curve'. If for say a storm surge height of 1 meter, 50% of all assets are affected, and the damage to these affected assets is 5% of their total value, the PAA is 0.5 and MDD 0.05. In the case of value signifying exposed population, PAA is used to reflect affected individuals, while MDD could be used to parameterize some sort of impact to the affected individuals (e.g. using disability or quality adjusted life years, DALY/QALY[27]). The *DamageFunID* is used to relate to the corresponding assets and *peril_ID* to indicate for which peril/hazard the function shall apply. Please note that there can be a damage function with *DamageFunID* equal to 1 for more than one peril, say 'TC' and 'EQ'. This way, one can run the same assets for more than one hazard.

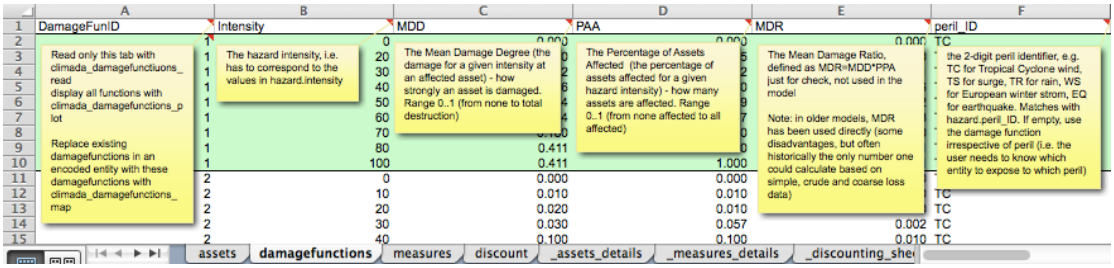


Figure: the damagefunctions tab, see ../data/entities/entity_template.xls. **Mandatory fields are DamageFunID, Intensity, MDD, PAA and peril_ID**. MDR (=MDD*PAA) is ignored, just in the Excel sheet for information.

Additional (optional) columns in the damagefunctions tab are *Intensity_unit* to specify the unit of the intensity (for each entry, such as 'm/s') and *name*, a free name, eg. 'TC default'.

The tab '**measures**' contains the list of climate adaptation measures[28]. It contains the costs of the measures, i.e. the net present value of CAPEX and OPEX for each measure. It also contains the parameterized impact of the measures on the hazard and damage function. Imagine a coastal study region and say a mangrove forest. Outside of climada, is has been calculated that the net present cost of this measure amounts to 1'234'567 USD. Let's assume this mangrove forest slows down the wind of a tropical cyclone by a certain amount, say 5 percent reduction in wind speed. Both the cost as well as this 'parameterized' impact is hence entered in the 'measures' tab for this particular measure, cost goes into the *cost* column (obviously) and the 5% windspeed reduction by putting 0.95 into the column hazard_intensity_impact_a, since the resulting hazard intensity equals the original hazard intensity times *hazard_intensity_impact_a* (plus *hazard_intensity_impact_b*,

[26] But first make yourself familiar with climada as described on the following pages, as this result viewer is rather for advanced use.
[27] See http://www.iac.ethz.ch/edu/courses/master/modules/climate-risk.html (about lecture 9) for a discussion of measures such as DALY and QALY.
[28] note that for pure damage calculations (`climada_EDS_calc`), this information is not needed, i.e. one can provide an entity Excel file with just the tabs assets and damagefunctions.

set to zero by default, or simply i=i_{orig}*a+b). Note that climada can handle parameterized impacts of higher complexity, too (please refer to the comments for each column in the Excel template).

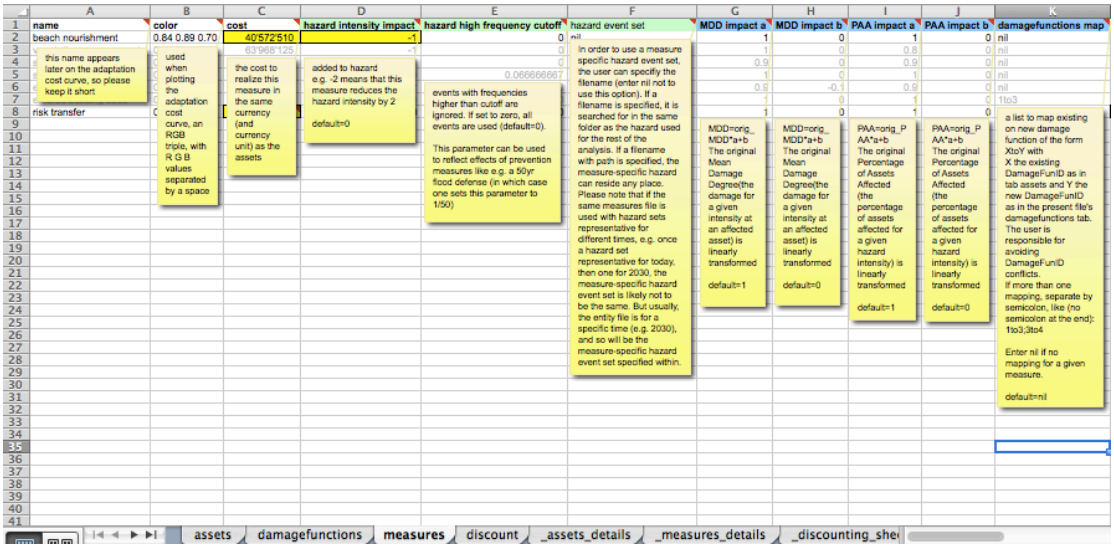


Figure: the measures tab, see ../data/entities/entity_template.xls. **Mandatory fields are name, cost and MDD_Impact_a and MDD_impact_b**.

The (optional) tab '**names'** contains[29] some speaking names for fields in other tabs that are IDs, such as *Category_ID* and *Region_ID*. It just provides a name to be shown e.g.in GUIs. There is a special use to communicate the reference year also via this tab: If there is an entry *reference_year* in the Item column, a 0 in the ID column and the reference year as a string in the name column, this value is stored into the `entity.assets.reference_year` (otherwise, the default reference year is used, see `climada_init_vars`). For ADVANCED users, the ***names*** tab also allows to define global variables, such as the encoding distance, the default currency or even folders such as `hazards_dir` etc., which are originally defined in `climada_init_vars` (see section "Writing your own code" further below) but can easily be redefined this way[30].

Please note again that each column header in the Excel contains a detailed explanation as a comment. The reference Excel sheet, called entity_template.xls can be found in the entities sub-folder of the climada data folder[31].

Note: If you use climada as an end-user (i.e. not developing anything, just to 'process' your Excel input and produce the waterfall and adaptation cost curve), the simple call `climada` prompts the user to select the entity Excel file for today and in the future as well as the hazard set for today and future, then runs all calculations and shows the final adaptation cost curve. On subsequent calls, the routine suggests last inputs - and if the first file selection is the same as on previous call, even asks to re-run with previous call's inputs without asking for confirmation. This way, one can edit the entity Excel file and then just call `climada` again.

A note on coordinates: climada works best with standard geographical coordinates[32] (longitude -180..180, latitude -90..90). Please see `climada_dateline_resolve` to

[29] See ../data/entities/entity_template.xlsx (there exists a .xls version for backward compatibility)
[30] See See ../data/entities/entity_template_ADVANCED.xlsx, but please be aware of the impacts (as one can re-define reference years etc. this way).
[31] ../data/entities/entity_template.xls

resolve issues around the dateline (e.g. Fiji, where it is advisable to center the coordinate system either somewhat left or right of the dateline in order to avoid troubles with distance calculations).

A note on Excel and Open Office file formats and their tolerance in MATLAB and Octave

Instead of .xls or .xlsx (use .xls 95 or 97 with MATLAB before R2015, and .xlsx with latest MATLAB and Octave), climada also supports .ods (Open Office). If using .ods, please avoid any cell comments, also see "Notes on Octave" further below. Please do not use field format 'Percentage' in Open Office, but just 'General' or 'Number', such that e.g. the *discount_rate* on tab *discount* is 0.02, not plain '2%' in the .ods file (2% works fine in .xls and .xlsx files).

Please note further that starting Octave might be easiest in a shell (terminal window), with path, e.g. /Applications/Octave.app/Contents/Resources/usr/bin/octave

Constructing your own entity

A user might want to construct an entity from scratch, i.e. not import assets, damagefunctions (and measures) from an Excel (or OpenOffice) file, but from any other source (or define all in a MATLAB code file). In this case, it is advisable to first familiarize with the Excel template (see above) to know the mandatory and optional fields.

There are two options, once can either start from the entity template[33], or really from scratch:

- If one starts from the template, replace fields with your content, please make sure all fields have the same final length (i.e. if you define 150 assets, i.e. enter them in `entity.assets.lon`, `entity.assets.lat`, `entity.assets.Value`, make sure all other fields in `entity.assets` are of dimension 1x150).
- If one starts from scratch, populate the mandatory fields, see the comments in the Excel template and the header section of `climada_entity_read`. Make sure all fields in assets, damagefunction etc. have the same (corresponding) length.

Once you defined your entity, please

- run `climada_assets_complete`, `climada_damagefunctions_complete` and (if you define measures) `climada_measures_complete` to check entity components for completeness.
- run `entity.assets=climada_assets_encode(entity.assets)` in order to encode to a hazard.
- consider to run `measures=climada_measures_encode(measures)` in order encode measures (i.e. convert some fields to machine-readable format (i.e. if you populated `entity.measures.damagefunctions_map`, this fills in `entity.measures.damagefunctions_mapping`[34]).

[32] but one could use it on any other topology, as encoding does merely find nearest neighbours etc.
[33] See ../data/entities/entity_template.xlsx (there exists a .xls version for backward compatibility)
[34] This is the field used in climada_measures_impact (not `entity.measures.damagefunctions_map`)

Finally, test your entity by calling `climada_EDS_calc` and, if you defined measures, also `climada_measures_impact` and carefully observe any warnings/errors[35].

[35] If you get really stuck, consider contacting the climada developers…

From tropical cyclone hazard generation to the adaptation cost curve[36]

In this section, we are going to illustrate the whole process step-by-step, using tropical cyclone as the hazard and a few assets in South Florida for illustration purposes. Note already here that climada provides global coverage for tropical cyclone wind (often referred to as TC wind[37]) and storm surge (often referred to as TC surge[38]) as well as other hazards, such as global earthquake[39] – see "climada modules" section further below. For a comprehensive list of climada functions, please refer to ../docs/code_overview.html

Instead of starting with a simple hazard set generation, the user might also jump to the damage calculation right away, skip section "Hazard set" below and jump to the second next section "Assets and damage functions". Please note that due to slower processing speed of some explicit loops in Octave, the demo differs somewhat from the MATLAB version as documented below (also with respect to certain graphics features).

Hazard set

First, obtain the historic tracks[40], i.e. define the name and location of the raw text file with historical tropical cyclone tracks[41]

```
global climada_global  % to get access to climada_global[42]
tc_track_file=[climada_global.data_dir filesep ...
      'tc_tracks' filesep 'tracks.atl.txt'];
tc_track=climada_tc_read_unisys_database(tc_track_file,2);
% same as[43]
tc_track=climada_tc_read_unisys_database('tracks.atl.txt',2);
```

Why 2 as last input? See `help climada_tc_read_unisys_database` and check the description of the 2nd input parameter (it forces re-reading the database each time).

Let's have a look at the output:
`tc_track(i)` contains position `tc_track(i).lon(j)` and `tc_track(i).lat(j)` for each timestep j as well as the corresponding intensity `tc_track(i).MaxSustainedWind`. E.g. track number 1170 is hurricane Andrew:

[36] See the climada code `climada_demo_step_by_step` which performs all the steps and illustrates the intermediate results by plots, just as shown here. Run `climada_demo_step_by_step` in debug mode to follow (and understand ;-) each step.
[37] Part of climada core module (i.e. the module this manual is part of)
[38] Obtain it from https://github.com/davidnbresch/climada_module_tropical_cyclone and see the manual(s) there.
[39] See https://github.com/davidnbresch/climada_module_earthquake_volcano
[40] See the function `climada_tc_get_unisys_databases` to automatically download all databases from the internet (from weather.unisys.com/hurricane).
[41] Note that the filename is defined using `climada_global.data_dir` in ordert to be machine and file-system independent.
[42] No need to look into this now, the structure `climada_global` just provides some machine and file-system independent parameters. Later on, the advanced user might study the section about `climada_init_vars` and `climada_global` further below.
[43] Since most climada functions assume the default data (sub) folder if only the name (without path) is passed.

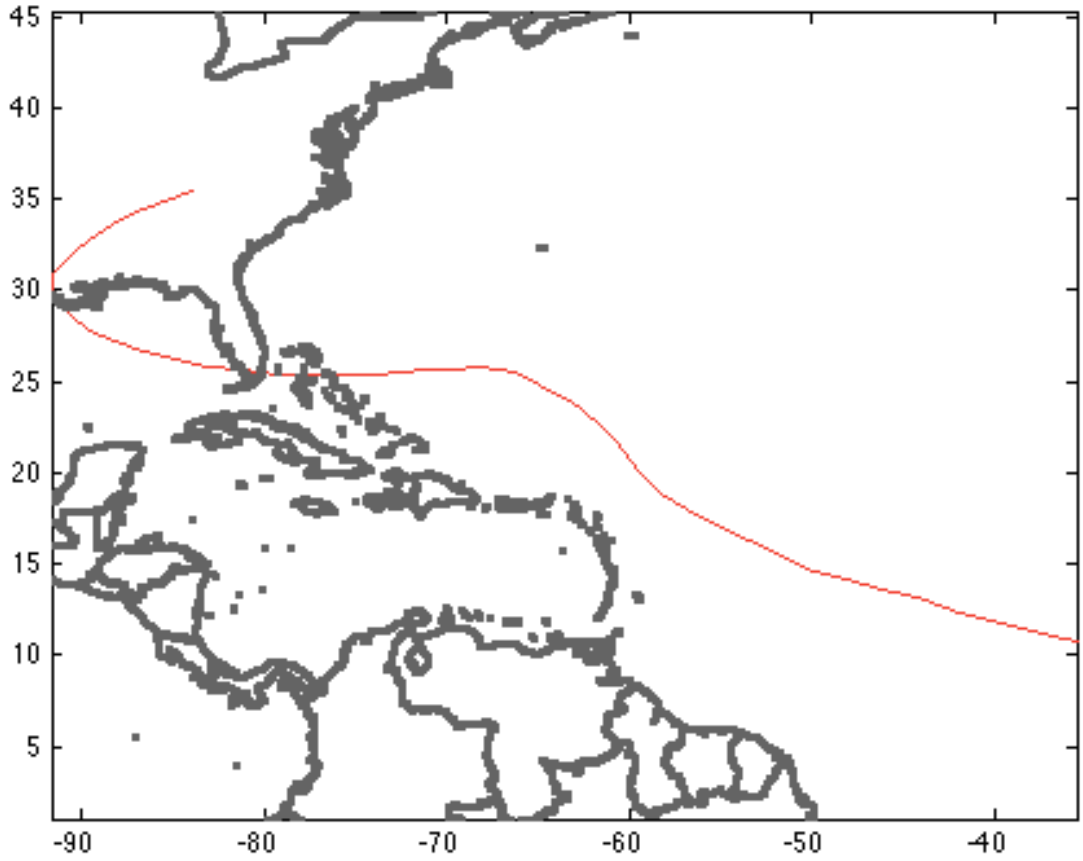


Figure: `plot(tc_track(1170).lon,tc_track(1170).lat,'-r'); hold on;`
`set(gcf,'Color',[1 1 1]); axis equal`
`climada_plot_world_borders(2,'','',1) % plot world borders (for orientation)`

In order to calculate the windfield of this particular single track, we first generate a series of points on which to evaluate the windfield, we call these points centroids[44]:

```
centroids.lon=[];centroids.lat=[]; % init
next_centroid=1; % ugly code, but explicit for demonstration
for i=1:10
    for j=1:10
        centroids.lon(next_centroid)=i+(-85);
        centroids.lat(next_centroid)=j+  20;
        next_centroid=next_centroid+1;
    end % j
end % i
centroids.centroid_ID=1:length(centroids.lat);
```

Next, calculate the windfield[45] for a single track (Andrew again) as

```
gust = climada_tc_windfield(climada_tc_equal_timestep(tc_track(1170)),centroids);
```

[44] Centroids are stored in a special folder ../data/centroids, see e.g. `climada_centroids_read`. Please note that most routines requiring centroids are tolerant in the sense to also accept an entity instead (where the assets with their coordinates are). See further below, just keep this in mind.

[45] We implement a windfield according to Holland, G. J., 1980: An analytic model of the wind and pressure profiles in hurricanes. Monthly Weather Review, 108, 1212-1218. In addition to the axisymmetric vortex, we take forward speed into account. See also Holland, G. J., 2008: A Revised Hurricane Pressure–Wind Model, Monthly Weather Review, 136, 3432-3445. A natural next step would be the consideration of roughness (not implemented), see e.g. Vickery, P.J. et al., 2009: A Hurricane Boundary Layer and Wind Field Model for Use in Engineering Applications. J. Appl. Meteor. Clim.

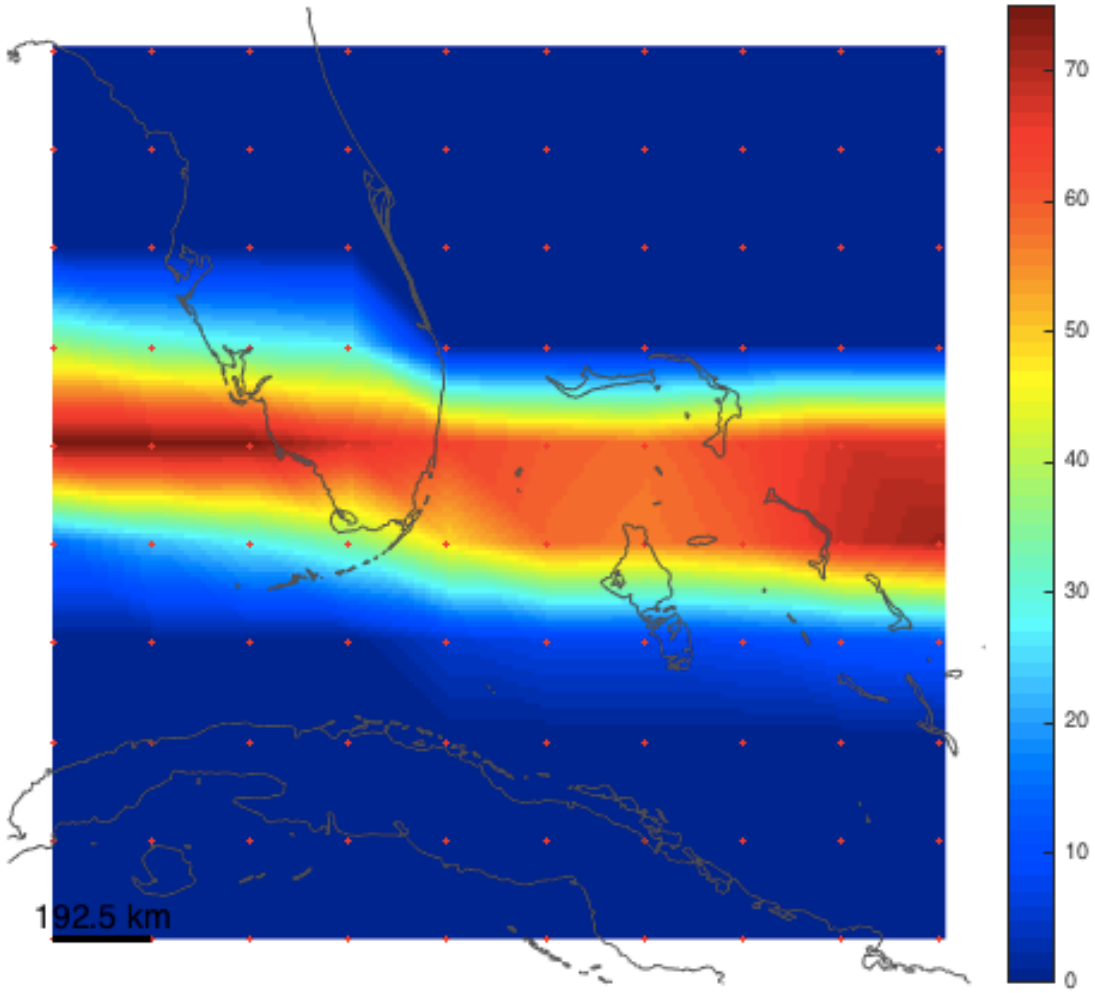


Figure: Gust wind field (in m/s) of Andrew, 1992: `climada_color_plot(gust,centroids.lon,centroids.lat)` Note that without `climada_tc_equal_timestep` in the call `climada_tc_windfield` above, we would not get a continuous footprint due the fast forward speed of Andrew (try this by omitting `climada_tc_equal_timestep` in the calculation of `gust`.

