Potsdam Institute for Climate Impact Research

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On the estimation of damages due to coastal floods

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Outline

0. Sea level rise

1. Extremes matter

2. Damage functions

3. Expected damages and uncertainty

Recent sea level rise estimates by M. Vermeer et al. 2009 (PNAS)

R07: $$\frac{\mathrm{d}H}{\mathrm{d}t} = a(T - T_0)$$

base temperature (parameter)

temperature measurement

parameter

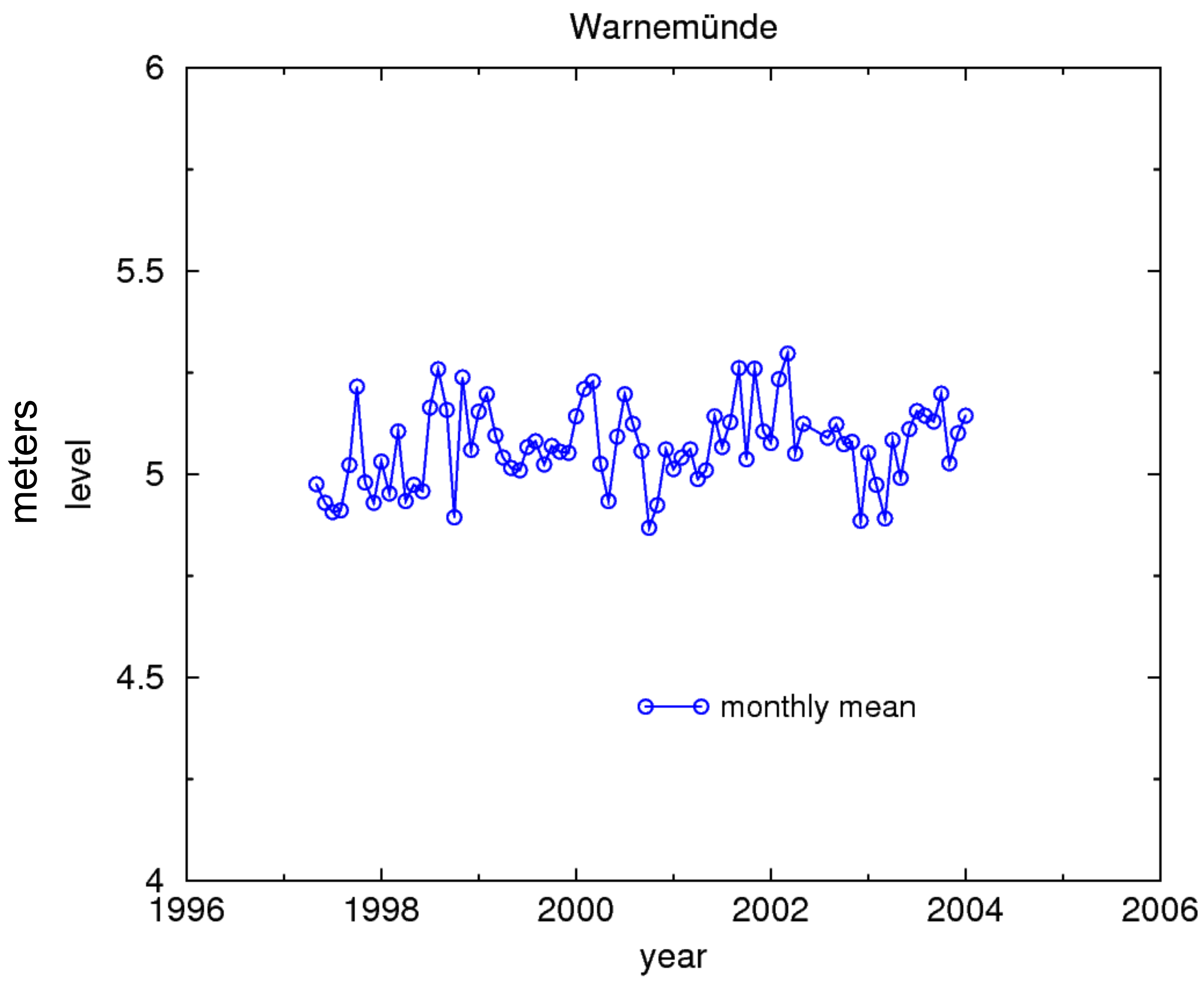
rate of rise of sea level

V09: $$\frac{\mathrm{d}H}{\mathrm{d}t} = a(T - T_0) + b\frac{\mathrm{d}T}{\mathrm{d}t}$$

