Potsdam Institute for Climate Impact Research

Climate change & development group

Cities as complex systems – towards a structural view on climate change challenges

Diego Rybski et al.

Newcastle University | 17.3.2014 | 13:00-14:00

Outline

Defining cities

Modeling cities

Examples of impact studies

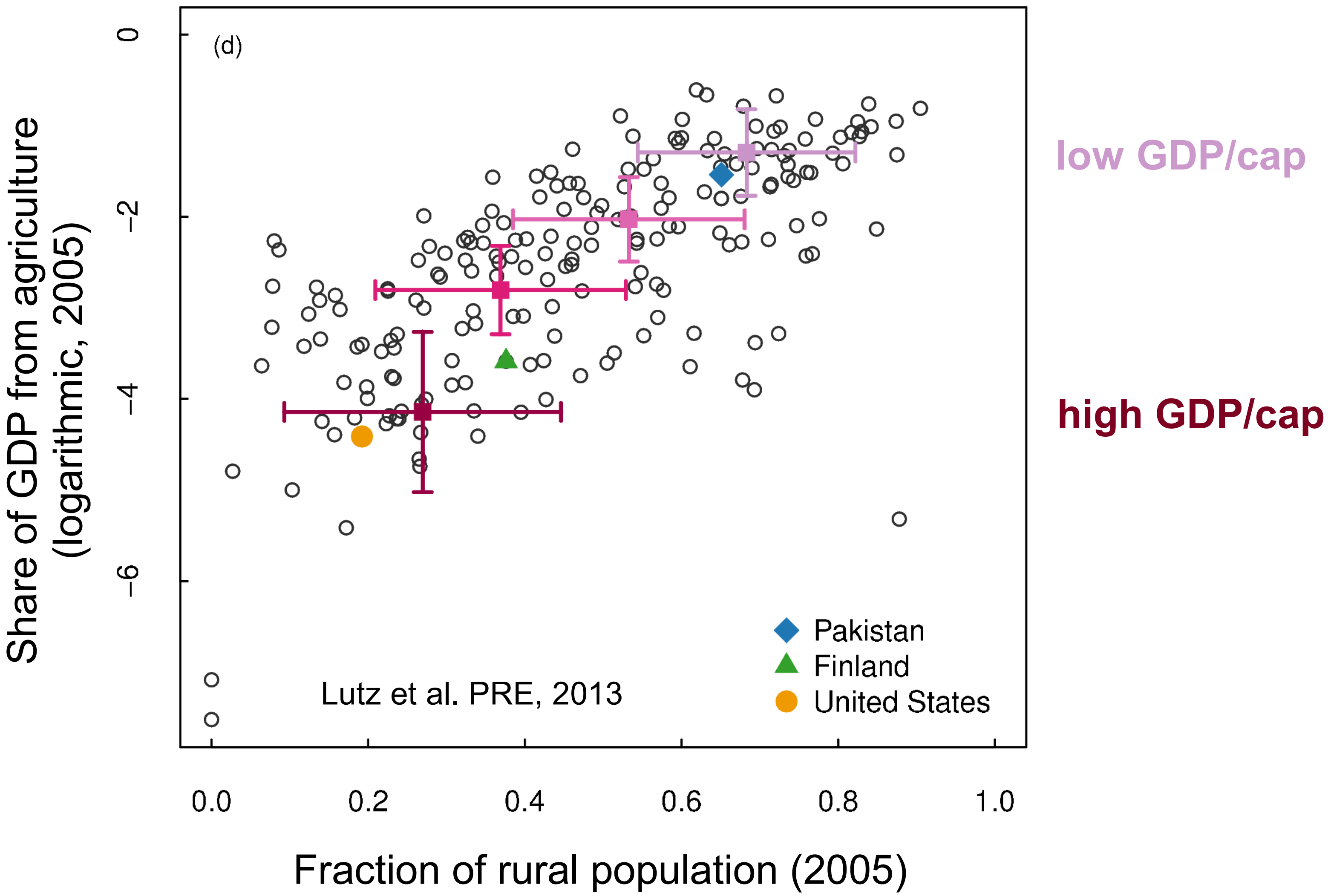
Defining cities

A brief history of cities

Major historical landmarks:

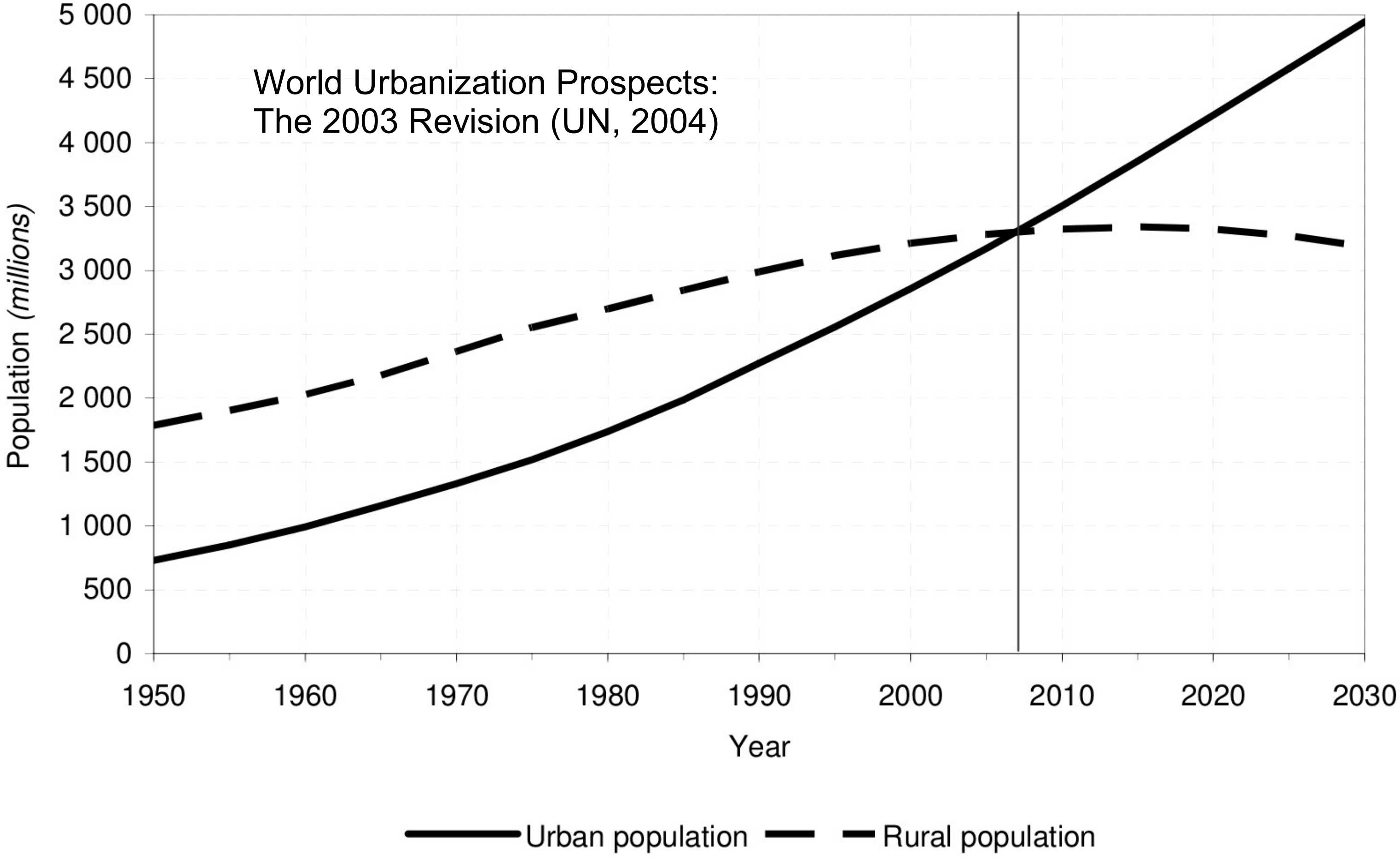
Neolithic Revolution	10 000 BCE hunter-gatherer to agricultural practices permament buildings next to working sites settlements, villages, small cities
Industrial Revolution	18th..19th century industrial sector, factories employment in cities, migration, pop. growth tall buildings (steel frame, elevators) modern cities
Globalization	complex and controversial relocation of production processes to less developed countries corresponding cities migration mega-cities

Urbanization and development



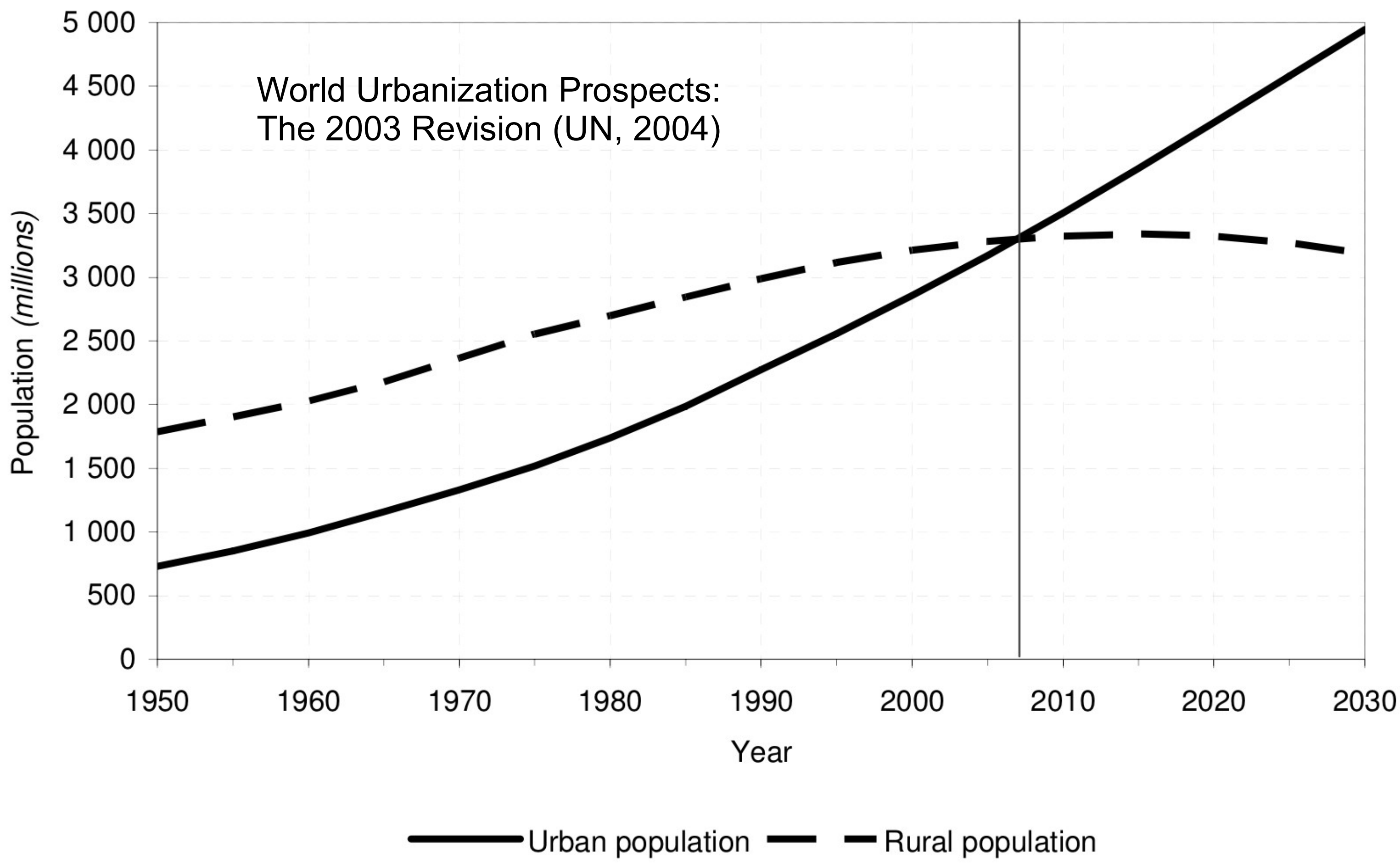
Urban vs. rural

Figure I.1. Urban and rural populations of the world: 1950-2030



Urban vs. rural

Figure I.1. Urban and rural populations of the world: 1950-2030



But what is urban (rural)?

