POTSDAM INSTITUTE FOR CLIMATE IMPACT RESEARCH

PIK

Climate change & development group

Climate change impacts and adaptation in cities: A damage function approach in the context of sea-level rise

Diego Rybski et al.

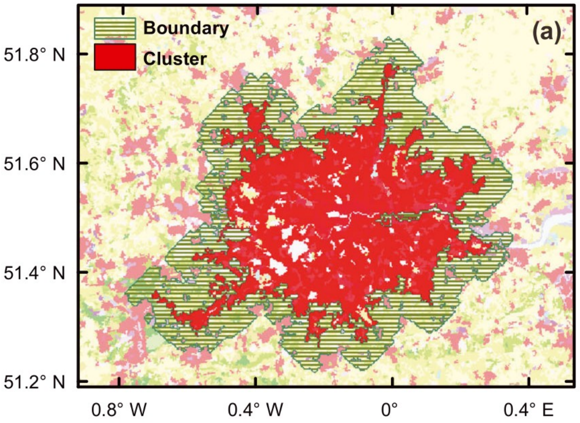
CCSI Seminar
JICS Auditorium
May 16, 2016 – 2pm

Argument

Cities

Climate Change Impacts & Adaptation
where people live and work

Cities exhibit extreme densities of
people and assets



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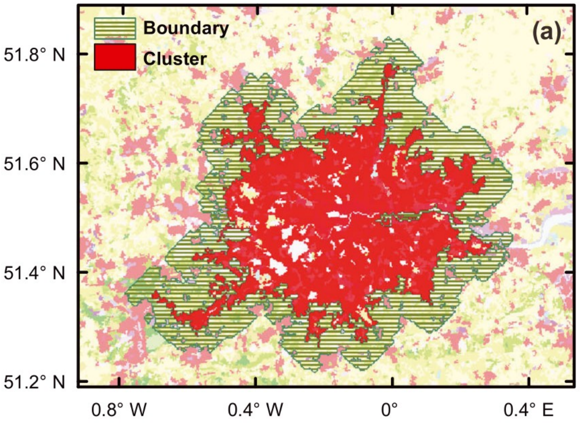

Extreme events

Most impacts manifest in intensifying
extreme events

e.g. more frequent and severe
storm surges

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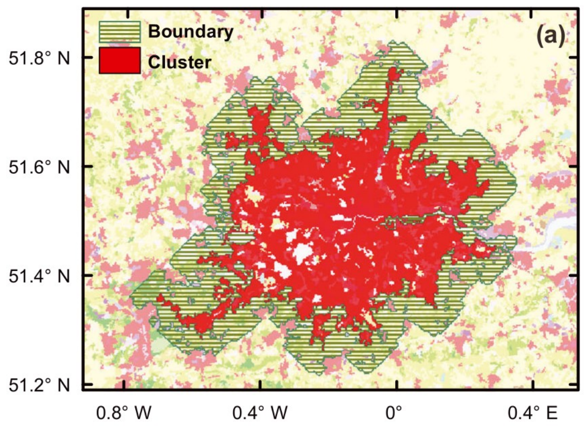

Extreme events

Most impacts manifest in intensifying
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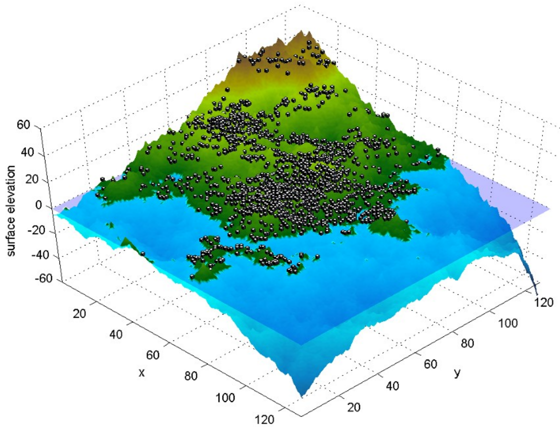
e.g. more frequent and severe
storm surges

Generic approach

What do cities have in common, instead of
what makes individual ones special

General and transferable approach
on the large scale

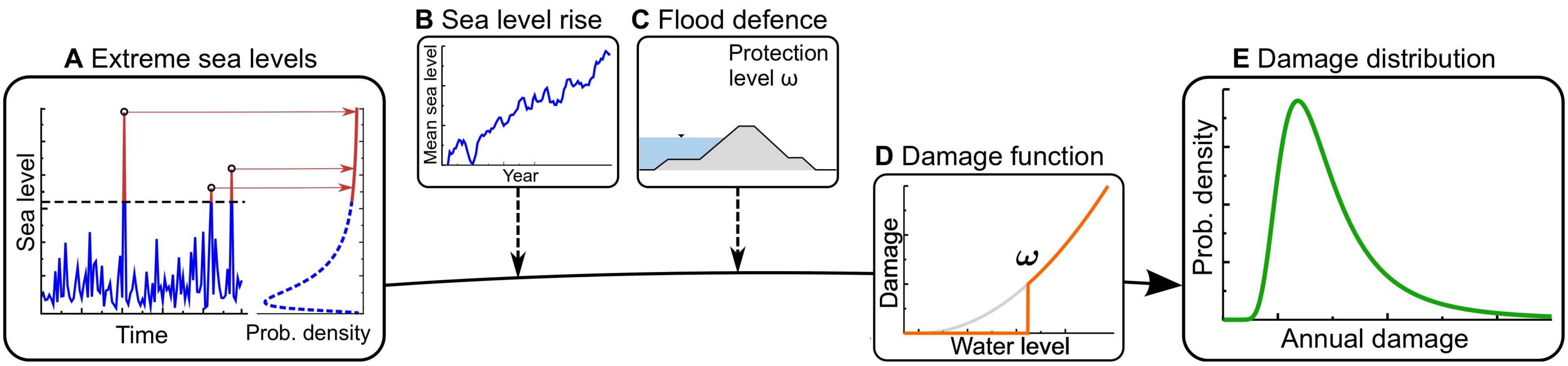


Outline

Goal:

- estimate damage loss from climate change
- estimate adaptation cost and residual damage
- sea-level rise (least uncertain impact)

Impacts / Adaptation Framework

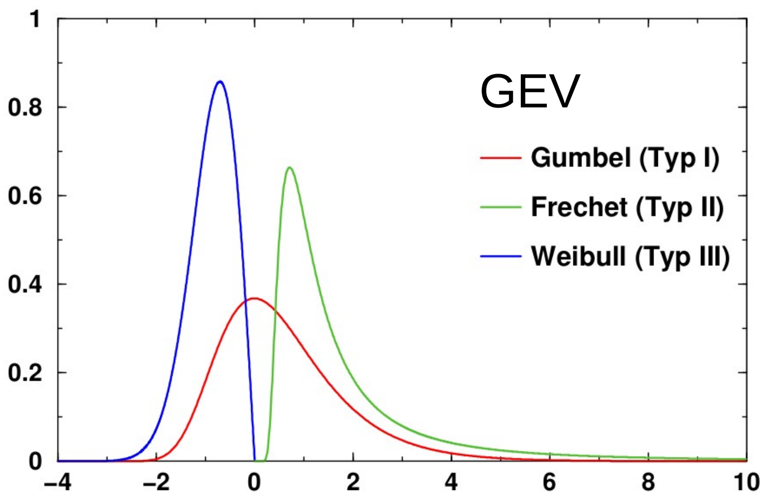


A Probability density of natural hazard (e.g. sea level)
D Damage function
E Probability density of damages

B Sea level rise alters A (shift of distribution)
C Flood defense alters D (sea wall represent threshold)

How do damages from coastal floods increase with sea-level rise or are reduced with protection?

generalized Pareto distribution (3 shapes)



JF Eichner, Diss, 2006

GPD-parameters:

- threshold
- scale
- shape

point process (Poisson)

average number of flood events & 1-year event

power-law damage function $F(x) \sim x^{\gamma}$

Analytically derived results

		Varying parameter		
		1-year event μ	Scale σ	Protection height ω
Λ	$\xi = 0$:	$\sim e^{\mu/\sigma}$	~ 1	$\sim e^{-\omega/\sigma}$
	$\xi < 0$:	$\sim \mu^{-1/\xi}$	~ 1	$\overset{\omega \to x_{\max}}{\sim} (x_{\max} - \omega)^{-1/\xi}$
	$\xi > 0$:	$\overset{\mu \to \mu_{\max}}{\sim} (\mu_{\max} - \mu)^{-1/\xi}$	~ 1	$\sim \omega^{-1/\xi}$
E_{D_i}	$\xi = 0$:	~ 1	$\sim \sigma^{\gamma}$	$\sim \omega^{\gamma}$
	$\xi < 0$:	$\sim \mu^{\gamma}$	$\sim \sigma^{\gamma}$	$\overset{\omega \to x_{\max}}{\sim} 1$
	$\xi > 0$:	$\overset{\mu \to \mu_{\max}}{\sim} 1$	$\sim \sigma^{\gamma}$	$\sim \omega^{\gamma}$
E_D	$\xi = 0$:	$\sim e^{\mu/\sigma}$	$\sim \sigma^{\gamma}$	$\sim \omega^{\gamma} e^{-\omega/\sigma}$
	$\xi < 0$:	$\sim \mu^{\gamma - 1/\xi}$	$\sim \sigma^{\gamma}$	$\overset{\omega \to x_{\max}}{\sim} (x_{\max} - \omega)^{-1/\xi}$
	$\xi > 0$:	$\overset{\mu \to \mu_{\max}}{\sim} (\mu_{\max} - \mu)^{-1/\xi}$	$\sim \sigma^{\gamma}$	$\sim \omega^{\gamma - 1/\xi}$
SD_{D_i}	$\xi = 0$:	~ 1	$\sim \sigma^{\gamma}$	$\sim \omega^{\gamma - 1}$
	$\xi < 0$:	$\sim \mu^{\gamma}$	$\sim \sigma^{\gamma}$	$\overset{\omega \to x_{\max}}{\sim} x_{\max} - \omega$
	$\xi > 0$:	$\overset{\mu \to \mu_{\max}}{\sim} \mu_{\max} - \mu$	$\sim \sigma^{\gamma}$	$\sim \omega^{\gamma}$
SD_D	$\xi = 0$:	$\sim e^{0.5\mu/\sigma}$	$\sim \sigma^{\gamma}$	$\sim \omega^{\gamma} e^{-0.5\omega/\sigma}$
	$\xi < 0$:	$\sim \mu^{\gamma - 0.5/\xi}$	$\sim \sigma^{\gamma}$	$\overset{\omega \to x_{\max}}{\sim} (x_{\max} - \omega)^{-0.5/\xi}$
	$\xi > 0$:	$\overset{\mu \to \mu_{\max}}{\sim} (\mu_{\max} - \mu)^{-0.5/\xi}$	$\sim \sigma^{\gamma}$	$\sim \omega^{\gamma - 0.5/\xi}$

Table B1. The asymptotic behaviour of the number of annual flood events Λ, the expected damage from a single event E_{D_i} and the total annual damage E_D as well as the corresponding standard deviations SD_{D_i} and SD_D, as functions of the 1-year event μ (with regard to a shift of all events), the scale parameter σ and the protection level ω. The values $\mu_{\max} = u + \sigma/\xi$ and $x_{\max} = \mu - \sigma/\xi$ represent upper limits for the parameters μ and ω in the case $\xi > 0$ and $\xi < 0$ respectively.