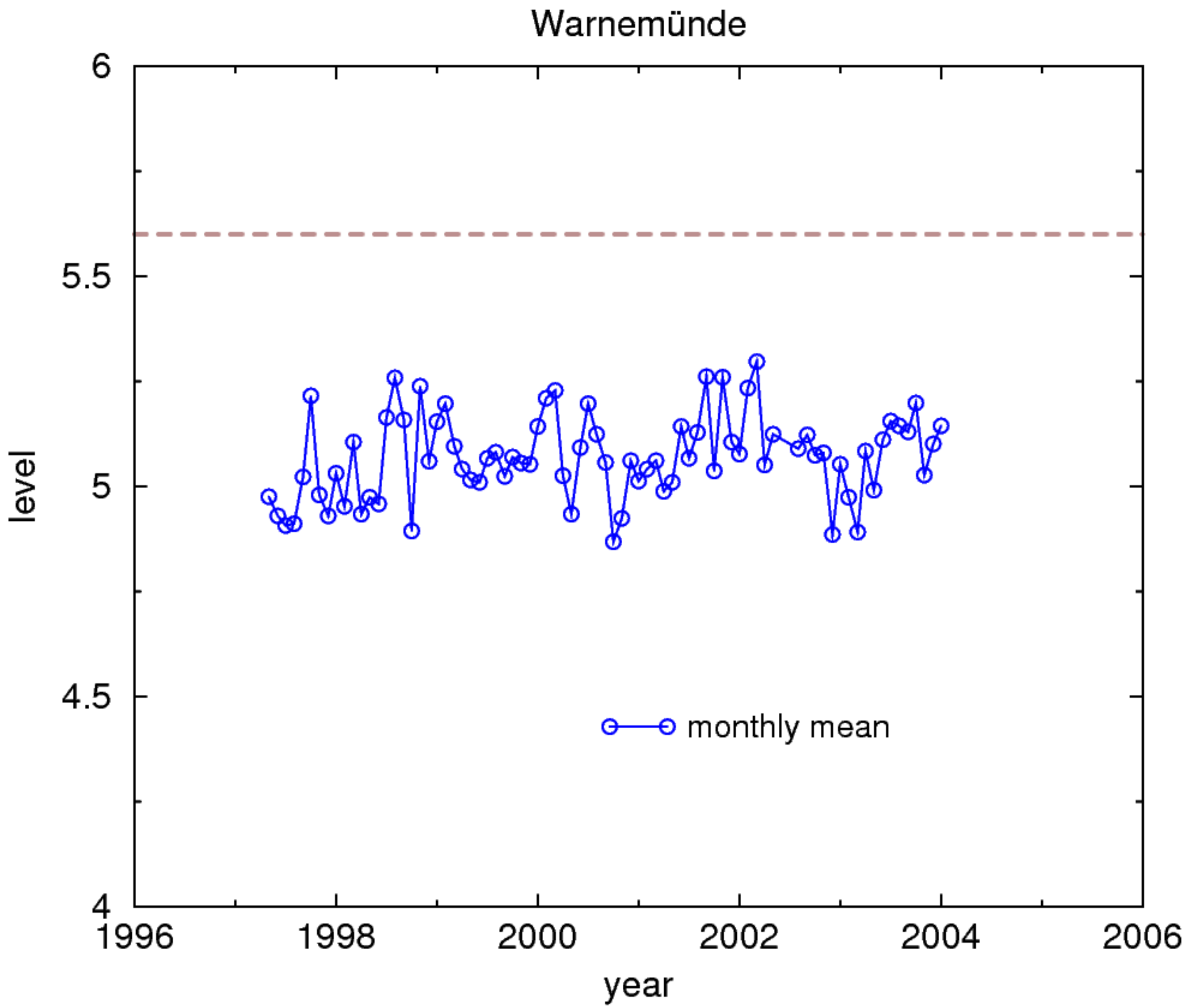
parameter

'instantaneous' sea level response

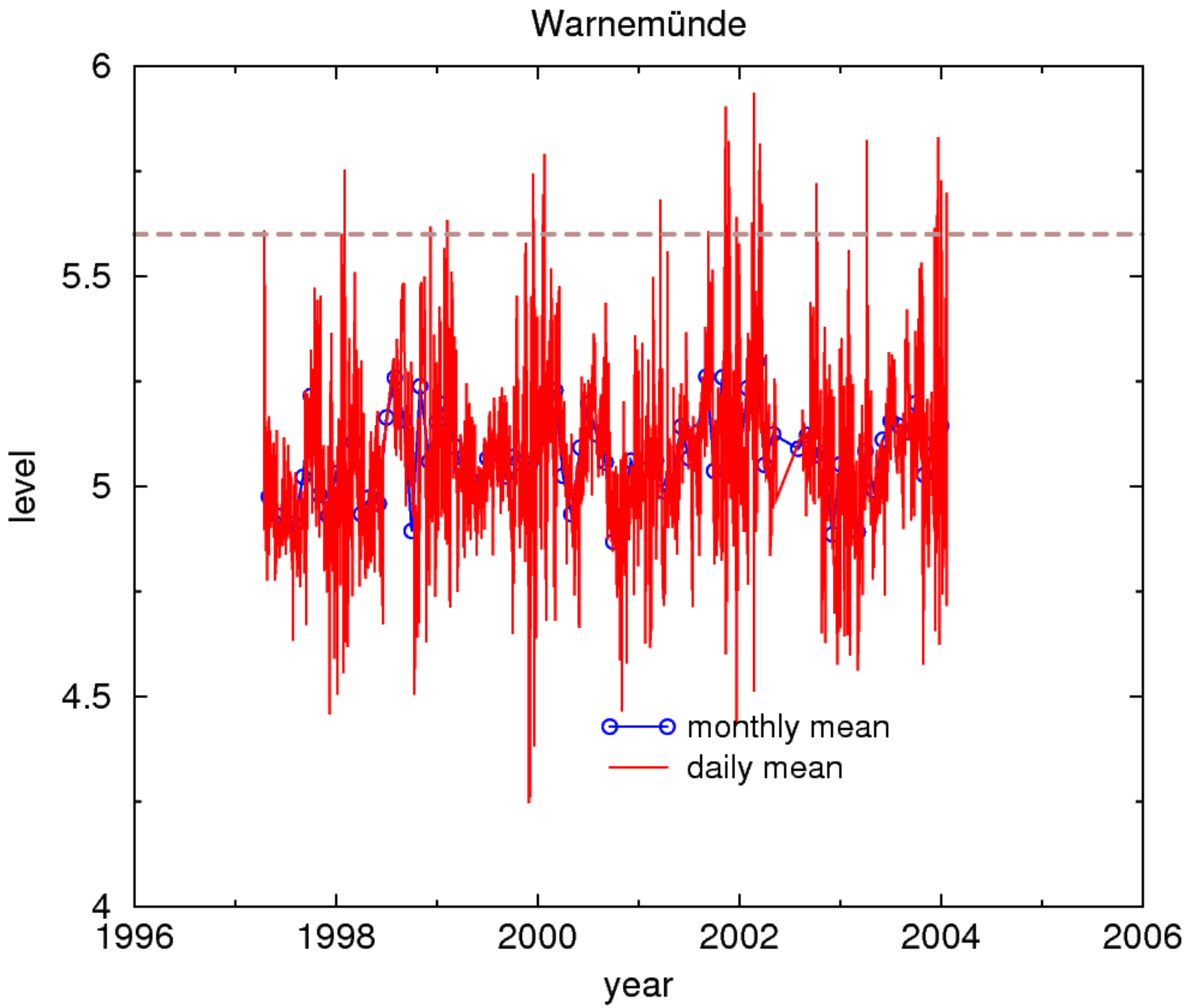
Sea level rise and fluctuations



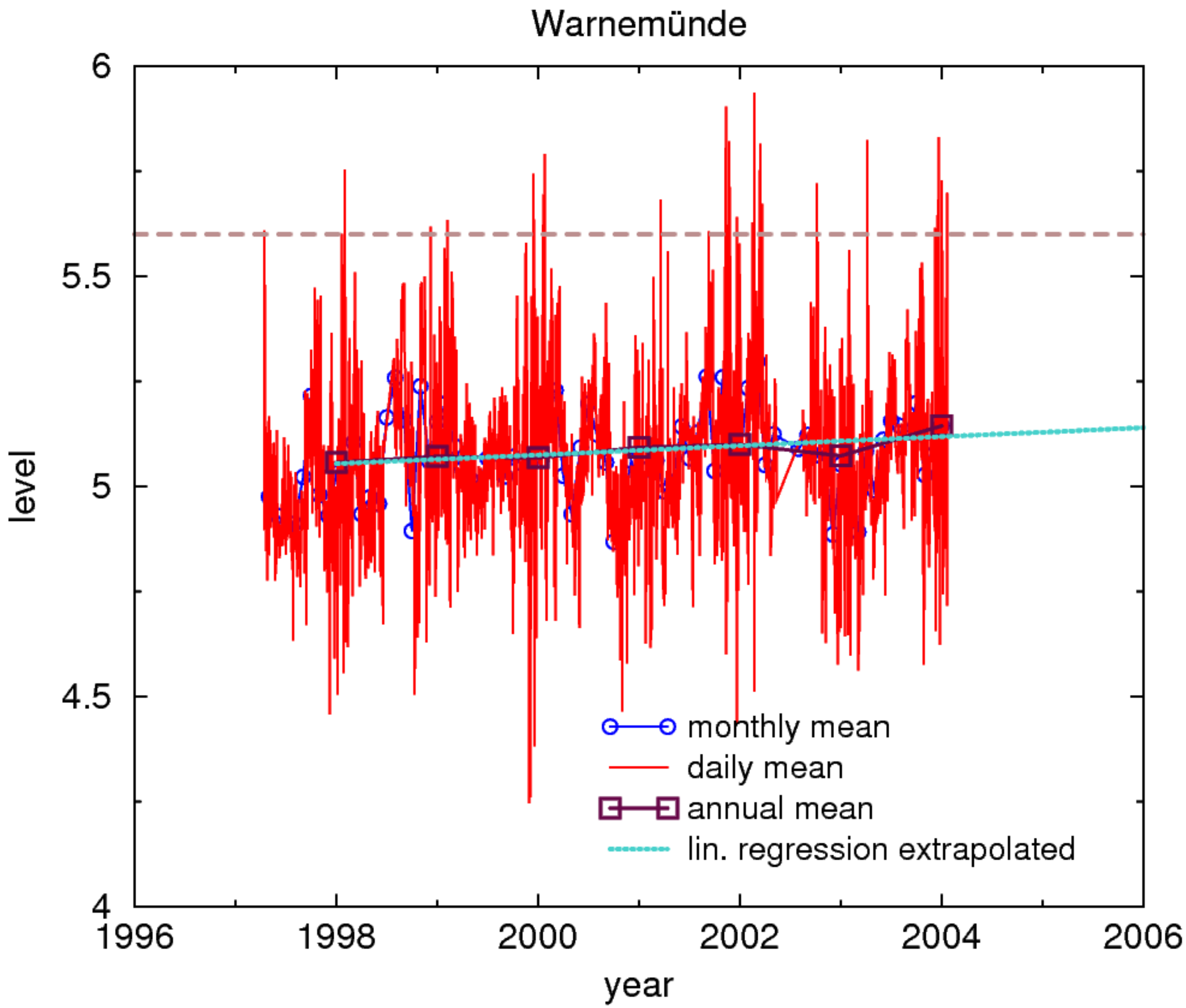
Sea level rise and fluctuations

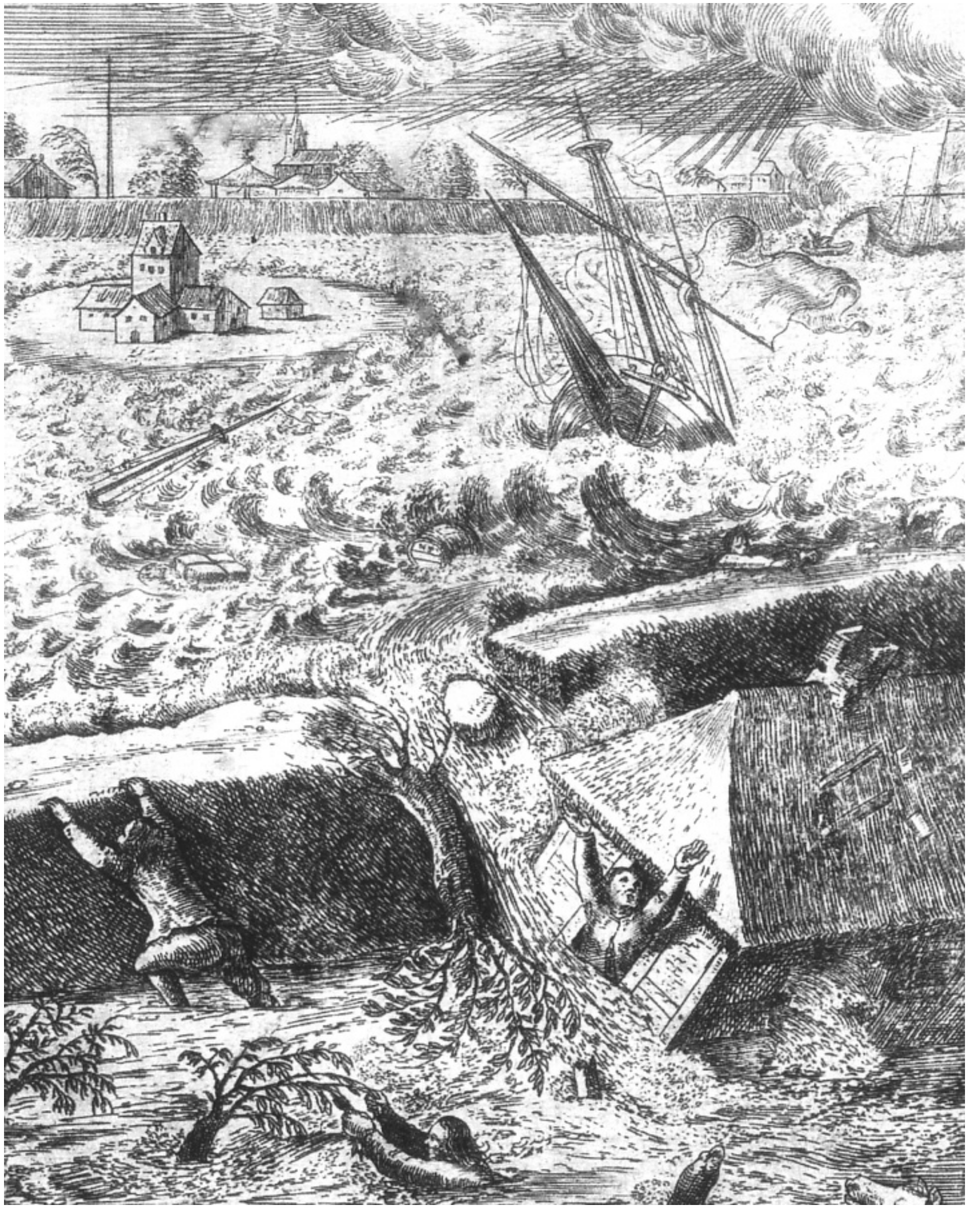


Sea level rise and fluctuations



Sea level rise and fluctuations





wikipedia: Kupferstich "Deichbruch" von Winterstein 1661

Motivation

How to estimate damages from (coastal) floods?

How do they change with sea-level-rise?

How are they influenced by protection measures?

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How to estimate damages from (coastal) floods?

How do they change with sea-level-rise?

How are they influenced by protection measures?

- consider distribution of extremes
- combine with damage function
- study distribution of damages
- dependence on GEV-parameters and protection

Motivation

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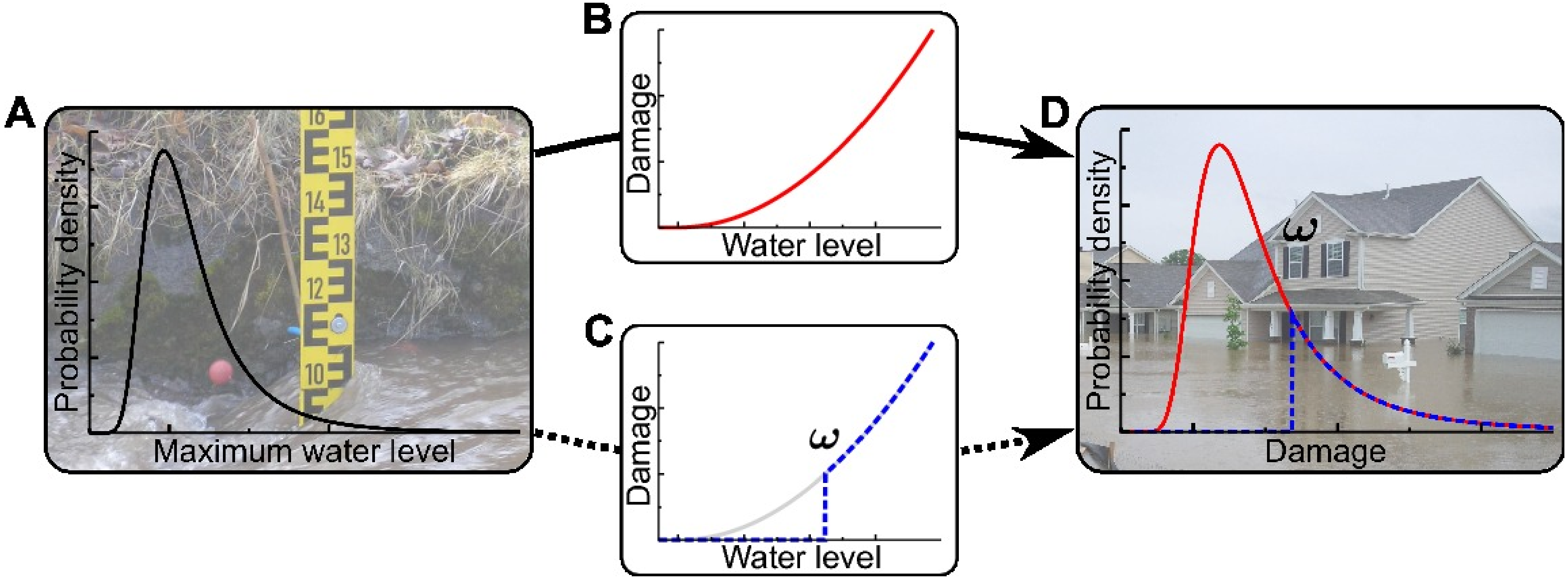