Defining cities

Descriptive views on cities could be categorized into:

(i) people
(ii) usage/sector
(iii) physical features

Defining cities

Descriptive views on cities could be categorized into:

(i) people
(ii) usage/sector
(iii) physical features

which are related/correlated, e.g.
employees work in offices in tall buildings

Defining cities

Descriptive views on cities could be categorized into:

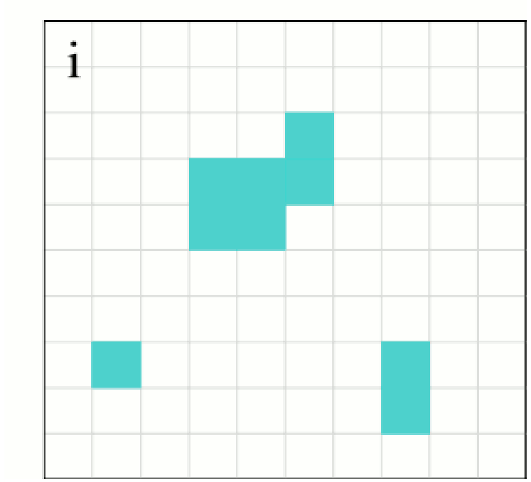
(i) people
(ii) usage/sector
(iii) physical features

which are related/correlated, e.g.

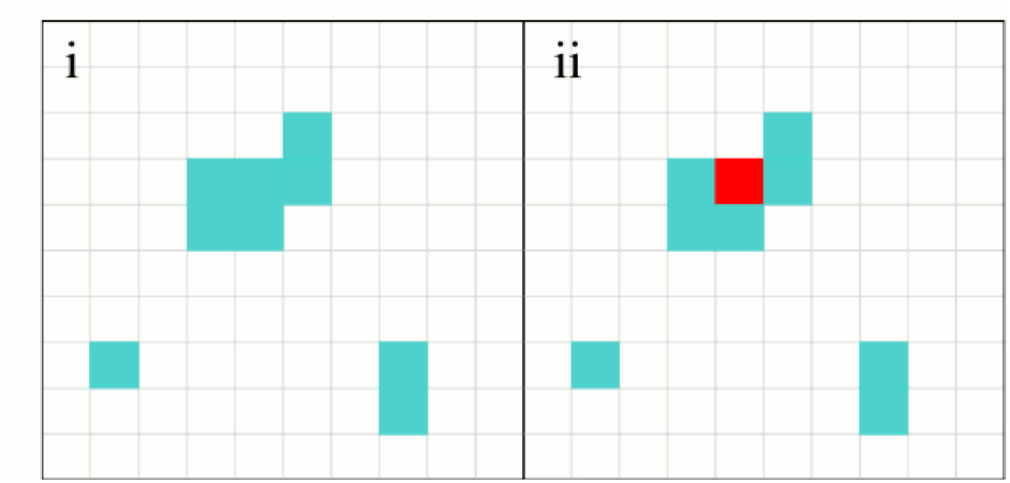
employees work in offices in tall buildings

We (mostly) employ physical definition:
Cities as maximally connected urban clusters
City Clustering Algorithm (CCA)
physical phenomena
data availability (developing countries)

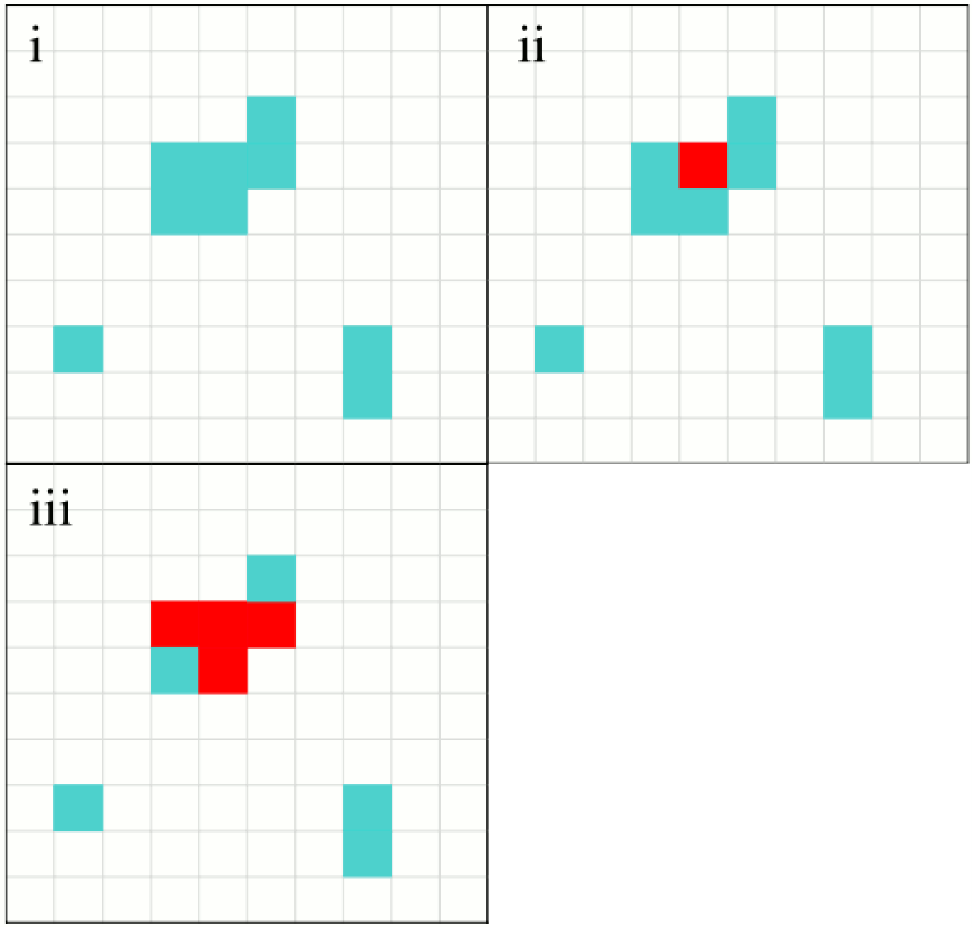
City Clustering Algorithm (CCA)



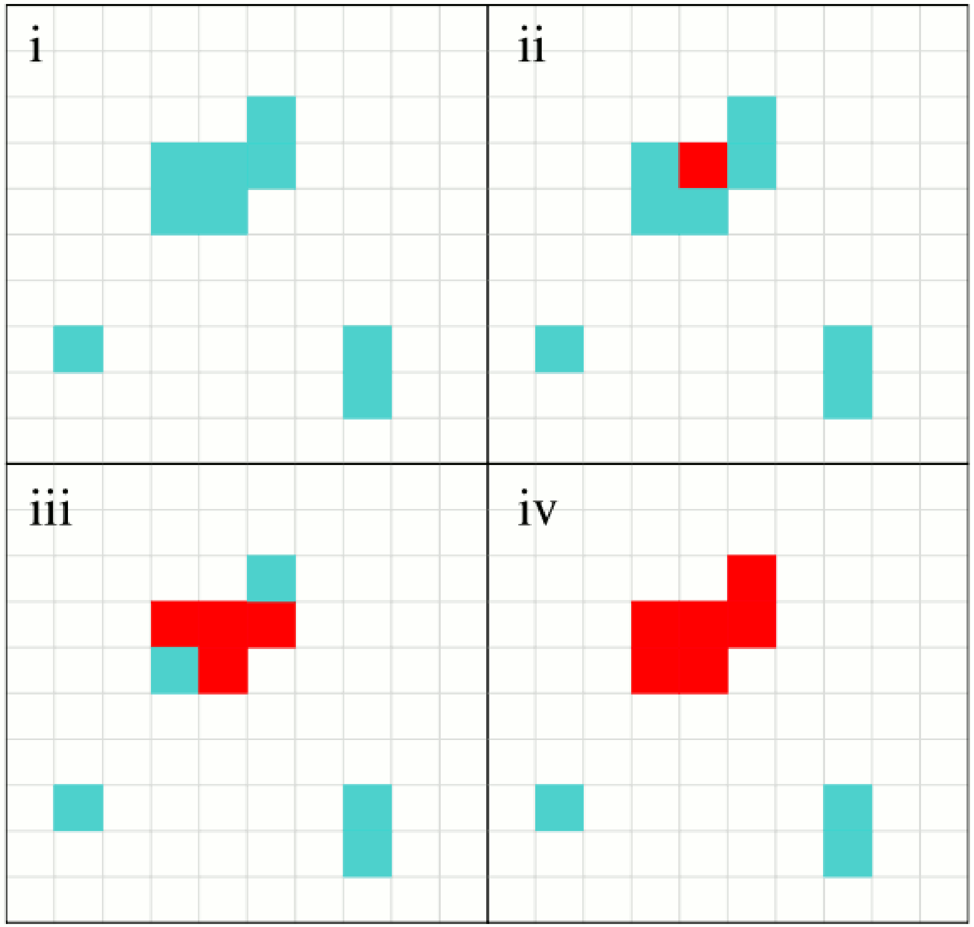
City Clustering Algorithm (CCA)



City Clustering Algorithm (CCA)



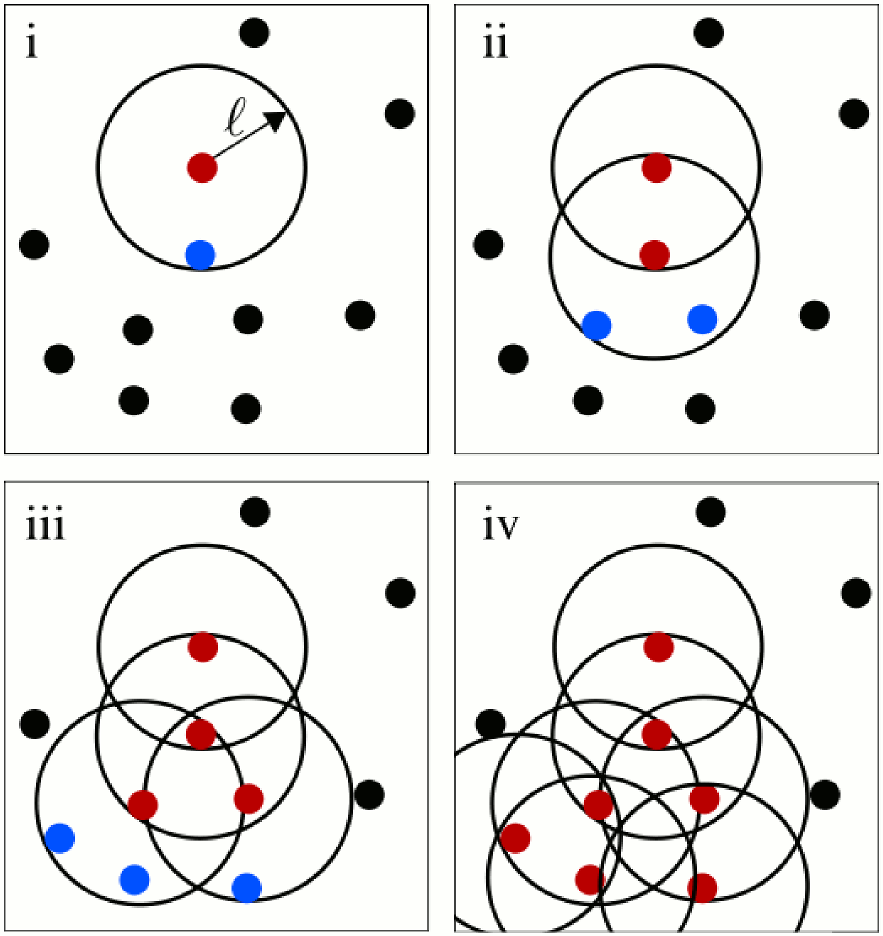
City Clustering Algorithm (CCA)