We now generate the wind field not for one single hurricane, but for all events and store them in an organized way, the so-called hazard event set:

```
hazard = climada_tc_hazard_set(tc_track,'atl_hist',centroids);
```

This hazard event set now contains the single Andrew wind field we generated before in `hazard.intensity(1170,:)` and therefore we can reproduce the same wind field with the following command (note the full(*), as we store a sparse matrix)

```
climada_color_plot(full(hazard.intensity(1170,:)),...
      hazard.lon,hazard.lat,'none')
```

Or, instead, we can plot all hazard intensities at a given point (green circle) like

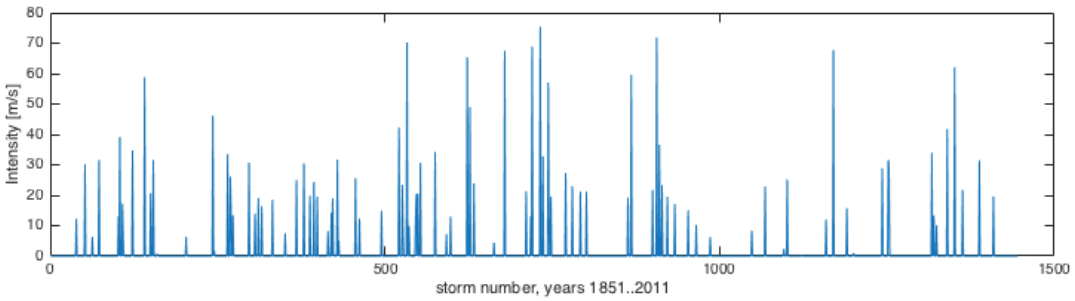


Figure:
```
figure; subplot(2,1,1) % only lower part shown here
climada_color_plot(full(hazard.intensity(1170,:)),...
hazard.lon,hazard.lat,'none'); hold on; plot(-81,26,'Og');
plot(centroids.lon(36),centroids.lat(36),'Og','MarkerSize',10);
subplot(2,1,2)
plot(full(hazard.intensity(:,36))); set(gcf,'Color',[1 1 1]);
xlabel(sprintf('storm number, years
%i..%i',tc_track(1).yyyy(1),tc_track(end).yyyy(end)))
ylabel('Intensity [m/s]')
```

Instead of only historic tracks, we can generate artificial or probabilistic tracks, simply by 'wiggling' the original tracks, e.g. for Andrew 1992 again:

```
tc_track_prob=climada_tc_random_walk(tc_track(1170));
```

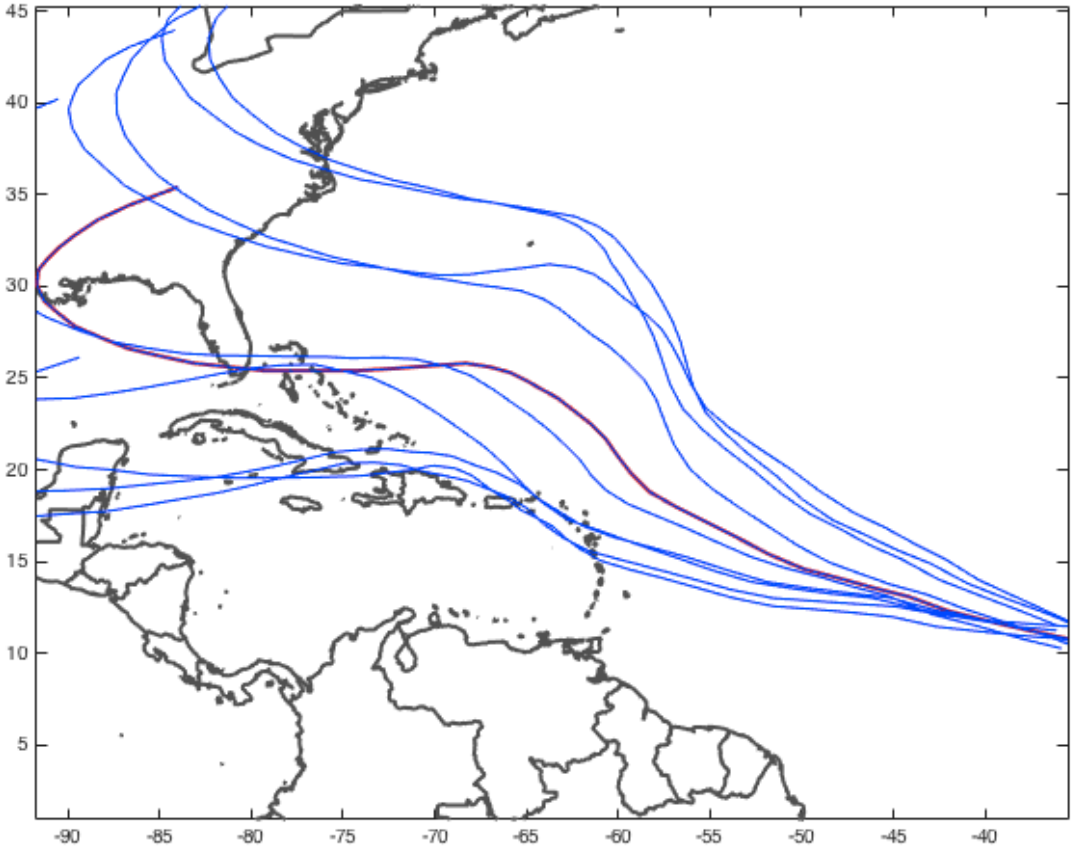


Figure:
```
plot(tc_track(1170).lon,tc_track(1170).lat,'-r','LineWidth',2);
hold on; set(gcf,'Color',[1 1 1]); axis equal
climada_plot_world_borders(2,'','',1)
for track_i=1:length(tc_track_prob)
      plot(tc_track_prob(track_i).lon,tc_track_prob(track_i).lat,'-b');
end
```

And repeated for all historic tracks, we obtain the full probabilistic track set

```
climada_global.waitbar=0; % switch waitbar off, speeds up
% hence the next line will take approx. 3 sec
tc_track_prob=climada_tc_random_walk(tc_track);
```

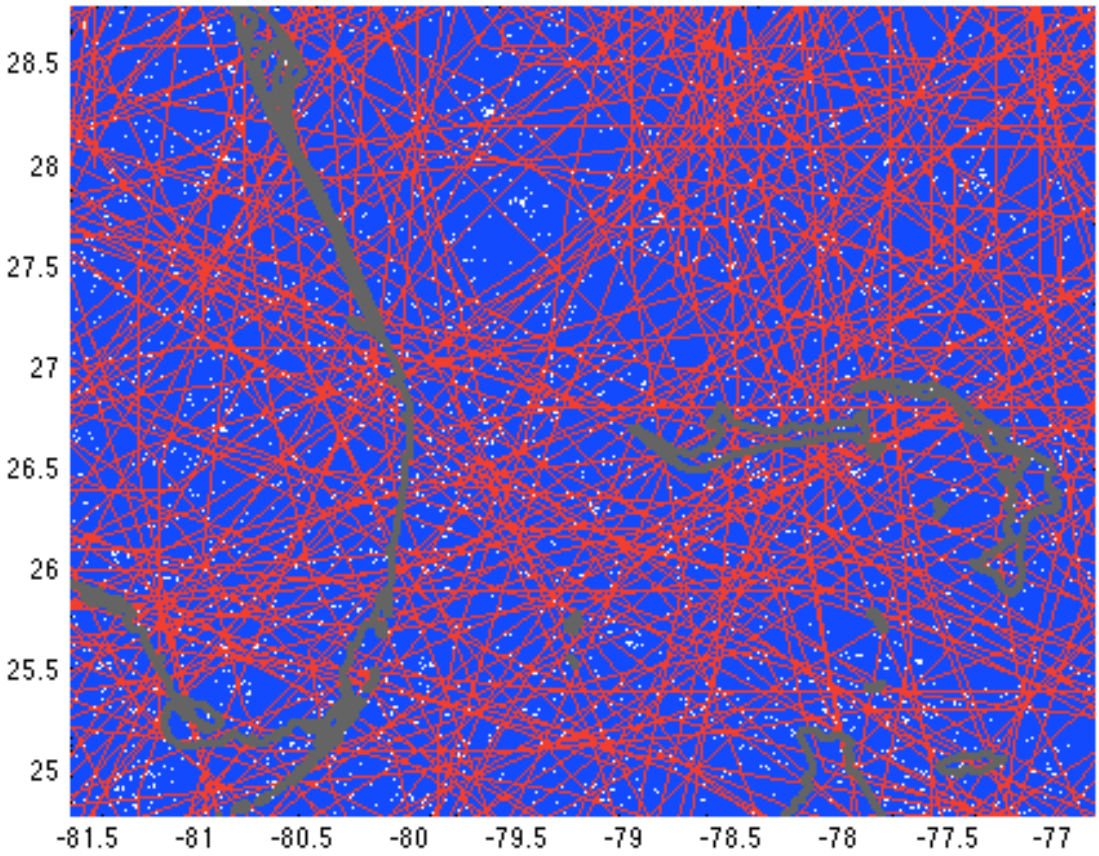


Figure (manually zoomed in, Southern tip of Florida):

```
for track_i=1:length(tc_track_prob)
      plot(tc_track_prob(track_i).lon,tc_track_prob(track_i).lat,'-b');
      hold on;end
for track_i=1:length(tc_track)
      plot(tc_track(track_i).lon,tc_track(track_i).lat,'-r');end
climada_plot_world_borders(2,'','',1); set(gcf,'Color',[1 1 1]);
```

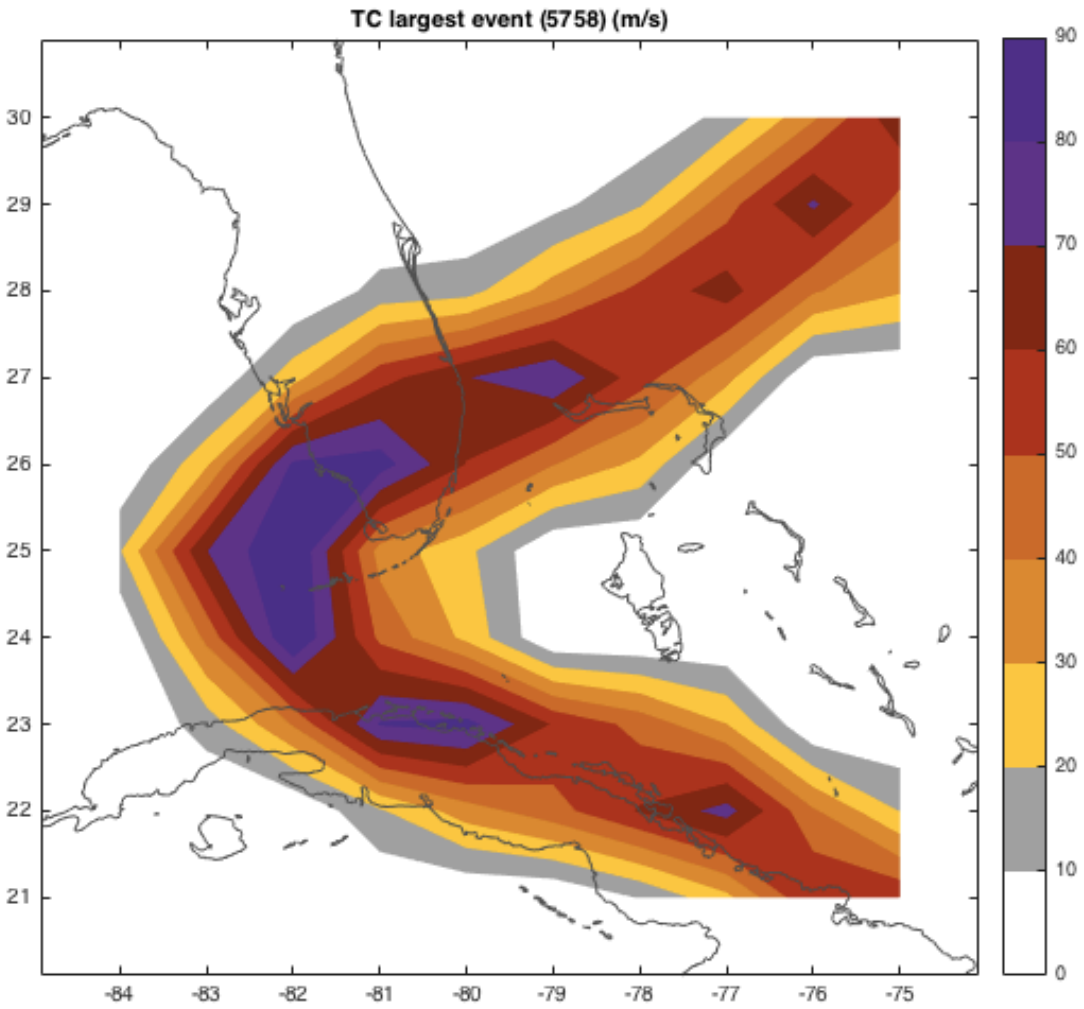
Note: Instead of this explicit code, consider `climada_tc_info` to print track information (name, date....) to stdout and to show (nice) plots of historic (and probabilistic) tracks.

Next, we generate the wind fields for all 14'450 probabilistic tracks (takes a bit less than 2 min on a MacBook Air[46])

```
hazard=climada_tc_hazard_set(tc_track_prob,'atl_prob.mat',centroids);
```

The hazard set now contains more than ten thousand (in fact 14'450) tropical cyclone footprints, each stored at all centroids. We can for example plot the largest single event with:

[46] Consider to set climada_global.parfor=1 before calling `climada_tc_hazard_set` . This invokes parallel processing (parallel pool, using `parfor`).




```
figure; climada_hazard_plot(hazard);
```

and generate the windspeed maps for several return periods:

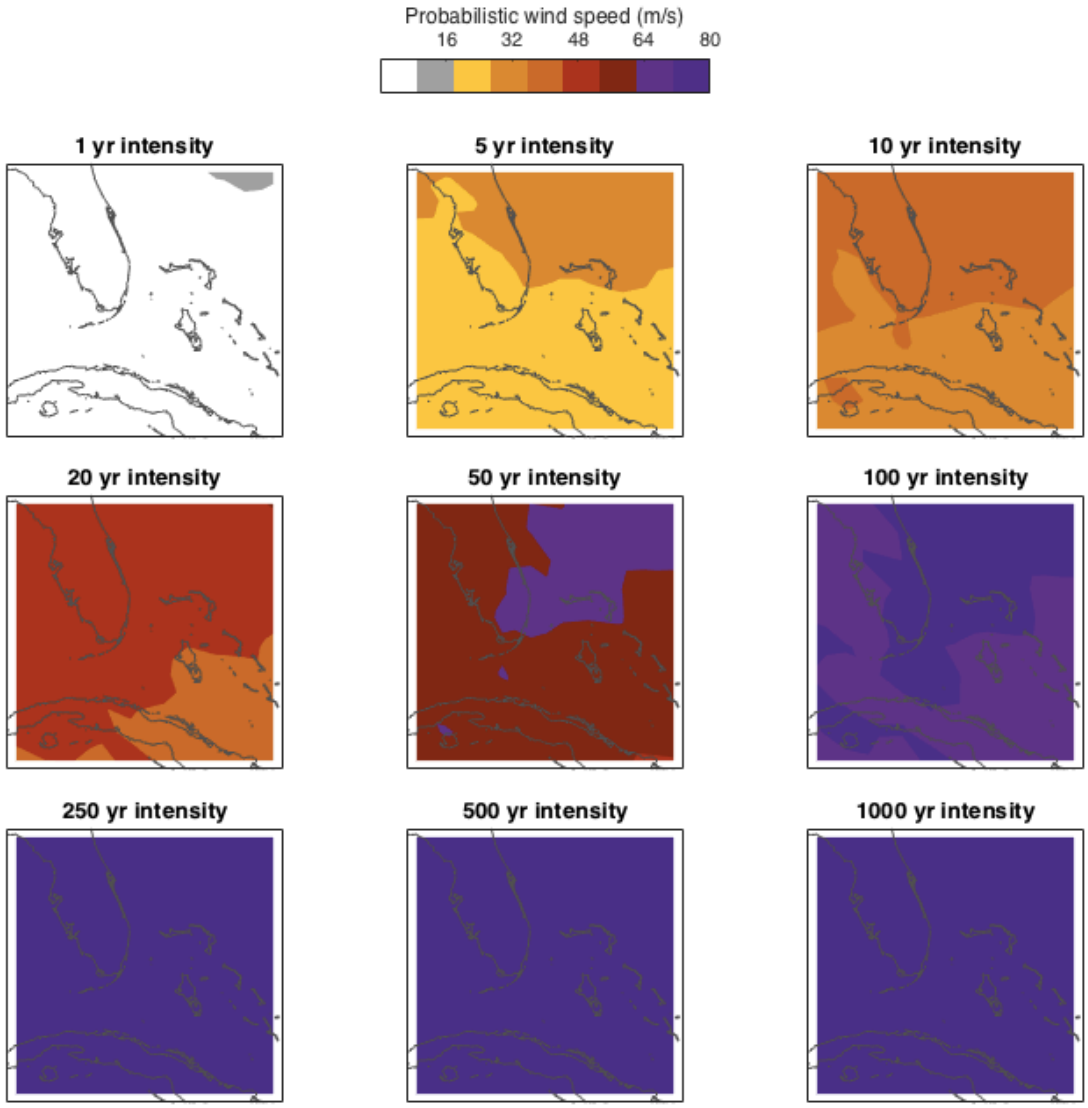


Figure: `climada_hazard_stats(hazard);`

Before we move on, let's explain the key elements of the hazard structure: `hazard.lon(i)` and `hazard.lat(i)` contain the coordinates of centroid i, hence `hazard.intensity(j,i)` contains the hazard intensity of event j at centroid i. Further `hazard.frequency(j)` contains the single event frequency of event j. These are in fact the key elements of the hazard structure; note that `hazard.intensity` is a sparse array (refer to e.g. `help sparse` in MATLAB[47]). You might refer to functions such as the mentioned `climada_tc_hazard_set` or `climada_excel_hazard_set`[48] to see how a hazard event set is generated.

[47] In essence, a sparse array stores the non-zero elements of an array only. Since a single event hits only a few centroids – especially true for a hazard set covering a larger geographical region – we save a lot of memory and speed up the calculations substantially.

[48] This function generates a hazard event set based on Excel input. The Excel sheet needs to contain all the event footprints. An easy method to use climada with a finite (small) number of predefined events (more hazard event scenarios then a full probabilistic set). See file ../data/hazards/ Excel_hazard.xls which contains a small example (for Mozambique).

Assets and damage functions

So much for the hazard event set, let's now import an asset base (the small asset example as used in `climada_demo`, the demonstration GUI as shown above[49]). Before we do so, we load the hazard set file as used in `climada_demo`, in order to later reproduce the results:

```
hazard=climada_hazard_load('TCNA_today_small.mat')
```

and are now in a position to import the Excel file with all the asset information[50]:

```
entity=climada_entity_read('demo_today.xls',hazard) % note[51]
```

Such an entity structure contains the asset, damage function and adaptation measures information, the tabs in Excel are named accordingly, and so are the elements of the imported structure[52]. In the asset sub-structure, we find[53] `entity.assets.lat(k)` and `entity.assets.lon(k)`, the geographical position of asset k (does not need to be the same geographic location as centroid i, since assets are encoded to the hazard[54])
`entity.assets.Value(k)` contains the Value of asset k. Please note that Value can be a value of any kind, not necessarily a monetary one, e.g. it could be number of people living in a given place.
`entity.assets.DamageFunID(k)` contains a reference ID (integer) to link the specific asset with the corresponding damage function (see Excel tab damagefunctions and `entity.damagefunctions`). Before we move on the the damagefunctions, note that `entity.assets.centroid_index(k)` contains the centroid index onto which asset k is mapped in the hazard event set[55].

---

[49] One can also generate assets (value distributions) in climada, see e.g. the climada module https://github.com/davidnbresch/climada_module_GDP_entity or https://github.com/davidnbresch/climada_module_country_risk . Please note that the two column names Latitude and Longitude are shortened to lat and lon in climada's entity.assets structure – not least to ease typing on the command line, e.g. `plot(entity.assets.lon,entity.assets.lat)`

[50] Please have a look at the Excel file, each column header is explained by a small comment (tiny yellow triangel in the upper right corner of the cell). Please consider (later) to use e.g. `climada_entity_country` to generate a basic entity for any country worldwide (at 10 km resolution).

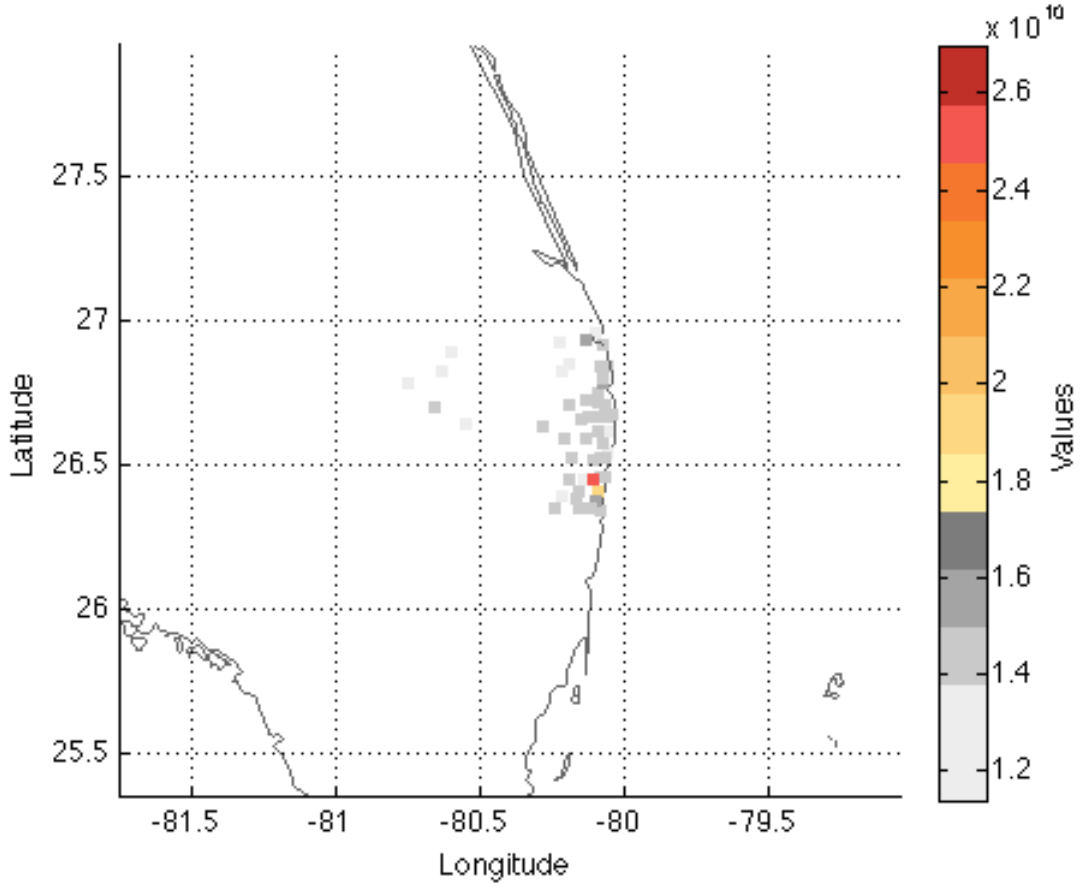
[51] Please note that `climada_entity_read` stores a `.mat` file of the imported entity structure to speed up re-reading. But in case you edit the original (.xls or similar) file, climada re-reads from the latest version (i.e. overwrites the `.mat` file). This check is performed by `climada_check_matfile`, which might be useful to the advanced (programming) user.