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E_D	$\xi = 0$:	$\sim \mathrm{e}^{\mu/\sigma}$	$\sim \sigma^{\gamma}$	$\sim \omega^{\gamma} \mathrm{e}^{-\omega/\sigma}$
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SD_{D_i}	$\xi = 0$:	~ 1	$\sim \sigma^{\gamma}$	$\sim \omega^{\gamma - 1}$
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	$\xi > 0$:	$\overset{\mu \to \mu_{\max}}{\sim} \mu_{\max} - \mu$	$\sim \sigma^{\gamma}$	$\sim \omega^{\gamma}$
SD_D	$\xi = 0$:	$\sim \mathrm{e}^{0.5\mu/\sigma}$	$\sim \sigma^{\gamma}$	$\sim \omega^{\gamma} \mathrm{e}^{-0.5\omega/\sigma}$
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How do damages from coastal floods increase with sea-level rise?

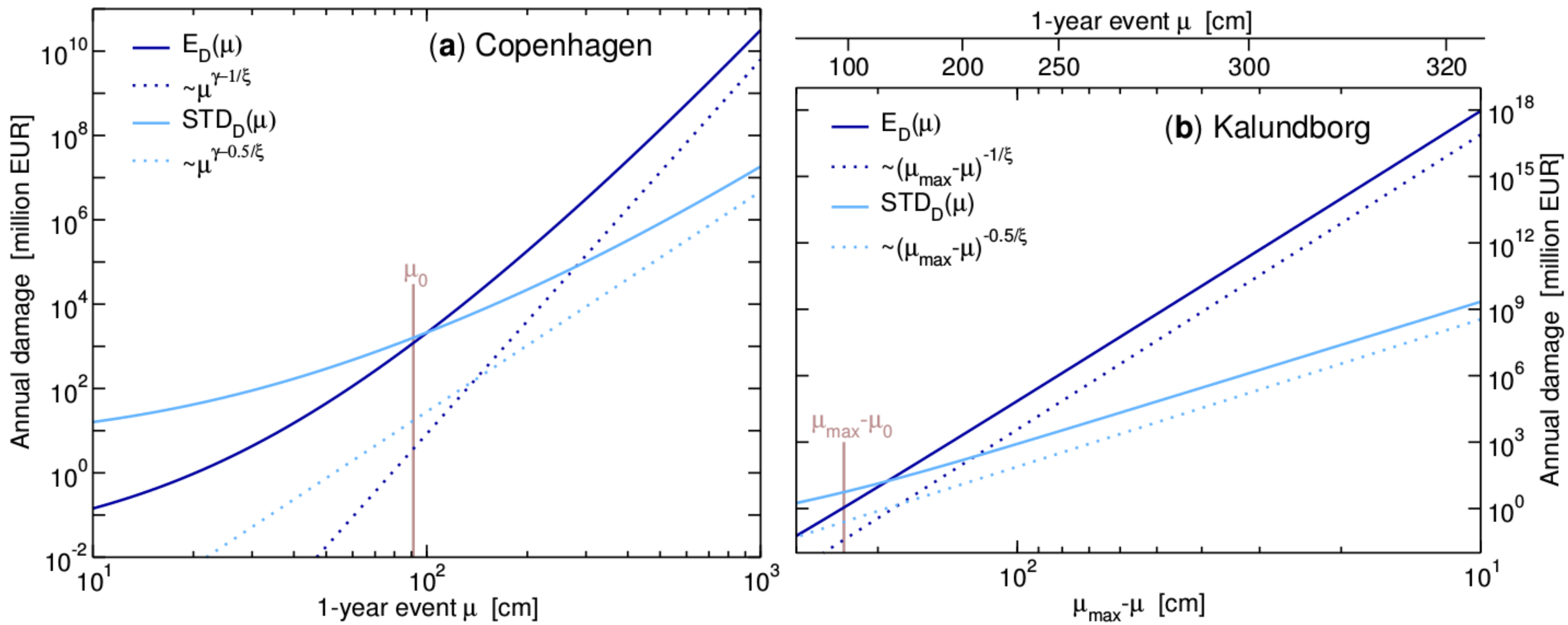


Fig. 4 Expected annual damages (dark blue) and standard deviations (light blue) in (**a**) Copenhagen and (**b**) Kalundborg as a function of the mean sea level (parameterised by the 1-year flood μ). The dotted lines show the asymptotic relations Eqs. (12), (13) and (14) with $\gamma = 1.57$ and $\xi = -0.14$ (Copenhagen) and $\gamma = 4.06$ and $\xi = 0.08$ (Kalundborg). The values for the current 1-year floods $\mu_0 = 91.21\,\text{cm}$ (Copenhagen) and $\mu_0 = 95.35\,\text{cm}$ (Kalundborg) are indicated by brown vertical lines. The abscissa in the right panel is inverted and shows the difference between the 1-year flood μ and $\mu_{\max} = 332.04\,\text{cm}$ (at the top, the corresponding 1-year floods are displayed).

How damages from coastal floods are reduced with protection

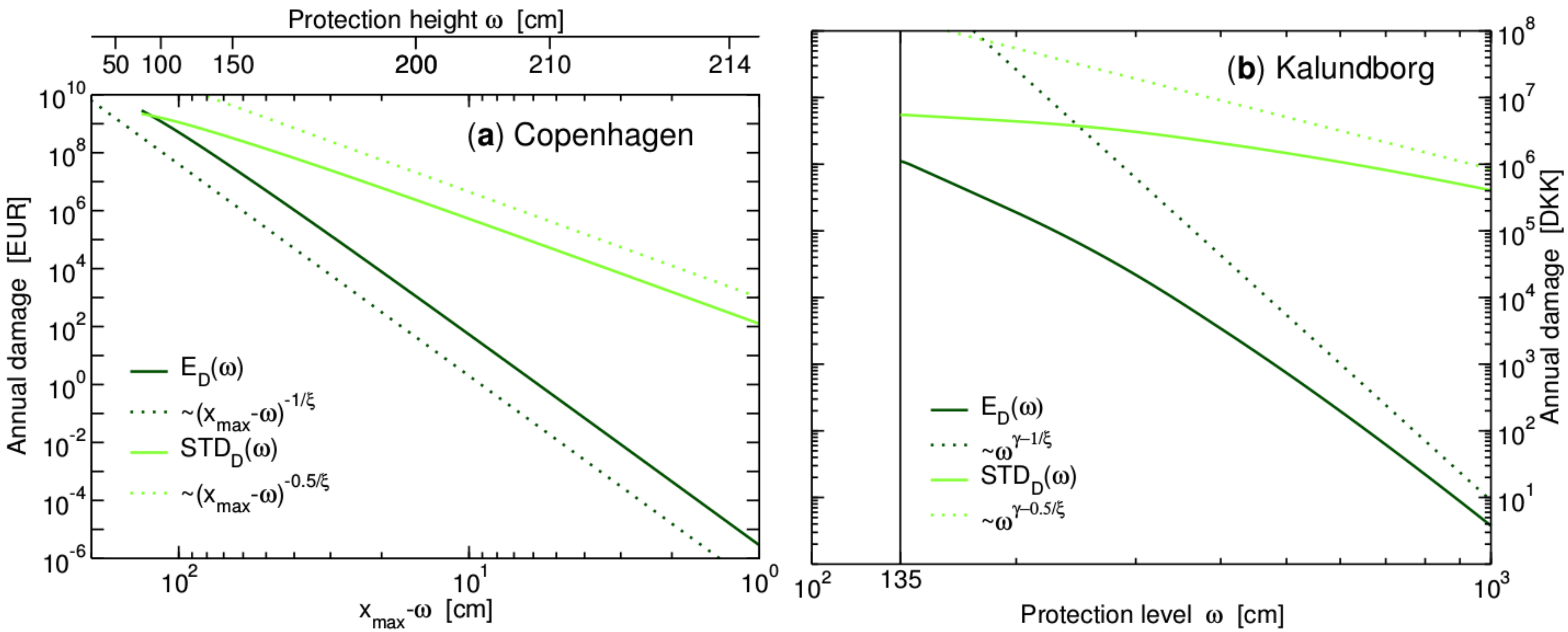


Fig. 6 Expected annual damages (dark green) and standard deviations (light green) in (**a**) Copenhagen and (**b**) Kalundborg as a function of the protection level ω. The abscissa in the left panel is inverted and shows the difference between the protection level ω and the maximum possible water level $x_{\max} = 215.28\,\text{cm}$ (at the top, the corresponding protection heights are displayed). Since no considerable damage occurs in Kalundborg for sea levels below 135 cm, only protection levels above $\omega = 135\,\text{cm}$ (black vertical line) are considered. The dotted lines follow the power laws from Eqs. (15) and (16) with the estimated damage function exponents $\gamma = 1.57$ (Copenhagen) and $\gamma = 4.06$ (Kalundborg).