How do they change with sea-level-rise?

How are they influenced by protection measures?

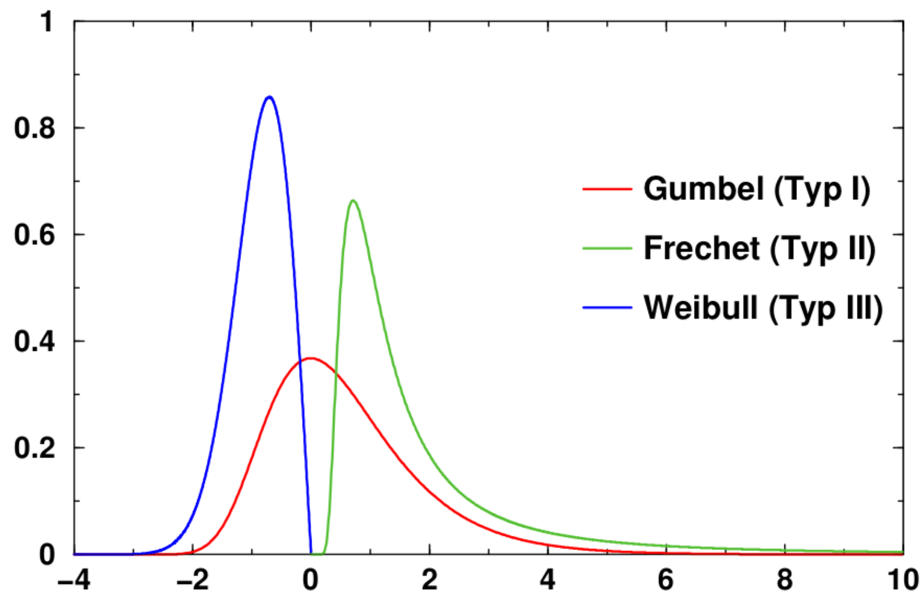


Generalized Extreme Value distributions

The GEV distributions, expressing the probability that the maximum of a sample is beneath the value s, are given by:

$$P^{\mathrm{GEV}}_{(s)} = \begin{cases} \exp\left[-\left(1+\xi\dfrac{s-\nu}{\gamma}\right)^{-\frac{1}{\xi}}\right] & \text{for } \xi \neq 0 \\ \exp\left[-\mathrm{e}^{-\frac{s-\nu}{\gamma}}\right] & \text{for } \xi = 0\,. \end{cases} \tag{1}$$

They are defined on $\left\{s : 1+\xi\frac{s-\nu}{\gamma} > 0\right\}$ and have a location parameter, $\nu \in \mathbb{R}$, a scale parameter, $\gamma \in \mathbb{R}^+$, as well as a shape parameter, $\xi \in \mathbb{R}$. According to the shape, one distinguishes three cases: (i) the Gumbel distribution ($\xi = 0$), (ii) the heavy-tailed Fréchet distribution ($\xi > 0$), and (iii) the bounded-tailed *reversed* Weibull distribution ($\xi < 0$).