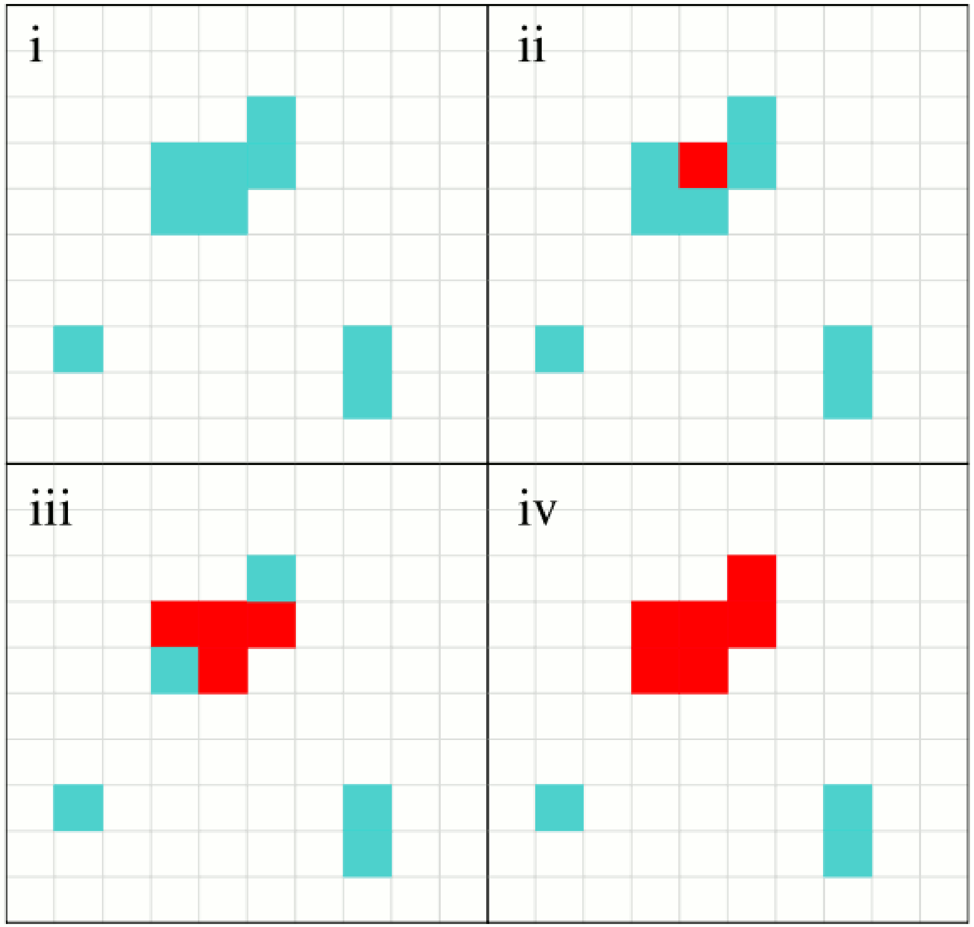
Raster

City Clustering Algorithm (CCA)

Rozenfeld, HD, et al. AER, 2011

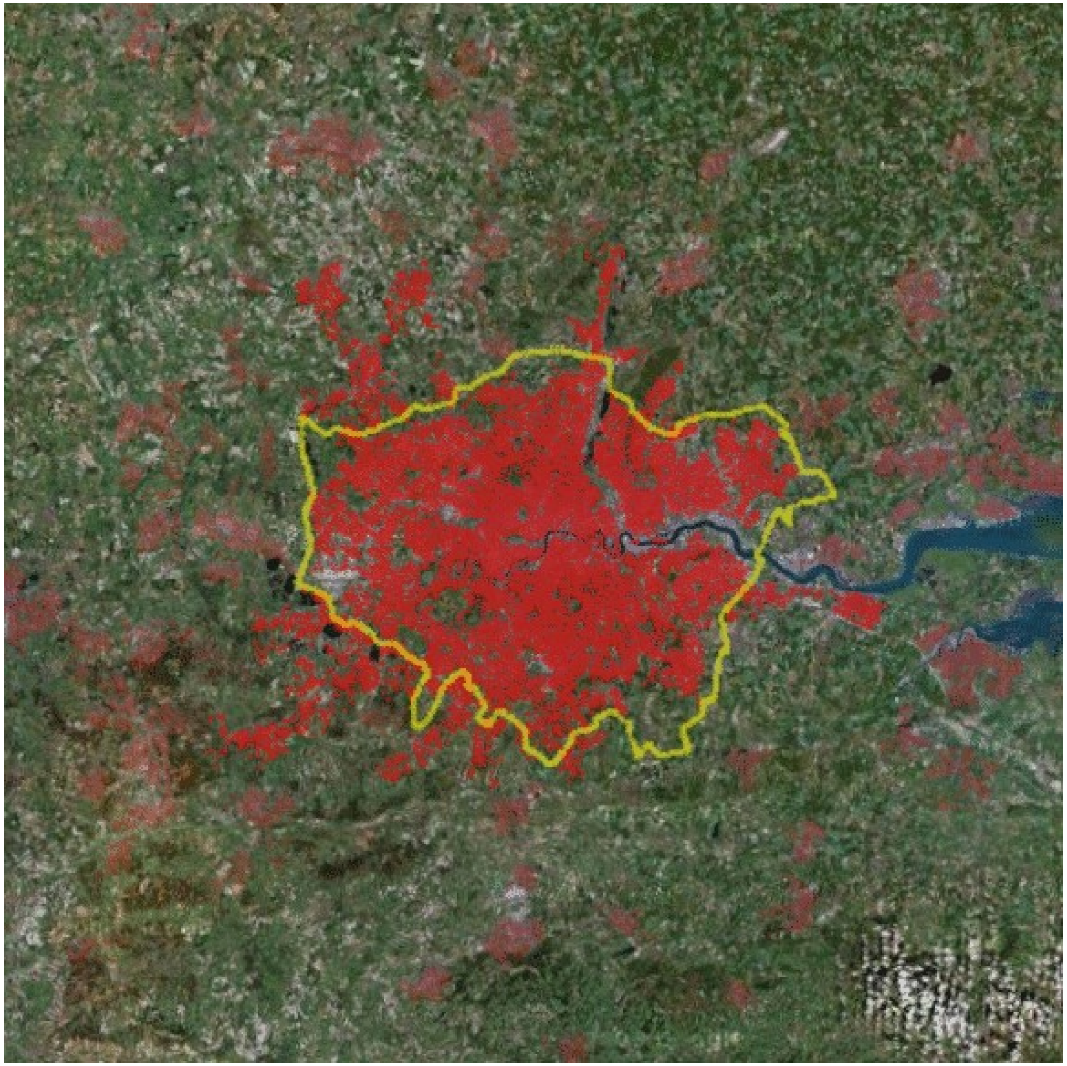


Point



Raster

Greater London



Modeling cities

Benchmarks for the modeling of cities

A reductionist point of view …

(i) City **size** distribution
power-law probability density, exponent ≈2
(Zipf-Auerbach law)

Abb. 10 EDVARD MUNCH, **Felix Auerbach**, 1906,
Öl auf Leinwand, 83,8 x 76,2 cm, Verbleib
unbekannt

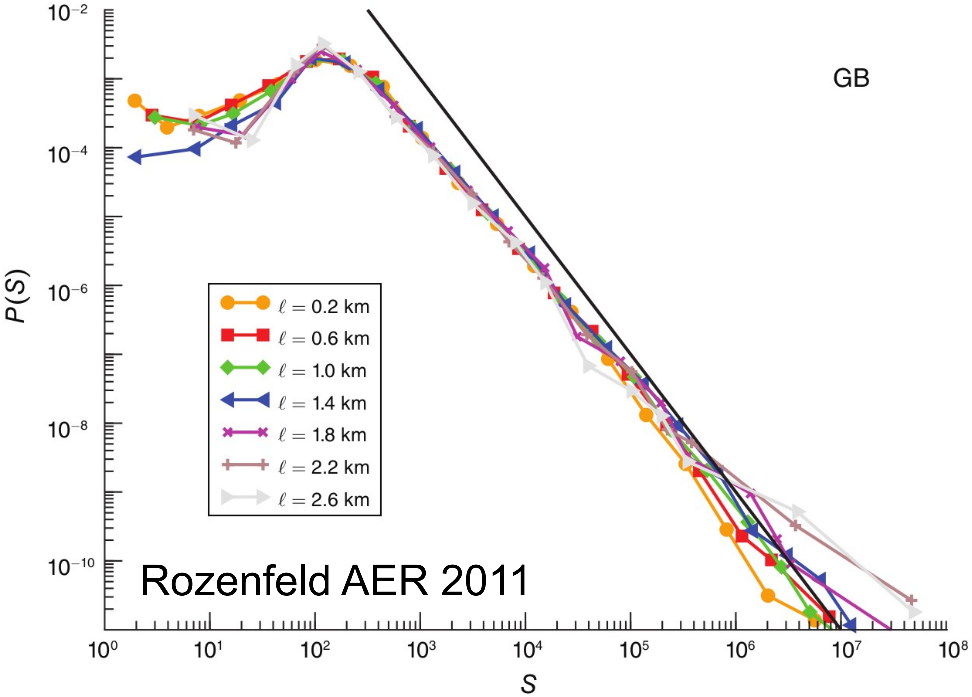


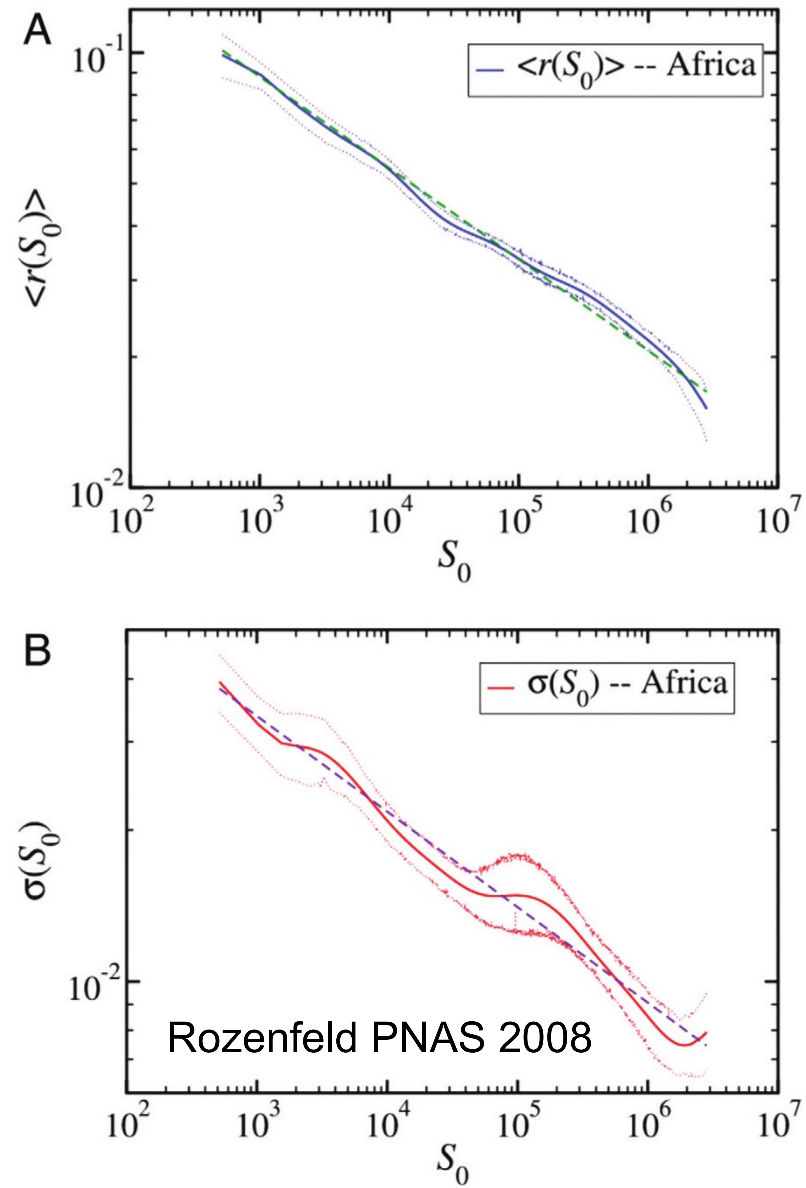
FIGURE 4. PROBABILITY DISTRIBUTION $P(S)$ FOR GB AT DIFFERENT COARSE-GRAINING SCALES ℓ

Note: The black solid line denotes a power law function with density exponent −2, i.e., Zipf's law.