Example: Copenhagen

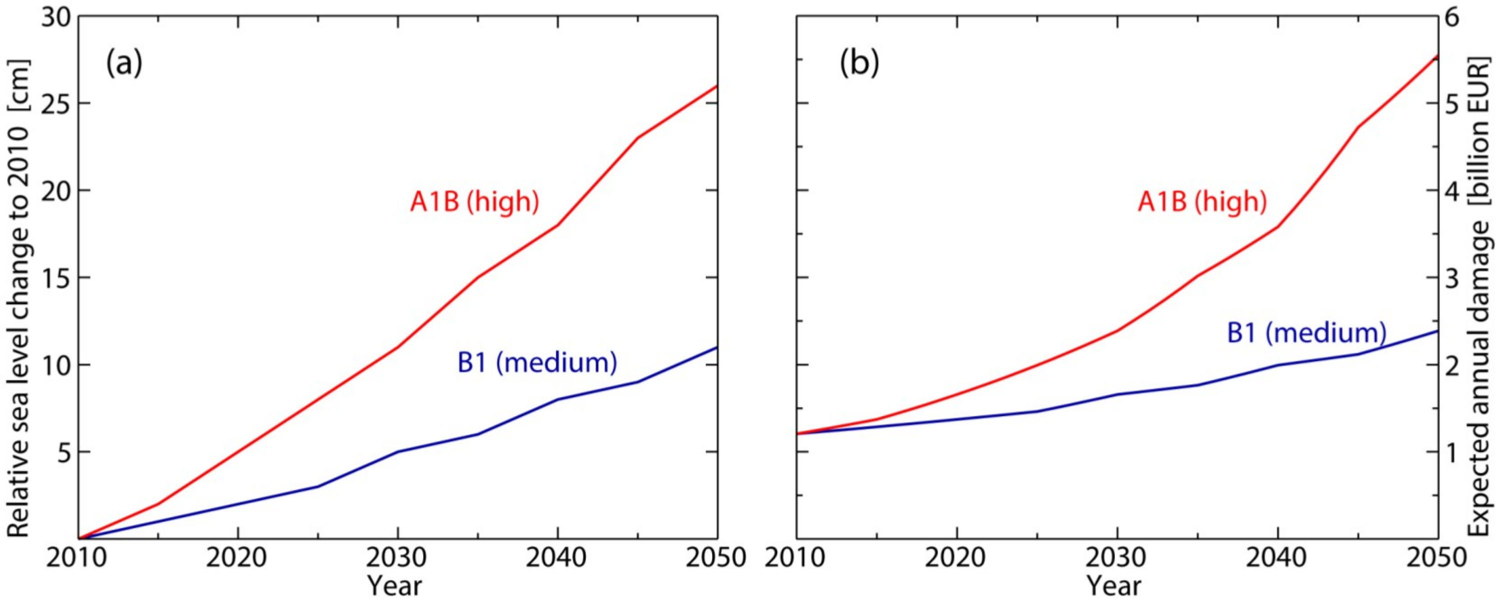
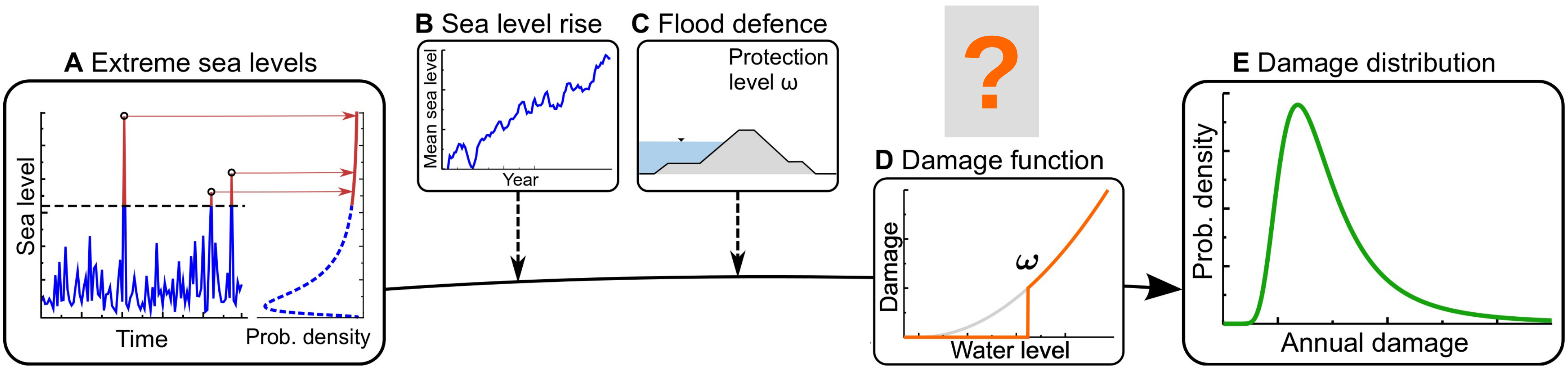


Figure 5. (a) Mean sea level projections for the SRES scenarios A1B (high climate sensitivity) and B1 (medium climate sensitivity) in Copenhagen provided by the DIVA tool (Hinkel and Klein, 2003; Vafeidis et al., 2008). **(b)** The expected annual damage as a function of time, based on the two scenarios.

Damage functions



direct,
monetary
(mostly)

Damage functions: storm

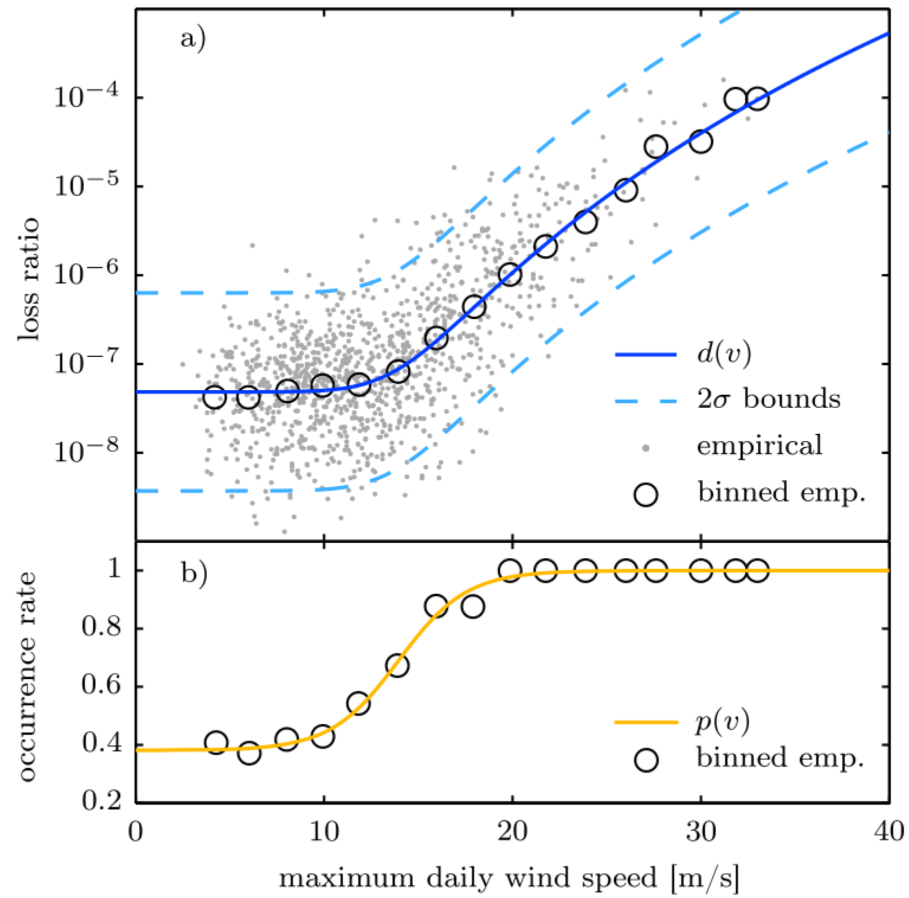
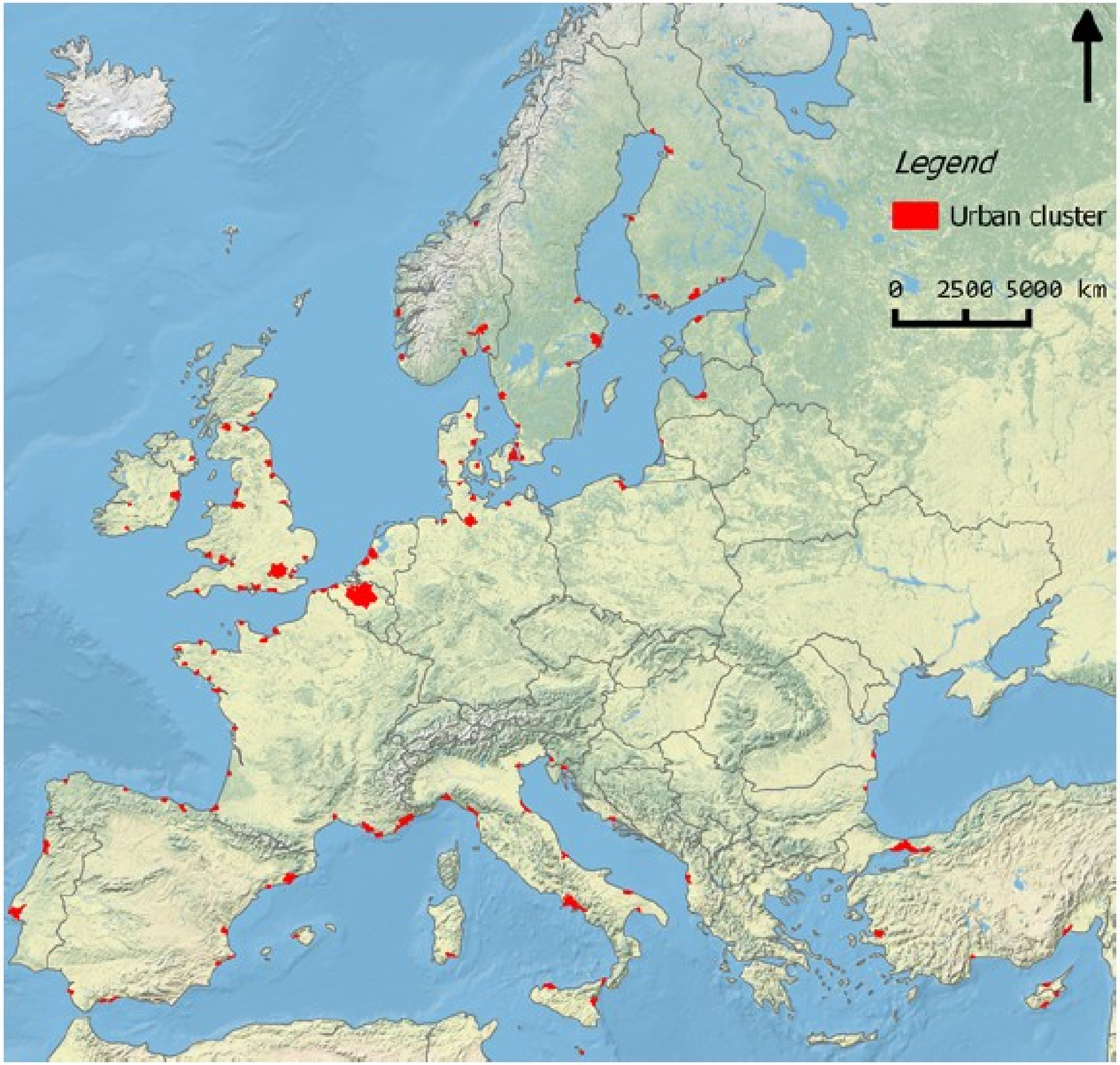


Figure 1. Example of damage function and occurrence probability for an arbitrary district. (a) The damage function $d(v)$ is plotted against the maximum daily wind speed v. Confidence bounds of $\pm 2\sigma$ are shown by dashed lines. Grey points represent daily loss data. (b) The fitted occurrence probability $p(v)$ is shown. Binned empirical data, shown as circles, are given as reference only.