JF Eichner, Diss, 2006

Damage functions

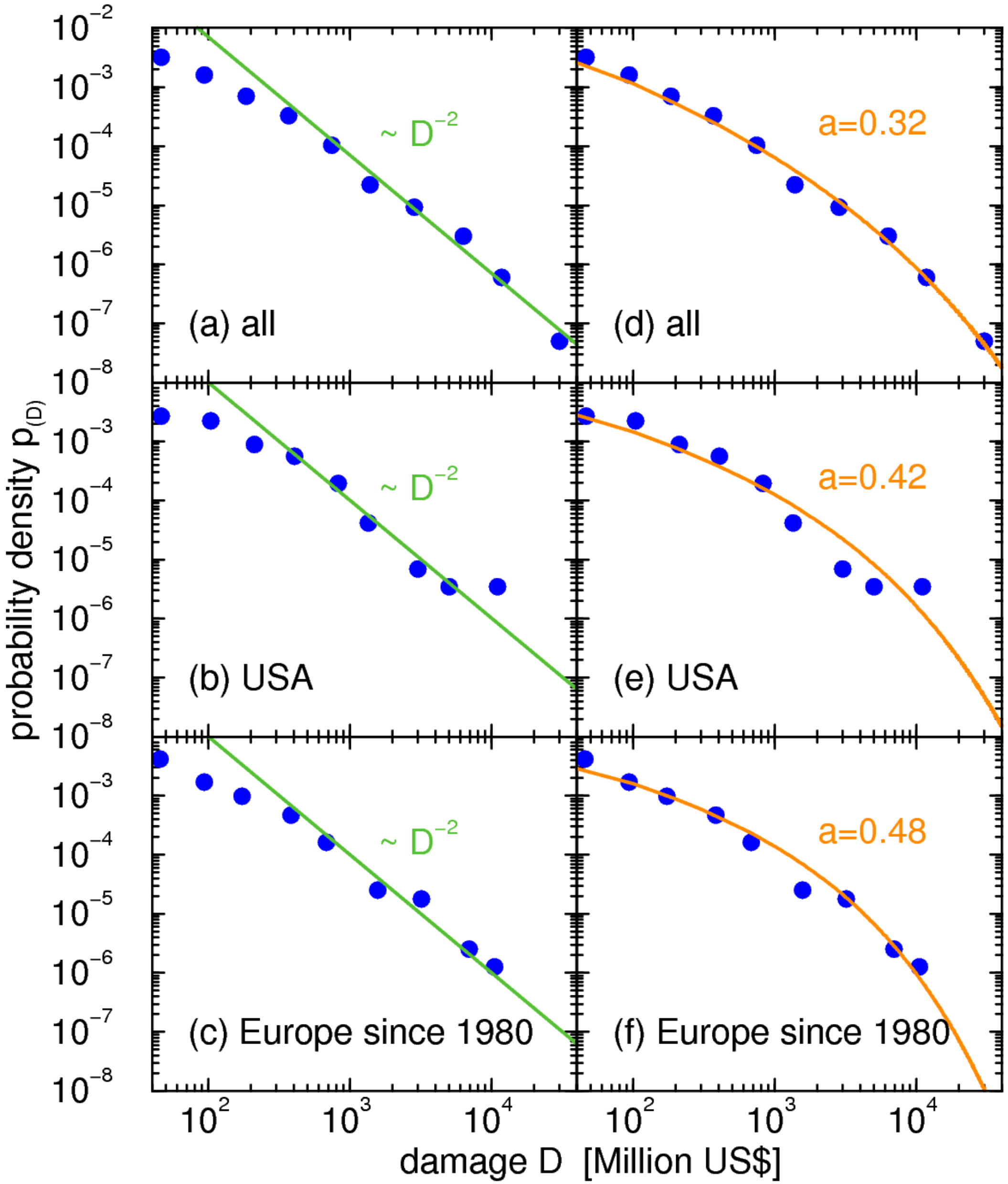
intuitively: the higher the flood, the more damage

damage function: typical damage for flood of certain height

problem: how to determine damage functions?
- empirical data (here: indirectly)
- case study

later: assume power-law

Damage functions from damage records



Zipf's law

stretched exponential

Which damage function is required so that GEV transforms into observed distribution of damages?

→ density transformation

data: CRED [EM-DAT, 2009], damages due to floods worldwide in the years 1950-2008

Damage functions from damage records

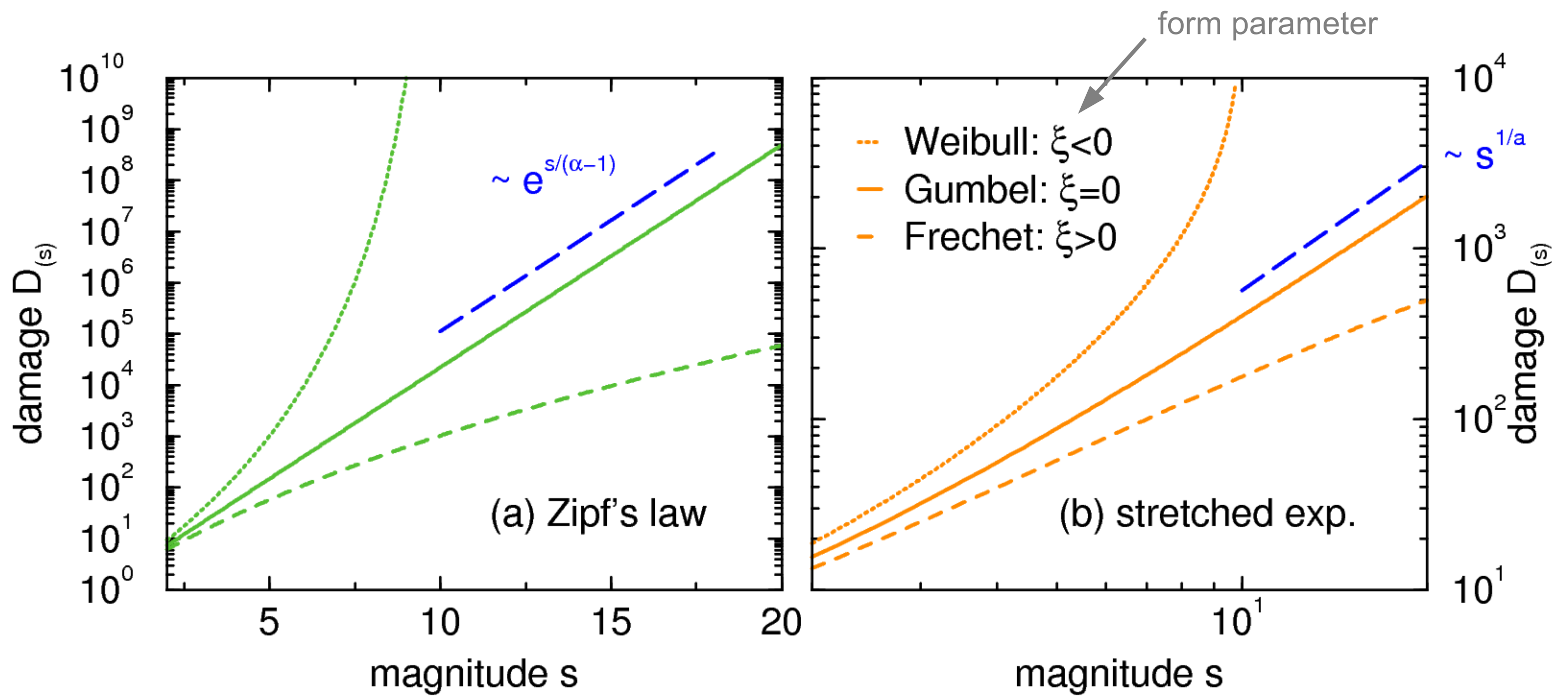
Gumbel:

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

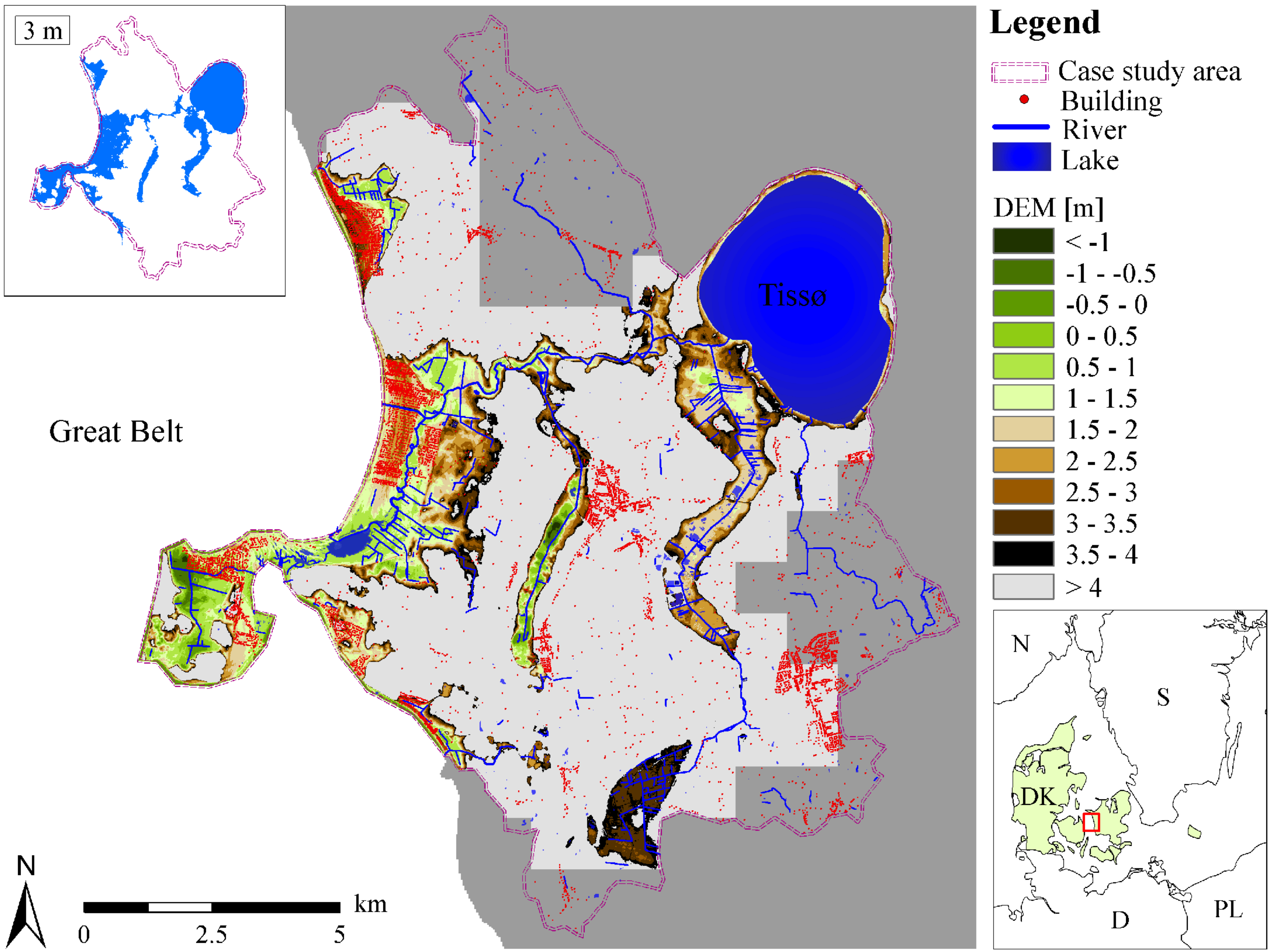
Damage functions from damage records

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

scale parameter



Damage functions from case study - Kalundborg (DK)



Damage functions from case study
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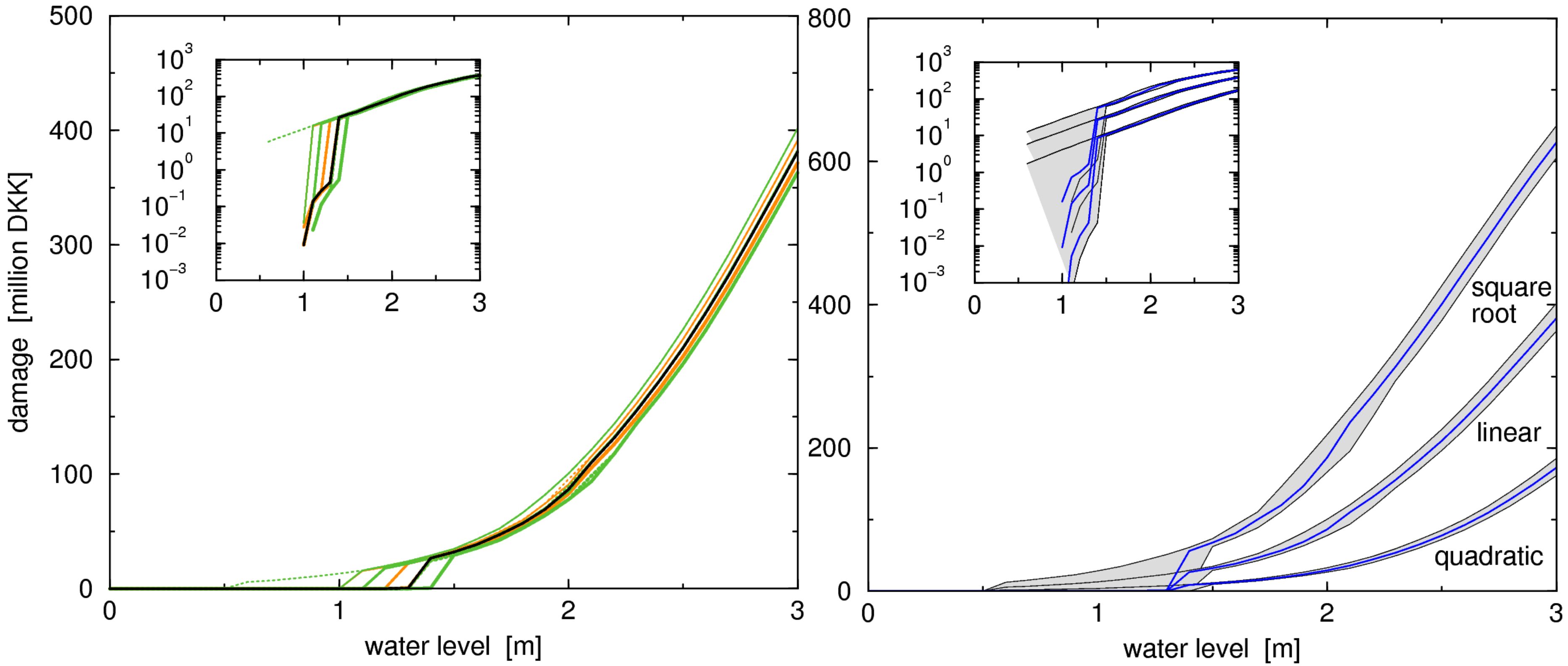
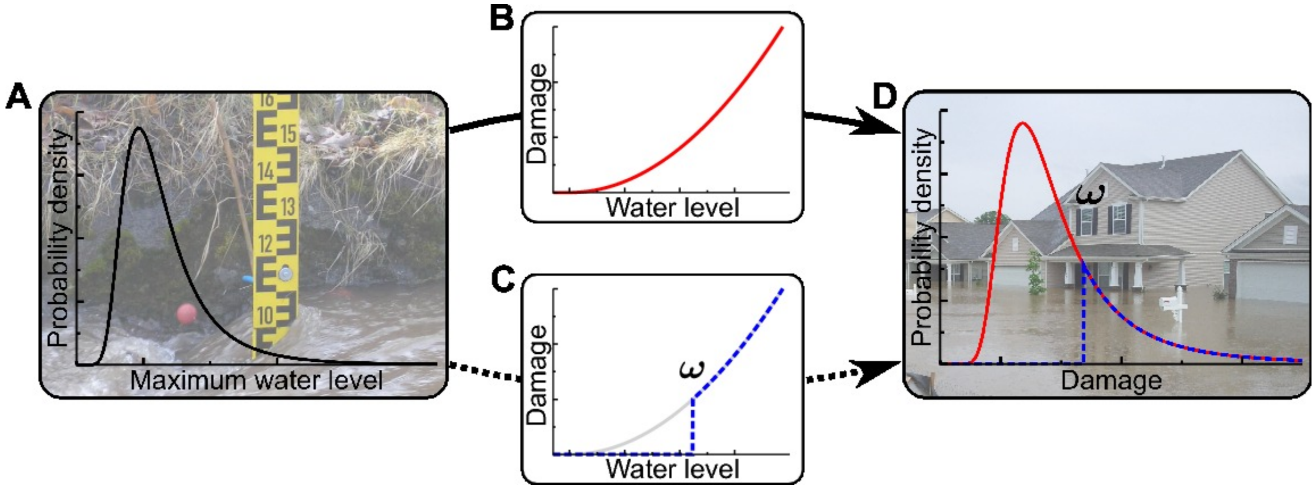


hydro-dynamical modeling
more convenient: flood fill

Expected damages and uncertainty



damage costs	location μ	scale σ	protection height ω
E expectation value			
STD standard deviation			

