On the estimation of damages due to coastal floods (EGU2012 – NH5.5 – XY299)

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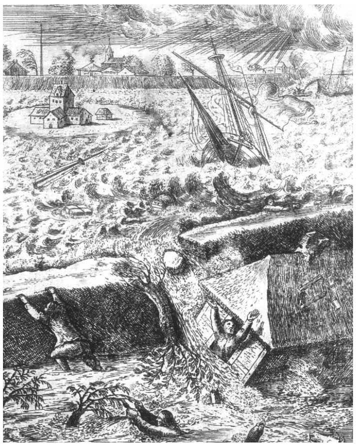
Sea level rise is going to affect the statistics of extreme sea levels. If one wants to calculate damages due to upcoming storm surges, it is necessary to estimate the damage due to individual flood events. In the case of (coastal) floods, so called stage damage functions are employed, which provide for a flood of certain maximum level a typical damage that occurs at a considered location. We investigate how changes in the extreme value statistics affect the expected damages and find surprisingly simple relations. Our results show that in addition to the knowledge about local sea level rise, it is essential to know the actual form of damage functions which usually follow power-laws. Thus, we estimate damage functions (i) from historical flood damages and (ii) from a limited case study.

Introduction

In order to estimate the damage costs of future storm surges one can apply the concept of stage-damage functions which provide for a flood of certain water level a corresponding direct monetary damage. Combined with extreme value statistics, the risk can be calculated. Both components, extreme value statistics and damage functions, involve uncertainties and crucially influence the outcome.



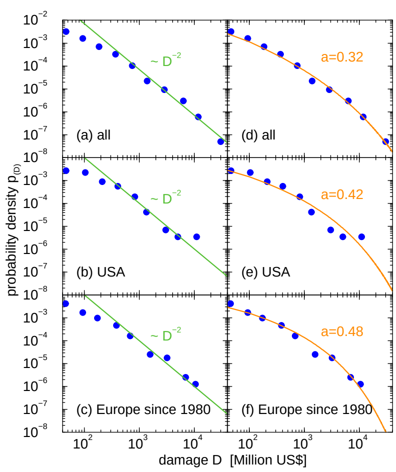
wikipedia: Kupferstich "Deichbruch" von Winterstein 1661

A macroscopic stage-damage function (i.e. a function that represents the total damage in the entire considered area) can be obtained by summing up all damages of a lower scale (e.g. building scale) or by an indirect approach. Following the former approach to assess the macroscopic damage function of a case study area in Denmark it is necessary to determine the inundation height of each asset (e.g. building) for certain flood events in order to calculate the corresponding damage. Since hydrodynamic modeling requires more effort and computational power, many studies use a simple flood fill algorithm, i.e. they determine the intersection between the plane of the raised water level and the digital elevation model (DEM), and treat the entire connected area between sea and intersection as inundated. This procedure overestimates the flooded area since it corresponds to an asymptotic filling of all land that would be flooded at a certain permanent sea level.

Motivation:

- How to estimate damages from (coastal) floods?
- How do they change with sea-level-rise?
- How are they influenced by protection measures?

Indirect identification of damage functions from damage records



Probability densities of damages due to floods in the years 1950-2008 (data: CRED)

In summary, we characterize distributions of recorded flood damages, argue that they are caused by extreme events, and employ density transformation to deduce damage functions relating both. For Gumbel distributed extreme events ($\xi = 0$) we find asymptotically

$$D_{(s)} \sim \begin{cases} e^{\frac{s}{\tilde{\gamma}(\alpha-1)}} & \text{for } \tilde{p}_{(D)} \sim D^{-\alpha} \text{ with } \alpha > 1 \\ \left(\frac{1}{\tilde{\gamma}} s\right)^{\frac{1}{a}} & \text{for } \tilde{p}_{(D)} \sim \frac{a}{b} D^{a-1} e^{-\frac{D^a}{b}} \text{ with } a > 0\,. \end{cases} \quad (1)$$

The involved GP parameters are in an ultimate sense and in practice penultimate approximations might be necessary.

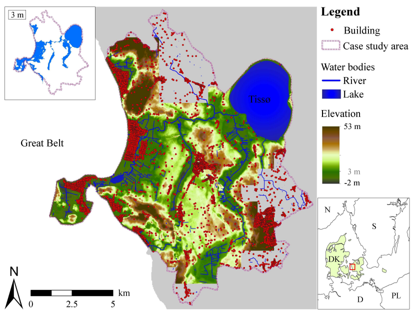
Kalundborg case study

The case study area is situated in the south of the city of Kalundborg in Denmark. The considered area belongs to the municipality of Kalundborg which itself is located on the west coast of the island of Zealand. To the west, the case study area borders at the Jammerland Bay, the Musholm Bay, and the Great Belt which connects the Baltic Sea with the marine area Kattegat. There are a few small rivers and the fourth-largest lake of Denmark, Lake Tisso, in the area.

The case study area has a size of approx. 143 km2. The available DEM covers 115 km2 which corresponds to the low-elevation area. The DEM 2̃013 obtained from the Kalundborg municipality (DEM owned by BlomInfo A/S, Denmark) 2̃013 is based on a LIDAR dataset from 2007 and relates to the reference system DVR90 (Dansk Vertikal Reference 1990). It does not take account of any artificial elevations, such as buildings (therefore it is sometimes referred to as a digital terrain model, DTM). Currently, there exist no flood defence measures apart from natural protecting elevations that need to be considered. The cell size of the DEM is 1.6m1.6 m, with a vertical resolution of 10 cm. The region is predominantly rather flat with a range in elevation of almost 55 m. However, some areas lie below sea level (approx. 0.9 km2).