[52] Please note that we discuss the measures information further below

[53] We focus on the key content here, please inspect the structure in MATLAB yourself.

[54] See function `climada_assets_encode`. Encoding means: map asset positions to calculation centroids of the hazard event set. This step is required to allow the user to freely specify asset locations, rather than stick to the centroids the hazard set has been stored at. A beginner-level user should not need to deal with such technical details, though. See also the remark about encoding in the section "Process on one page" above.

[55] As mentioned in a previous footnote, the beginner level user does not need worry too much about, this simply speeds up damage calculation substantially. See code `climada_assets_encode_check` to (visually) check the encoding.

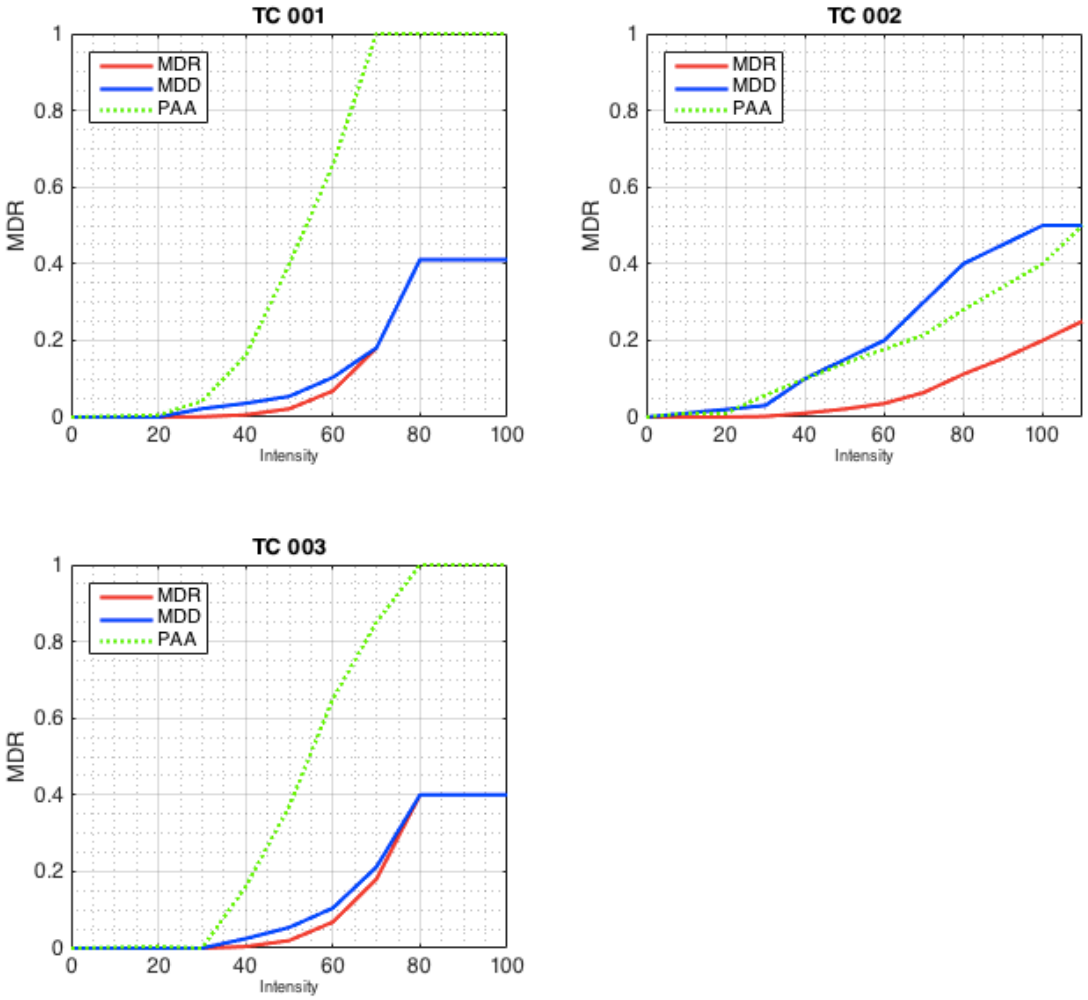


`figure;climada_entity_plot(entity,4);%` The asset distribution as stored in entity (read from Excel sheet)

The damagefunctions sub-structure contains all damage function information, i.e. `entity.damagefunctions.DamageFunID` contains the IDs which refers to the asset's DamageFunID. This way, we can provide different damage functions for different (groups or sets of) assets. `entity.damagefunctions.Intensity` contains the hazard intensity, `entity.damagefunctions.MDD` the mean damage degree and `entity.damagefunctions.PAA` the percentage of affected assets. Last but not least, `entity.damagefunctions.peril_ID` contains the peril ID (2-digit character) which allows to identify specific damage functions with perils. This way, we can in fact use DamageFunID 1 in the assets to link to damage function one, which can exist several times, one for each peril. The damagefunctions are stored in a bit a special format, since we get the first damagefunction as[56]

```
pos=find(entity.damagefunctions.DamageFunID==...
      entity.damagefunctions.DamageFunID(1))
plot(entity.damagefunctions.Intensity(pos),...
      entity.damagefunctions.MDD(pos)) % not shown, see next figure
```

[56] In the case there is only one perilID, see further details in `climada_damagefunctions_plot`



`figure;climada_damagefunctions_plot(entity);%` The three damage functions as defined in the damagefunctions tab of the Excel file. TC is the peril ID and stands for tropical cyclone, while 001, 002 and 003 denote the DamageFunID. The horizontal axis denotes the hazard intensity (here tropical cyclone windspeed, in m/s), the vertical axis is the same for MDD, PAA and MDR.

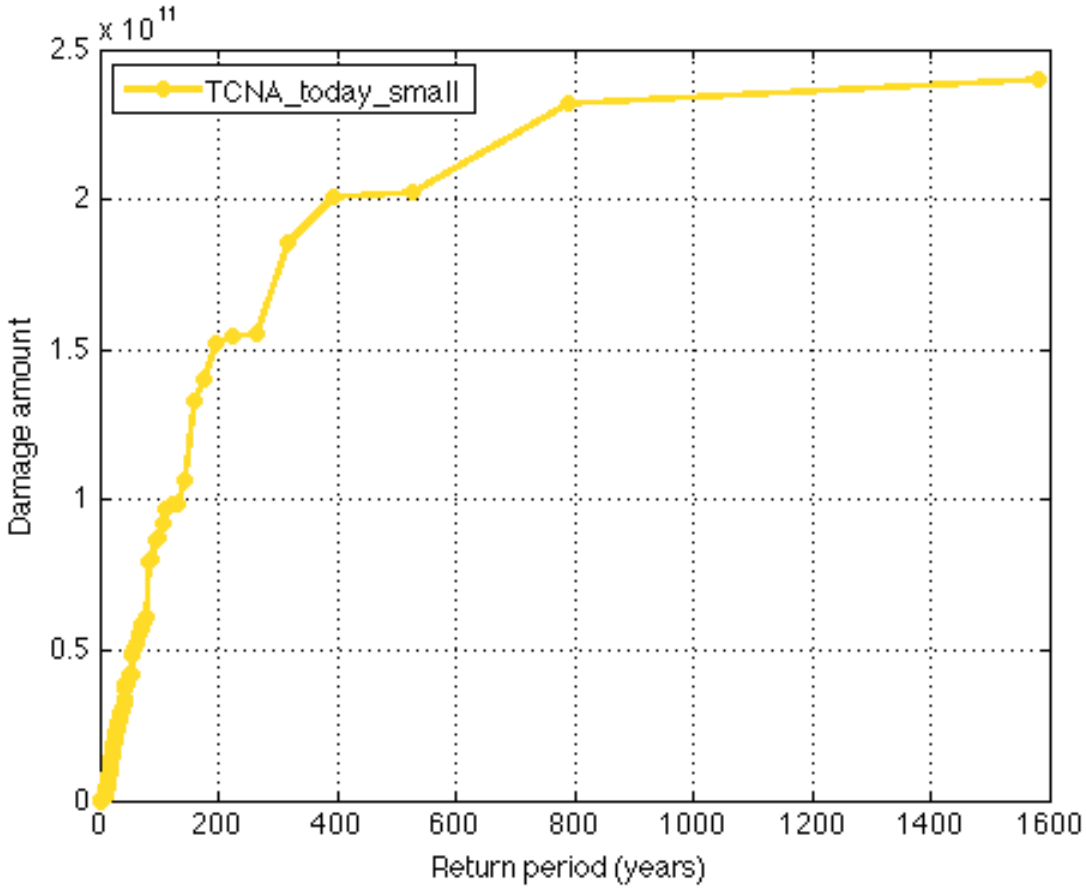
Damage calculation

And with that, we're ready for the damage calculation, simply as:

```
EDS=climada_EDS_calc(entity,hazard)
```

Where `EDS` contains the event damage set, it contains the annual expected damage in `EDS.ED`, the event damage for event j in `EDS.damage(j)`, the event frequency in `EDS.frequency(j)` and the event ID in `EDS.event_ID(j)`. In further fields it stores the link to the original assets, the damagefunctions and hazard set used. Instead of plotting the event damage set (here a vector with 14'450 elements), one rather refers to the damage exceedance frequency curve (DFC)[57]:

[57] The damage (exceedance) frequency curve (DFC) is an annual per-occurrence damage exceedance frequency curve, showing the return period of a certain damage level to be reached or exceeded for a given return period. A DFC is constructed by sorting a per-occurrence damage event set (as shown for historic events in Fig 2) by descending damage amount and assigning the corresponding return periods, as given by the temporal extent of the damage event set. If the damage event set spans say 100 years and contains for example only three damaging events of amounts a, b and c, with a>b>c, the largest damage reached or exceed only once in these 100 years is a, while a damage level of b is reached or exceeded twice in these 100 years, hence the return period for a damage level of b is 50 years, and c is



`figure; climada_EDS_DFC(EDS); % show damage exceedance frequency (DEF) curve`
The horizontal axis denotes the return period in years, the vertical axis the damage (in units the Values were provided, here USD). The label of the curve denotes the hazard set used.

While one would in a proper application of climada now calculate the damages of future assets (to obtain the effect f economic growth) and then further repeat the calculation with a future hazard set (to obtain the effect of climate change), we illustrate the benefit of adaptation measures by simply using the assets and hazard we have already used.

But before we do so, one remark about uncertainty – *the first time reader shall either skip or at least not spend time with the following short section*. But since I've got so many questions about dealing with uncertainty, I decided to cover the bare essentials early on.

Dealing with uncertainty

In climada, we follow 'measurement theory of probability'[58] and do not assume any prior or suggest a possibly inappropriate approach[59]. The user is responsible for ANY

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reached and/or exceeded three times, hence its return period is 33.3.. years.
Further, see e.g. McNeil, A.J., R. Frey, and P. Embrechts, *Quantitative risk management: concepts, techniques and tools*. Vol. Revis. 2005, Princeton, N.J: Princeton Univ Press. and also Rice, J.A., *Mathematical statistics and data analysis*. Vol. 3rd. 2007, Belmont, CA: Thomson/Brooks/Cole.

[58] See e.g. https://www.countbayesie.com/blog/2015/8/30/picture-guide-to-probability-spaces

[59] e.g. one could (relatively easily) implement a beta-distribution on the damage uncertainty, but some damage might be bound by an upper limit.

uncertainty calculation, as this way, he is in full control of the drivers (and sensitivities). If user therefore might decide to quantify the effect of uncertainty around damage functions, he would specify the distribution explicitly and just run his own uncertainty assessment (from a simple trial to e.g. full Monte-Carlo approach). Since all damage calculations a re easy to call functions, it is very easy to write a small script that 'samples' e.g. several damage functions and runs the respective statistics on the results, in the ***bare essence*** this could look something like:

Assume we have an entity with assets and damagefunctions and a hazard ready (as at this stage the case), hence can just run the damage calculation with some samples[60] around the original damage function:

```
sample_multiplier=[.7 .8 .9 1.1 1.2 1.3];
entity_orig=entity; % copy
EDS=climada_EDS_calc(entity,hazard); % the 'default' and to init EDS
for sample_i=1:length(sample_multiplier)
   entity.damagefunctions.MDD= ...
      entity_orig.damagefunctions.MDD*sample_multiplier(sample_i);
   EDS(end+1)=climada_EDS_calc(entity,hazard);
end % sample_i
```

Since the annual expected damage (just to take one risk measure) is within each EDS structure, to run some stats, we convert to an array (note that the first element in ED is the default run, followed by the samples), e.g.

```
ED=[];for i=1:length(EDS),ED(end+1)=EDS(i).ED;end
```

And with that, one can run any statistics like `mean(ED),std(ED)`

Or, if one would like to run statistics on e.g. the 100 year return period damage, simply convert the EDS into a DFC (that's the elegance of it ;-):

```
DFC=climada_EDS2DFC(EDS,100); % calculate 100 year damage
damage_100=[];for i=1:length(EDS),damage_100(end+1)=DFC(i).damage;end
mean(damage_100),std(damage_100)
```

Adaptation cost curve

As mentioned, the entity structure contains not only assets and damagefunctions, it also holds the adaptation measures[61]. `entity.measures.name{m}` contains the name of measure m, `entity.measures.cost(m)` the cost[62]. The following fields allow the parameterization of the measure's impact on both the hazard as well as the damage function. `entity.measures.hazard_intensity_impact(m)` allows to reduce the hazard intensity (e.g. -1 reduces tropical cyclone windspeed by 1 m/s) for measure m. The `hazard_high_frequency_cutoff`[63] allows to specify a frequency below which damages are suppressed due to the measures, e.g. the construction/design level of a dam (`hazard_high_frequency_cutoff=1/50`

[60] We use multipliers here to keep the code snippet simplest. But one could switch to another set of damage functions or consider non-linear transformations, such as MDD=MDD.^2 or =MDD.^1/2 or … (just in the e.g. MDD or PAA case make sure max(MDD) or max(PAA) do not exceed 1, e.g. use MDD=min(MDD,1), unless you want that). One will very likely also 'wiggle' other parameters, such as hazard intensity (start with simple tests such as e.g. hazard.intensity= hazard.intensity*.95).
[61] Please refer tot he measures tab in the Excel file and the comments in each of the header fields.
[62] entity.measures.color{m} contains the color (RGB) as shown in the adaptation cost curve of measure m. `colorRGB` contains this converted into an RGB triple.
[63] We do not repeat `entity.measures.X(m)` any more, just refer to `X`.

means the dam prevents damages up to the 50 year return period). `hazard_event_set` allows to specify a measure-specific hazard event set, i.e. for this particular measure, climada switches to the specified hazard event set instead of the one used to assess the damages of the reference case. `MDD_impact_a` and `MDD_impact_b` allow a linear transformation of the MDD (mean damage degree) of the damage function, such that MDD_{eff} = `MDD_impact_a` + `MDD_impact_b` * MDD. Similarly, PAA_{eff} = `PAA_impact_a` + `PAA_impact_b` * PAA. `damagefunctions_map` allows to map to a new damage function to render the effect of measure m, i.e. '1to3' means instead of DamageFunID 1, DamageFunID 3 is used[64]. `risk_transfer_attachement` and `risk_transfer_cover` define the attachement point and cover of a risk transfer layer[65].

The simple call

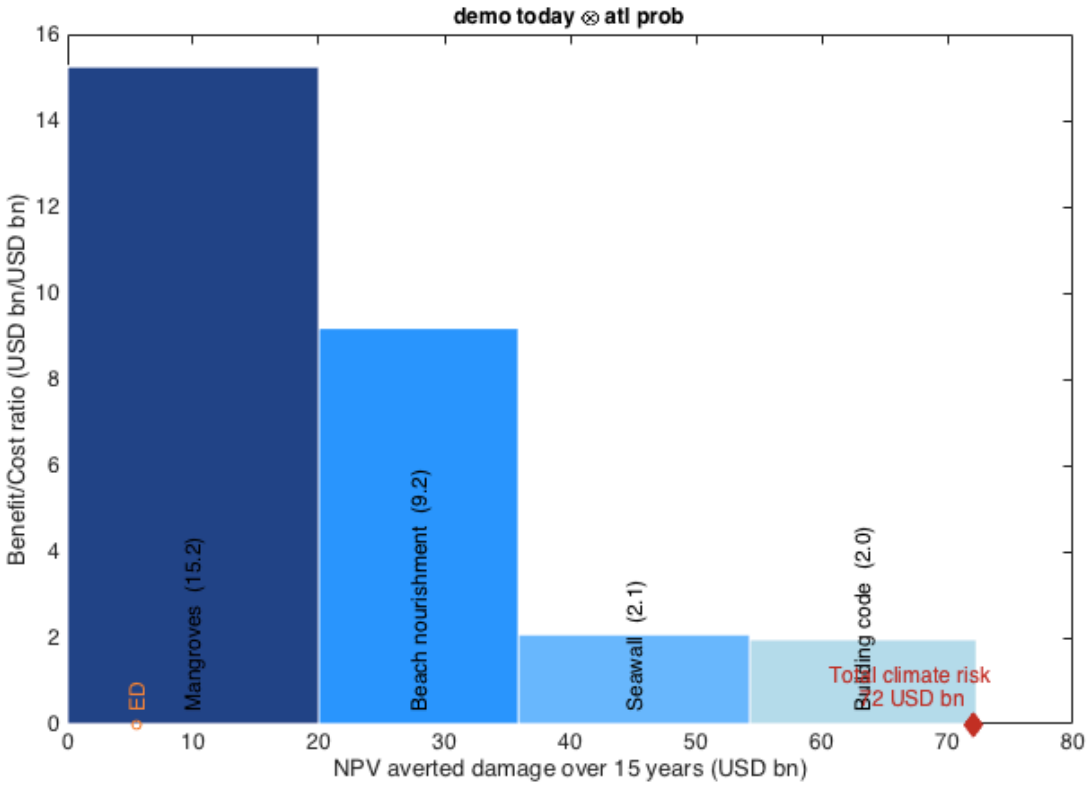
```
measures_impact=climada_measures_impact(entity,hazard,'no');
```

does it all, e.g. it takes the entity and first calculates the EDS_{ref} using hazard in order to create the baseline (situation with no measure applied). It then takes measure m (m=1…), adjusts either hazard and/or damagefunctions according to the measure's specification and calculates a new EDS_m. The difference to EDS_{ref} (i.e. EDS_m-EDS_{ref}) quantifies the benefit (averted damage) of measure m. By doing this on the event damage set, a variety of measures can be compared, even account for measures which for example only act on high frequency events (see `hazard_high_frequency_cutoff`) or risk transfer layers (see `risk_transfer_attachement` and `risk_transfer_cover`). This function further handles all the measure impact discounting etc.[66]

Since it would be quite cumbersome for the user to manually construct the adaptation cost curve based on the detailed output provided by `climada_measures_impact`, the following function does it all:

```
climada_adaptation_cost_curve(measures_impact)
```

[64] The filed entity.measures.damagefunctions_mapping contains the details, i.e. the mapping as used in climada, a kind of 'parsed' version of e.g. '1to3'.
[65] Please refer the tot he lecture, www.iac.ethz.ch/edu/courses/master/modules/climate_risk
[66] See function `climada_NPV`



and finally the effect of adaptation measures on different return periods:

```
climada_adaptation_event_view(measures_impact)
```

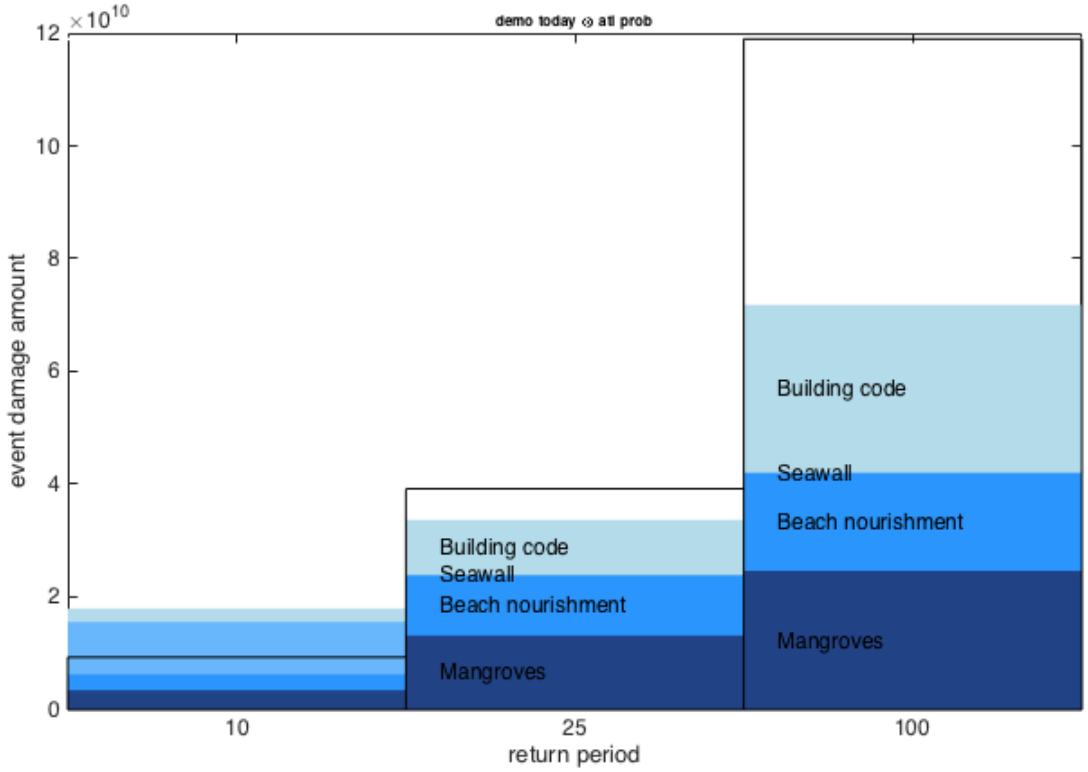


Figure: the effect of adaptation measures on return periods of 10, 25 and 100 years. Note that the 10-year event can be fully mitigated by proposed measures, about 70% of the 50-year and about half of the 100-year event.