e.g. changing weather patterns
e.g. sea-level-rise

Expected damages and uncertainty - as a function of the *location*

damage function: $$D(x) \sim x^{\gamma}$$

flood height
damage cost

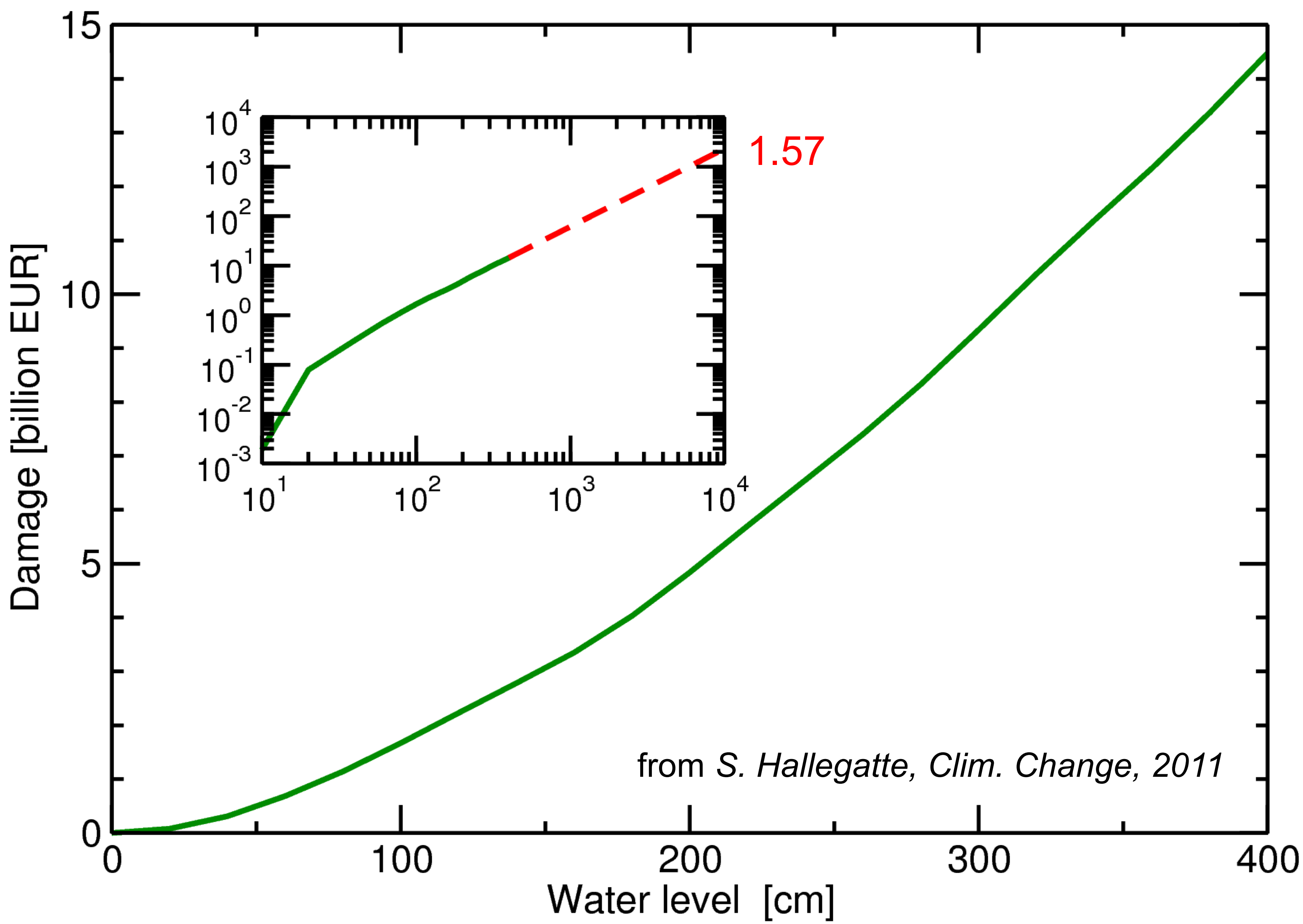
expectation value: $$\mathrm{E}(C) \sim \mu^{\gamma}$$

location

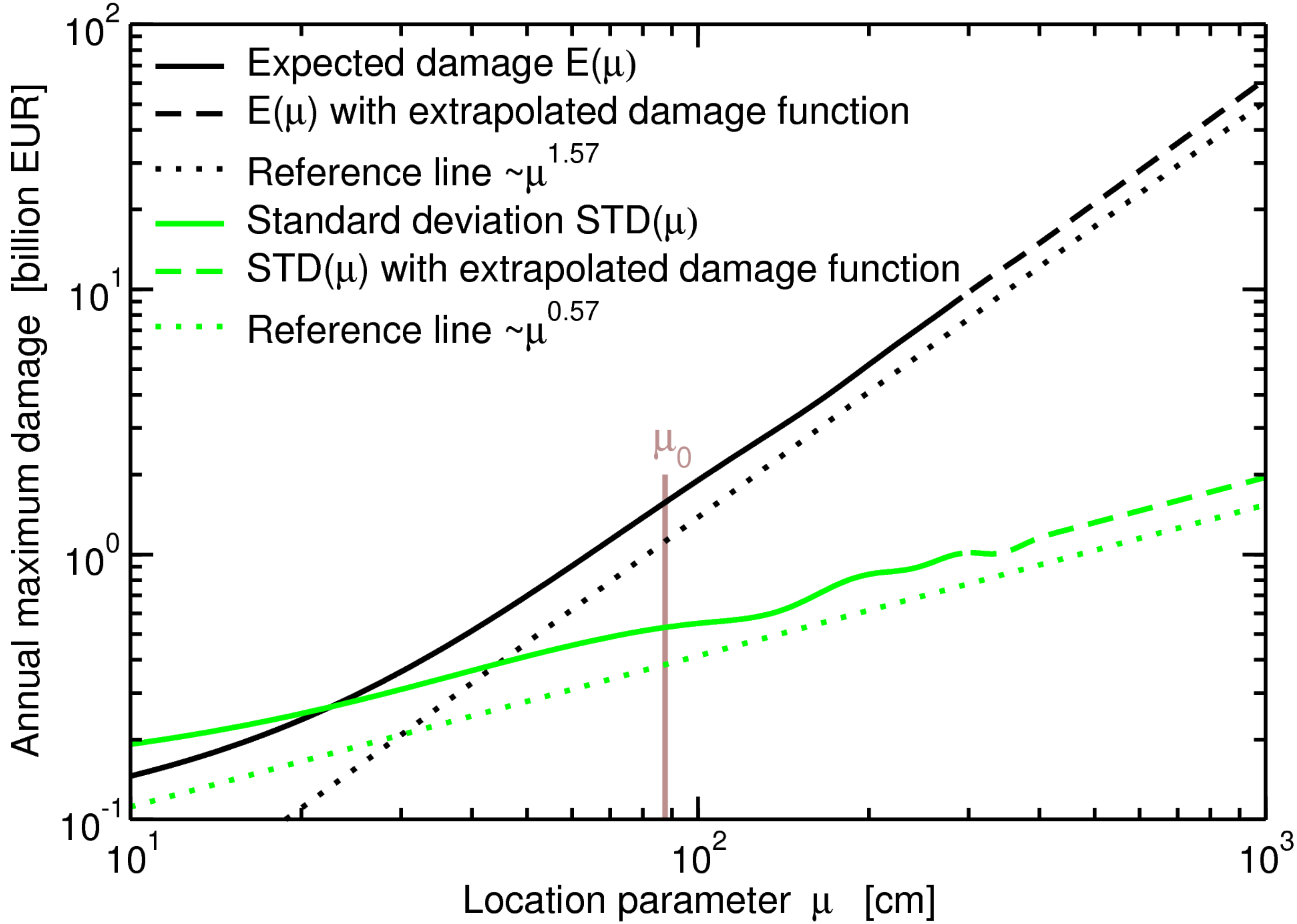
standard deviation: $$\mathrm{STD}(C) \sim \mu^{\gamma-1}$$

asymptotically
independent from GEV-type (!)
relative uncertainty *decreases*
damage function exponent is decisive

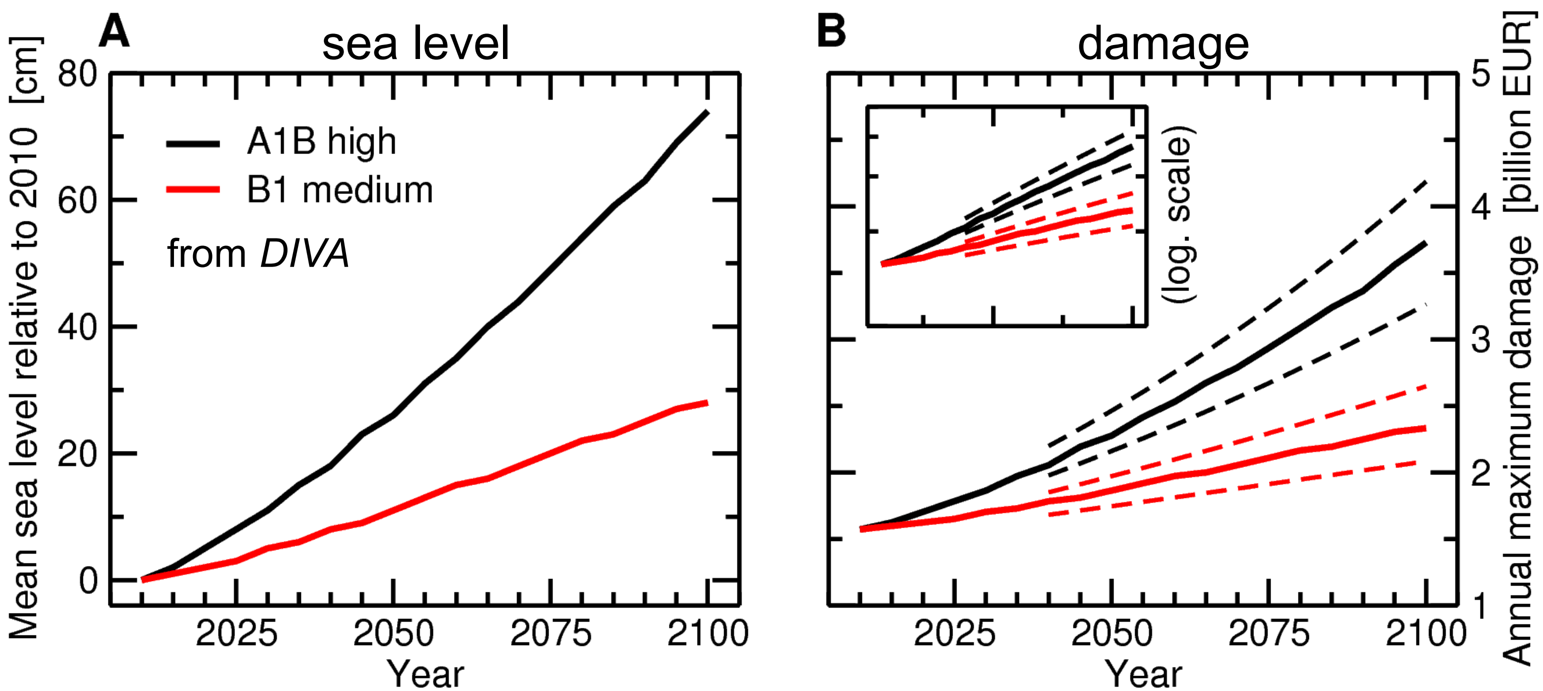
Expected damages and uncertainty - case study Copenhagen