Damage functions: 140 coastal cities



Flood damage functions from land-cover data

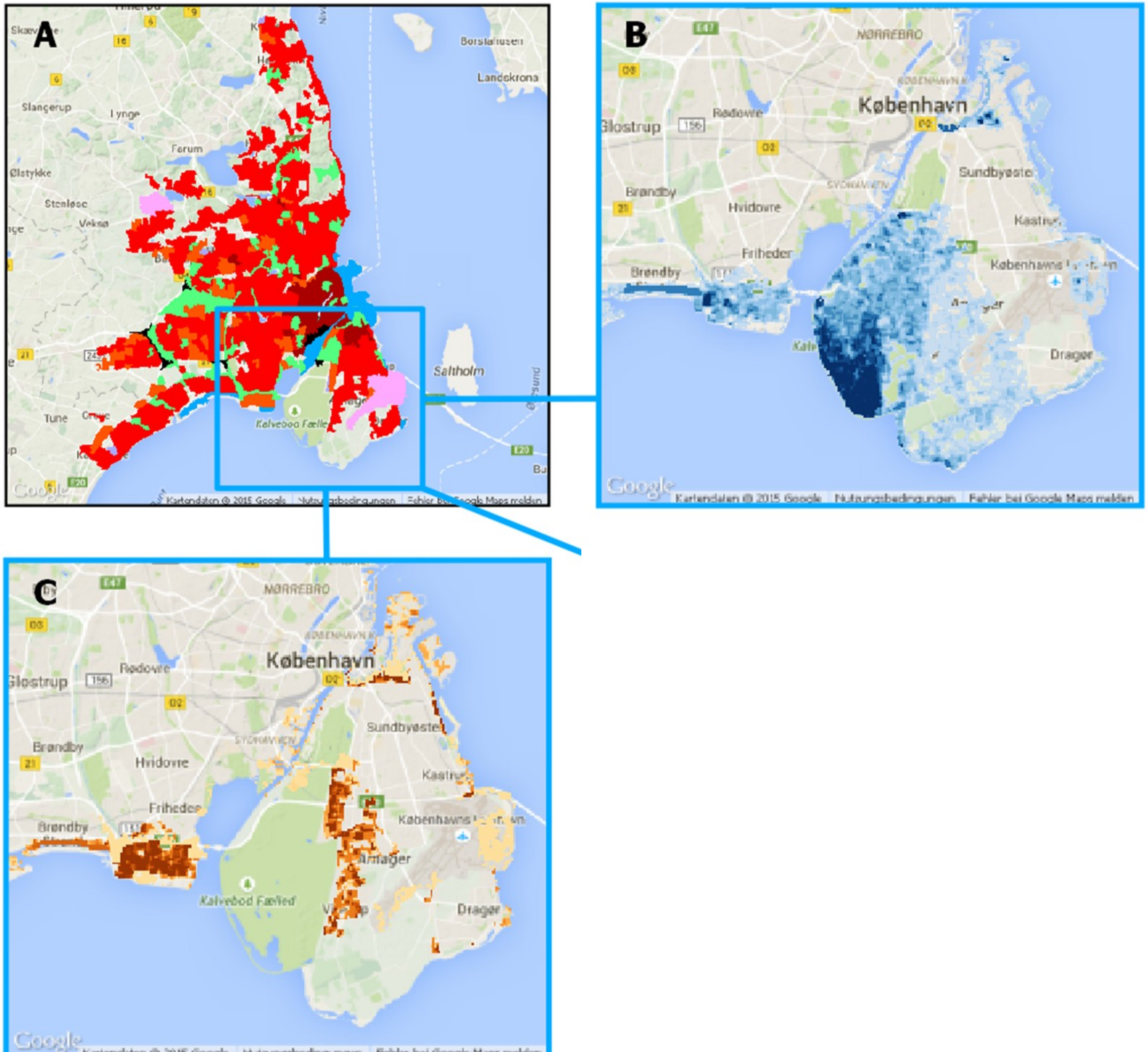
Table 4: Relative damage functions for several land uses from Huizinga (2007) as fraction of the maximum possible damage.

	Flood level								
Land use	0 m	0.5 m	1 m	1.5 m	2 m	3 m	4 m	5 m	6 m
Residential (incl. inventory)	0	0.25	0.4	0.5	0.6	0.75	0.85	0.95	1
Commerce (incl. inventory)	0	0.15	0.3	0.45	0.55	0.75	0.9	1	1
Industry (incl. inventory)	0	0.15	0.27	0.4	0.5	0.7	0.85	1	1
Infrastructure (roads)	0	0.25	0.42	0.55	0.65	0.8	0.9	1	1
Agriculture	0	0.3	0.55	0.65	0.75	0.85	0.95	1	1

Table 5: Average maximum damage values for the year 2004 (Huizinga 2007).

Land use	Average maximum damage value [€/m^2]
Residential buildings	750
Commerce	621
Industry	534
Roads	24
Agriculture	0.77

Copenhagen



A Urban CLC classes

- Continuous urban fabric
- Discontinuous urban fabric
- Industrial or commercial units
- Road/rail networks
- Port areas
- Airports
- Mineral extraction sites
- Dump sites
- Construction sites
- Green urban areas

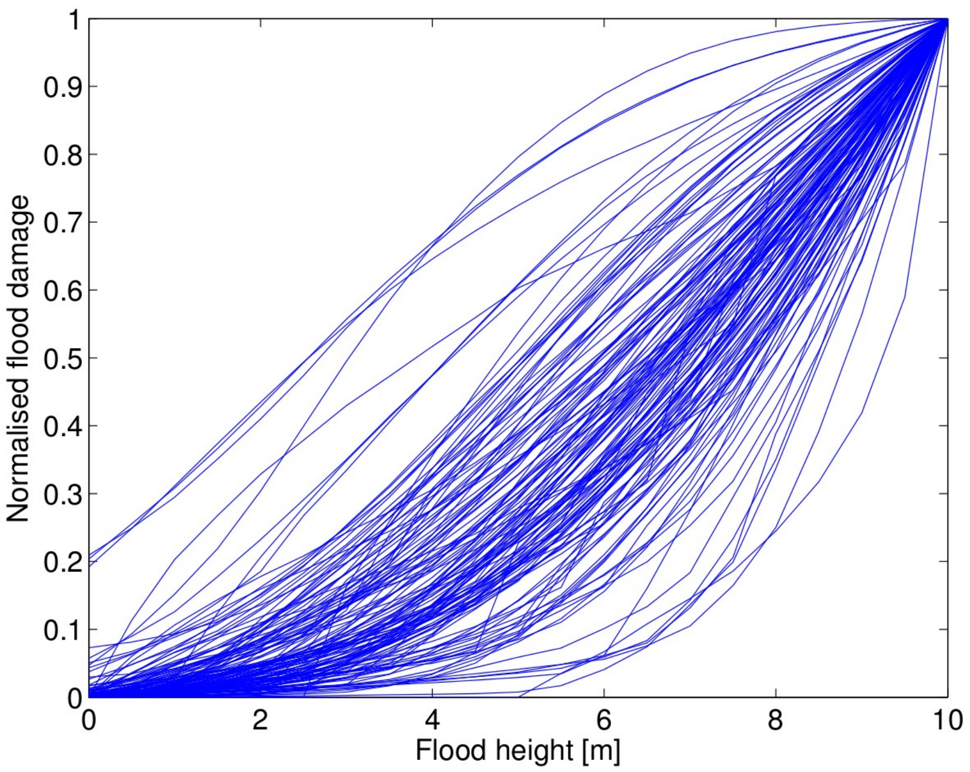
B Inundation depth at 1.5m flood level [m]

- >4
- 4
- 3
- 2
- 1

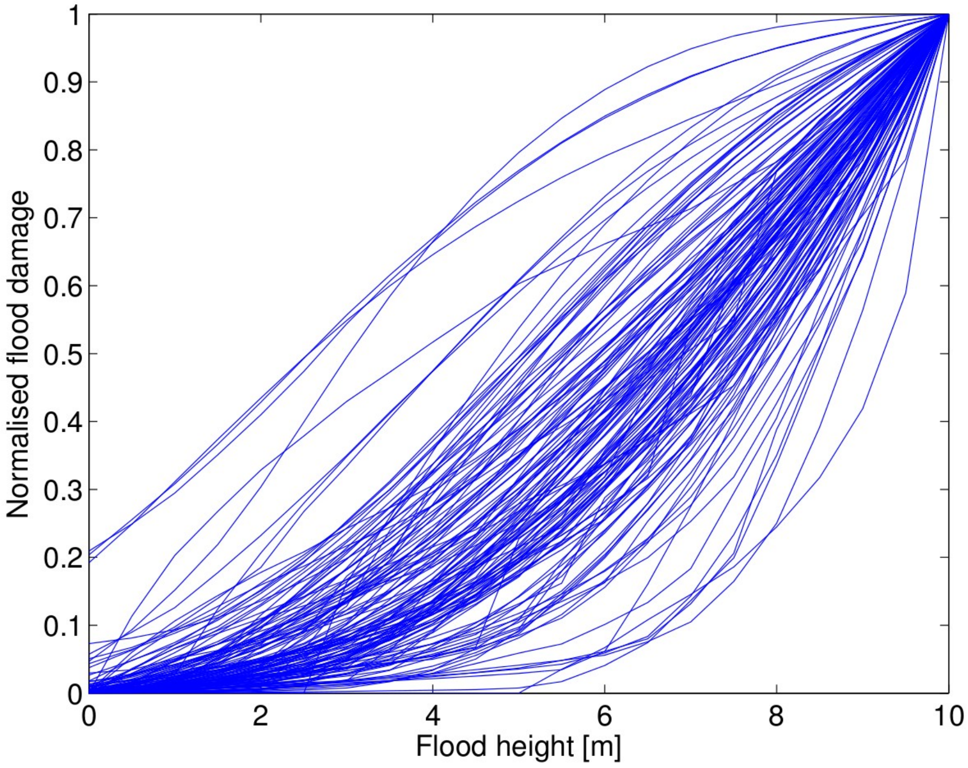
C & **D** Estimated damages [€/m²]