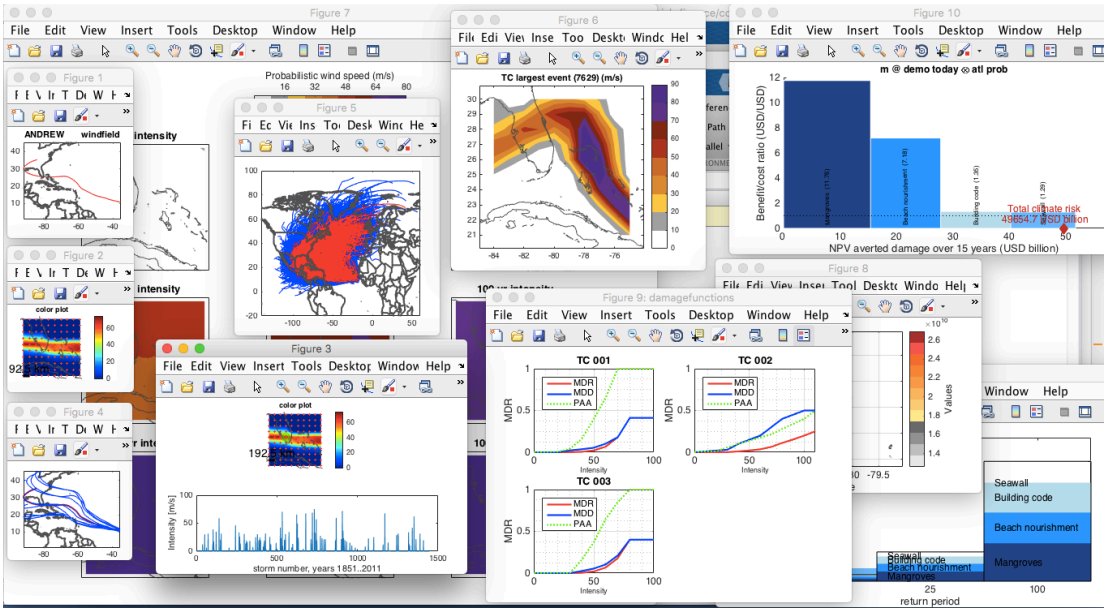


Figure: all output figures from **`climada_demo_step_by_step`** on one screen (resized) in order to allow for an easy check whether your local installation of climada does produce the correct output. Please note that exact figures and single numbers might be slightly different (say values differing +/- 10%) due to the use of a random number generator in the probabilistic track set and potentially later versions of the historical tropical cyclone database – plus advancement of the climada engine itself.

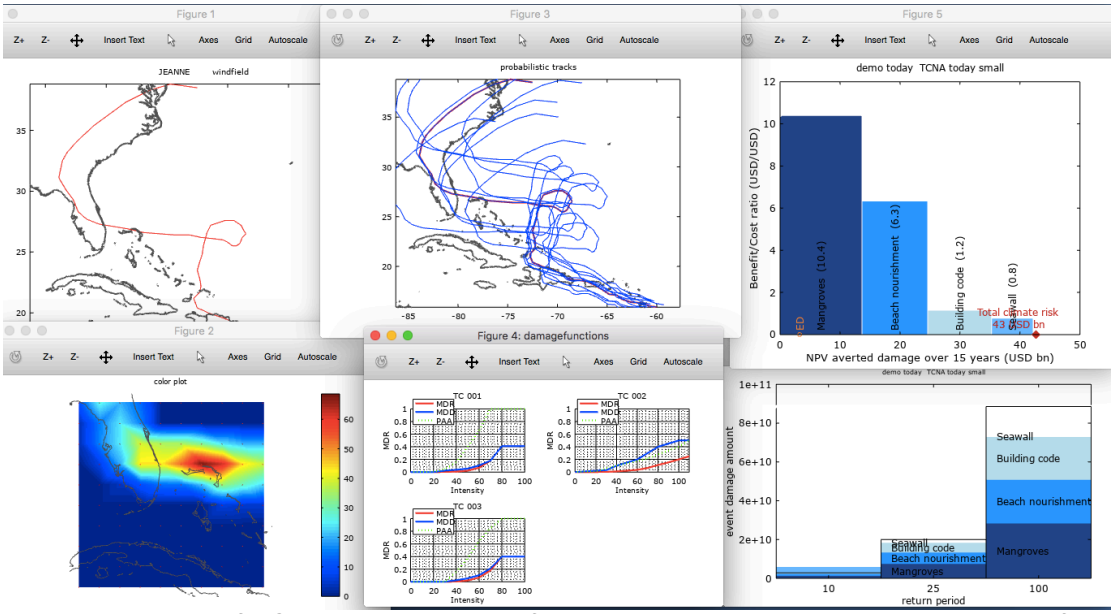


Figure: as above, but for Octave in order to allow for an easy check whether your local installation of climada does produce the correct output.

A climada application example – tropical cyclone ensemble damage forecasts

At this stage, you might consider to look into a climada 'application', i.e. a GUI (or for Octave, a command-line tool) which allows to calculate (forecast) damage for tropical cyclones, both for the forecast track as well as for an ensemble of probabilistic tracks, all around the globe (MATLAB GUI: `climada_tc_guess`, Octave and MATLAB command line: `climada_tc_event_damage_ens`). Note that it does require the country_risk module[67].

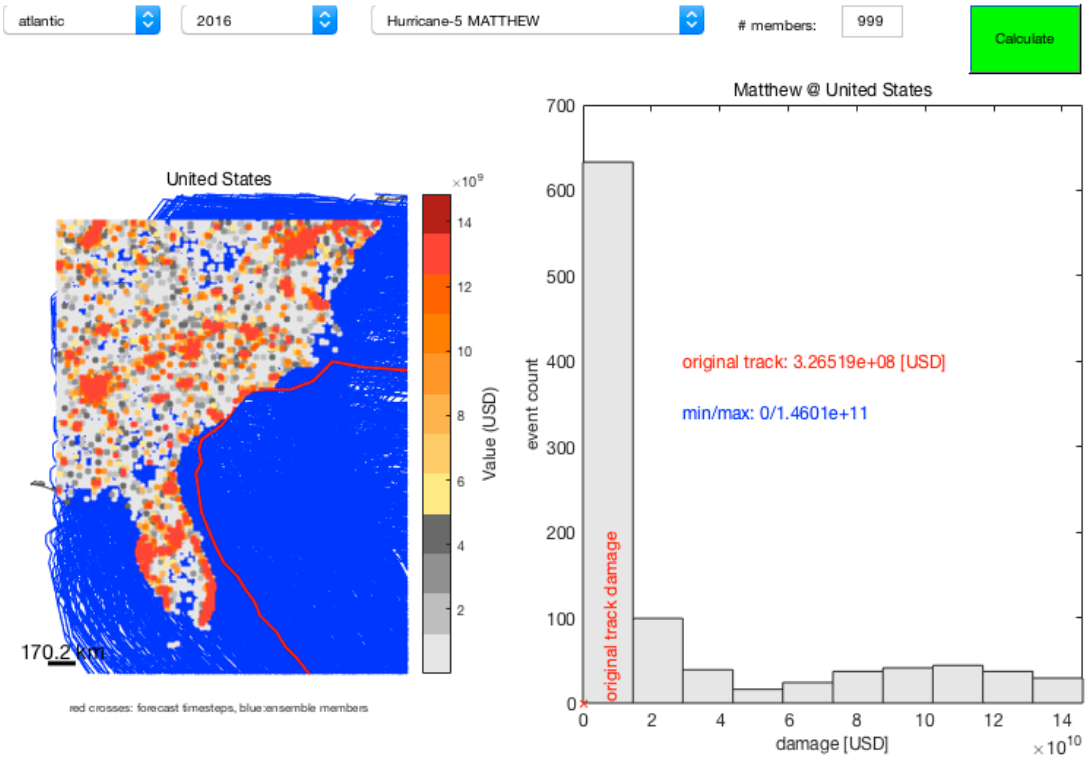


Figure: The `climada_tc_guess` GUI, here shown for Matthew hitting the United States.

[67] See https://github.com/davidnbresch/climada_module_country_risk

Function reference

This section makes reference to key climada functions in order to provide the user with a starting point – the function are provided in a somewhat logical order, i.e. one would usually use functions listed further down later in the process. Please refer to each functions detailed header (use `help functionname` in MATLAB). You might also run `compile_all_function_headers` once in order to generate a .html file with all function headers for fast reference[68].

`climada_demo`: the demo GUI as documented above
`climada_demo_step_by_step`: the step-by-step demo as documented above

Basic entity functions

`climada_entity_read`: read entity from Excel file
- `climada_entity_load`: load a previously saved entity (`climada_entity_read` saves a .mat file – which speeds up subsequent read, unless the original Excel file has been changed, in which case it is re-read and the .mat file overwritten, see `climada_check_matfile`)
- `climada_entity_save`: save an entity (i.e. after modification in MATLAB)
- `climada_entity_country`: generate a basic entity for any country worldwide
- `climada_damagefunctions_read`: read damagefunctions tab only
- `climada_measures_read`: read measures tab only
- `climada_measures_encode`: encode measures, i.e. interpret them for use in `climada_measures_impact`
- `climada_dateline_resolve`: resolve issues around dateline
- `climada_{assets|damagefunctuons|measures}_complete`: a handy function to check for completeness of the respective sub-structure of an entity (e.g. if edited in command line)

`climada_entity_plot`: plot assets distribution of an entity (entity.assets)
`climada_entity_value_GDP_adjust`: scale total asset value to GDP*blowup
`climada_assets_encode`: encode assets (i.e. to switch to another hazard event set[69])
- `climada_assets_encode_check`: check encoding, plot asset locations and centroids

`climada_damagefunctions_plot`: plot damagefunctions
`climada_damagefunctions_map`: map damagefunctions (i.e. to another entity[70])
`climada_damagefunction_replace`: replace a damage function
`climada_damagefunction_generate`: generate generically shaped damage function, then use `climada_damagefunction_replace`.

Core calculations

`climada_EDS_calc`: calculate event damage set (EDS)
- `climada_EDS_stats`: some statistics of an EDS

[68] The file ../climada/docs/code_overview.html does contain the headers of all functions of all modules (and the links to the source code); hence you might consult this file (e.g. use full text search within) and might need to install the respective module in order to use the specific function.
[69] climada_entity_read prompts for a hazard event set and hence encodes to the selected hazard's centroids already. For speedup, this is done prior to calling climada_EDS_calc, as mapping all asset locations to the centroids oft he hazard event set usually does not need to be repeated each time (e.g. only once for the series of calculations involved in assessment of adaptation measures). In case multiple hazards (perils) are assessed, re-encoding is required indeed (that's why climada measures impact works for one hazard at a time only – this code does indeed checl for encoding).
[70] This is especially useful if the user stores all damage functions in a kind of ‚reference' file and attaches the damage functions after reading any new entity, which might itself not contain (all) damage functions (in this case, just disregard the warnings issues by climada_entity_read).

climada_EDS_save: save EDS
climada_EDS_load: load EDS

climada_EDS_DFC: plot damage frequency curve(s)
climada_damage_exceedence: the damage exceedance calculation
climada_EDS_DFC_report: write an Excel or .csv report of the DFC(s)
climada_EDS2DFC: just convert an EDS to a DFC as a structure, do not plot (for that, see climada_EDS_DFC).

climada_waterfall_graph: plot the waterfall graph (with the elements risk today, Δeconomic, Δclimate)

climada_measures_impact: calculate the impact of adaptation measures
climada_NPV: net present value (NPV) calculation

climada_adaptation_cost_curve: show the adaptation cost curve

climada_adaptation_event_view: the event view on adaptation measures

climada_EDS2YDS: convert an event (per occurrence) damage set (EDS) into a year damage set (YDS).

climada_EDS_combine: Combine two (or more) event damage sets (EDS), e.g. add damages of TC and TS (same main peril) or EDS for global EQ across several countries.

Basic hazard functions

climada_hazard_plot: plot hazard events, max intensity etc.

climada_hazard_load: load hazard event set

climada_hazard_stats: plot hazard intensity return period maps

climada_hazard_check: show hazard intensity histogram, useful to compare two hazard sets in general.

climada_excel_hazard_set: create a hazard set based on scenarios as provided in an Excel file, see ../data/hazards/Excel_hazard.xls

climada_hazard_cleanup: cleanup a hazard event set (check for internal consistency)

climada_hazard_clim_scen: create a climate scenario version of a hazard event set

climada_IFC_plot: plot **i**ntensity/**f**requency relationship at **c**entroid (needs climada_hazard2IFC)

climada_asci2hazard: import hazard data from en external modeling tool

Further display functions

climada_plot_world_borders: plot world borders[71]

climada_circle_plot: plot any values at coordinates as circles

climada_color_plot: plot any values at coordinates as colored area

climada_DFC_compare: compare a damage frequency curve (DFC) with other model output

climada_event_damage_animation: create animation (a movie, such as .mp4) of hazard and damage calculation. See also climada_event_damage_data_tc

climada_event_damage_data_tc: prepare tropical cyclone hazard, assets, damage and cyclone track data to be rendered as an animation using climada_event_damage_animation

[71] Uses ../data/system/admin0.mat for the border shapes, see the file admin0.txt there and also climada_shaperead('SYSTEM_ADMIN0'). The user can specify an other shape file, either as parameter or in climada_global.map_border_file

Tropical cyclone (TC) specific functions[72]

`climada_tc_get_unisys_databases`: get all TC (besttrack) databases from www. Please note that the windspeed measurement is not the same across the globe, there are substantial differences e.g. between North Atlantic and West Pacific[73], such that the template damage function shall only be used with (utmost) caution.

`climada_tc_read_unisys_database`: read (besttrack) data

`climada_tc_random_walk`: generate probabilistic tracks

`climada_tc_windfield`: generate the windfield for one TC event

`climada_tc_hazard_set`: generate a TC hazard event set (and yearset)

`climada_tc_windfield_animation`: animate a single TC track's windfield

`climada_plot_ACE`: plot accumulated cyclone energy (ACE)

`climada_tc_stormcategory`: add Saffir-Simpson scale[74]

`climada_tc_read_unisys_track`: read a single track (see also `climada_tc_read_unisys_database` above)

Basic functions

`climada_xlsread`: read Excel file

`climada_odsread`: read .ods (Open Office) file, see also climada_init_vars to set this as default

`climada_shaperead`: read shape file (does require MATLAB mapping toolbox)

`climada_centroids_read` and `climada_centroids_load`: read and load centroids

`climada_centroids_plot`: plot centroids

`climada_hazard2octave`: deal with hazard saved with option –v7.3 in Octave

Admin functions

`climada_git_pull`: on a machine with GIT (https://github.com) installed, update all local code and data (much faster than using GIT Desktop)

`climada_git_clone`: on a machine with GIT (https://github.com) installed, clone most climada modules (much faster than using GIT Desktop)

`climada_code_copy`: (old, use `climada_git_pull` whenever possible!) copy all code into a folder for easy transfer

`climada_code_update`: update local code based on the file provided by `climada_code_copy`

`compile_all_function_headers`: generate a html file with headers of all functions (these headers explain all input and output of each function). You find this file in ../docs/code_overview.html

`climada_template`: the function template to start new code from

`climada_country_name`: get country name and admin0 ISO3 code, see also ../data/system/admin0.txt and admin.xls

`climada_init_vars`: init global varables (called upon startup[75] by `startup`)

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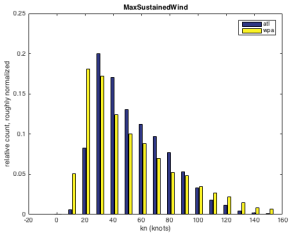
[72] Please note that we decided to use the TC hazard to illustrate core climada and some select features. Please refer to the climada modules (next section)for other hazards with similar functionality.



[73] A direct comparison of the historic storms' windspeeds reveals:

[74] See e.g. http://en.wikipedia.org/wiki/Saffir%E2%80%93Simpson_Hurricane_Scale

`climada_octave`: called by `climada_init_vars` to init if operating on Octave
`climada_init_folders`: init folder structure (useful when creating a new module)
`startup`: the startup function, sets root folder and manages MATLAB path[76]
`climada_check_matfile`: check whether the .mat (binary, fast access) version of a file is older than the (Excel) file, used e.g. in `climada_entity_read`, which reads the .mat file on second call, unless the Excel entity file has been edited.

Special functions (there are more)

`climada_code_optimizer`: remove some parts from core code (like `climada_EDS_calc`) for speedup (only for expert use)
`climada_distance_km`: calculate distance between points in km
`climada_nonspheric_distance_m`: more precise distance in m
`climada_collect_measures_impact`: collect impact files for two hazards created by `climada_measures_impact` (sometimes handy to process some measures separately)
`waitbar_toggle`: toggle waitbars (on/off), see also `climada_global.waitbar`
`climada_lonlat_cleanup`: migrate `entity.assets.Longitude` to `entity.assets.lon` ...
`climada_dateline_resolve`: resolve issues around dateline

climada modules

While the core climada provides the user with the core probabilistic damage calculation and climate adaptation measures assessment functionalities, it only contains a simple tropical cyclone hazard. Therefore, there are climada extensions, called modules, to add functionality. Since the core climada only contains a simple tropical cyclone hazard, one of the first modules to be considered might be tropical_cyclone, which improves the quality of the tropical cyclone hazard event set. There exist modules for other perils (to generate or make use of other hazards, such as storm_europe, flood and earthquake_volcano) and for other functionality, like automatic generation of assets (country_risk). Each module contains (similar to core climada) a code, data and docs folder, with a detailed documentation in the file {module_name}.pdf in the docs folder. Therefore, one might first inspect these files still on GitHub before downloading a specific module[77]. Please note that core climate runs without restrictions under both MATLAB and Octave, but some modules might not have been extensively tested in Octave – or might even require MATLAB libraries (would be stated in the respective module's manual).

advanced

https://github.com/davidnbresch/climada_advanced
This module provides advanced functionality, such as multi-hazard processing and management of sets of measures. It does also contain the interface to **ktools**[78], the loss calculation engine of **Oasis LMF** (http://www.oasislmf.org/the-toolkit). See module tropical_cyclone (below) for more realistic tropical cyclone wind fields (inland decay) etc.