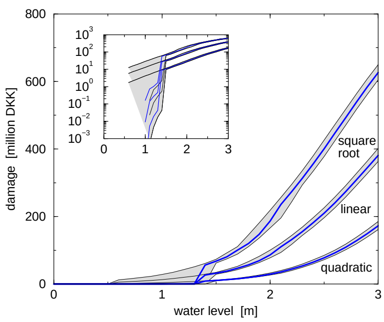
The case study area contains more than 6000 properties with almost 17 000 structures concentrated in a few settlements with approx. 200 to 4500 inhabitants. The cadastral dataset contains information about the building position, type of the building, property value and land value but not about the size and shape of the structures. This implies, that the flood flow procedure cannot consider the buildings as barriers, which is only a minor limitation, since most buildings stand separately and are not adjacent. Property and land value were obtained from the calculation basis for property taxes and were provided by the municipality. Their difference leads to the building value, which was used to estimate building damages in combination with relative stage-damage functions.

The buildings are grouped into six main types: garages, carports etc. (42%); year-round residential (25%); recreational purposes (18%); agriculture, industry etc. (13%); trade, transport etc. (1%); (social) institutions (1%). Accordingly, the case study area is characterized by small localities, a low population density, many summer cottages, agriculture, and minor industry.



Map of the case study area and location within Northern Europe.

We find that after a sudden jump, in any case the macroscopic damage functions increase exponentially up to a certain water level above which they change to a less steep increase, whereas the cross-over level depends on the assumed building damage function. Moreover, the range covered by the final damage functions obtained from the various modes of inundation determination differ by an approximately constant factor. In particular, we show that for large events the assumed building damage function dominates the final damage, while for small events the spatial resolution has a dominating influence on the estimated damage.



Macroscopic damage functions assuming different building damage functions.

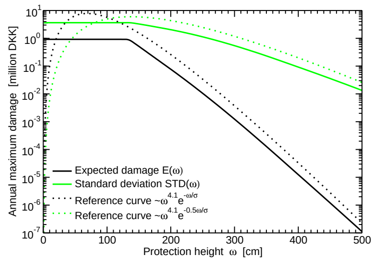
In general, we conclude that different regimes of a damage function have to be considered. With regard to low and moderate sea levels an accurate DEM is indispensable, since it provides information about whether low-lying properties are flooded or not. This can affect the total flood risk decisively because of the high frequency of such water levels. On the other hand, at higher flood levels, the building damage function becomes more dominant than the quality of the DEM and although such events are very rare, the corresponding damages need careful estimations due to their catastrophic consequences.

Extreme values and damage functions

	location μ	scale σ	protection height ω
E	$\sim \mu^{\gamma}$	$\sim \sigma^{\gamma}$	$\sim \omega^{\gamma} e^{-\omega/\sigma}$ if $\xi = 0$ $\sim \omega^{\gamma-1/\xi}$ if $\xi > 0$ $\sim (x_{\max} - \omega)^{-1/\xi}$ if $\xi < 0$
STD	$\sim \mu^{\gamma-1}$	$\sim \sigma^{\gamma}$	$\sim \omega^{\gamma} e^{-0.5\omega/\sigma}$ if $\xi = 0$ $\sim \omega^{\gamma-0.5/\xi}$ if $\xi > 0$ $\sim (x_{\max} - \omega)^{-0.5/\xi}$ if $\xi < 0$

Asymptotic behavior of expected damages and the standard deviations.

We derive how the expectation value and the standard deviation depend on changing extreme value parameters, i.e. due to *sea-level rise* (location parameter) and due to *changing weather regime* (scale parameter). We find universal and simple relations for the asymptotic behavior. The results imply (i) that the relative uncertainty remains constant with increasing location parameter μ and (ii) decreasing relative uncertainty with increasing scale parameter σ. Moreover, we calculate how the damage decreases with increasing protection hight and obtain that the functional form depends on the shape parameter ξ.



Expectation and standard deviation vs protection level.

The analytical predictions agree asymptotically with the numerically integrated results of the Kalundborg case study.

Discussion

Considering current CO_2 emission pathways, further global warming seems unavoidable and severe impacts need to be anticipated as likely consequences. In the general debate, adaptation is considered as complementary preventive measure to cope with those impacts. In order to assess the efficiency of adaptation via cost-benefit analysis the upcoming economic consequences of climate change need to be estimated. As one of the most perceivable effects, sea level rise will affect the magnitude of extreme sea levels, which can have huge economic impacts. Although, in general, the effects of global warming on extreme floods are vague, we find that the dependence of associated annual damages on changing extremes follow simple relations. Moreover, taking into account protection measures, which may reduce the impacts from moderate flooding (e.g. by sea dikes), we obtain further expressions for the decay of damages if a predefined protection level is supposed. Applying the approach to the city of Copenhagen, our general results can be confirmed and a steeper increase of expected damages than the rise of mean sea levels is found. Our findings have important implications for the estimation of future damages and therefore for the allocation of adaptation funds.

Publications:

- "On the influence of sea level rise on coastal flood damages", Boettle M, Rybski D, Kropp JP, in preparation 2012.
- "Indirect identification of damage functions from damage records", Steinhauser JM, Rybski D, Kropp JP, in preparation 2012.
- "About the influence of elevation model quality and small-scale damage functions on flood damage estimation", Boettle M, Kropp JP, Reiber L, Roithmeier O, Rybski D, Walther C, Natural Hazards and Earth System Sciences, 11 (12): 3327-3334, 2011.

see **http:\\diego.rybski.de**

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