Benchmarks for the modeling of cities

A reductionist point of view …

(ii) City **growth**
power-law dependence of growth-rates on size (generalized Gibrat's law)



Benchmarks for the modeling of cities

A reductionist point of view …

(i) City **size** distribution
power-law probability density, exponent ≈2
(Zipf-Auerbach law)

(ii) City **growth**
power-law dependence of growth-rates on size
(generalized Gibrat's law)

(iii) **Fractality**
Self-similarity, fractal dimension between 1 and 2
(e.g. via box-counting)

Gravitational city model

"*Everything is related to everything else, but near things are more related than distant things.*"

(W.R. Tobler, 1970)

Gravitational city model

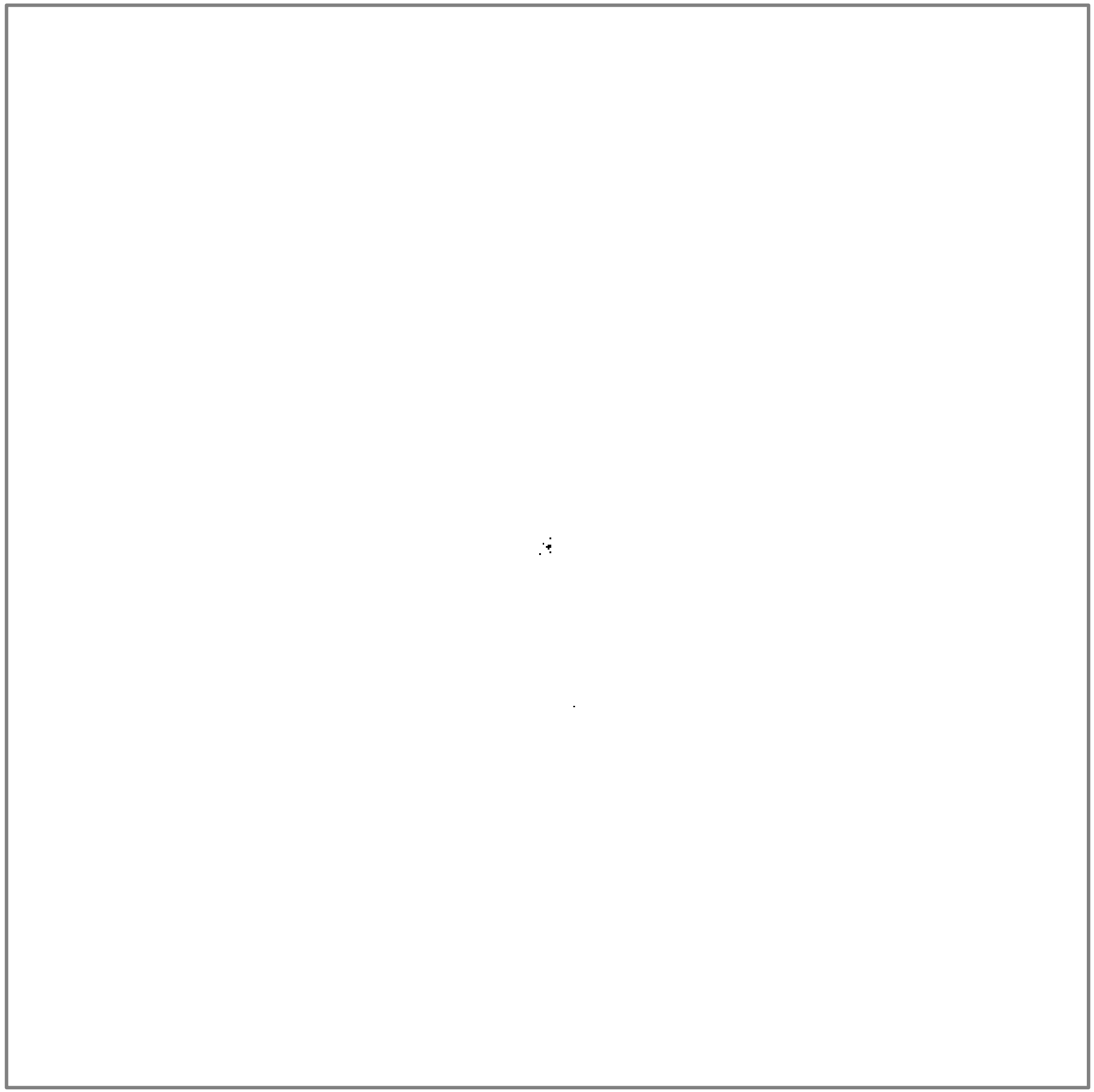
The cells of a grid with the coordinates i can either be occupied ($w_i = 1$) or empty ($w_i = 0$). Iteratively each site is tested for being populated. Therefore, the probability to become populated is given by

$$p_i = C \frac{\sum_{j \neq i} w_j d_{i,j}^{-\gamma}}{\sum_{j \neq i} d_{i,j}^{-\gamma}} \quad , \tag{1}$$

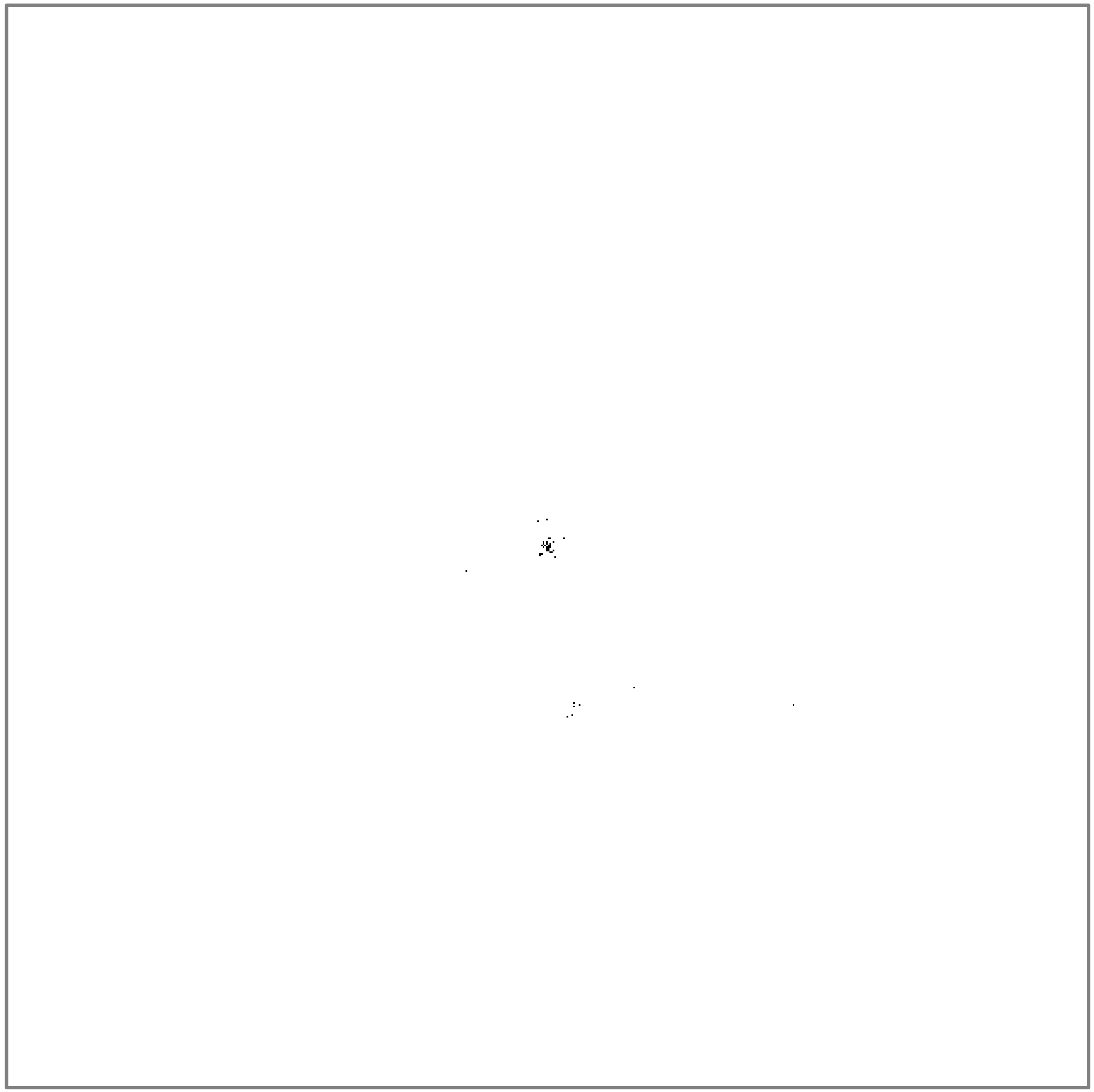
where $d_{i,j}$ is the distance between the points i and j. The index j runs over all sites with $w_j = 0$, i.e. already populated sites are not further considered. Finally, the probabilities are normalized according to $\max(p_i) = 1$.