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[75] Does also check for operating system being MATLAB or Octave (in the latter case also calling `climada_octave`)
[76] Adds paths to all climada modules
[77] Please refer to the section ‚Getting started' above about where to store the module(s). The process is also described in each module's readme file.
[78] to run on a cluster (such as Euler at ETH) with tools installed, you need to set export `PATH=$PATH:/cluster/apps/climate/ktools/bin`

tropical_cyclone

https://github.com/davidnbresch/climada_module_tropical_cyclone

This module implements the tropical cyclone (TC) attenuation after landfall for probabilistic events and allows to generate the precipitation fields accompanying a tropical cyclone - the torrential rain (TR) hazard event set - as well as the associated storm surge (TS) events. Make yourself familiar with the core climada tropical cyclone hazard event set (and its generation) first. A good implementation of both the basic, probabilistic and advanced tropical cyclone hazard generation (including TC, TS, and TR) can be found in the climada module country_risk and there in the routine centroids_generate_hazard_sets.

storm_europe

https://github.com/davidnbresch/climada_module_storm_europe

This climada module contains the basic European winter storm (WS) hazard event sets[79] from 2010, an interface to the MeteoSwiss COSMO model output and further code related to European winter storms.

country_risk

https://github.com/davidnbresch/climada_module_country_risk

This module runs all (available) perils for one country (or list of countries). It generates country or admin1 (state/province) assets (consisting of centroids, used later e.g. to generate a hazard event set of matching resolution and assets – if requested scaled to the country GDP or proxy asset value for today and future), the earthquake (EQ), tropical cyclone (TC), torrential rain (TR) and storm surge (TS) hazard event sets, checks for European winter storm (WS) exposure and runs all risk calculations for a given country. Note: this module contains also the former GDP_entity module.

isimip

https://github.com/davidnbresch/climada_module_isimip

This module implements isimip-specific functionality (a community-driven climate-impacts modelling initiative, see www.isimip.org, and the climada page within at: www.isimip.org/impactmodels/details/243). It allows climada to connect to and work from isimip datasets, e.g. assets, hazards and damage functions.

earthquake_volcano

https://github.com/davidnbresch/climada_module_earthquake_volcano

This module implements a raw global earthquake (EQ) and volcano (VQ) model. Consider climada modules country_risk or GDP_entity to generate the centroids.

elevation_models

https://github.com/davidnbresch/climada_module_elevation_models

This module implements ETOPO, a global bathymetry (and topography) dataset. It's a separate module, since topographic (and bathymetry) information can be used in various contexts – and since the dataset is quite large (ETOPO1 is 933 MB, ETOPO2 still 233 MB).

meteorite

[79] Schwierz, C., P. Köllner-Heck, E. Zenklusen Mutter, D. N. Bresch, P.-L.Vidale, M. Wild, C., and Schär, 2010: Modelling European winter wind storm losses in current and future climate. Climatic Change (2010) 101:485?514, doi: 10.1007/s10584-009-9712-1.

https://github.com/davidnbresch/climada_module_meteorite
This module implements a basic meteorite global hazard. Consider climada modules country_risk or GDP_entity to generate the centroids.

flood
https://github.com/davidnbresch/climada_module_flood
Implements a first (simple) flood model (FL) and a landslide model. The flood model is in early stage and very much still work in progress (contributions welcome!).

barisal_demo and salvador_demo
https://github.com/davidnbresch/climada_module_barisal_demo and https://github.com/davidnbresch/climada_module_salvador_demo
Barisal, Bangladesh, and San Salvador demo module, all numbers and results are for demonstration purposes only.

kml_toolbox
https://github.com/davidnbresch/climada_module_kml_toolbox
To write kml files, e.g. to visualize asset distribution and hazard/damage animations in Google Earth.

octave_io_fix
https://github.com/davidnbresch/Octave_io_fix
Provides a crude fix for this issue by providing Octave io (e.g. read .xls, .xlsx and .ods files) as a climada module instead of a proper Octave package. This climada module contains the CRUDE work-around for cases where the Octave package io-2.2.6.tar cannot be installed by using `pkg`. Tested on Mac Air, under OS X Yosemite, Version 10.10.1 (computer in Octave returns x86_64-apple-darwin13.0.0) and Octave version 3.8.0. Note that the issue did not occur on Mac Air with OS X version 10.9.5 and not any more with OS X (El Capitan) version 10.11.13 (computer in Octave returns x86_64-apple-darwin13.0.0).

Programmer's hint: in order to access data stored in other modules, you first need to figure the actual path of that module. To use the etopo netCDF file directly, you would find it at e.g.

```
etopo_data_file=[fileparts(fileparts(which('etopo_elevation_m'))) ...
      filesep 'data' filesep 'ETOPO1.nc']
```

Some hints to useful data sources

We do mention key sources in the respective climada modules, but some data we came across is worth mentioning in more general terms.

- http://www.naturalearthdata.com and directly http://www.naturalearthdata.com/downloads: global shape files (see e.g. climada_shaperead and the module country_risk). One will likely need the MATLAB mapping toolbox to ease working with these files. Could be used to either improve hazard sets (e.g. using location of reefs in surge model…) or assets.
- http://download.geofabrik.de: highly detailed shape files for most countries (e.g. more than 1.5 mio shapes of building's outlines in Switzerland). Could be used in conjunction with climada module country_risk to further refine the asset base. See also http://www.openstreetmap.org/about, https://mapzen.com and http://planet.openstreetmap.org

- Also www.diva-gis.org/gdata and www.diva-gis.org/Data for GIS data almost any country[80] and also www.eea.europa.eu/data-and-maps/data/urban-atlas
- GIS data for Seychelles https://www.webgis.gov.sc/map_default.phtml
- SRTM elevation data (3-arc seconds resolution ~90m) http://srtm.csi.cgiar.org/SELECTION/inputCoord.asp and generally http://srtm.csi.cgiar.org
- Hydrosheds, based on SRTM, manipulated for river routing http://hydrosheds.cr.usgs.gov/index.php
- http://www.geoportal.org/web/guest/geo_home_stp
- https://www.drought.gov/drought/content/products-current-drought-and-monitoring-drought-indicators/palmer-drought-severity-index
- http://beta.sedac.ciesin.columbia.edu/data/collection/gpw-v4/sets/browse population density, water bodies, admin center points with population estimates (http://beta.sedac.ciesin.columbia.edu/data/set/gpw-v4-admin-unit-center-points-population-estimates)
- https://search.earthdata.nasa.gov earth data search
- https://datahub.io/ open data sets of various kinds
- http://databank.worldbank.org/data/home.aspx macroeconomic data
- http://databank.worldbank.org/data/reports.aspx?source=subnational-population sub-national population (admin1)
- http://www.trademap.org/Index.aspx trade statistics
- http://www.cger.nies.go.jp/gcp/population-and-gdp.html population and GDP
- http://data.footprintnetwork.org global country-level data on footprint etc.
- https://hazards.fema.gov/femaportal/wps/portal/NFHLWMSkmzdownload FEMA, US
- http://www.nws.noaa.gov/gis/shapepage.htm NOAA shape files (mainly US)
- http://www.mapcruzin.com/free-netherlands-arcgis-maps-shapefiles.htm NLD shape files, http://www.mapcruzin.com/do-it-yourself-gis-maps-shapefiles/ mainly US and http://www.mapcruzin.com/free-world-country-arcgis-maps-shapefiles.htm global
- http://floodobservatory.colorado.edu floods
- https://freegisdata.rtwilson.com good global overview of free GIS data

Models

- http://www.hrc-lab.org Hydrologic Research Center, (local) flood model

Writing your own code

While climada does provide quite a range of functionality, the advanced user will soon feel the need or even desire to start developing its own code. It is strongly advised to start from the template[81], since this code (fragment) does provide access to the climada global variables[82] and provides the standard function header[83]. Please do take the time to keep the function header always up to date – upon first use, this looks a bit like over-engineering, but as soon as one would like to share code, it

[80] See also e.g. http://data.geocomm.com/catalog
[81] ../code/climada_template.m
[82] See also `climada_init_vars` and the global variable `climada_global`
[83] Use of the standard header is recommended, even required, as the code which generates he overview of all climada functions (see `compile_all_function_headers`) does parse all headers of all functions.

becomes a requirement. The template code further exemplifies the usual file dialog and the standard use of waitbar in a for-loop (and the progress update to stdout in case of waitbar suppressed[84]).

It is always a good idea to browse existing code as a place to start from – most likely code such as `climada_tc_hazard_set`, `climada_EDS_calc` or `climada_EDS_DFC` come to one's mind, but also code in modules such as `country_risk_calc` in moduel country_risk or `tc_surge_hazard_create` in module tropical_cyclone.

Since climada is designed to provide utmost flexibility and (recursive) use of functionality, please write any code such that all parameters have reasonable default values (often defined either in the argument check or in the `PARAMETERS` section of each function) and that every function can be run from command line, with any GUI (like file dialog) only popping up in case not all function parameters are defined upon call. Only exceptions are proper GUI's, such as `climada_demo`.

Instead of adding code to climada core, it is highly recommended to start a new **module**, as code development can much easier be managed this way. Just create a new folder in the modules folder[85] and sub-folders code[86], data and docs, as you find it in all other modules. This way, your code folder gets automatically added to the path upon next startup. This approach also eases later upload of your code as an additional climada module in GitHub[87].

climada_init_vars

Since the code `climada_init_vars` is sourced at startup and defines some core global variables, it is worth briefly mentioning the most important ones, as the programmer shall always make use of in order to keep the code machine and file-system independent etc.

First, some paths are set[88]:

- `climada_global.root_dir`: the folder where all climada resides, there should be no need for climada to access folders 'above' this level. This is figured by `startup.m`
- `climada_global.data_dir`: the main data folder, either within climada (../climada/data) or on the same level as climada (../climada_data, i.e. {`climada_global.root_dir`}/ climada_data). The advanced user can set this folder to any place for a specific project, i.e. to store one project's entities and hazards at a specific place[89]. Such a user might keep

[84] i.e. if `climada_global.waitbar=0`

[85] Best to create a folder climada_modules parallel to the core climada folder (i.e. ion the same level - in the same parent folder - as core climada). It is also possible to put it as ../climada/modules, but not recommended.

[86] Please note that a code folder can have ONE level of sub-folders to better organize your code. `startup` does add these sub-folders tot he MATLAB path, too.

[87] See https://help.github.com/articles/create-a-repo/

[88] Please ONLY use `filesep` and never any explicit file separator, since ,/' or ,\' etc. depend on the file system – and climada shall be independent of any file system.

[89] In case you do so, please make sure you call `climada_init_vars(3)`, wich sets `climada_global.centroids_dir`, `climada_global.entities_dir`, `climada_global.hazards_dir`, `climada_global.results_dir` accordingly (i.e. relative to (subfolders of) climada_global.data_dir). This call (with option 3) does NOT change `climada_global.system_dir` and `climada_global.tc_tracks`.

climada_global.system_dir unchanged, as system files are very unlikely to be project-specific.

- climada_global.system_dir: usually a sub-folder of climada_global.data_dir with the key system files (such as admin0.mat, coastline.mat...)
- climada_global.centroids_dir: usually a sub-folder of climada_global.data_dir with the centroid files.
- climada_global.entities_dir: usually a sub-folder of climada_global.data_dir with the entity files.
- climada_global.hazards_dir: usually a sub-folder of climada_global.data_dir with the hazard files.
- climada_global.results_dir: usually a sub-folder of climada_global.data_dir with the results.

Some key files are defined:

- climada_global.map_border_file: the map border file as used by climada_plot_world_borders, see the short documentation in {climada_global.system_dir}/admin0.txt and see also[90] climada_shaperead('SYSTEM_ADMIN0')
- climada_global.coastline_file: the global coastline file, as used by climada_distance2coast_km (see the short documentation in {climada_global.system_dir}/coastline.txt) and see also climada_shaperead('SYSTEM_COASTLINE')
- climada_global.csv_delimiter: the country- and machine-specific .csv delimiter (to read and convert to Excel properly)
- climada_global.spreadsheet_ext: the default spreadsheet type, either '.xls' (default) or '.ods'. The user can always select from 'All Files', the default is only used to compose the default filename.

Evaluation and NPV (net present value) specific parameters:

- climada_global.present_reference_year: the reference year for 'today'
- climada_global.future_reference_year: the reference year for 'future'
- climada_global.impact_time_dependence: time dependence of impacts (1 for linear, default). >1 concave (e.g. 2: cubic), <1 for convex (e.g. 1/2: like square root). Concave means: damage increases slowly first (see climada_measures_impact)

And further:

- climada_global.DFC_return_periods: Standard return periods for DFC report
- climada_global.waitbar: whether we show waitbars for progress (e.g. in climada_EDS_calc).
- climada_global.EDS_at_centroid: whether we store the damage (=1) at each centroid for each event (an EDS for each centroid). Heavy memory, see climada_EDS_calc; therefore: default=0. Please note that EDS.ED_at_centroid is always calculated (only a vector length number of centroids)
- climada_global.re_check_encoding: whether the code checks for (possible) asset encoding issues and re-encodes in case of doubt (might take

[90] Requires country_risk module https://github.com/davidnbresch/climada_module_country_risk

time...). See `climada_EDS_calc` (and also its input parameter `force_re_encode`).

climada startup

The file `startup.m`[91] is sourced at startup (see Getting started above) and mainly defines the root folder (using `pwd`) and locates all installed climada modules and adds their code folders[92] to the MATLAB path. In case the advanced user would like to have other variables etc. defined at startup, one might write a separate `my_startup.m`[93] which first calls `startup`. Editing `startup.m` is not recommended, as this will fork compared to the climada repository.

Description of key climada structures

The detailed descriptions are of most use once the advanced user is familiar with concepts and process as described in 'From tropical cyclone hazard generation to the adaptation cost curve' above.

The entity structure contains assets, damage functions and measures, as described in 'Excel interface to climada' above. Fields in the data structures have the exact same name as the column headers[94] in the Excel interface – and entity contains a sub-structure for each tab (i.e. assets, damagefunctions, measures and discount). Therefore, we do not repeat the detailed description here, please inspect the comment fields in the excel file. A few additional fields warrant some comments:

- `entity.assets.DamageFunID(asset_i)`: links to the corresponding damage function, see `entity.damagefunctions.DamageFunID`. Please consider usage of `climada_damagefunctions_map` to map to another set of damagefunctions, i.e. in the case you store your (reference) damage functions in one Excel (using `climada_damagefunctions_read`, or even just a MATLAB structure) and hence will call this mapping after import of the assets into climada.
- `entity.assets.distance2coast_km(asset_i)`: the distance to coast in km, as added by `climada_distance2coast_km`, e.g. in case the entity has been produced by `climada_nightlight_entity`[95].
- `entity.assets.elevation_m(asset_i)`: the elevation of asset_i, as added by etopo_elevation_m[96].

---

[91] It resides at the root level, usually `../climada/startup.m`

[92] and two levels of sub-folders within each module's code folder. This way, real 'helper' functions can be put in a sub-folder to keep the main code folder(s) easier to inspect

[93] Or any other name...

[94] Only exception are Latitude and Longitude, which are named lat and lon in climada (i.e. get renamed upon import from Excel). For backward compatibility, one column is still named „hazard intensity impact", but the MATLAB internal name is `hazard_intensity_impact_b`, since the hazard transformation in measures is analog to MDD and PAA, i.e. intensity=$intensity_{orig}$*a+b, wich b the value from `hazard_intensity_impact_b`. Therefore, the user can also add a colunm named „hazard intensity impact a" which multiplies the hazard intensity.

[95] See climada module country_risk, https://github.com/davidnbresch/climada_module_country_risk. To add this field to an existing entity, use `entity.assets.distance2coast_km= climada_distance2coast_km(entity.assets.lon,entity.assets.lat).` We do not add this information by default (e.g. in `climada_entity_read`) as it might take some time to calculate – especially in case of thousands o fasset locations.

[96] See climada module etopo, https://github.com/davidnbresch/climada_module_etopo. To add this field to an existing entity, use `entity.assets.elevation_m=etopo_elevation(entity.assets.lon,entity.assets.lat)`

- `entity.assets.centroid_index(asset_i)`: the centroid index of the centroid nearest to asset_i in a hazard event set. See the function `climada_assets_encode` to (re)encode to a (new) hazard event set. See also `climada_global.re_check_encoding` (described above in 'climada startup') to force (re)encoding. You can also simple delete this field to force re-encoding, e.g. `entity.assets=rmfield(entity.assets, 'centroid_index')`.
- `entity.assets.Values(year_i,asset_i)`: the asset value for year i. `entity.assets.Value` does contain `entity.assets.Values(1,:)`, hence the user needs to 'shuffle' other times (usually years) into Value before e.g. passing to climada_EDS_calc, see `entity.assets.Values_yyyy`.
- `entity.assets.Values_yyyy(year_i)`: the year the assets are valid for.

The hazard structure contains a hazard event set. While some key features have been introduced in 'From tropical cyclone hazard generation to the adaptation cost curve' above, we provide more details here (fields in *italic* are not mandatory, i.e. the user shall make use of `isfield` to check before referencing, the few **bold** fields are the core fields the damage calculation is essentially based upon):

- **`hazard.intensity`**`(event_j,centroid_i)`: the hazard intensity for event_j at centroid_i. A sparse matrix, hence use `full` in some instances (e.g. when using `fprintf`).
- `hazard.fraction(event_j,centroid_i)`: the fraction (range 0..1, default=1) of centroid_i affected by the event_j. A sparse matrix, hence use `full` in some instances (e.g. when using `fprintf`). Set `hazard.fraction= spones(hazard.intensity)` as default, as it only makes sense to define fraction for non-zero elements of intensity.
- **`hazard.frequency`**`(event_j)`: the single event occurrence frequency of event_j
- `hazard.lon(centroid_i)` and `hazard.lat(centroid_i)`: the coordinates of centroid_i.
- `hazard.reference_year`: the year the hazard is representative for. This information is used in `climada_measures_impact` to discount (future) benefits of measures accordingly, i.e. if `hazard.reference_year=2030`, all benefits occurring in 2030 are discounted back to NPV as of the today (and today is defined in `climada_global.present_reference_year`).
- `hazard.centroid_ID(centroid_i)`: the ID of centroid_i, currently not much used, but might be helpful to match centroids without comparing lat/lon.
- `hazard.orig_years`: the number of original years the hazard set is based on.
- `hazard.orig_event_count`: the number of original events the hazard set is based on
- `hazard.event_count`: the number of events (original and probabilistic combind) in the hazard set.
- `hazard.event_ID(event_j)`: a unique ID for event_j, currently not much used.
- `hazard.orig_event_flag(event_j)`: =1 if event_j is an original (e.g. historic) event, =0 for probabilistic events.
- *`hazard.yyyy(event_j)`*: the year (4 digits) of event_j, for probabilistic events, the same as the original event the probabilistic one is based upon. Not all original data might have event dates, hence this field is not mandatory (and anyway not used in any damage calculation).

- *hazard.mm(event_j)*, *hazard.dd(event_j)*, *hazard.hh(event_j)*: month, day and hour of the original event.
- *hazard.nodetime_mat(event_j)*: the MATLAB date/time number, just yyyy,mm,dd and hh converted into one number, see `datenum` and `datestr`.
- *hazard.name{event_j}*: a free name, e.g. name of the TC event
- *hazard.matrix_density*: the density of the sparse matrix hazard.intensity. Just for information, not used.
- `hazard.peril_ID`: the peril ID, such as TC, TS, TR, WS, EQ, FL…
- `hazard.filename`: the filename of the hazard event set, should be the same as the name (without path) of the .mat file
- *hazard.orig_yearset*: the year set, grouping original events into years. A structure with fields
    - `hazard.orig_yearset(year_i).yyyy`: the original year (4 digit)
    - `hazard.orig_yearset(year_i).event_count`: the number of events in this year
    - `hazard.orig_yearset(year_i).event_jndex`: the vector of event indices for all the original events in year_i, such that `hazard.orig_yearset(year_i).event_jndex(1)` is event_j of the first event in year_i, i.e. you can reference e.g. `hazard.intensity(hazard.orig_yearset(year_i).event_jndex(1),centroid_i)` which contains the intensity of the first event in year_i at centroid_i.

  See `climada_tc_hazard_set` about how the yearset is constructed and `climada_EDS2YDS` to convert an event (per occurrence) damage event set (EDS) into a year damage set (YDS). Please note that the grouping of probabilistic events is currently assumed to be sequential to the original events, such that if the original event is at event_j, the probabilistic derived events (sometimes also called daughters) are to be found at `event_j+1..event_j+ens_size`, where `ens_size` is the number of probabilistic events per original event (as in `climada_tc_random_walk`). See `climada_EDS2YDS` for a proper use of such a yearset[97].
- `hazard.comment`: a free comment. There might (an can) be additional fields in a hazard event set – the user is pretty free to build on.

The link between the geographical resolution of the assets and the hazard is provided by centroids (whose coordinates are stored in hazard.lon and hazard.lat, too). But there are centroids stored separately to ease some applications. The centroids structure only needs to contain the fields (optional ones in *italic*):

- `centroid.centroid_ID(centroid_i)`: a unique ID for `centroid_i`
- `centroid.lon(i)` and `centroids.lat(i)` the coordinates of `centroid_i`
- *centroid.distance2coast_km(centroid_i)*: distance to coast in km, added by `climada_distance2coast_km` or `climada_centroids_distance_to_coast`
- *centroid.onLand(centroid_i)*: whether `centroid_i` is on land (=1) or not (=0). Added by some TC routines.

[97] In case events are NOT sorted as recommended, i.e. in the case a hazard set would first comprise all historic events, followed by all probabilistic ones, the user hast wo options: either to re-arrange events in hazard to comply with the order as required by yearset (highly recommened), or to define a yearset also for each probabilistic year, then to set `hazard.orig_event_count= hazard.event_count` and to ignore the warning issued by `climada_EDS2YDS` with repsect to orig event flag etc.

The event damage set (EDS) structure has also been briefly introduced in 'climada demo step by step' above, here follow the details (as quite some fields are just copied from the hazard event set, see descriptions above).

- **`EDS.frequency`**`(event_j)`: the single event occurrence frequency of event_j (just a copy of `hazard.frequency(event_j)`.
- **`EDS.damage`**`(event_j)`: the single event damage for event_j in units as units of assets.
- `EDS.ED`: the annual expected damage, simply `EDS.damage*EDS.frequency'`.
- `EDS.Value`: the total value of assets used in the damage calculation. Useful to express damage as percentage of asset value.
- `EDS.reference_year`: the year the hazard is representative for, a copy of `hazard. reference_year`, see description above.
- `EDS.event_ID`: a copy of `hazard.event_ID`
- `EDS.orig_event_flag`: a copy of `hazard.orig_event_flag`
- `EDS.ED_at_centroid(centroid_i)`: the annual expected damage at centroid_i. See `EDS.assets.lon(centroid_i)`, `EDS.assets.lat(centroid_i)` and `EDS.assets.Value(centroid_i)` for the corresponding coordinate and total asset value at centroid_i (again useful to express `ED_at_centroid` as percentage of local asset value).
- `EDS.hazard.filename`: the filename of the hazard set used to calculate `EDS.damage`.
- `EDS.damagefunctions`: either just with the field `EDS.damagefunctions.filename` to point to the filename the damage functions came from or a full `damagefunctions` structure (see `entity.damagefunctions`).
- `EDS.annotation_name`: the annotation as used e.g. in `climada_EDS_DFC`, usually a short version of the hazard event set name.
- `EDS.comment`: a free comment

The year damage set (YDS) structure sums damages up over years, especially useful for perils with (quite) likely more than one event per year – or series of events, such as tropical cyclones and European winter storms. See `climada_EDS2YDS` and the comments with respect to `hazard.orig_yearset` above, too. In essence, a DYS contains the same information as an EDS, just `YDS.frequency(year_i) =1/length(YDS.damage)` for all years[98] and `YDS.damage(year_i)` the sum of damages for year_i. Likewise, `YDS.orig_year_flag=1` if the year_i is an original year and =0 otherwise.