Expected damages and uncertainty - case study Copenhagen



Expected damages and uncertainty - case study Copenhagen



using local sea level projections from *DIVA*-tool

temporal evolution of expected damage

Expected damages and uncertainty - as a function of the *scale*

expectation value: $$\mathrm{E}(C) \sim \sigma^{\gamma}$$

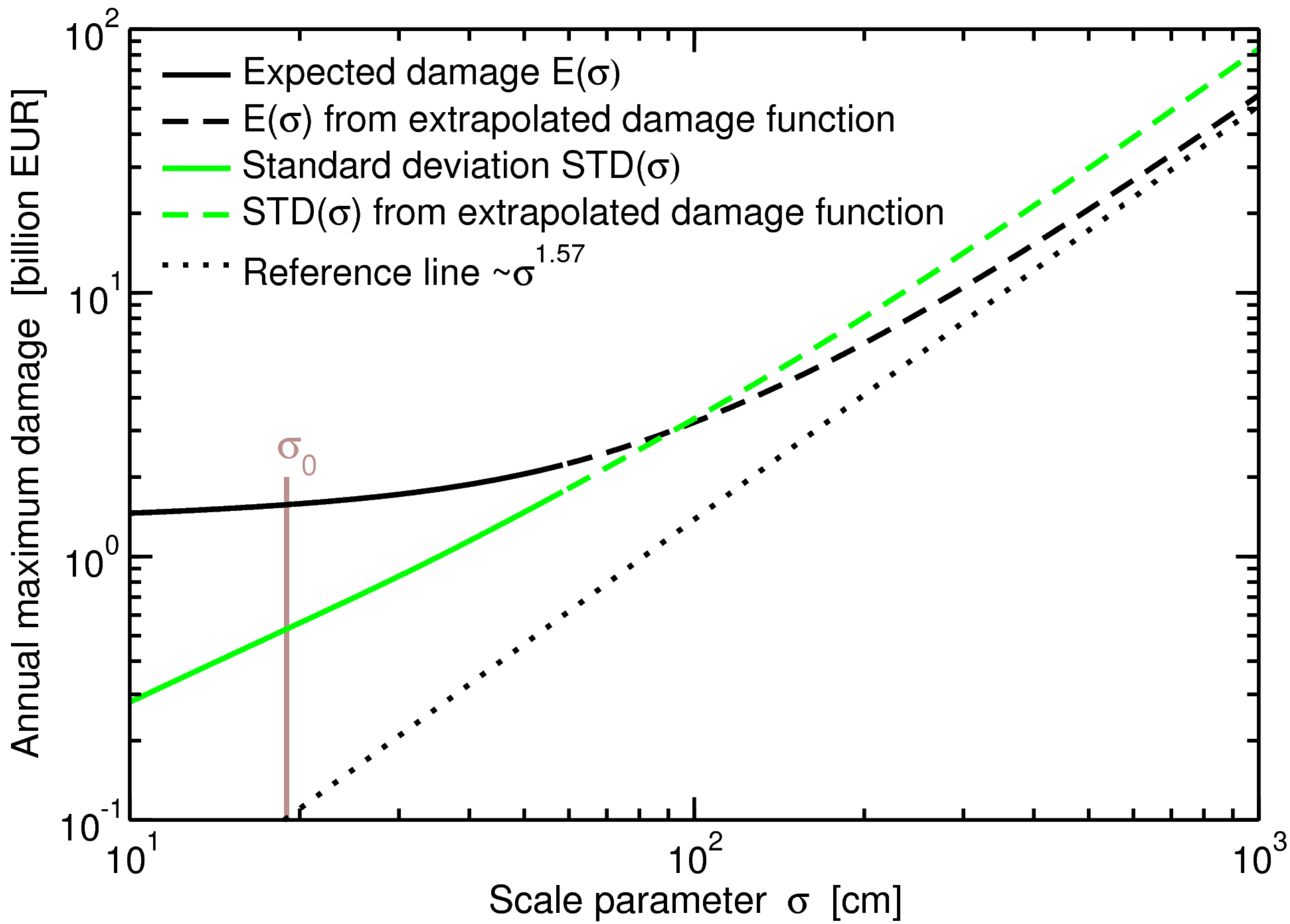
scale

standard deviation: $$\mathrm{STD}(C) \sim \sigma^{\gamma}$$

asymptotically
independent from GEV-type (!)
relative uncertainty is *constant*
damage function exponent is decisive

$$\mathrm{STD}(C) \sim \mu^{\gamma-1}$$

Expected damages and uncertainty - case study Copenhagen



Expected damages and uncertainty - as a function of *protection height*

I.e. how does the expected annual damage decrease with increasing protection height?

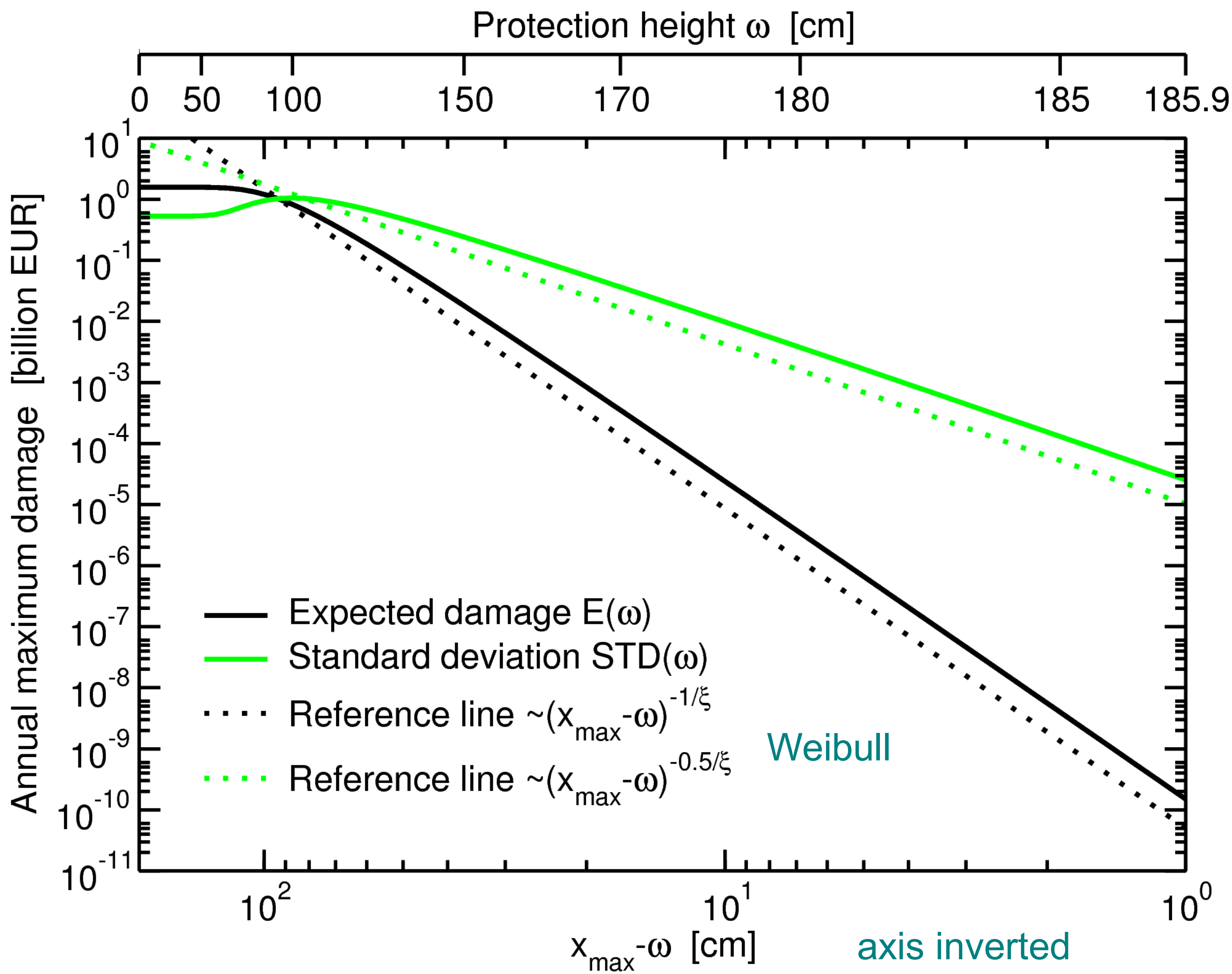
Gumbel: $$\mathrm{E}(C) \sim \omega^{\gamma} \mathrm{e}^{-\omega/\sigma}$$ scale parameter