Example

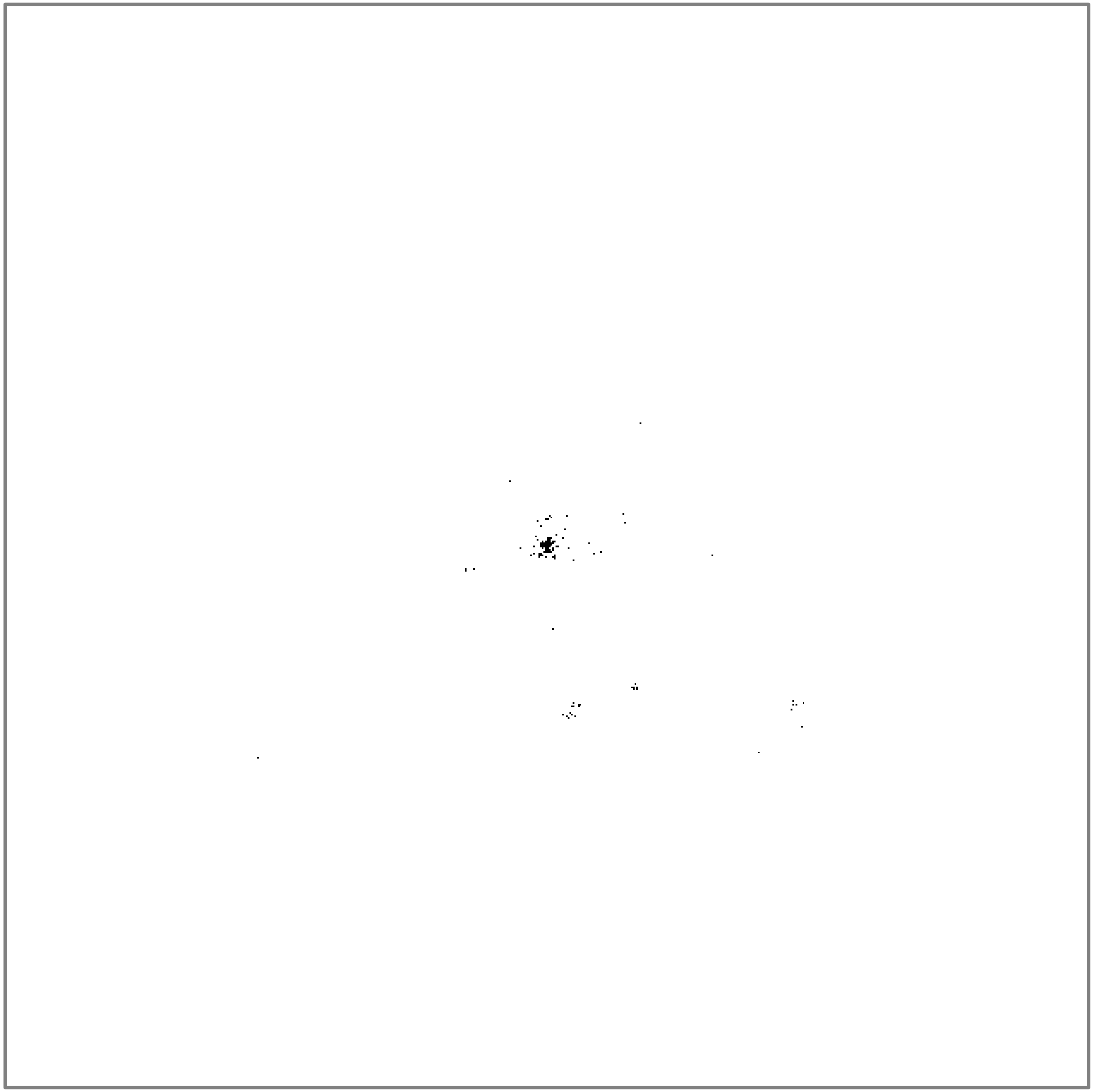
630 x 630
γ=2.5



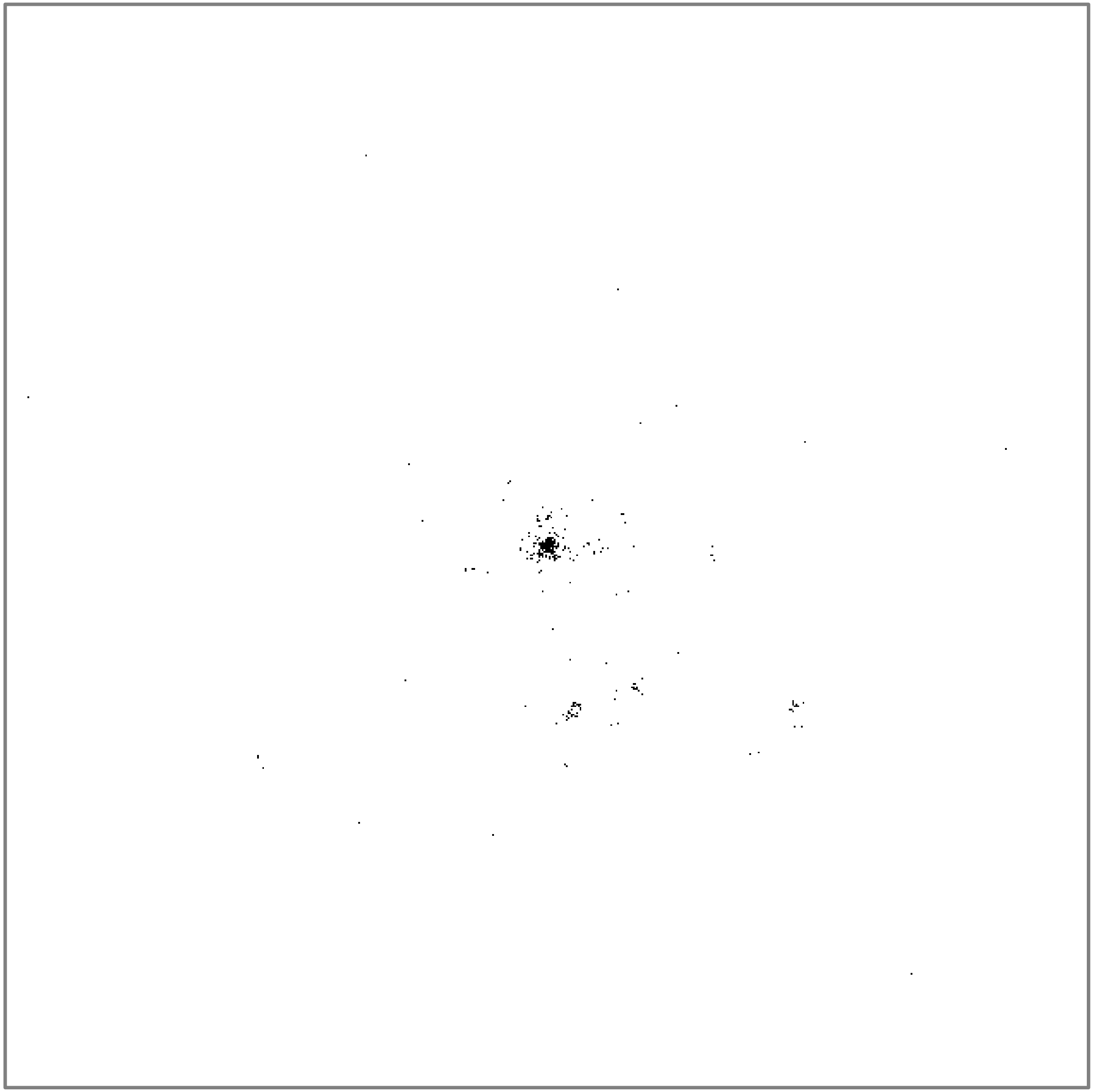
Example



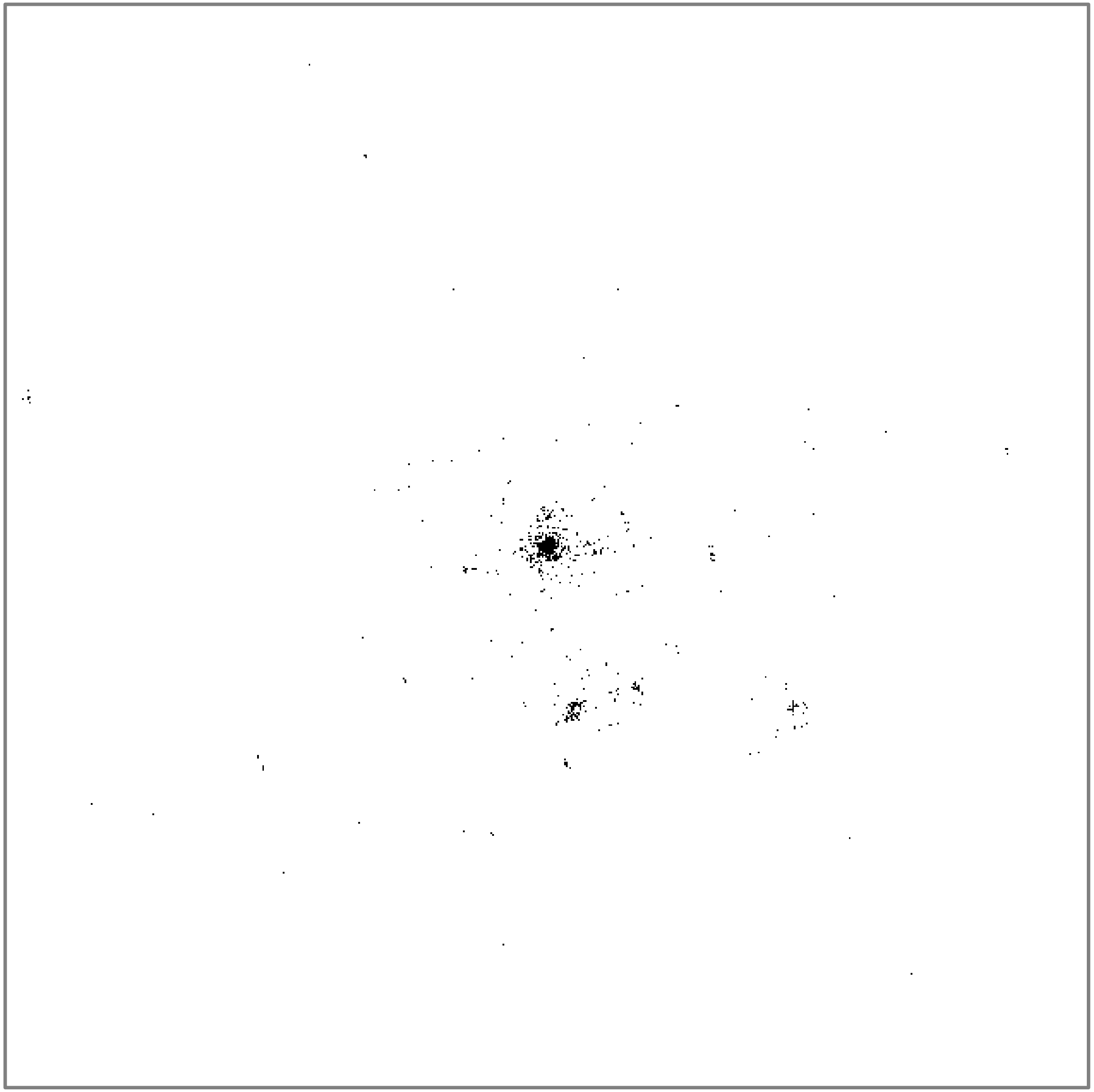
Example