[98] This way, one can use `climada_EDS_DFC(YDS)` to plot the *annual* frequency curve (instead of the *per-occurrence* frequency curve for EDS).

Notes on Octave (and OpenOffice)

climada has initially been developed in MATLAB and runs on both **MATLAB** (version 7[99] and higher) and **GNU Octave** (version 3.8.0 and higher, see https://www.gnu.org/software/octave). Some modules might not have been thoroughly tested using Octave, but core climada works without limitations[100], except for some figures being slow in creation and sometimes a bit limited in display features. Core climada does not make use of any MATLAB toolboxes, but some climada modules might do so (and this should be stated at the beginning of the respective modules' documentation) – hence note that Octave might not provide similar toolboxes.

There is one distinct difference we observed during testing: While MATLAB on machines without a full Excel COM environment (like a Mac with no Office installed) works best with Excel 95 (or 97) .xls files, Octave seems to prefer .xlsx files. Therefore, just open any Excel file which causes troubles upon import and save as .xlsx to ease use with climada on Octave.

Reading .ods (Open Office) spreadsheets works properly if you

- avoid cell comments[101] in tabs *assets*, *damagefunctions*, *measures* and *discount* of the entity .ods file.
- Make sure the cell format for numbers is Number or General (but not e.g. Percentage[102]) and that zeros show as '0', not as '-'.

We observed a few limitations with respect to plotting, complex plots like `climada_entity_plot` (or usage of e.g. `pcolor` more generally) take very long or even never complete. It looks as if Octave does not like the switch `'-v7.3'` in the MATLAB save command[103], hence use `'-v7'`. `climada_EDS_calc` checks for this and throws an Error with the suggestion to save the hazard event set in MATLAB as `'-v7'` again. On Mac computers, we observed that double-clikcing the Octave icon might not work. In such cases use a shell and a command like `/Applications/Octave.app/Contents/Resources/usr/bin/octave &` instead.

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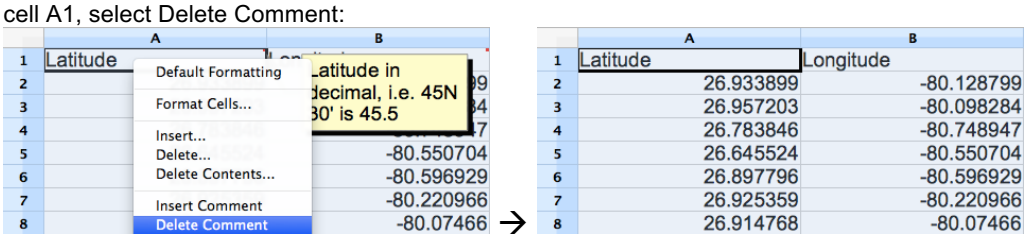
[99] see e.g. ch.mathworks.com/products/matlab

[100] In addition to core Octave, one needs the io package in order to import Excel files into climada. Please install Octave's io package directly from source forge with: `pkg install -forge io -auto`
In case this fails, get the io package first from Octave source forge and then install from the downloaded package: pkg install {local_path}/io-2.2.5.tar –auto
In case this fails (e.g. troubles with pkg, consider the climada module fix Octave_io_fix (https://github.com/davidnbresch/Octave_io_fix) which provides a crude fix for this issue by providing Octave io as a climada module instead of a proper Octave package.
Note further that Octave (on Mac at least) properly reads .xlsx files, while MATLAB before version 9.x preferred .xls (Excel 95 even). Therefore, if you mainly (or solely) use Octave, just open any non-.xlsx file and save it as .xlsx in order to work properly in Octave.

[101] I.e. the comments that pop up if mouse over. To be on the safe side, select all cells and right-click on cell A1, select Delete Comment:



[102] Specifically, in the discount tab oft he entity file, use 0.02 and not 2%.

[103] Which saves a better compressed version and supports data items greater than or equal to 2GB on 64-bit systems.

Appendices

The appendices contain detailed description of relevant aspects and shall provide the advanced user with further information and especially serve those consider expanding climada functionality.

climada, the inner workings

This section describes the core damage calculation. The damage is calculated for each single asset at each location for each scenario or event, so basically

damage = asset value * damage function

where damage is summed up over assets and events, i.e. above line is at the core of two loops, the outer one over assets, the inner one over events. More precisely:

damage = asset value * MDD * PAA, where

- MDD * PAA is the damage function
- damage is the damage 'from ground up', from the first dollar, so to speak
- asset value is the total value of the asset. Note again that value does not need to a monetary value, it can also e.g. signify number of people at a given location.
- MDD is the Mean Damage Degree (the damage for a given intensity at an affected asset) - how strongly an asset is damaged. Range 0..1 (from none to total destruction). In the case of asset value signifying number of people at a given location, MDD represents the severity with which those people are affected.
- PAA is the Percentage of Assets Affected (the percentage of assets affected for a given hazard intensity) - how many assets are affected. Range 0..1 (from none affected to all affected). In the case of asset value signifying number of people at a given location, PAA represents the percentage of people affected. As the product MDD*PAA ultimately counts, the user shall just make sure this product makes sense for the class of assets under consideration.

So far, the hazard intensity did not show up in the calculation, did we miss something? Well, the damage is a function of the hazard intensity, hence:

MDD = f(hazard intensity)
PAA = f(hazard intensity, hazard fraction)

where hazard intensity is the hazard's intensity at each asset for each event and fraction the part of the centroid affected (i.e. if for one event fraction=.25, only a quarter of the assets at the centroid are affected by this particular event). Since the damage also depends on the asset type, we have in fact:

MDD = f(hazard intensity, asset type)
PAA = f(hazard intensity, asset type) * hazard fraction

While the hazard intensity is simply the `entity.damagefunctions.Intensity`, the asset type is referred to by the `DamageFunID`, i.e. for a certain type of assets, the user defines a specific `DamageFunID` in the assets tab and the corresponding

damage function (`MDD` and `PAA` as function of `Intensity`) in the *damagefunctions* tab of the entity Excel file.

Implementation

The core calculation is done by `climada_EDS_calc`, where EDS stands for event damage set, i.e. a vector with calculated damage for each event (or simply the vector of event damages). The variables in the code have speaking names, but the inner loop is vectorized, hence warrants some comments.

```
for asset_i=1:n_assets
      temp_damage=entity.assets.Value(asset_i)*MDD.*PAA
end % asset_i
```

- `temp_damage` since it will be added in an 'outer loop' over asset_i
- `entity.assets.Value(asset_i)` is the Value of asset_i
  entity is a structure which contains all asset and vulnerability data
- `MDD` is here a vector of MDDs, one element for each hazard event, `PAA` is the vector or PAAs, also one element for each hazard event.
- `.*` is the element-wise (scalar) multiplication

So far, the hazard intensity did not show up in the calculation, did we miss something? Well, the damage function is a function of the hazard intensity, hence:

MDD = f(hazard intensity) and PAA = f(hazard intensity)

where hazard intensity is the hazard intensity at asset_i for event_j, but event_j never shows up in the code, since the code is vectorized along the event dimension for performance reasons.

And now, it gets technical (no way around this, sorry, about line 170ff of `climada_EDS_calc`) – how to get the vector of MDDs.

Remember: outer loop (explicit) over assets, inner loop (implicit) over events and also remember that the hazard event set contains

- `hazard.intensity(event_j,centroid_i)`: the hazard intensity (like windspeed in m/s) at centroid_i for event_j
- `hazard.fraction(event_j,centroid_i)`: the fraction (range 0..1, defauklt=1) of centroid_i being affected for event_j
- `hazard.frequency(event_j)` contains the event-frequency for event_j

```
for asset_i=1:n_assets % approx line 270ff in climada_EDS_calc.m

    % the index of the centroid for given asset in the hazard set
    asset_hazard_pos=entity.assets.centroid_index(asset_i);

    % find the vulnerability for the asset under consideration
    asset_vuln_pos=find(entity.vulnerability.VulnCurveID == ...
      entity.assets.VulnCurveID(asset_i));

    % convert hazard intensity into MDD: we need a trick to apply
    % interp1 to the SPARSE hazard matrix: we evaluate only at
    % non-zero elements, therefore need a function handle (the
    % @ below) to pass vulnerability to climada_sparse_interp:
    interp_x_table=entity.vulnerability.Intensity(asset_vuln_pos);
    interp_y_table=entity.vulnerability.MDD(asset_vuln_pos);
```

```
    % apply to non-zero elements only[104], note that for speedup reasons,
    % intensity is a vector containing only the non-zero elements (position
    % retuned in variable rows) of hazard.intensity at the given centroid
    % and fraction the corresponding elements of hazard.fraction
    [rows,~,intensity] = find(hazard.intensity(:,asset_hazard_pos));
    fraction=hazard.fraction(rows,asset_hazard_pos); % get fraction

    MDD=MDD_0; % get zero vector of full length
    % we only deal with the non-zero elements, hence store only a row positions
    MDD(rows)=interp1(interp_x_table,interp_y_table,...
        intensity,'linear','extrap');

    % similarly, convert hazard intensity into PAA. Note that we
    % multiply the percentage of affected assets with the fraction of
    % assets affected for the non-zero events
    interp_y_table=entity.vulnerability.PAA(asset_vuln_pos);
    PAA = PAA_0; % get zero vector of full length
    PAA(rows)=interp1(interp_x_table,interp_y_table,...
        intensity,'linear','extrap').*fraction;

    % calculate the from ground up (fgu) damage
    temp_damage=entity.assets.Value(asset_i)*MDD.*PAA;

    % add to the resulting EDS (event damage set) structure:
    EDS.damage=EDS.damage+temp_damage'; % add to the EDS[105]
    EDS.Value=EDS.Value+entity.assets.Value(asset_i); % add Value

end % asset_i
```

Next, you might consider “climada implementation of insurance conditions” further below.

Insurance remarks

Insurability & forms of insurance

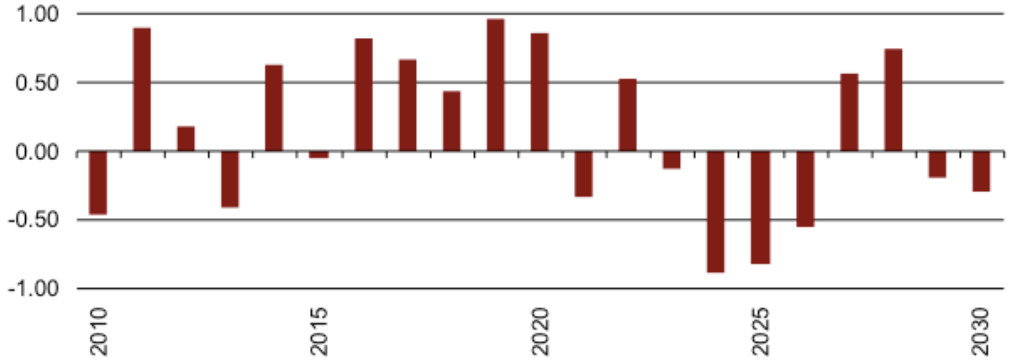
Insurance is the mutual cover of a fortuitous, assessable need of a large number of similarly exposed business [Alfred Manes, 1877-1963].

- mutuality: numerous exposed parties must join together to form a risk community, to share and diversify the risk ☾ large number
- fortuitous or randomness: time of occurrence must be unpredictable, occurrence itself must be independent of the will of the insured
- assessability: damage probability and severity must be quantifiable
- similarly exposed business: a large number of similar risks[106]
- plus: economic viability: private insurers must be able to obtain a risk-adequate premium

The following figures show the effect of insurance, including the working (and benefit) of risk reducing prevention measures. (Climate) adaptation measures work in a similar fashion, hence do not only reduce risk, but render insurance more attractive (i.e. affordable).

[104] `interp_x_table` and `interp_y_table` are passed as global variables to `climada_sparse_interp` for performance reasons
[105] A note on `'` : for historical reasons the `EDS.damage` vector is transposed
[106] see Euler’s “law of large numbers”. Hence assessability also applies to large numbers, i.e. one needs to be able to assess the average outcome over a large number of similarly exposed risks, not necessarily the specific outcome at each single risk.

Time series of annual result



average result 0.15, stddev 0.60

Time series of annual result (after prevention)

average result 0.19 (+25%), stddev 0.56 (-8%), prevention price 0.01
→ effect of prevention: stabilize result, reduce volatility

Time series of annual result (after prevention and insurance)

average result 0.17 (+12%), stddev 0.43 (-29%), prev+ins price: 0.13
→ effect of insurance: reduce (extreme) volatility

In summary, we therefore have:

	Result	stdev	price[107]
raw	0.15	0.60	
+ prevention	0.19 (+25%)	0.56 (-8%)	0.01
→ cost-effective adaptation (net gain of 0.04 at cost of 0.01)			
+ insurance (and prevention)	0.17 (+12%)	0.43 (-29%)	0.01+0.12
→ substantial reduction of volatility, result increase even after deduction of prevention cost and insurance premium → affordable!			
for comparison: insurance alone	*0.12 (-17%)*	*0.45 (-25%)*	*0.153*
→ prevention (strongly) incentivizes insurance			

Key drivers for risk transfer demand to complement risk reduction measures are:

- Volatility of (remaining) damage
- Level and trend of expected damage (related to budget)
- Damage clusters (relative to budget and financing capacity)
- Budget constraints and opportunity costs (e.g. school investments)
- Availability of emergency relief capital
- Subjective risk appetite

The last point shall no means be underestimated, as it refers also strongly to risk culture.

Risk transfer can be agreed upon based on different triggers:

- indemnity[108], also called incurred or occurred damage: The incurred damage is compensated for, i.e. the insured sends the bill for fixing the damage and gets reimbursed. Pro: exact amount paid, Con: takes time, involves damage assessment and may contain moral hazard (insurance fraud).
- parametric, also called index: A physical parameter exceeding a certain threshold (e.g. wind speed above 35 m/s) triggers the payment of a pre-agreed amount – or more generally an amount as a function of the parameter(s). Pro: fast, unbureaucratic, pre-agreed. Con: the pre-agreed value is paid, actual damage might differ (so called basis risk retained by the insured[109]).
- modeled (well, a form of parametric): A model is run after an event, based on the key properties of the event (e.g. a wind footprint as measured by a meteorological office) and the resulting modeled damage amount is paid

and with different partners, such as:

- policyholders – from macro (e.g. large corporates in Texas) to micro (e.g. smallholder farmers in Ethiopia) – and the usual single household
- insurers (reinsurers insure them)
- other reinsurers, called retrocession

[107] Note that price is already taken into account in result
[108] specific or market-share
[109] That's why one often finds hybrid solutions, but we refrain from getting into details.

- capital market, called insurance-linked security (ILS) or Cat Bond[110]
- public sector (public-private partnership, PPP)

and can be based either on free choice (whether the take up insurance or not) or mandatory[111] – or any shade in between. Please note the issue of adverse selection (especially pertinent for perils such as flood), i.e. that only the most at risk seek cover, rendering the scheme costly or even non-commercially viable – and hence the justified consideration of compulsory or mandatory schemes.

Insurance conditions

There are basically two types of insurance conditions, proportional and non-proportional. Proportional means the insured retains a proportional (linear) fraction of the damage, non-proportional in essence means the insured is covered above a certain threshold (called deductible) for a certain cover[112].

proportional: $damage_{after}=damage_{before} * share$
non-proportional: $damage_{after}=min(max(damage_{before} - deductible,0),cover)$

Where share needs to be defined depending on who shall be liable for damage after, i.e. if $damage_{after}$ is the damage to be reimbursed by the insurer, share is the insurer's share of the total or 'from ground up' damage. Likewise, $damage_{after}$ in above notation in the non-proportional case is the damage the insurer is liable for, as the deductible (and any damage exceeding the cover) remains with the insured.

[110] Not this one:

[111] See e.g. Source: Efficient Monopolies. The Limits of Competition in the European Property Insurance Market, Thomas von Ungern-Sternberg, Oxford University press, 2004. ISBN 0-19-926881-9

[112] There are unlimited covers, but this stretches the second principle of insurability, namely the ability to assess the outcome.

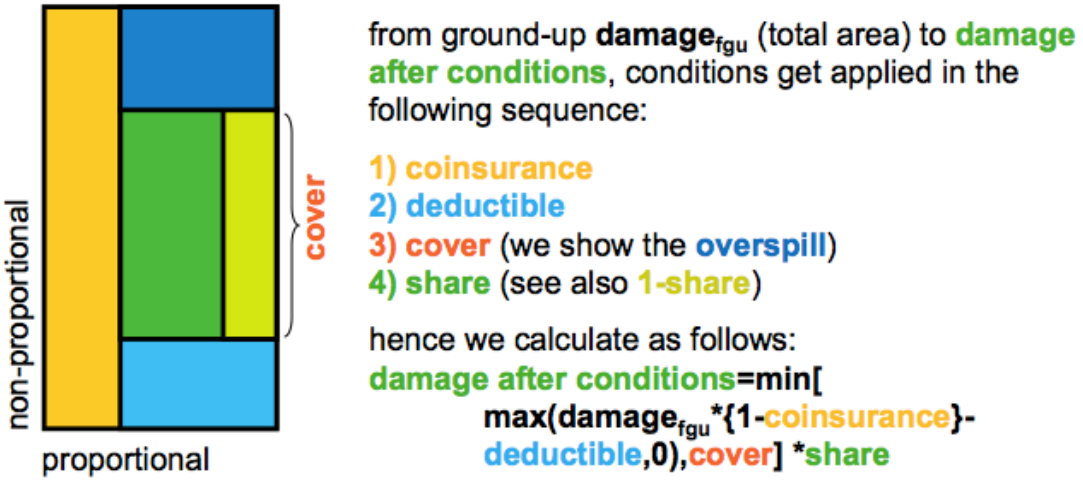


Figure: the elements of insurance conditions. The event based approach as followed in climada does allow for the consideration of all these elements.

climada implementation of insurance conditions

Please read the above section “” carefully first. Remember that the outer (explicit) loop is over assets, the inner (implicit) one over events.

```
for asset_i=1:n_assets % approx line 170 in climada_EDS_calc.m
     […]
     % calculate the from ground up (fgu) damage
     temp_loss=entity.assets.Value(asset_i)*MDD.*PAA;

     if entity.assets.Deductible(asset_i)>0 || ...
        entity.assets.Cover(asset_i) < entity.assets.Value(asset_i)

        % apply Deductible and Cover
        temp_damage=min(max(temp_damage-...
            entity.assets.Deductible(asset_i)*PAA,0),...
            entity.assets.Cover(asset_i));
     end

     % add to the resulting EDS (event damage set) structure:
     EDS.damage=EDS.damage+temp_damage'; % add to the EDS
     […]
end % asset_i
```

Similarly, any conditions on the event damage set (EDS) can be evalaued, always of the form min(max(loss-deductible,0),cover), i.e. a non-proportional per-event cover (CatXL) can be evaluated on the EDS as:

`EDS.damage` = share * min(max(`EDS.damage` -deductible,0),cover)

For any index based risk transfer, the EDS can be computed starting from the hazard event set and calculating the index value for each event. In the case of the simplest index, just a wind speed threshold T at a given location, payout P of $10 per m/s above threshold, this might look as simple as:

```
temp_hazard      = hazard.intensity(*,hazard_pos);
nz_pos           = find(temp_hazard);
EDS_index        = min(temp_hazard(nz_pos)-T,0)*P
```

where `hazard_pos` contains the index of the centroid next to the station (determined using `climada_geo_distance`). Note that due to the sparsity of `hazard.intensity`, the min function is speeded up by using find first.

More specifically, and to ease the use of risk transfer measures, they can also be specified in the measures tab of the entity Excel sheet[113]. In column 'risk transfer attachment', one enters the attachment point (synonym for deductible) in the same currency and currency unit as all other figures, and in column 'risk transfer cover' the cover. In column 'cost', one only needs to enter the cost in addition to the pure expected damage (which is calculated within climada, when the risk transfer gets applied). Costs for risk transfer are – to keep it simple here – a fixed amount for management expenses and capital costs that scale first order with the cover[114]. As an approximation, one might use rules of thumb to determine a proxy for the sum of management expenses and capital costs, like (GLM stands for geometric layer mean):

1. determine `sqrt(GLM)`, where `GLM=sqrt(attachment_point*cover)`
2. look up the probability of a damage of size `sqrt(GLM)` on the DFC (without measures, to keep it simple)
3. proxy for sum of costs is `max(sqrt(probability of damage),0.01)*cover`

Note on scenarios

Since climada makes use of scenarios in at least three instances, it might be worthwhile providing a definition and some remarks.

climada uses scenarios e.g. in:

- hazard event set generation (generating artificial single hazard events or scenarios, such as by 'wiggling' path and intensity of tropical cyclones)

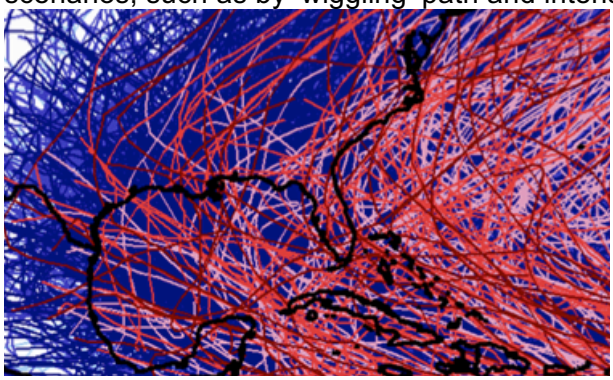


Figure: historic (red) and probabilistic (blue) storms, see functions `climada_tc_*`

- charting out economic pathways (the economic development scenarios, leading to future assets) and
- last but not least climada uses climate impact scenarios in the sense of modified hazard event sets (one could also see them as events compatible with future climate conditions).