- 30
- 60
- 90
- 120
- 150

Damage functions

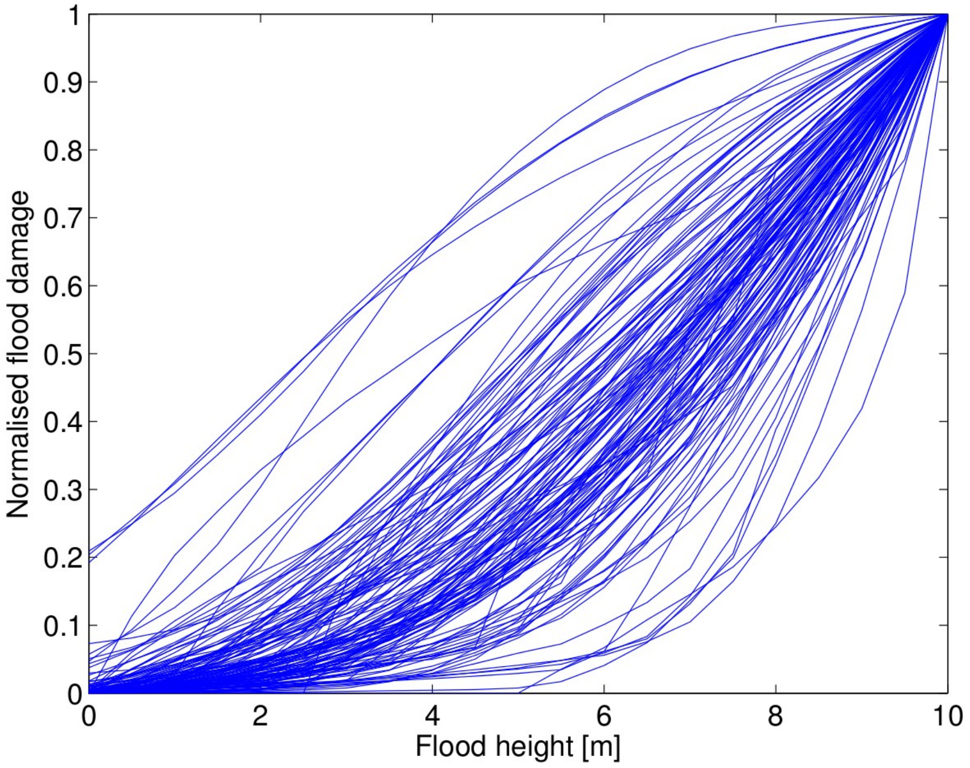


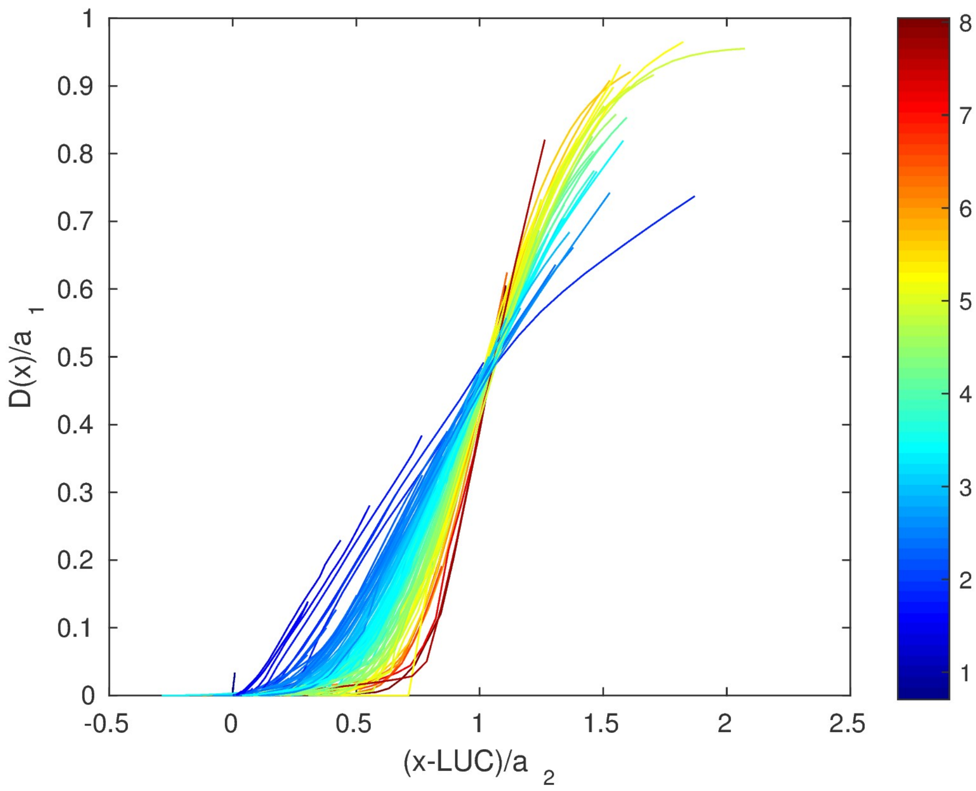
Damage functions



log-logistic function: $$D(x) := \frac{a_1}{1 + \left(\frac{x - L_0}{a_2}\right)^{-a_3}}, \quad \text{for } x > L_0$$