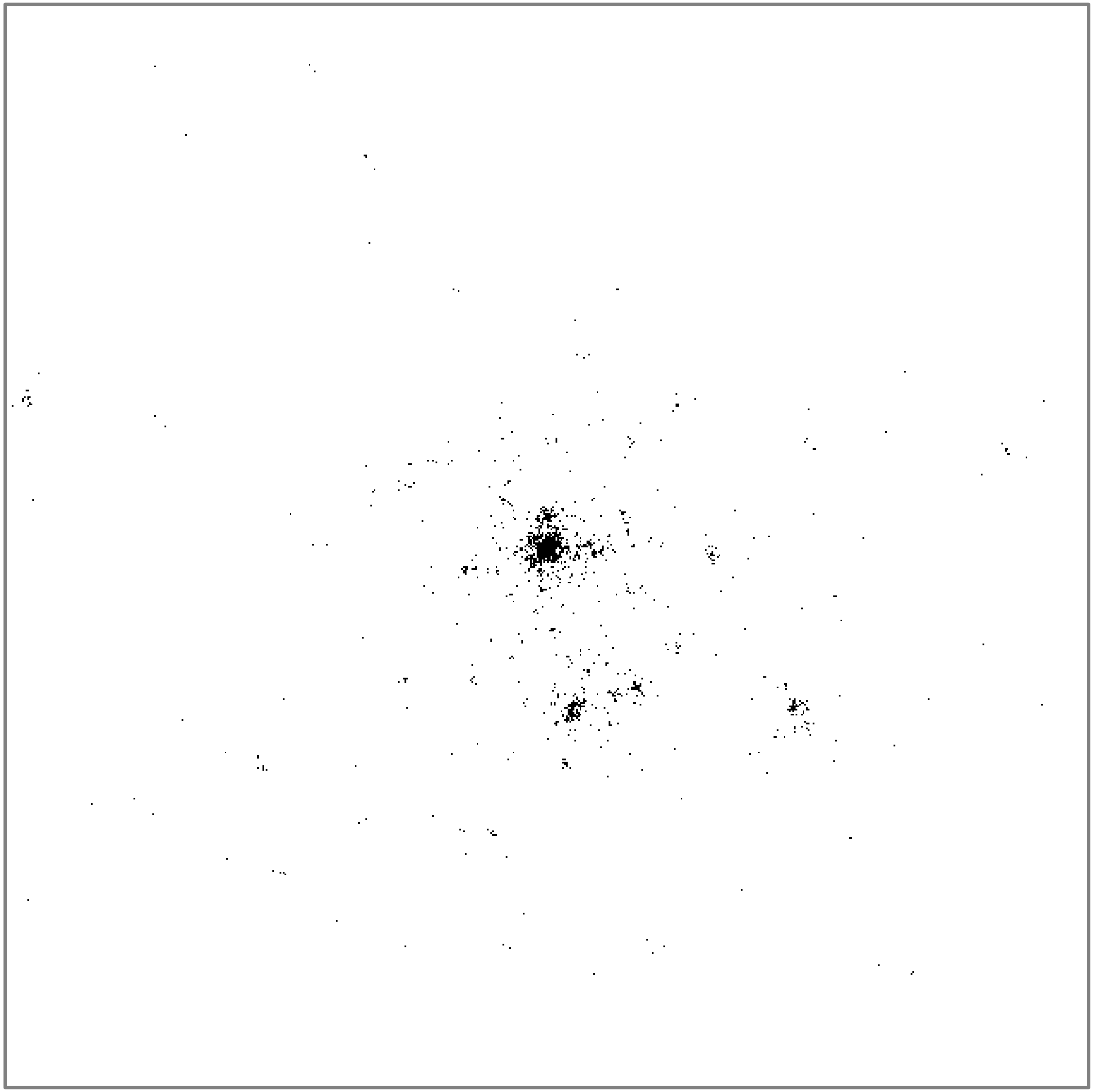
Example



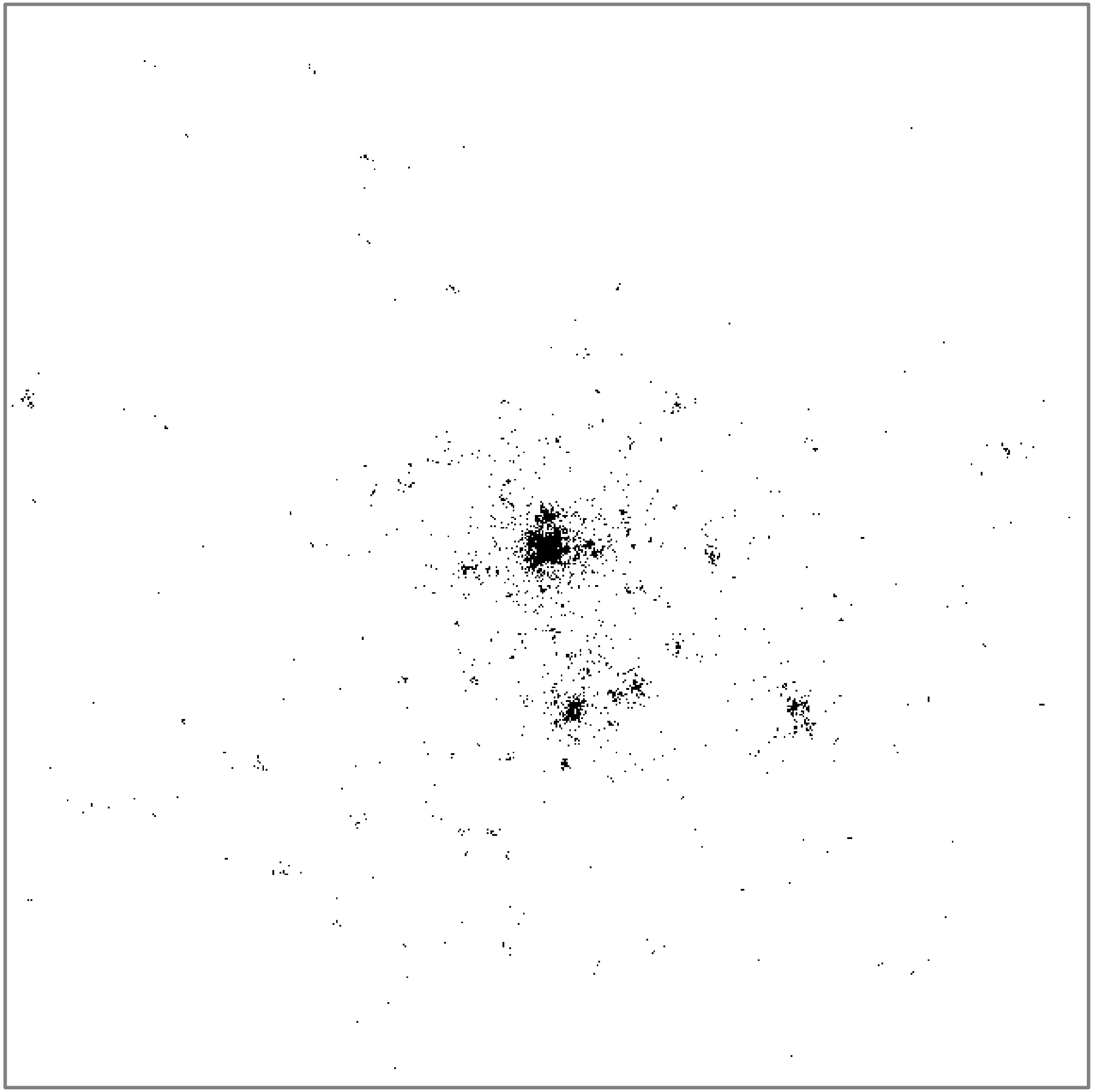
Example



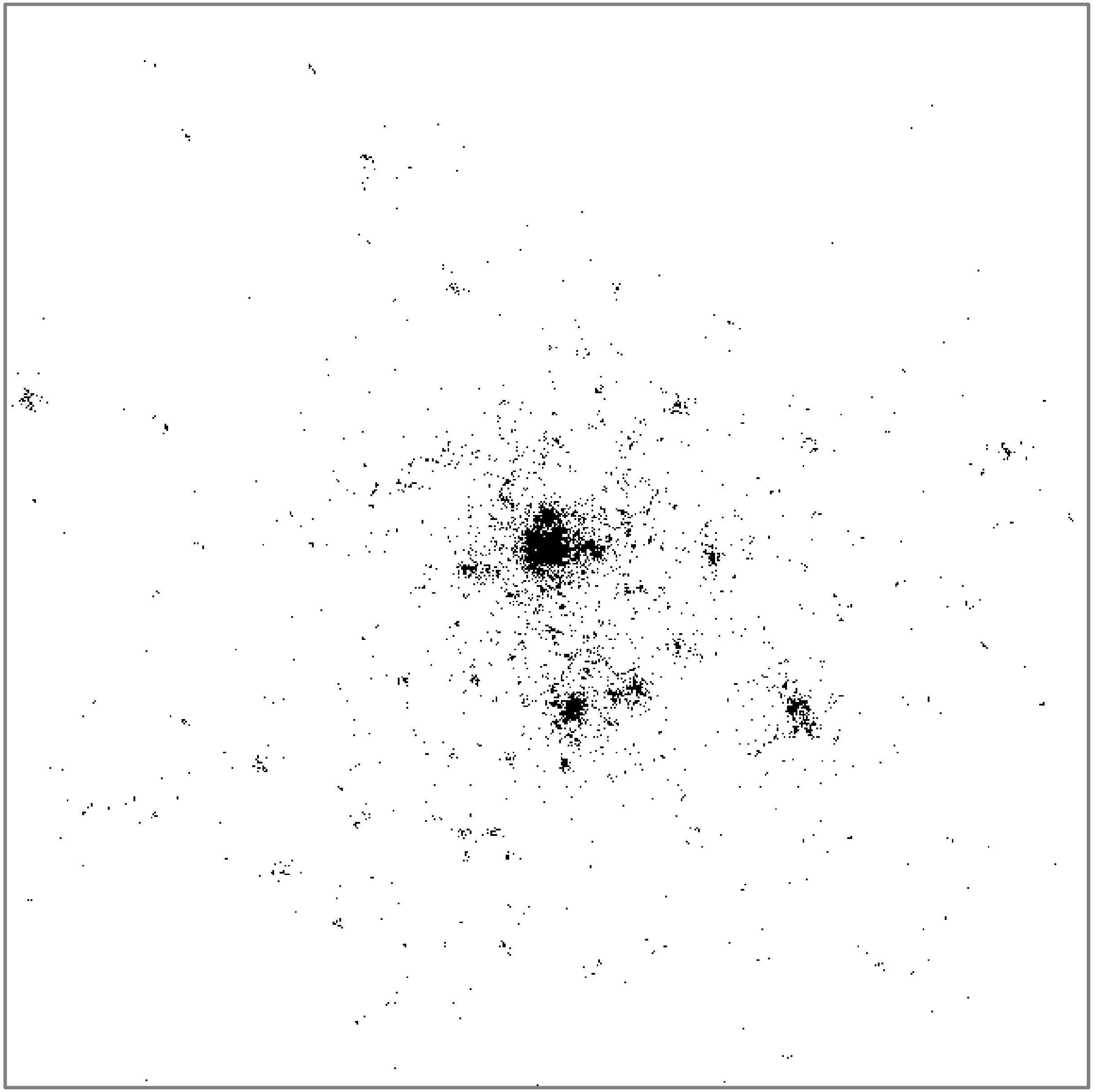
Example



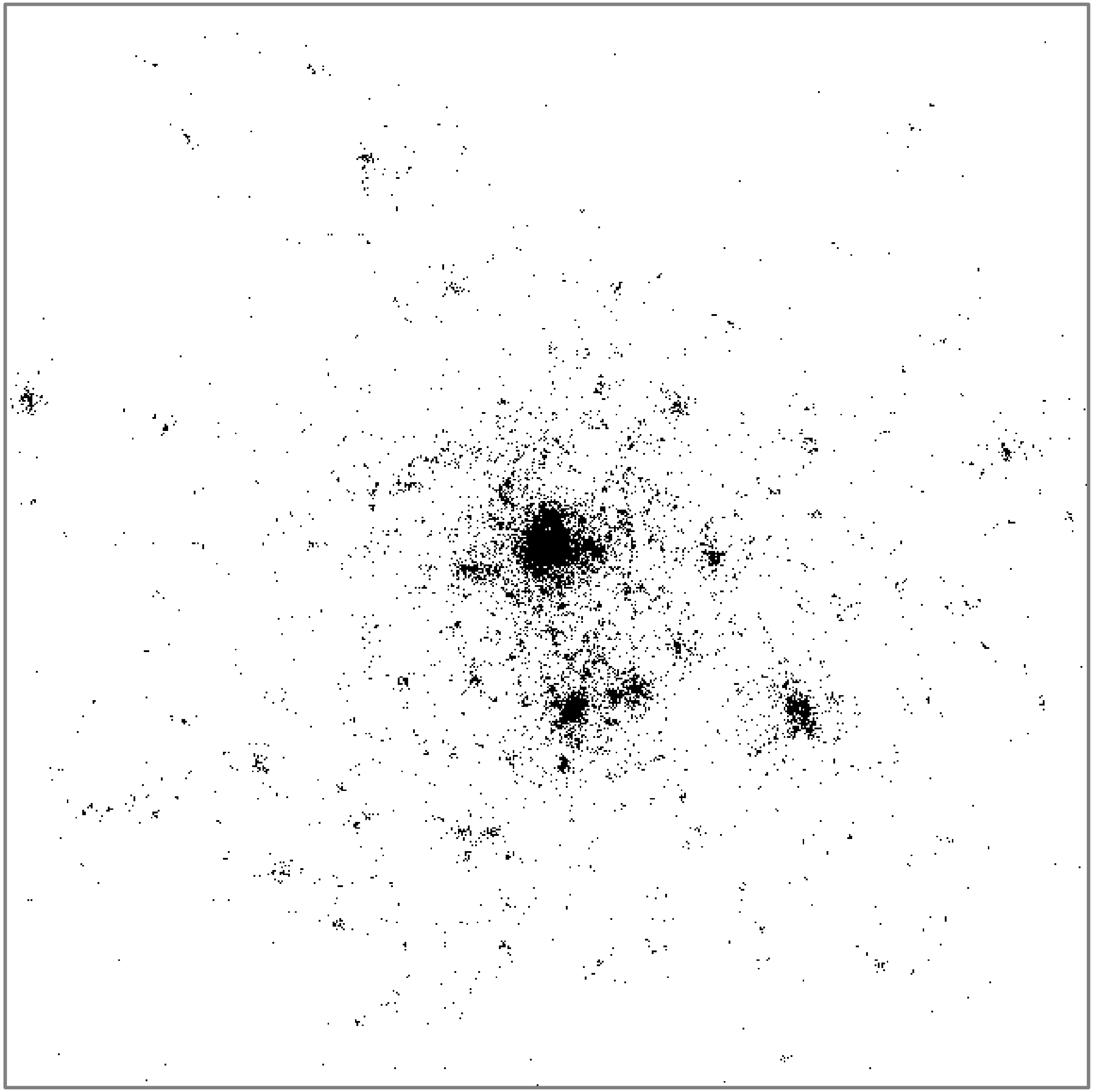