Definition: A scenario is a snapshot that describes a possible and plausible future. Scenario analysis is a systematic approach to anticipate a broad range of plausible future outcomes.

[113] See ../data/entities/entity_template.xls

[114] this is a very crude assumption. As climada only adds the expected damage costs, one needs to be careful here.

Scenario analysis is used in general …

- as a risk management tool to assess the potential impact of an event or development to anticipate and understand risks (as e.g. in the climada hazard event sets)
- as a tool to spot new business opportunities and to discover strategic options[115] (e.g. as climada adaptation measures)
- as foresight in contexts of accelerated change, greater complexity and interdependency
- for evaluation of highly uncertain events that could have a major impact (e.g. climada climate change hazard event sets)
- to steer mitigation strategies, implementation and monitoring by reviewing and tracking different possible developments (as in the whole economics of climate adaptation assessment)

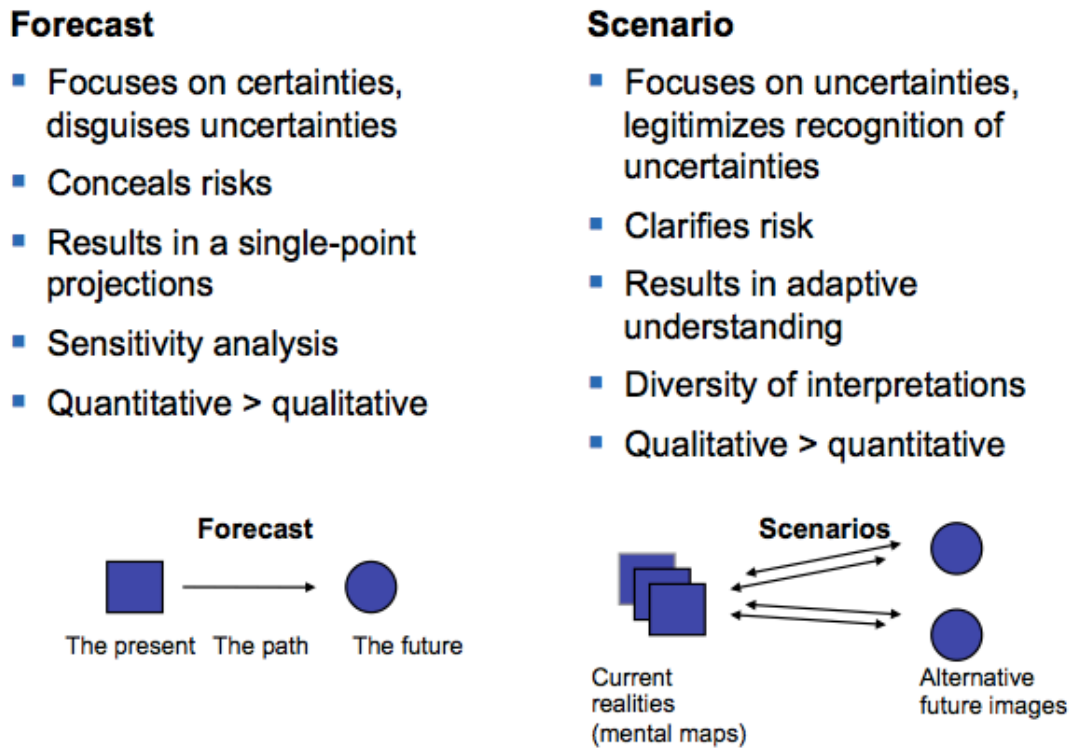


Figure: Some key properties of forecasts and scenarios in comparison.

climate impact scenarios – remarks on climada implementation

There are different ways to represent climate change scenarios in the model.

Representation is possible via

- Parameterized impact:
  Estimate the climate change impact on key hazard parameters and represent those changes in the probabilistic event set, either by
  - re-generating the probabilistic event set based on these parameters (e.g. consider changing properties of `tc_track` prior to calling `climada_tc_hazard_set`) or by

[115] See e.g. the famous http://s03.static-shell.com/content/dam/shell-new/local/corporate/Scenarios/New_Lens_Scenarios_Low_Res.pdf

    - reflecting those changes by modification of the 'present climate' hazard event set (e.g. multiply the hazard intensity by a factor), see further below
- Downscaled event set:
  Extract events from a downscaled GCM-driven model chain[116]

Note that a changing climate might also have impacts on e.g. vulnerabilities

While there all degrees of freedom to implement climate change impact scenarios in climada, the following few remarks might be of value:

Remember that hazard contains the hazard event set, `hazard.intensity` the sparse array with intensities, `hazard.frequency` the vector of event (occurrence) frequencies. Therefore, the following cases are very straightforward (we use wind speed as example, works similarly for parameters such as flood height):

- Increase wind speed for all events by 5%:
  ```
  hazard.intensity =hazard.intensity *1.05;
  ```
- Increase event frequencies by 5%:
  ```
  hazard.frequency=hazard.frequency*1.05;
  ```
- Increase all wind speeds by 5 m/s (note that hazard.intensity is sparse, hence we first need to identify the non-zero elements);
  ```
  nz_pos=find(hazard.intensity) %non-zeros
  hazard.intensity(nz_pos)=hazard.intensity(nz_pos)+5;
  ```
- Increase only wind speeds > 45 m/s by 5 m/s:
  ```
  pos45=find(hazard.intensity>45);
  hazard.intensity(pos45)=hazard.intensity(pos45)+5;
  ```

The code `climada_hazard_clim_scen` allows for such impact parameterizations.

Climate impact scenarios – sources

Since the advanced user will likely construct own climate change impact scenarios, she might find relevant information at the following sources:

http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_AnnexI_FINAL.pdf and http://www.ipcc.ch/report/ar5/wg1/docs/ar5_wg1_annexI_all.zip: IPCC Atlas of Global and Regional Climate Projections
http://sealevel.climatecentral.org: domestic US coastal surge information until 2100
http://climate-adapt.eea.europa.eu: European adaptation site
http://www.meteoschweiz.admin.ch/home/klima/zukunft/klimaszenarien.html: Swiss climate impact scenarios
and last but not least: http://newclimateeconomy.report

Tropical cyclones – technical remarks

Windfield calculation

[116] Please refer to the climada module ws_europe (https://github.com/davidnbresch/climada_module_ws_europe) and see Schwierz, C., P. Köllner-Heck, E. Zenklusen Mutter, D. N. Bresch, P.-L.Vidale, M. Wild, C., and Schär, 2010: Modelling European winter wind storm losses in current and future climate. Climatic Change (2010) 101:485?514, doi: 10.1007/s10584-009-9712-1.

To determine the impact of any given storm, function `climada_tc_windfield` generates wind field resulting from single track of tropical cyclone. The function starts from ther track center `tc_track.MaxSustainedWind` in knots and generates the 2D windfield in `res.gust` in m/s.

Normally wind footprint calculation is tested on a single `tc_track` prior to generation of the hazard event set of all the entire historical and probabilistic track set (as shown in the step-by-step approach at the beginning of the manual, see `climada_demo_step_by_step`). The windfield calculations are speeded up by only calculating for centroids within 750 km distance of min/max track lon/lat.

```
res = climada_tc_windfield(tc_track(1170),centroids);
```

For details, see the header of `climada_tc_windfield`

Method

Currently, the code implements the Holland windfield[117].

$$S = \begin{cases} \max\left(0,\ \left(\left(M - \mathrm{abs}(T)\right)\cdot\left(\frac{R}{D}\right)^{3/2}\cdot e^{1-\left(\frac{R}{D}\right)^{3/2}}\right)+T\right) & D < 10\cdot R \quad \textit{from center to the outer c} \\ 0 & D > 10\cdot R \quad \text{out of radius} \end{cases}$$

In case one runs with pretty coarse centroids, where the 'average' distance between centroids is much larger than the storms radius of maximum wind (R), the wind speed (S) might better be parametrized by (see around line 290 in `climada_tc_windfield`):

$$S = \begin{cases} \min\left(M,\ M + 2\cdot T\cdot\frac{D}{R}\right) & D \le R \quad \text{in the inner core} \\ \max\left(0,\ \left(\left(M - \mathrm{abs}(T)\right)\cdot\left(\frac{R}{D}\right)^{3/2}\cdot e^{1-\left(\frac{R}{D}\right)^{3/2}}\right)+T\right) & D < 10\cdot R \quad \text{in the outer core} \\ 0 & D > 10\cdot R \quad \text{out of radius} \end{cases}$$

where *M* denotes the maximum sustained wind and *T* is the celerity (forward speed). In case where *D* is still ten times smaller than *R*, you find yourself in the outer core of the storm where the wind speed takes the form of the second line in the equation above. If none of these cases are true, the wind speed is set to zero.

[117] Holland, G. J., 1980: An analytic model of the wind and pressure profiles in hurricanes. Monthly Weather Review, 108, 1212-1218.

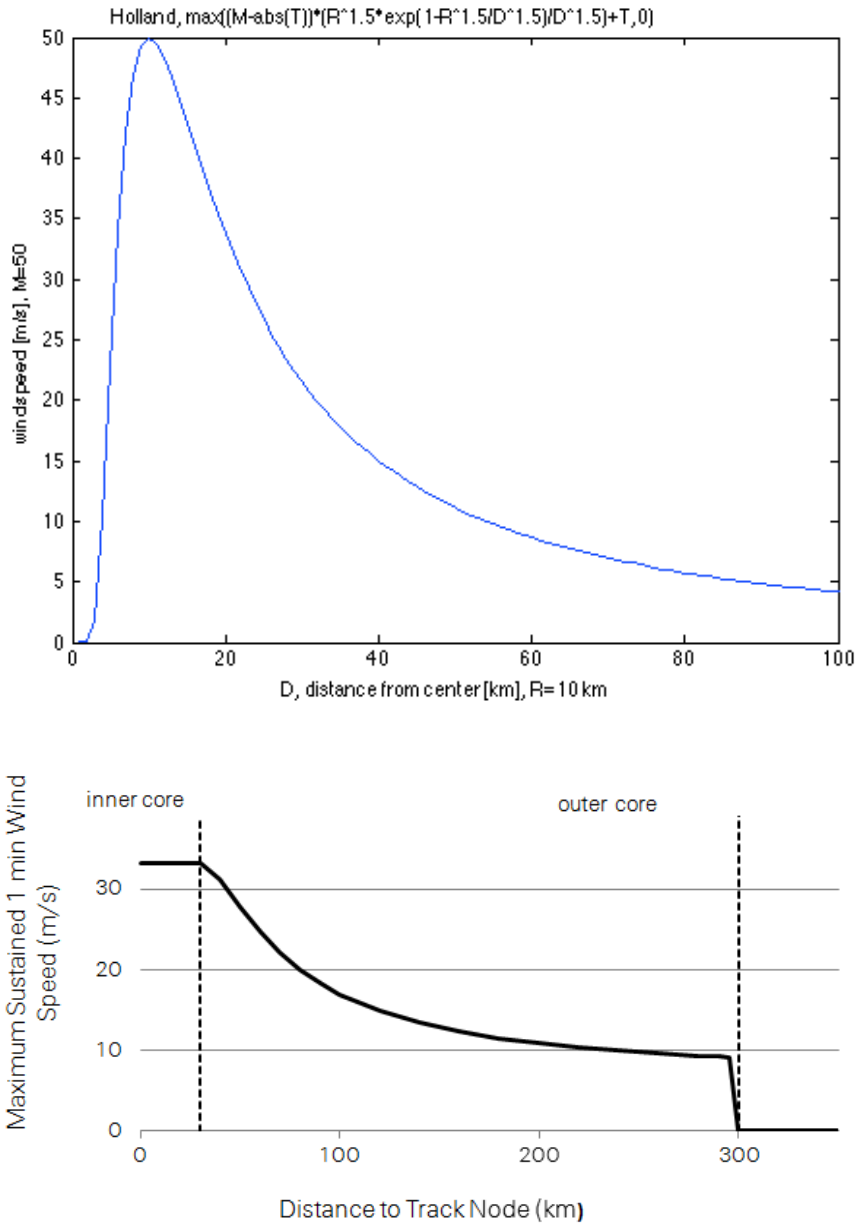


Figure: Maximum sustained 1 min wind speed in relation to the distance to the track node (top panel original Holland, lower panel for special case as described above).

The radius of maximum wind (R, in km) depends on the latitude of the track node (L) as follows:

$$R = \begin{cases} 30 & L \le 24° \\ 30 + 2.5 \cdot \mathrm{abs}(L) - 24 & L > 24° \\ 75 & L > 42° \end{cases}$$

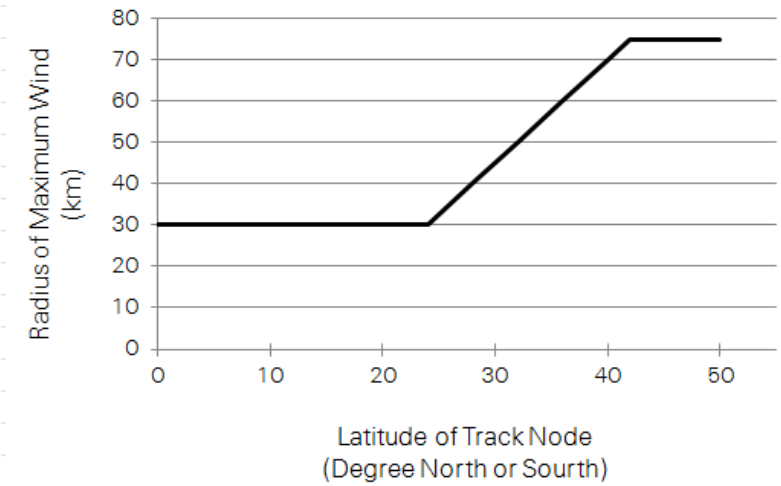


Figure: Radius of maximum wind in relation to latitude of track node.

Finally, the wind speed, *S*, describes the maximum sustained 1 min wind speed. To derive wind gusts lasting just a few seconds (3-5 s), we note that wind peaks are typically around 27% higher than a 1 min sustained wind in a hurricane environment. http://www.prh.noaa.gov/cphc/pages/FAQ/Winds_and_Energy.php

Any other wind field parameterization can be implemented in a similar fashion (just implement in a copy of `climada_tc_windfield`, e.g. `climada_tc_MY_windfield`, see also the routine `climada_tc_hazard_set` to change the caller when generating the probabilistic set).

In order to test the wind field calculation, the following might help:

Use the tc_track structure (should still be in memory), but start with only one track, e.g. tc_track(84) for the 84th track. Investigate tc_track.name to find a particular event. Use e.g. the following code to show a list of track number, year and name:

```
for i=1:length(tc_track)
     fprintf('%i %i %s\n',i,tc_track(i).yyyy(1),char(tc_track(i).name));
end
```

Obtain centroids (points at which to evaluate the winfield) using

```
centroids = climada_centroids_read('',1)
```

Note that this call with the 1 also plots the centroids (use the zoom function on the map). See also the parameter `check_plot` in the PARAMETER section of the `climada_tc_windfield` code or refer to the routine `climada_color_plot`.

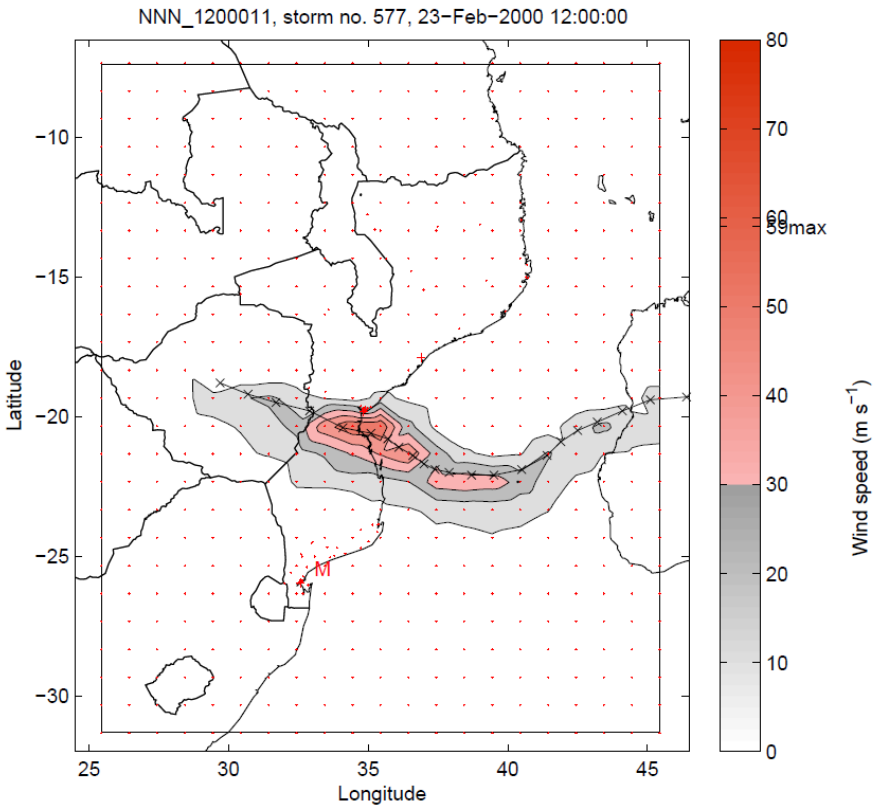


Figure: Wind field calculated based on track 577 of the South Indian Ocean. This particular track results in the second highest wind speed in the city of Beira, Mozambique.

Single cyclone track evolution animation

The function `climada_tc_windfield_animation`[118] refines `tc_track` to 1hour resolution, calculates wind field for every time step of 1h. The function displays the wind fields for selected aggregated time steps, e.g. 3h, 6h, 24h. Aggregation default is 6h.

[118] See climada module https://github.com/davidnbresch/climada_module_tc_hazard_advanced

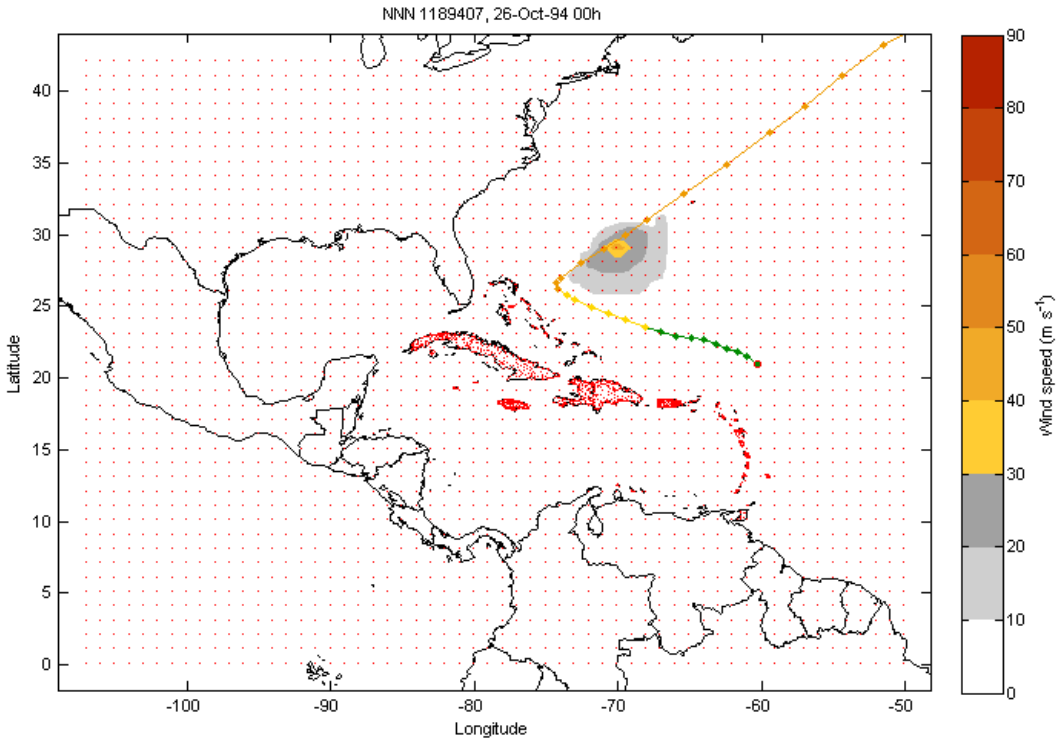


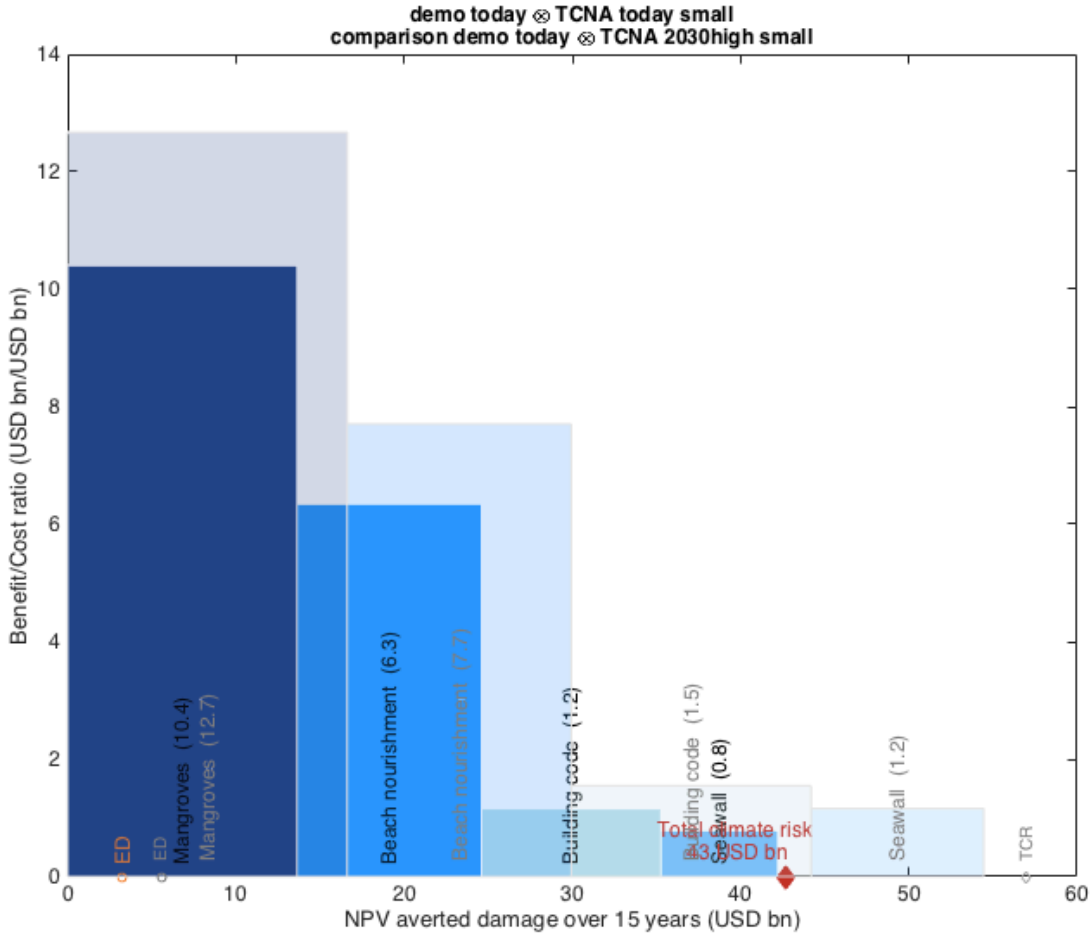
Figure: Snapshot from the animation, wind field calculated for every time step.