Damage functions





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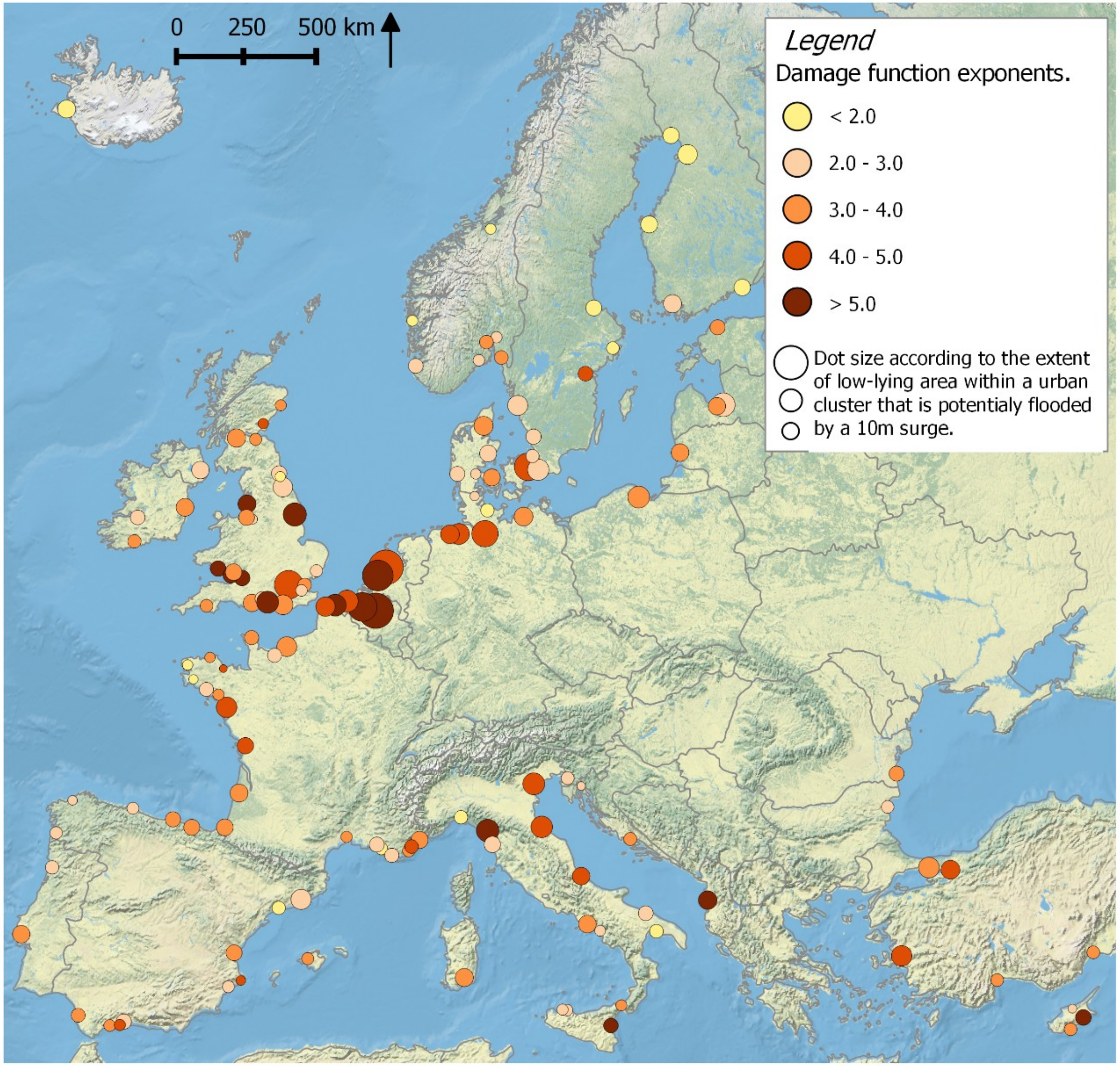
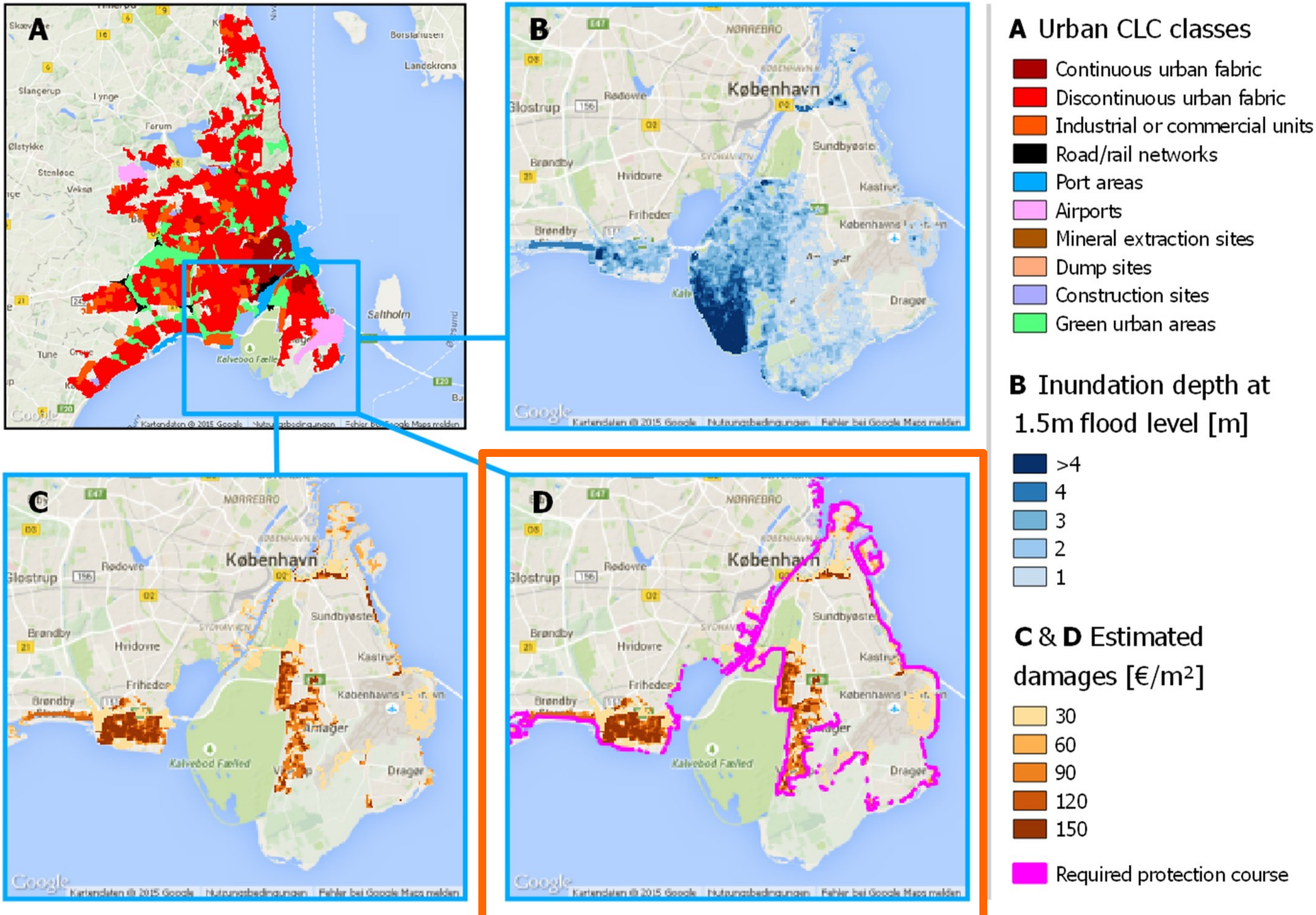
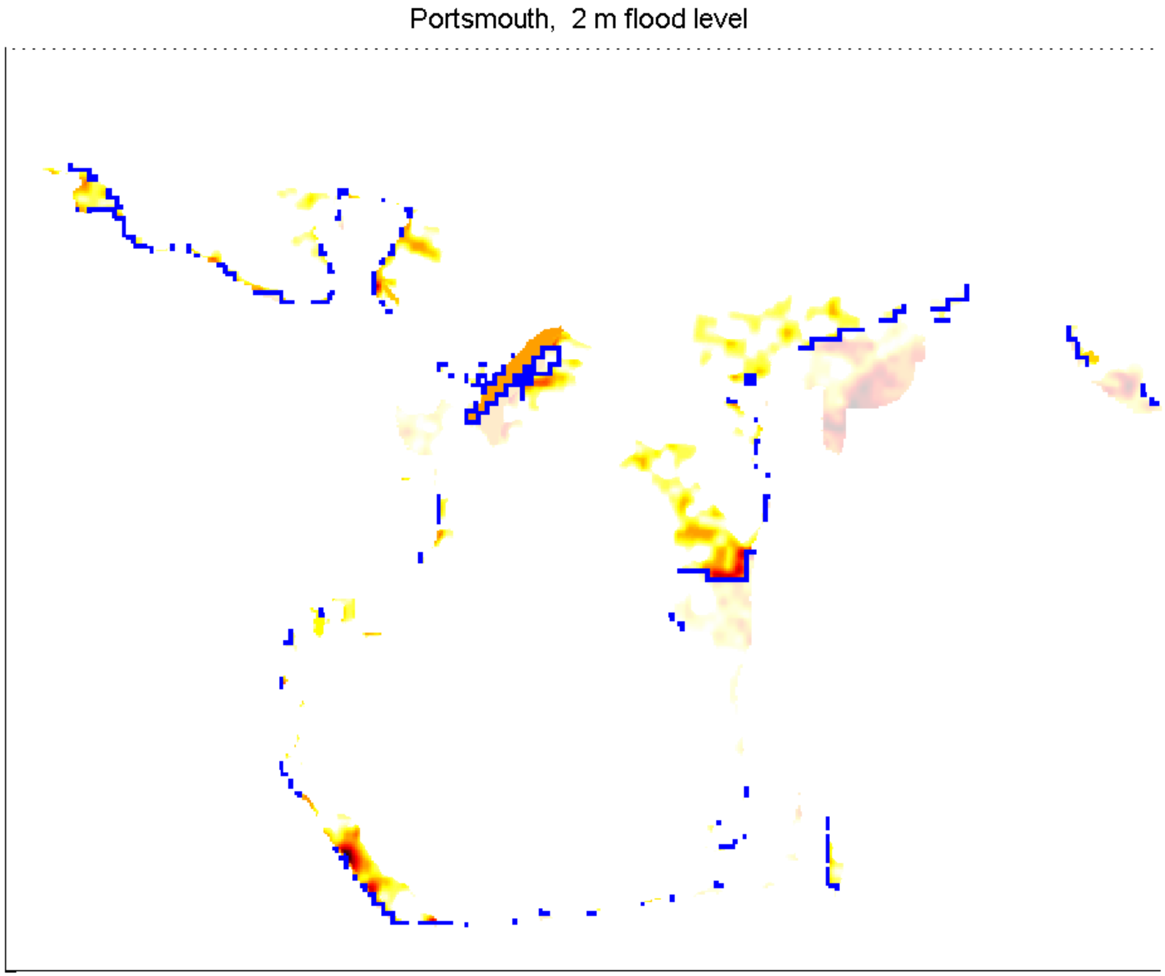
Damage function exponents