Example



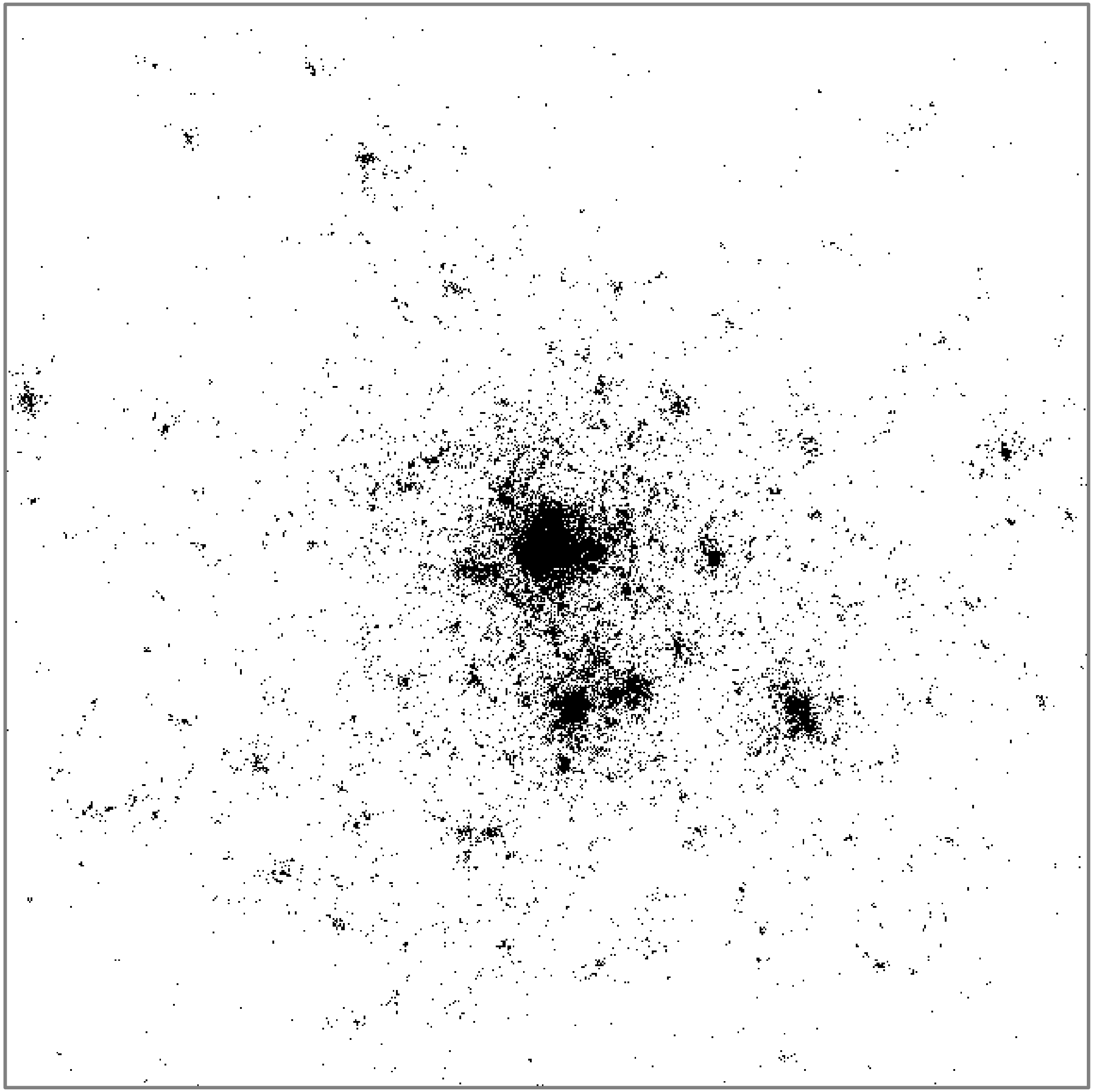
Example



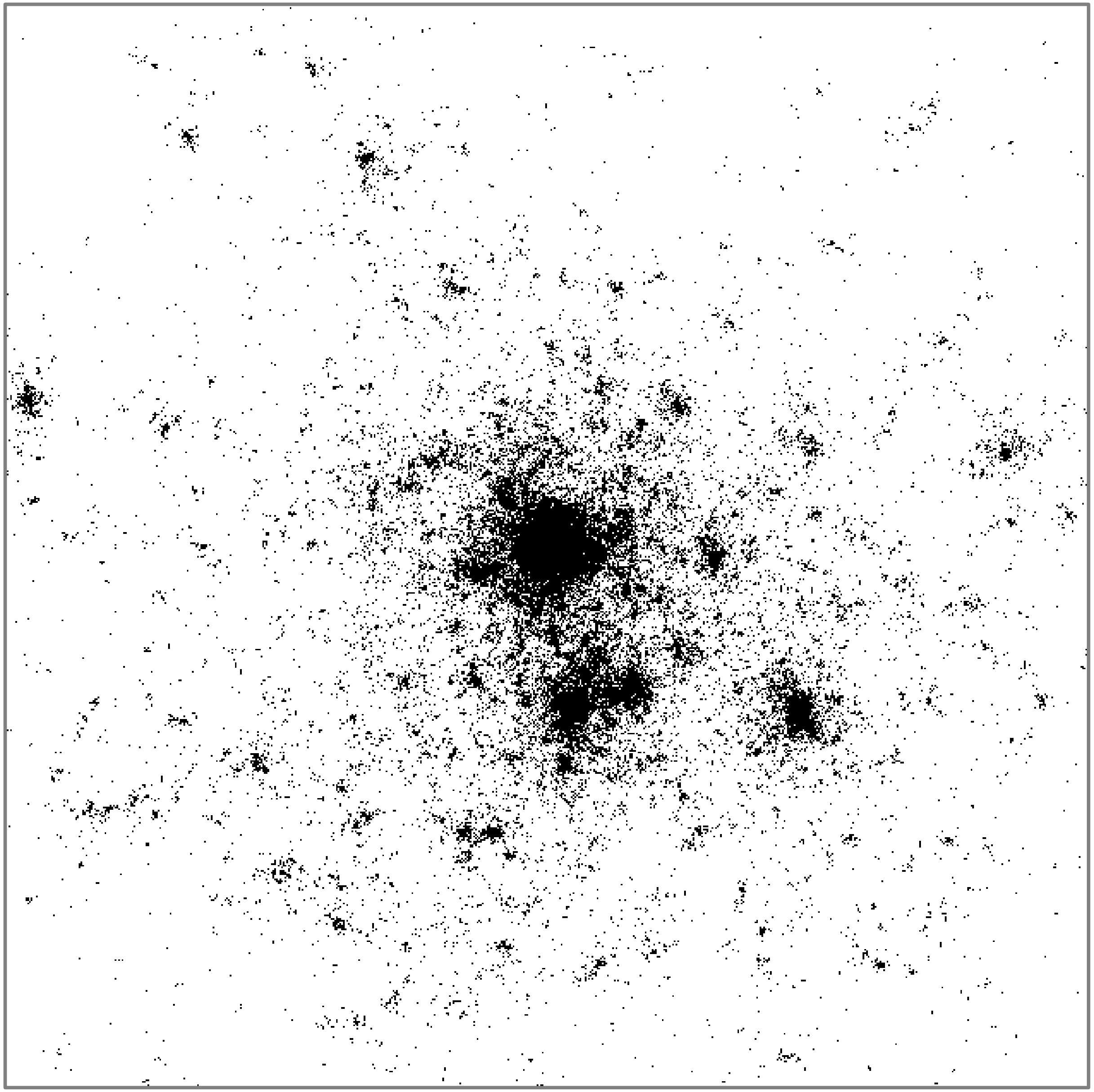
Example



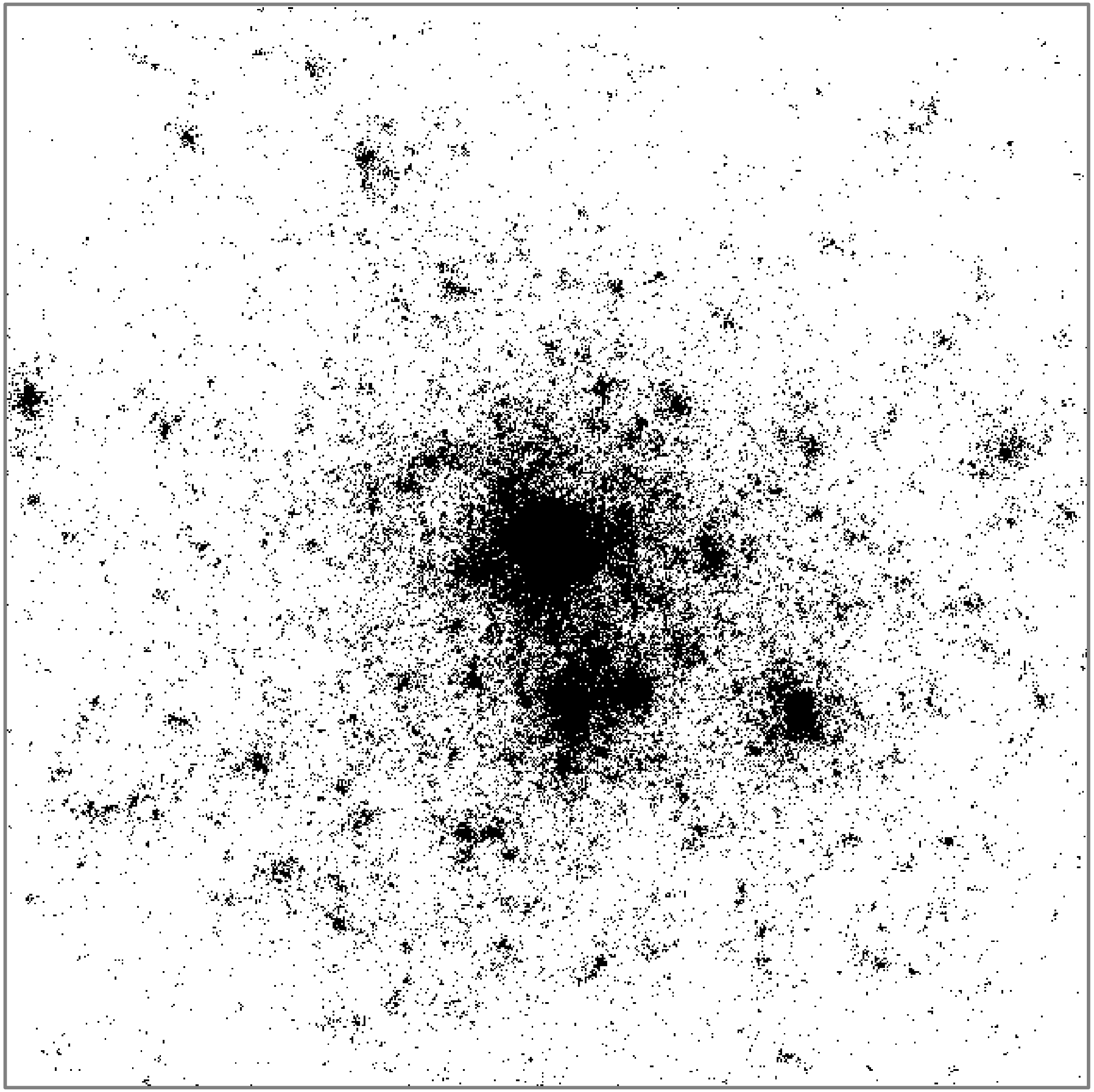
Example



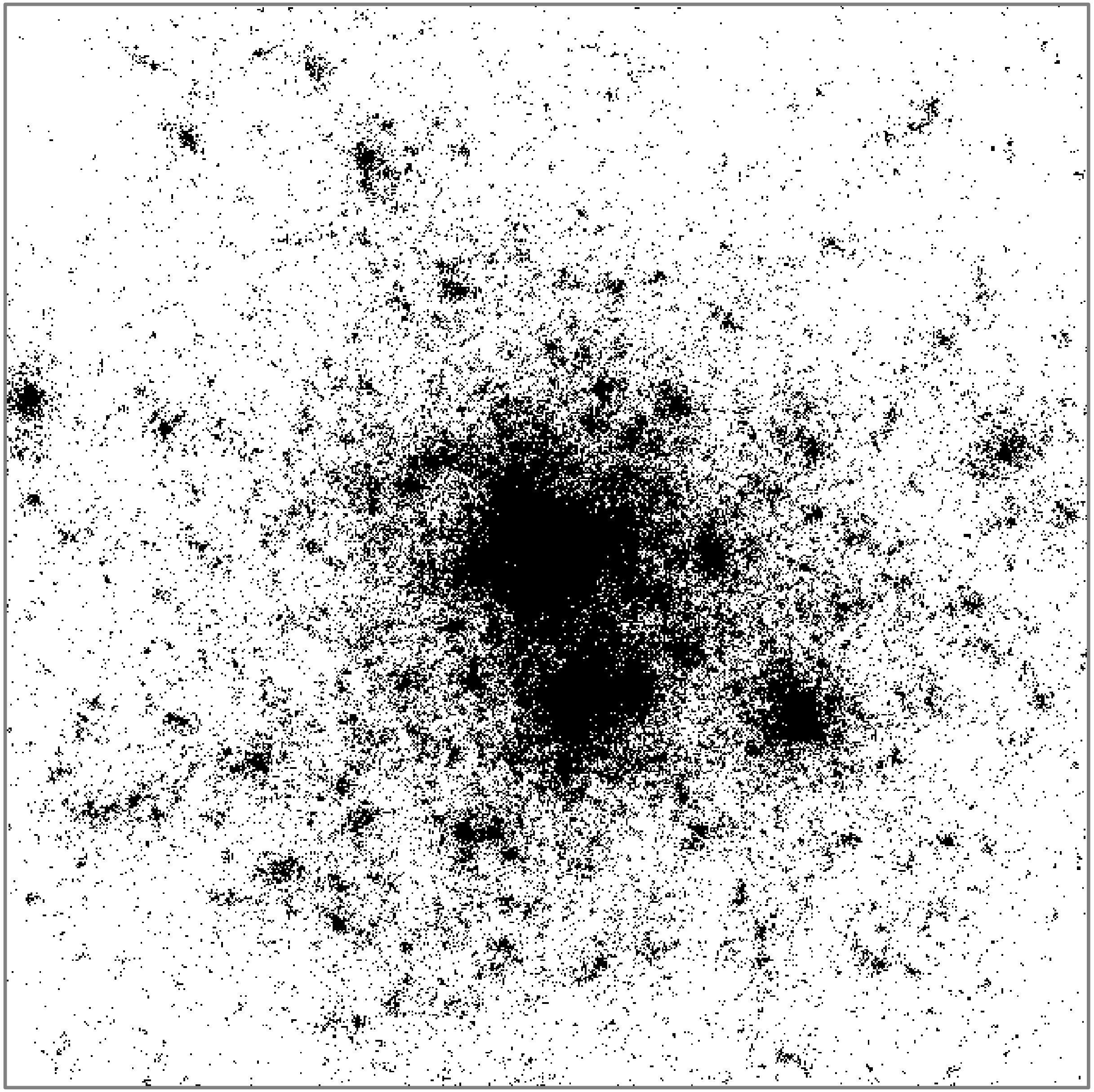