Economics of Climate Adaptation (ECA) – key routines

The function `climada_waterfall_graph` plots the waterfall figure for today's damage and future damage including economic growth and climate change for the annual expected loss or any specific return period. Inputs are the three event damage sets (e.g. EDS_today.mat, EDS_2030.mat, EDS_2030_clim.mat), prompted for if not given. Any specific return period or annual expected damage can be chosen.

Figure, see `climada_waterfall_graph`

The function `climada_adaptation_cost_curve` plots the adaptation cost curve, i.e. the cost/benefit (or benefit/cost) ratio for each measure on the vertical axis, the benefit on the horizontal axis. Note that all values are NPV.



Figure, showing the option to plot two adaptation cost curves for direct comparison, see `climada_adaptation_cost_curve`

Proposed colours to use for measures:

Color	red	green	blue	red	green	blue	for excel
1	211	205	177	0.82	0.80	0.69	0.82 0.8 0.69
2	194	186	148	0.76	0.73	0.58	0.76 0.73 0.58
3	231	179	75	0.90	0.70	0.29	0.9 0.7 0.29
4	250	192	144	0.98	0.75	0.56	0.98 0.75 0.56
5	255	219	105	1.00	0.86	0.41	1 0.86 0.41
6	188	226	146	0.73	0.88	0.57	0.73 0.88 0.57
7	152	193	129	0.59	0.75	0.50	0.59 0.75 0.5
8	181	195	184	0.71	0.76	0.72	0.71 0.76 0.72
9	162	202	190	0.63	0.79	0.74	0.63 0.79 0.74
10	162	194	232	0.63	0.76	0.91	0.63 0.76 0.91
11	112	189	210	0.44	0.74	0.82	0.44 0.74 0.82
12	174	214	224	0.68	0.84	0.88	0.68 0.84 0.88
13	255	175	175	1.00	0.68	0.68	1 0.68 0.68
14	205	183	201	0.80	0.71	0.79	0.8 0.71 0.79
15	255	209	248	1.00	0.82	0.97	1 0.82 0.97
16	174	167	139	0.68	0.65	0.54	0.68 0.65 0.54
17	155	147	113	0.61	0.57	0.44	0.61 0.57 0.44
18	200	140	57	0.78	0.55	0.22	0.78 0.55 0.22
19	238	153	110	0.93	0.60	0.43	0.93 0.6 0.43
20	255	184	80	1.00	0.72	0.31	1 0.72 0.31

21	149	193	112	0.58	0.75	0.44	0.58 0.75 0.44
22	117	154	98	0.46	0.60	0.38	0.46 0.6 0.38
23	142	156	145	0.55	0.61	0.57	0.55 0.61 0.57
24	125	164	151	0.49	0.64	0.59	0.49 0.64 0.59
25	125	155	202	0.49	0.61	0.79	0.49 0.61 0.79
26	85	150	173	0.33	0.59	0.68	0.33 0.59 0.68
27	136	177	190	0.53	0.69	0.74	0.53 0.69 0.74
28	255	137	137	1.00	0.54	0.54	1 0.54 0.54
29	167	144	163	0.65	0.56	0.64	0.65 0.56 0.64
30	255	171	232	1.00	0.67	0.91	1 0.67 0.91

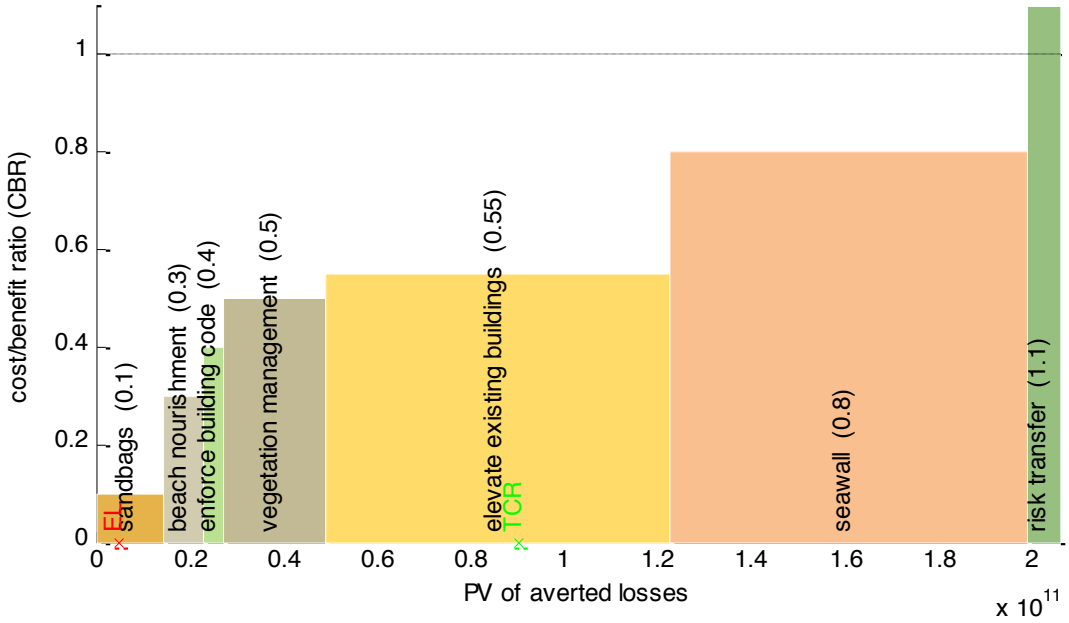


Figure: Example plot with proposed colours

See also `climada_adaptation_event_view`, which shows the effect of measures for events of different return periods.

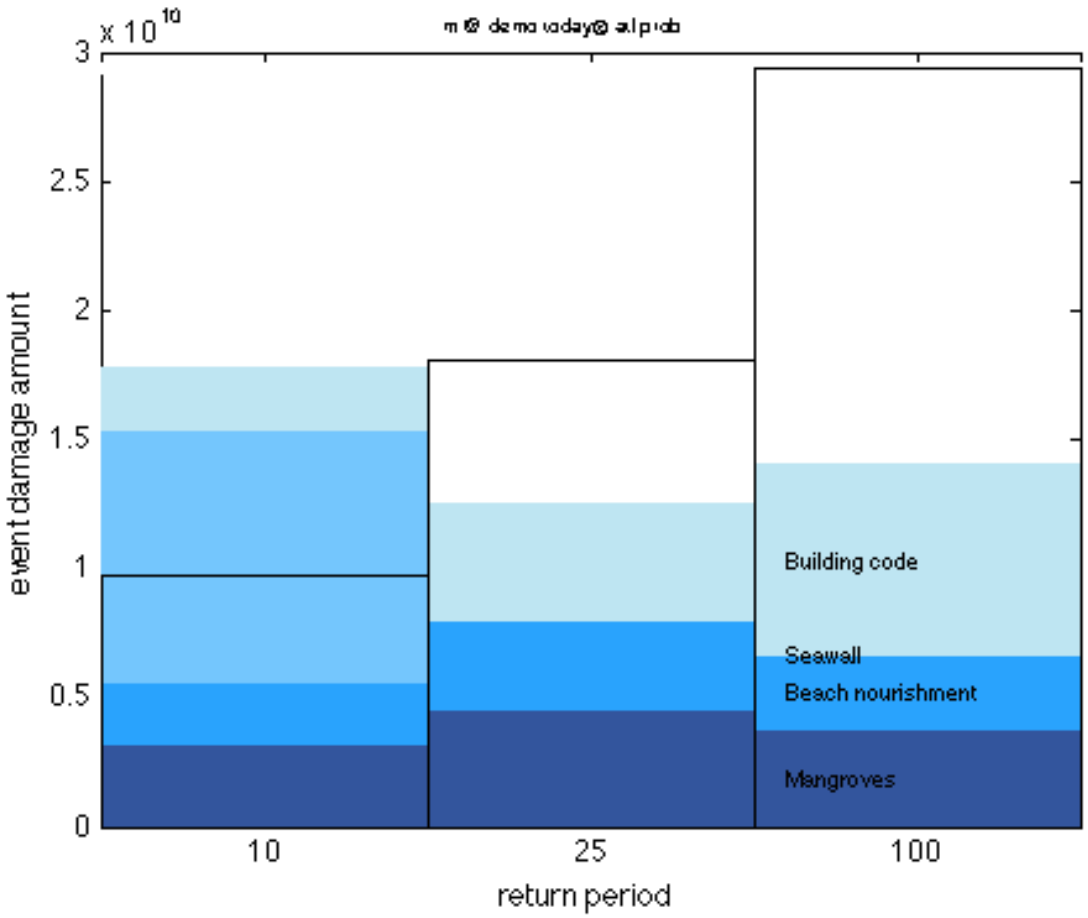


Figure: A sample plot of adaptation event view (see `climada_adaptation_event_view`). It shows the effectiveness for measures for events of a given return period (here 10, 50 and 100 years, event damage show as black rectangles, mitigating effect of measures in blue colors). Note that for the 10-year event, all modeld damage can be averted by the proposed measures, for the 50-year event still abut 70% and for the 100-year event, abput half of the damage. The plot shows has still one shortcoming: The seawall (second lightest blue) shows up very effectively for the 10-year event, but the labeling (provided on the 100-year event only) is hence difficult to read.

See also `climada_EDS_DFC` to visualize the effect of specific measures on the per occurrence damage exceedance frequency curves (DFC).

Please be reminded that the function `climada` does prompt for today's assets and today's hazard, future assets and hazard and perform all the calculations, resulting in the adaptation cost curve as well as the adaptation event view.

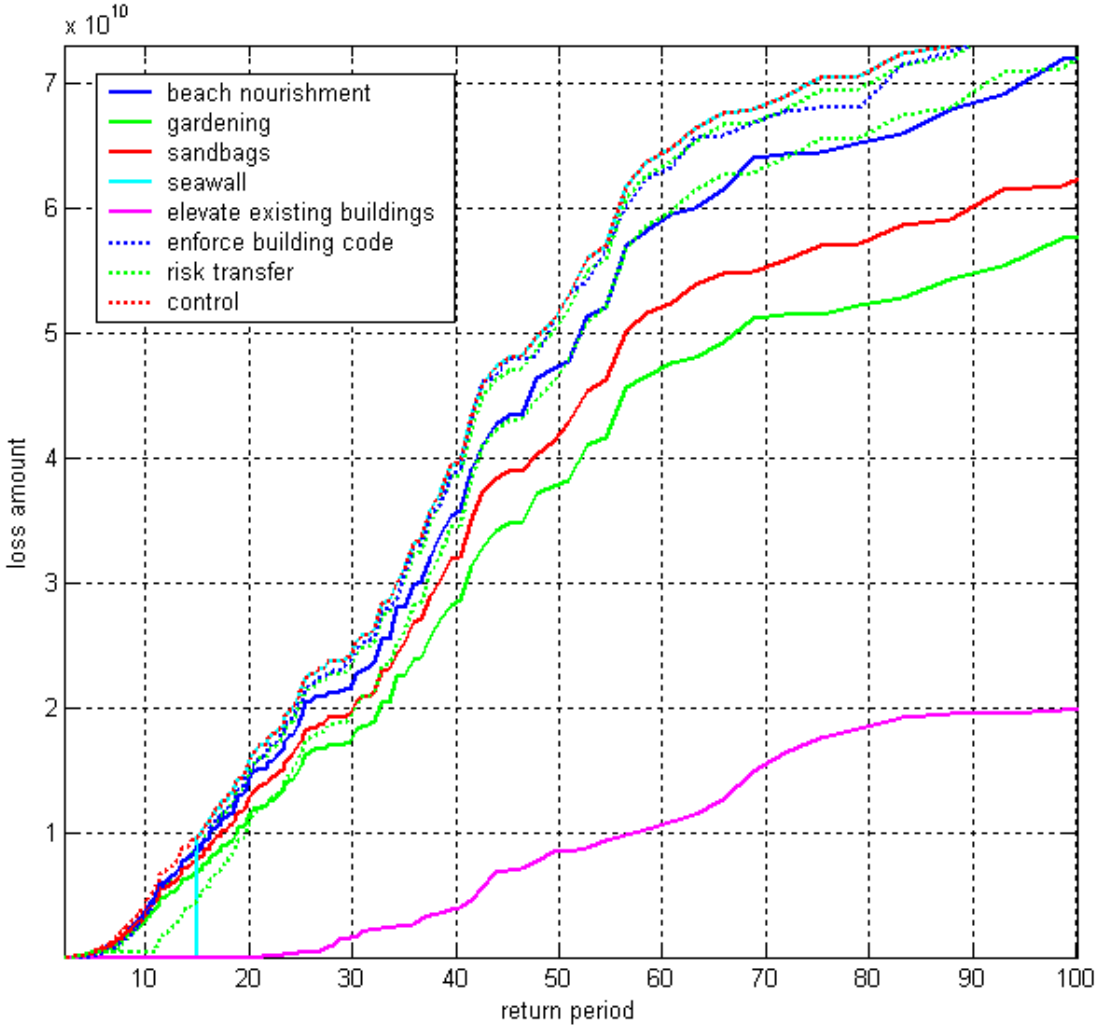


Figure: The per occurrence damage exceedance frequency curve (DFC) for today's hazard. Note the effect of the dam (cut-off at 15yr return period, light blue curve). Note further the prominent impact of 'elevate existing buildings', but this is entirely due to an optimistic modification of the underlying damage function.

A remark on loss, damage and vulnerability

Loss: irrevocable loss [unersetzbarer Verlust], e.g. loss of glaciers (due to warmer climate) or loss of coastal land (due to sea level rise) or loss of precipitation (due to changed weather patterns). Losses can only be compensated for, not re-stated or replaced. A risk management approach to loss does strongly suggest avoiding such losses due to their irrevocable nature. Risk management options such as intervention or sharing of risk can only deal with some of the consequences of the loss, not the loss itself. Irrevocable losses are uninsurable - still, some of their consequences can be insured (e.g. glacier melt is not random, hence cannot be insured, but the risk of a glacier lake bursting can be insured, since it's a random event. Likely: sea level rise and the loss of coastal land cannot be insured, since it's not random - but storm surge risk can be insured, since it's a random event).

Damage: replaceable damage [ersetzbarer Verlust], e.g. damage of property (can be repaired/rebuilt), consequential damage, like business interruption (can be monetarily compensated). Damage can be repaired or rebuilt at a cost. The full scale of risk management options can be employed: avoidance, prevention, intervention and risk transfer. Therefore, an economic analysis provides a suitable framework to assess

the damage and to determine the most effective combination of avoidance, prevention, intervention and risk transfer measures to address damage.

→ **Corollary**: Any mechanisms to deal with loss & damage has to make this differentiation - To propose a 'standard' risk management approach to replaceable damage and a (e.g. compensation) mechanism to the irrevocable loss. Since most adaptation measures as dealt with by climada a risk management ones, **we refer to 'damage' wherever possible in the climada context**.

Vulnerability (weadapt.org): The ordinary use of the word 'vulnerability' refers to the capacity to be wounded, i.e., the degree to which a system is likely to experience harm due to exposure to a hazard. The scientific use of 'vulnerability' has its roots in geography and natural hazards research but this term is now a central concept in a variety of research contexts such as natural hazards and disaster management, ecology, public health, poverty and development, secure livelihoods and famine, sustainability science, land change, and climate impacts and adaptation. In order to make sense of the range of definitions, the different interpretations and definitions can be seen to be rooted in three academic disciplines namely risk and hazard or biophysical approaches, political economy and the concept of ecological resilience. From a climate change perspective, according to the IPCC, vulnerability is "the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes".

Damage function: functional relationship between the hazard intensity and the resulting damage. The hazard intensity is measured (or modeled) at a given spatiotemporal point (a location, a given event) of a hazard (e.g. a flood height at a given latitude longitude at a given time). The damage is expressed as a percentage of the exposed (and hence possibly affected) asset. One often differentiates between the percentage of affected assets (PAA) as well as the mean damage degree (MDD). What's called a damage function in climada is often also referred to as 'vulnerability curve'.

If for say a storm surge height of 1 meter, 50% of all assets are affected, and the damage to these affected assets is 5% of their total value, the PAA is 0.5 and MDD 0.05. If the total asset value is 100, the resulting damage is hence 100 x 0.5 x 0.05 = 2.50

In the case of value signifying exposed population, PAA is used to reflect affected individuals; while MDD could be used to parameterize some sort of impact to the affected individuals (e.g. using disability or quality adjusted life years, DALY/QALY).

→ **Corollary**: While many modelers use 'vulnerability' or 'vulnerability curve' as a standard term to denote what is described as damage function above, **we refer to 'damage function' wherever possible in the climada context**.

Further sources of DRM/climate adaptation information/tools

Just for reference, with no aspiration for comprehensiveness, a small list of sites and sources:

- www.climatesmartplanning.net/tools.html collection of tools
- www.preventionweb.net/english/professional tools, training material and much more

- http://iri.columbia.edu/our-expertise/climate/tools collection of tools
- http://tilz.tearfund.org/en/themes/disasters/disaster_risk_reduction_drr/cost_benefit_analysis_of_drr cost-benefit analysis of DRR, also general interest: http://tilz.tearfund.org/en/themes/disasters/
- http://policy-practice.oxfam.org.uk/publications/applying-cost-benefit-analysis-at-a-community-level-a-review-of-its-use-for-com-303558 cost-benefit analysis
- http://www.climate-service-center.de/036238/index_0036238.html.en

Sites featuring climada
- https://resilience-exchange.sphaera.world/solutions/economics-of-climate-adaptation-assessment-model
- http://www.preventionweb.net/educational/view/42020

MATLAB/Python – some possibly useful tools

The MATLAB® Engine API for Python® provides a Python package named *matlab* that enables you to call MATLAB functions from Python. See http://ch.mathworks.com/help/matlab/matlab_external/get-started-with-matlab-engine-for-python.html

To run python from MATLAB, consider e.g. to set (assuming you installed Python 3.5 on a Mac[119]):
```
pyversion /Library/Frameworks/Python.framework/Versions/3.5/bin/python3.5
py.importlib.import_module('helper_advanced_windfield_global')
```

Just for reference, as one might consider converting code from Python to be used with climada – or parts of climada to be used in Python…

code → Python (not tested yet)
- Small Matlab to Python compiler: convert Matlab code to Python code, also developed here: SMOP@chiselapp
- LiberMate: translate from Matlab to Python and SciPy. Github repo.
- OMPC: Matlab to Python (a bit outdated)
- Matlab to Python conversion: No download files available

There's also oct2py which can call .m files within python, see https://pypi.python.org/pypi/oct2py. As climada runs in Octave, this is a viable alternative to converting to Python (for the time being). It requires GNU Octave, see right at the top of the manual.

Also, for those interested in an interface between the two languages and *not* conversion:
- pymatlab: communicate from Python by sending data to the MATLAB workspace, operating on them with scripts and pulling back the resulting data
- Python-Matlab wormholes: both directions of interaction supported
- Python-Matlab bridge: use Matlab from within Python, offers matlab_magic for iPython, to execute normal matlab code from within ipython
- PyMat: Control Matlab session from Python
- pymat2: continuation of the appearingly abandoned PyMat.
- mlabwrap, mlabwrap-purepy: make Matlab look like Python library (based on

[119] See https://www.python.org/downloads or get Python including many libraries from https://www.continuum.io/downloads#osx

PyMat)

- oct2py: run GNU Octave commands from within Python
- pymex: Embeds the Python Interpreter in Matlab, also on File Exchange
- matpy: Access MATLAB in various ways: create variables, access .mat files, direct interface to MATLAB engine (requires MATLAB be installed).
- MatPy: Python package for numerical linear algebra and plotting with a MatLab-like interface