Copenhagen – Adaptation

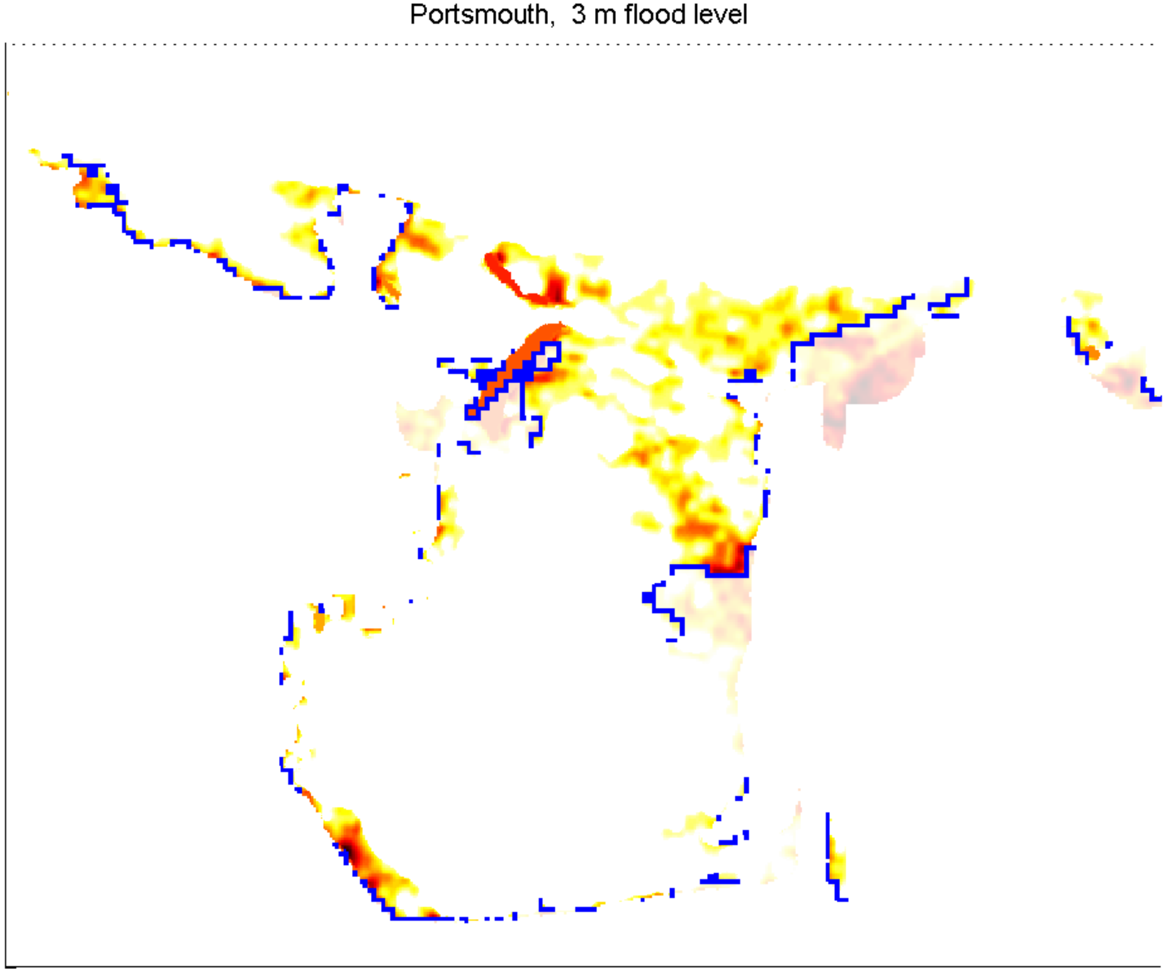


Adaptation: Portsmouth (UK), 2m



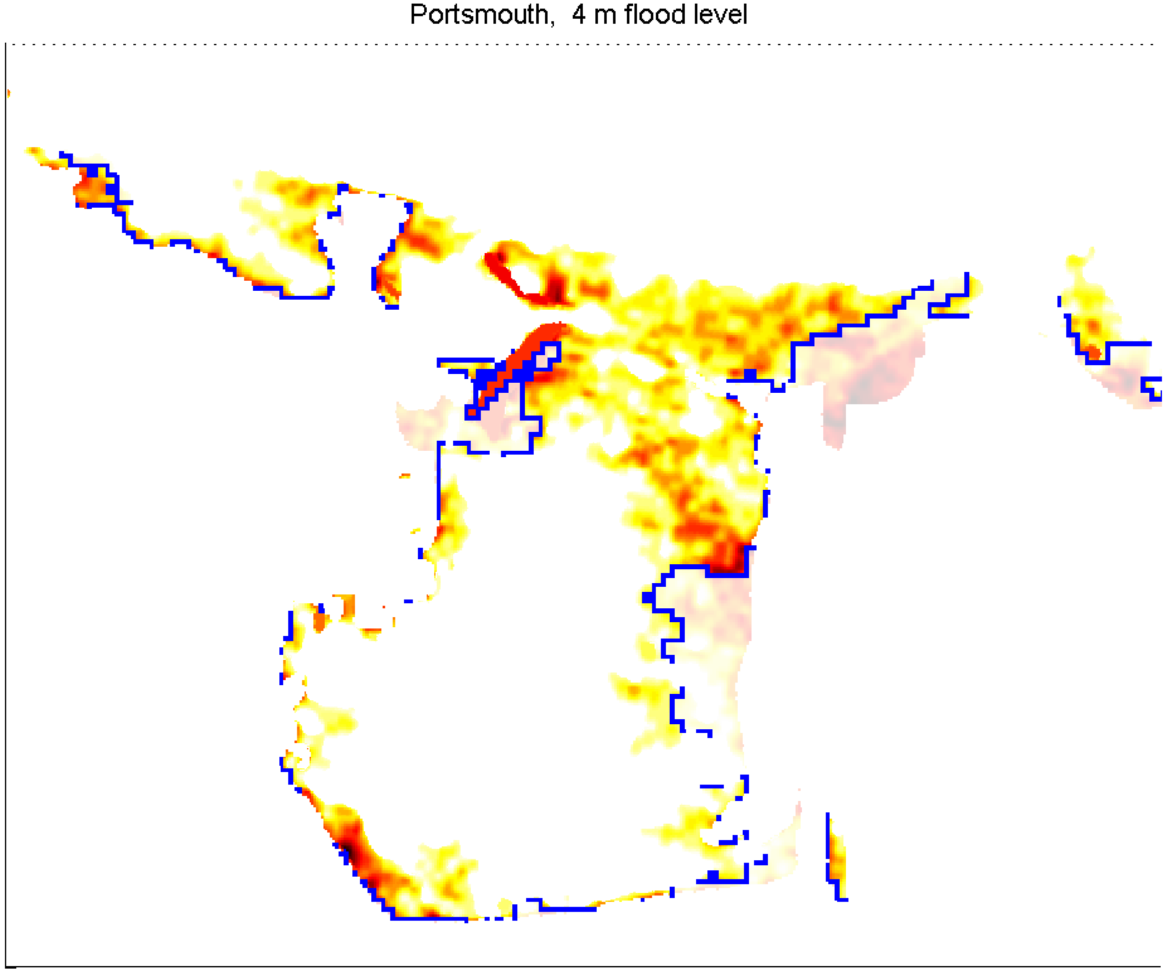
Boettle et al., in prep., 2016

Adaptation: Portsmouth (UK), 3m



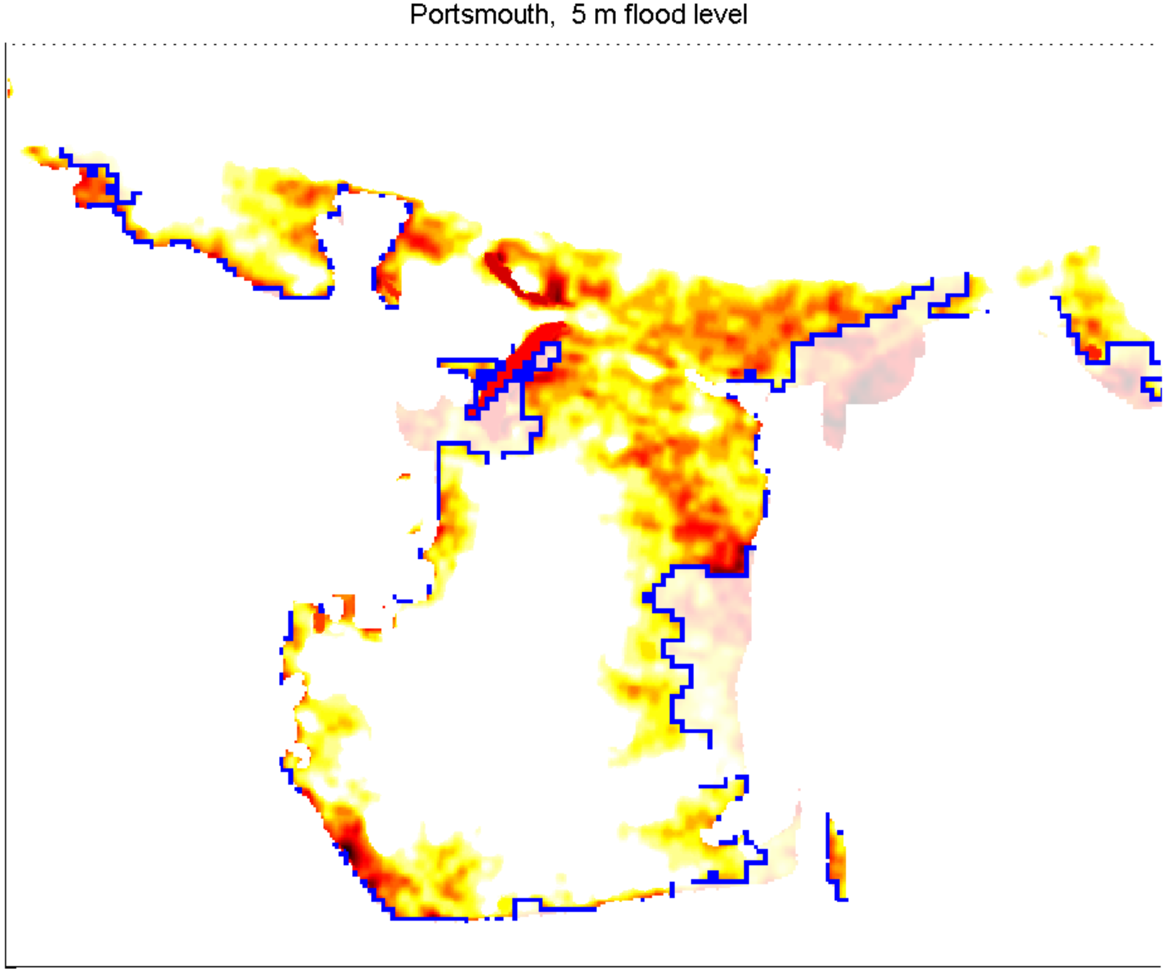
Boettle et al., in prep., 2016

Adaptation: Portsmouth (UK), 4m



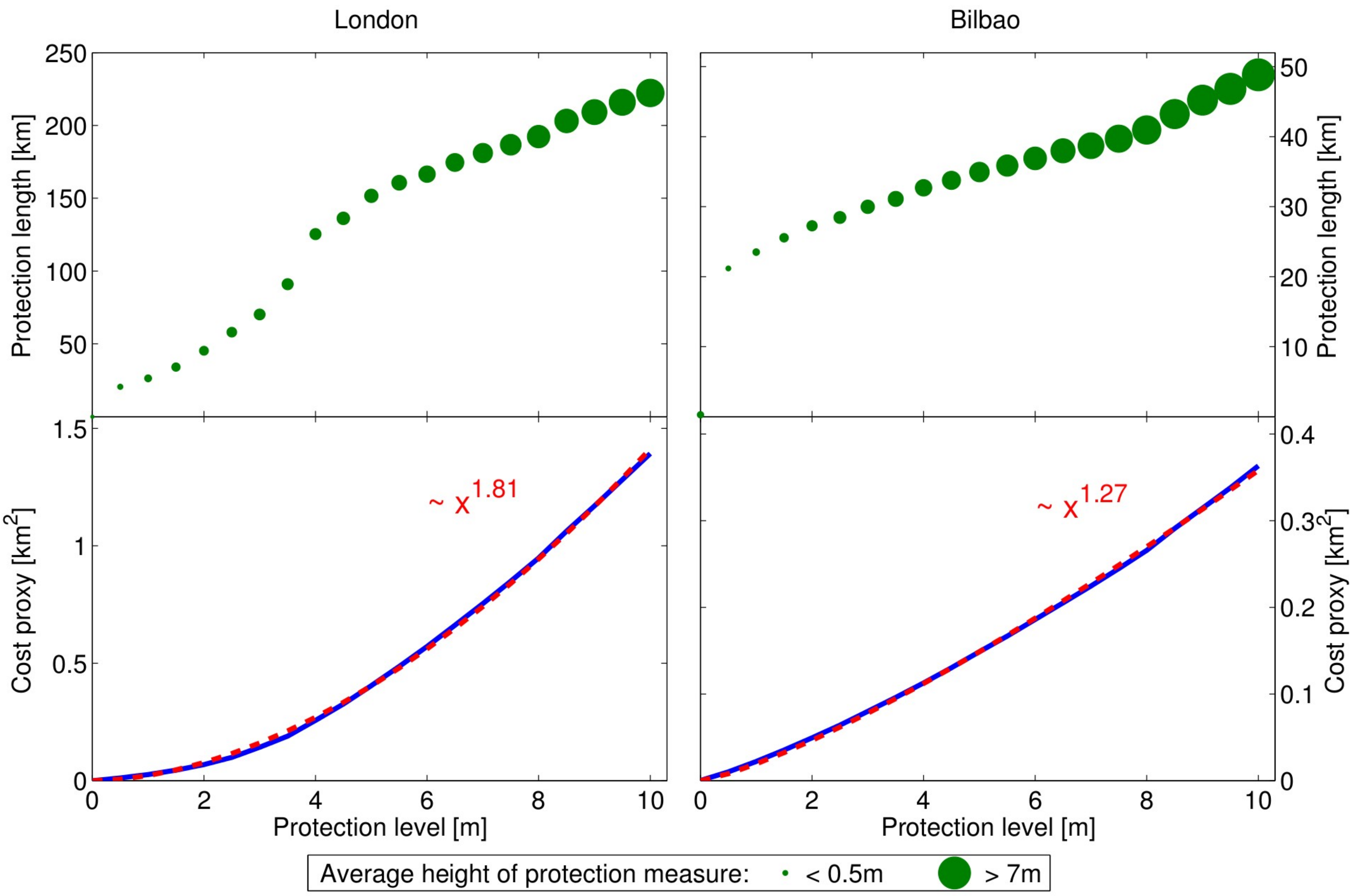
Boettle et al., in prep., 2016

Adaptation: Portsmouth (UK), 5m

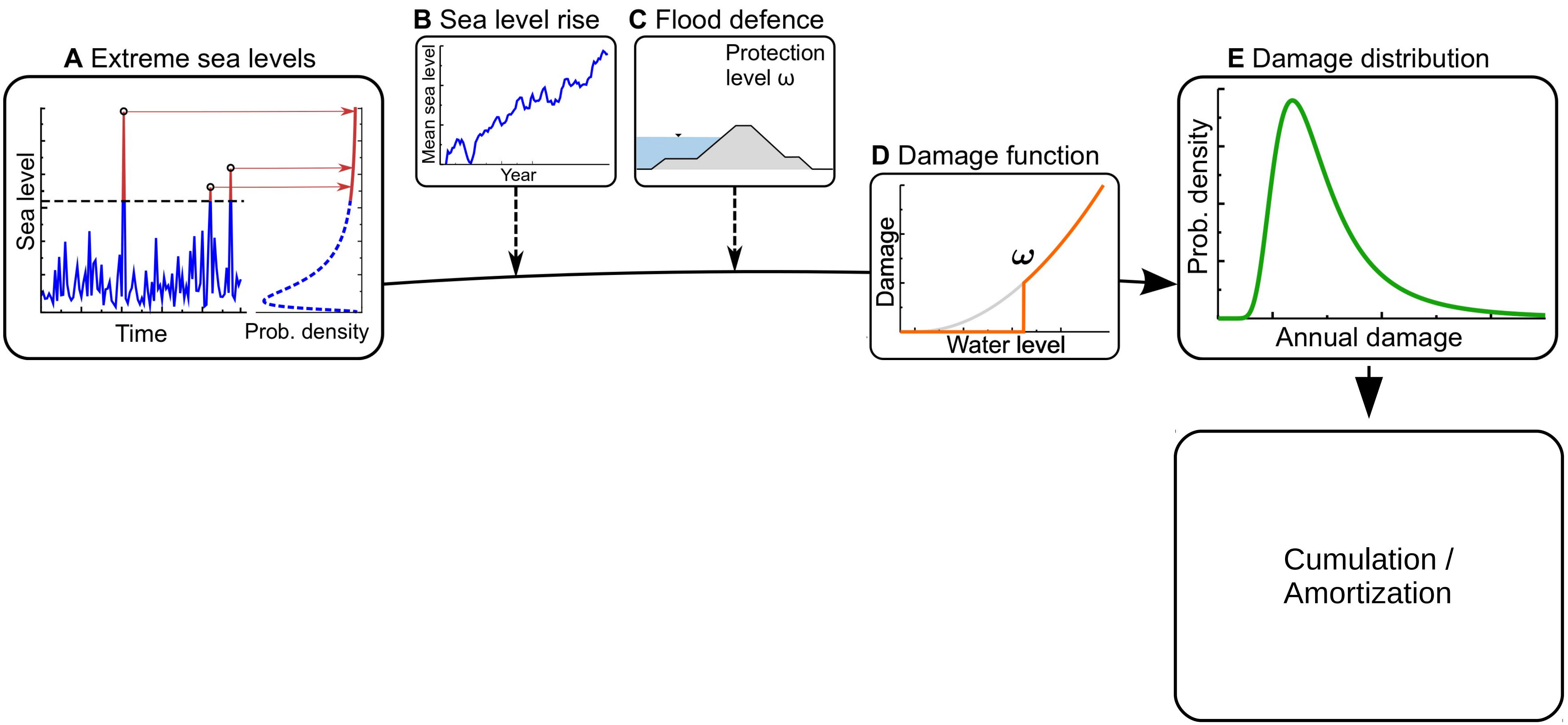


Boettle et al., in prep., 2016

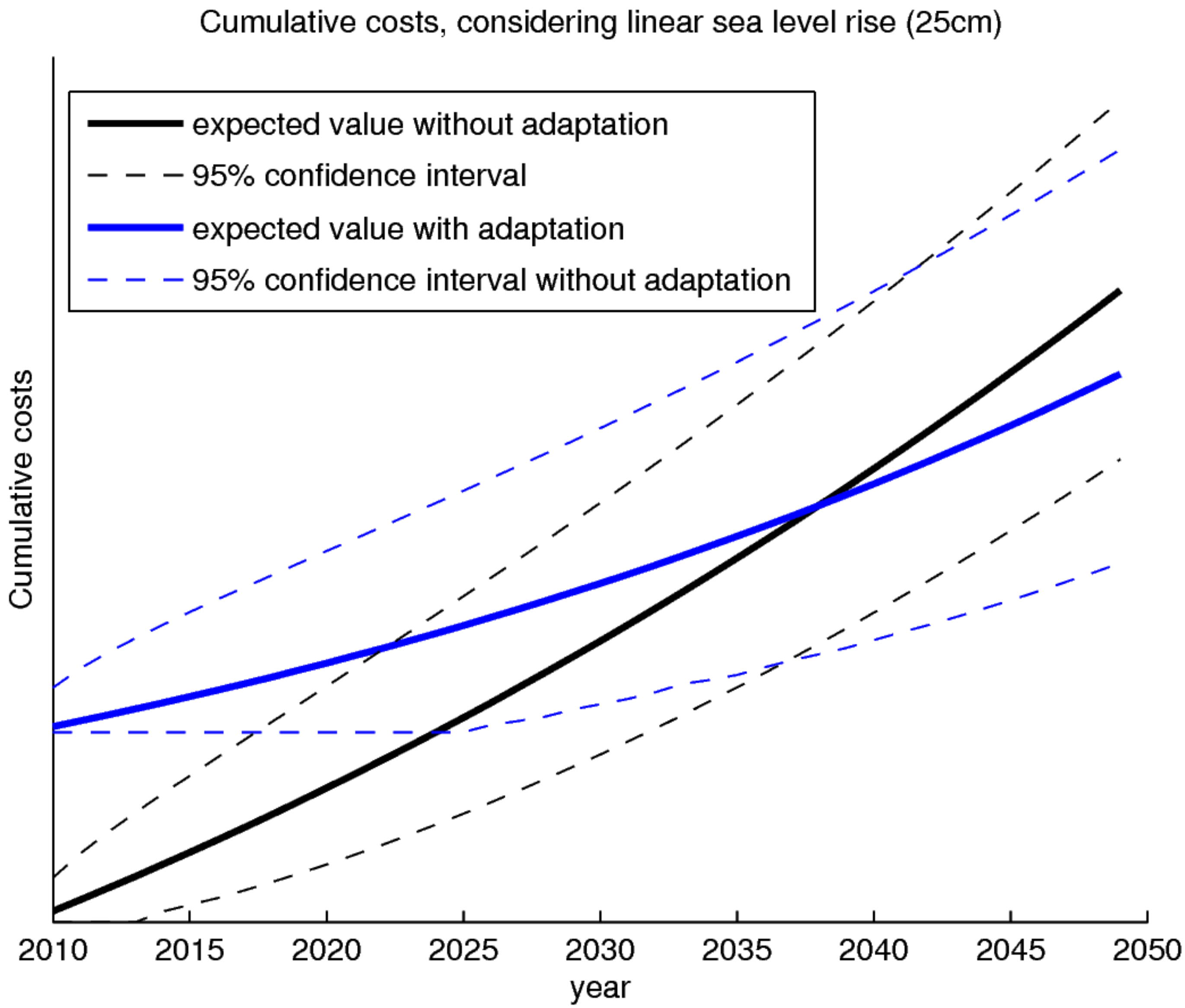
Protection functions



Cumulative damages



Cumulative damages: adaptation & amortization



Summary & Outlook

Summary

- Generic methodology for climate change intensified
  natural hazards hitting cities
- Damage and Adaptation function

Work in progress

- Stationary (present condition)
  Expected damage, Avoided damage, Adaptation costs, ...
- Non-stationary (future scenarios)
  Sea-level rise, Urbanization, Subsidence, Discounting, ...

Outlook

- global assessment
- other land-uses
- other impacts
- indirect damage

Acknowledgment

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RAMSES

Reconciling Adaptation, Mitigation and Sustainable Development for Cities

http://www.ramses-cities.eu

Thank you for your attention!

et al. are ...

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Sea-level rise

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2. Boettle M, Rybski D, Kropp JP   WRR   49 (3): 1199-1210, 2013
3. Boettle M, Costa L, Kriewald S, Zhou B, Kropp JP, Rybski D in preparation

Storm damage

4. Prahl BF, Rybski D, Burghoff O, Kropp JP   nhess   15 (4): 769-788, 2015
5. Prahl BF, Rybski D, Kropp JP, Burghoff O, Held H   GRL   39 (6): L06806, 2012

Unified damage function

6. Prahl BF, Rybski D, Boettle M, Kropp JP   nhess   accepted, 2016

http://diego.rybski.de/

http://www.pik-potsdam.de/members/rybski/