Frechet: $$\mathrm{E}(C) \sim \omega^{\gamma - 1/\xi}$$ form parameter

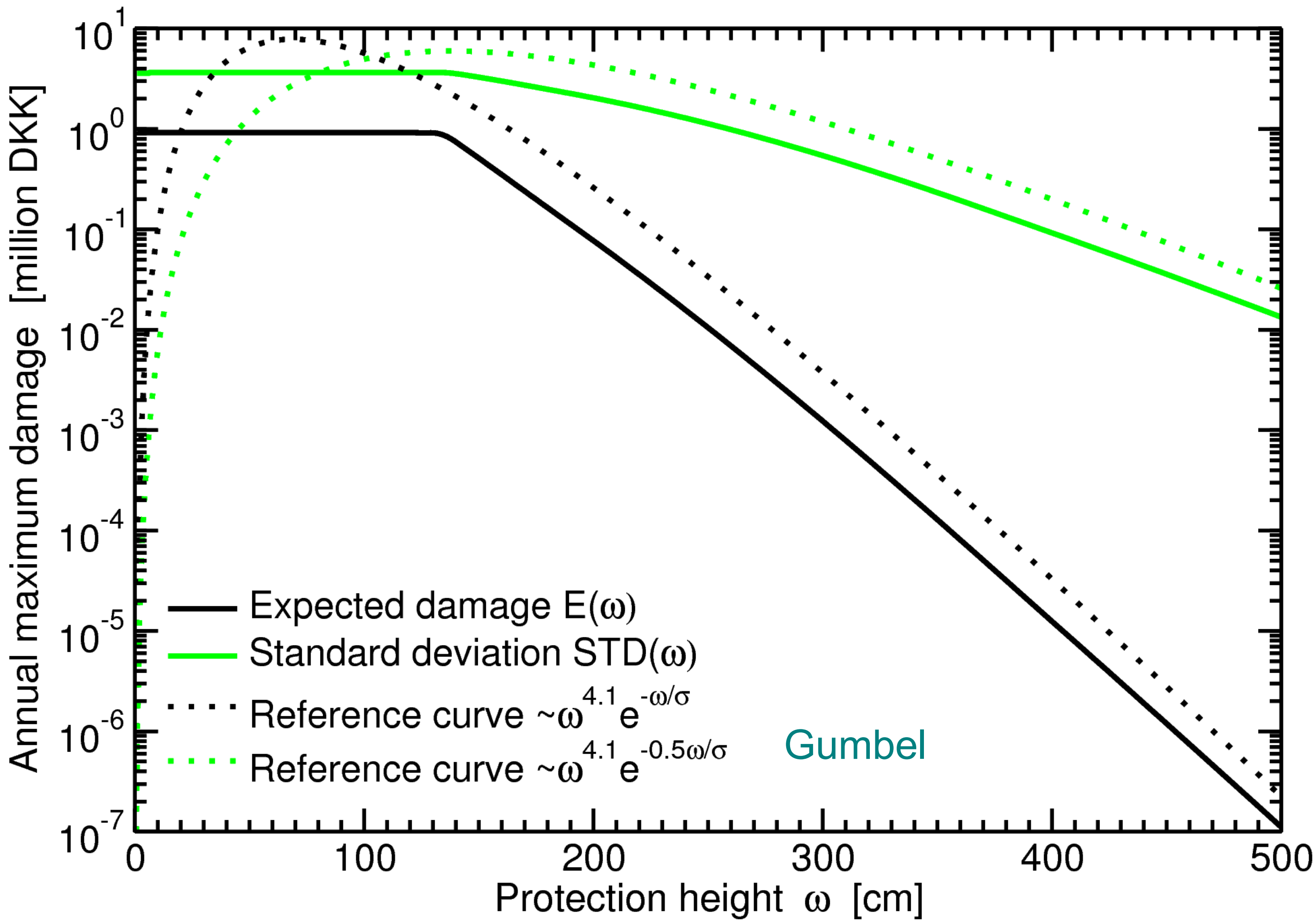
Weibull: $$\mathrm{E}(C) \sim (x_{\max} - \omega)^{-1/\xi}$$ independent of damage function exponent

asymptotically
3 fundamentally different cases
relative uncertainty is *increases*

Expected damages and uncertainty - case study Copenhagen



Expected damages and uncertainty - case study *Kalundborg*

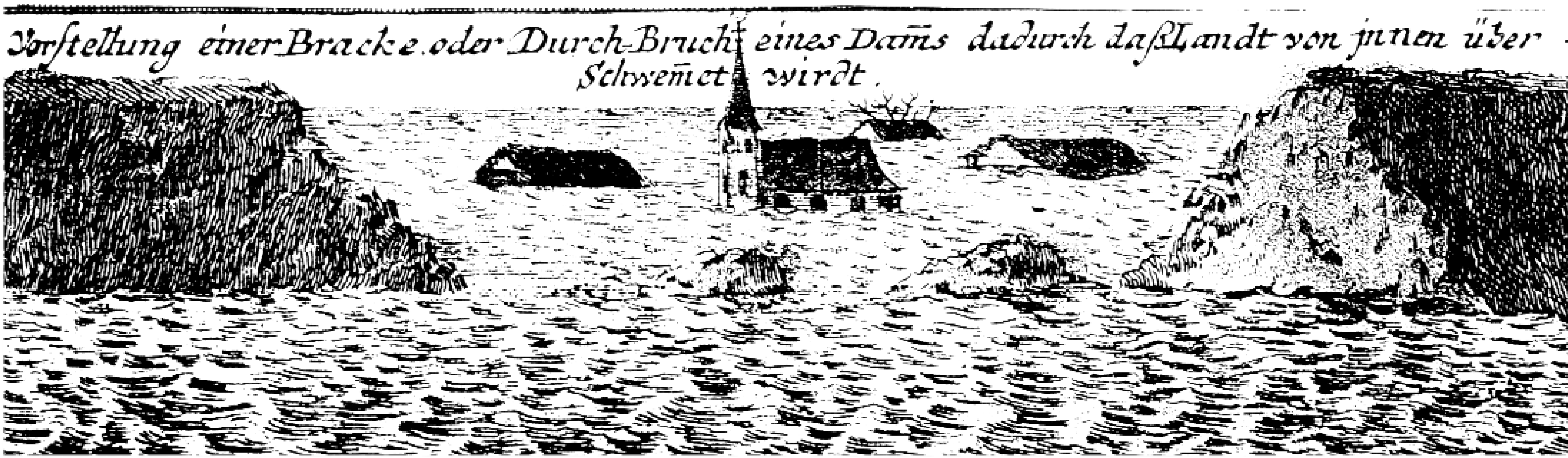


Expected damages and uncertainty - overview

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

differ only by the factor 0.5
in the exponent

uncertainty only due to the fact
that one does not know when
the extremes take place
(lower estimate)



Vorstellung einer Bracke oder Durch-Bruch eines Dammes dadurch dass Landt vor jinnen überschwemmet wirdt, wikipedia, prb. 1718

Acknowledgments

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Baltic Sea Region

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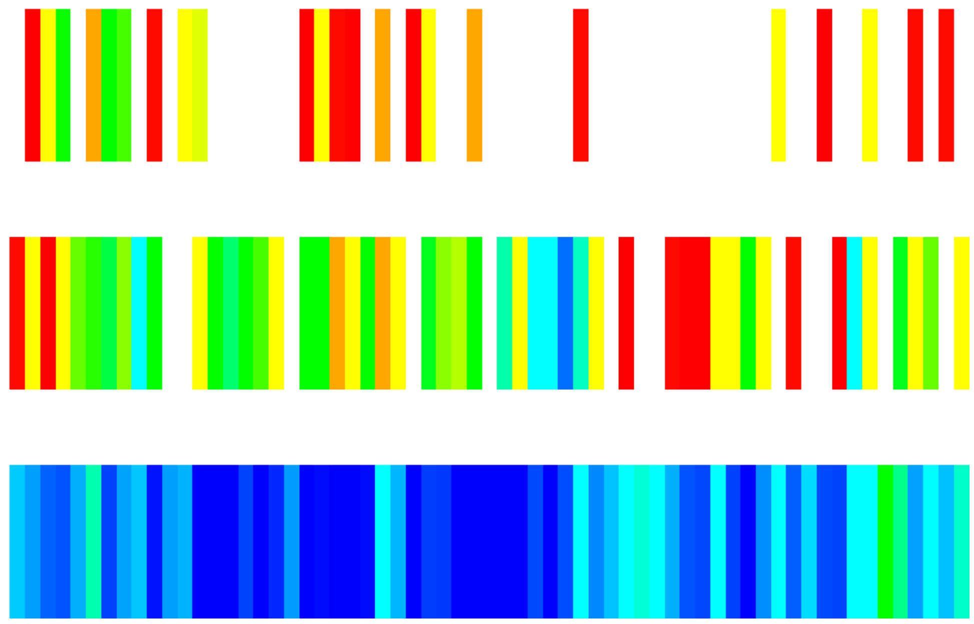
Thank you for your attention.



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