Example



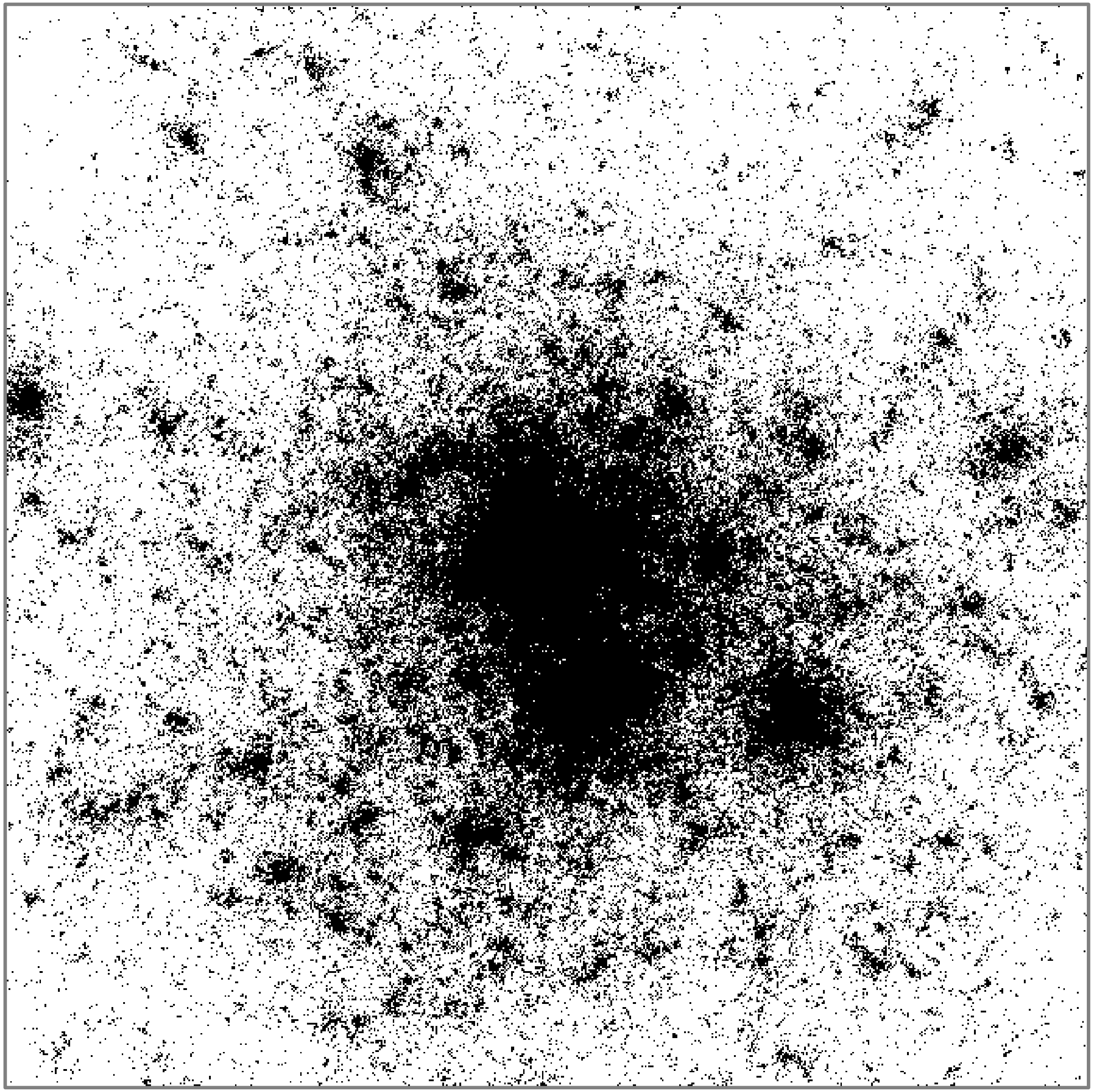
Example



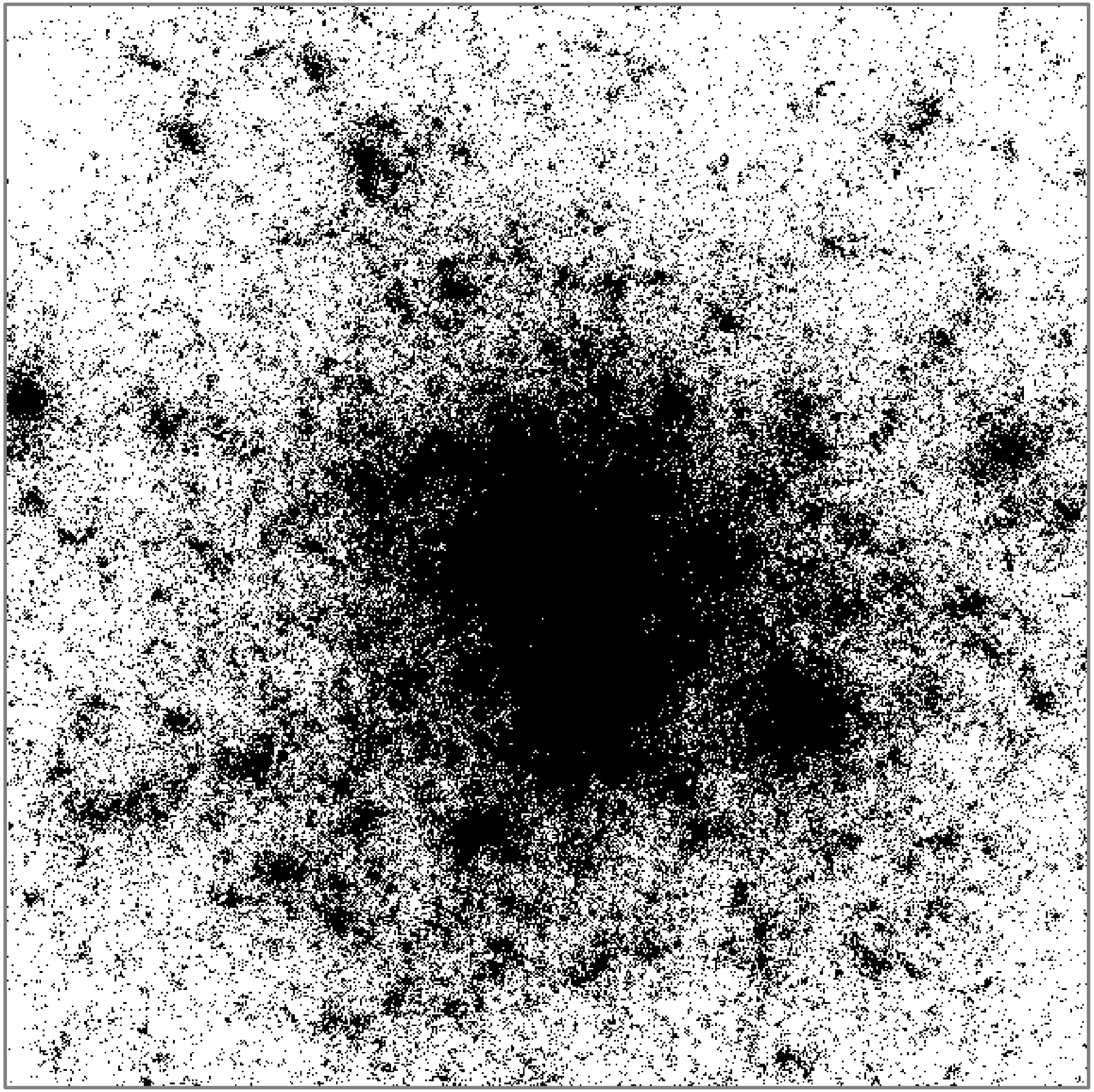
Example



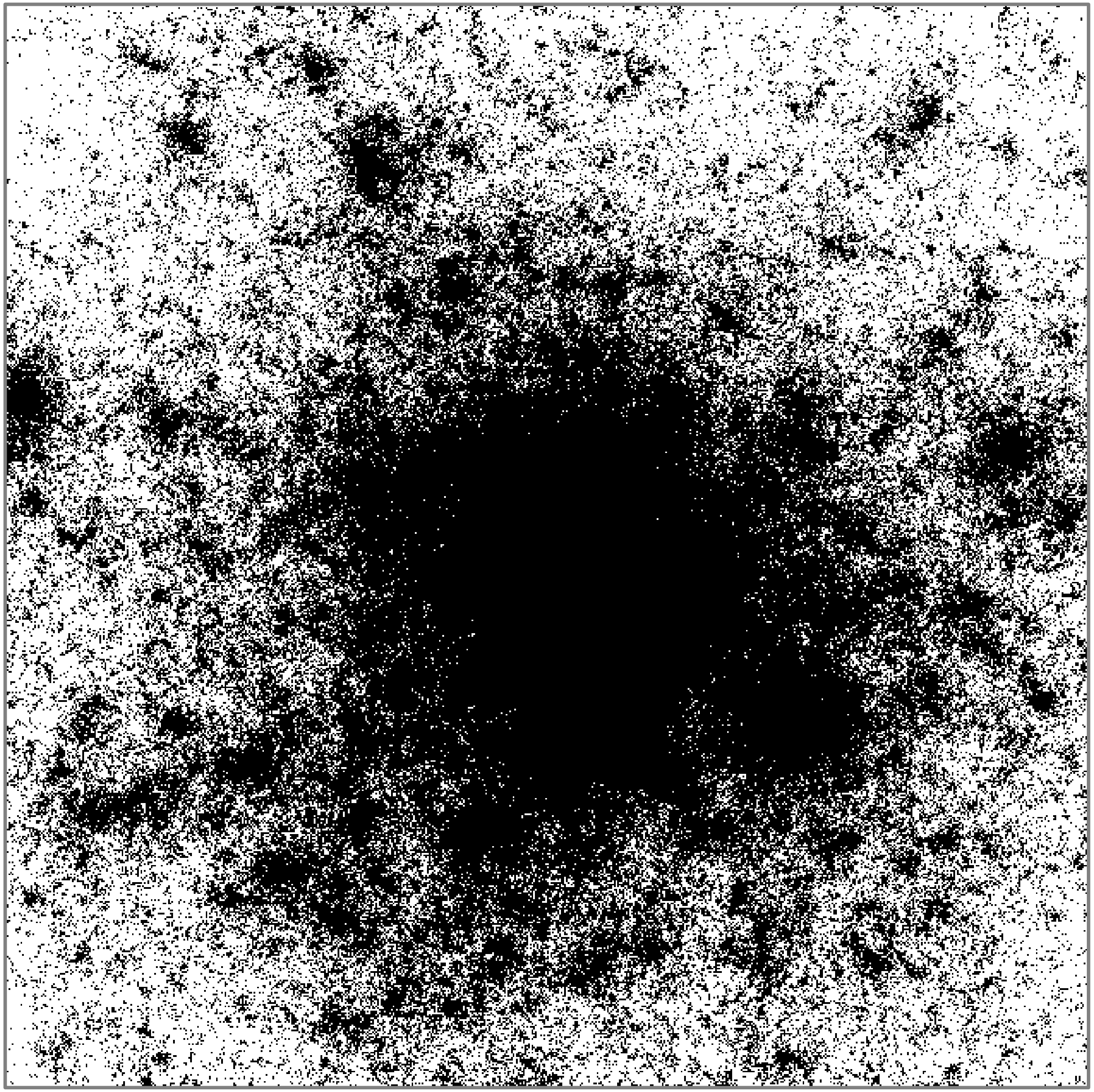
Example



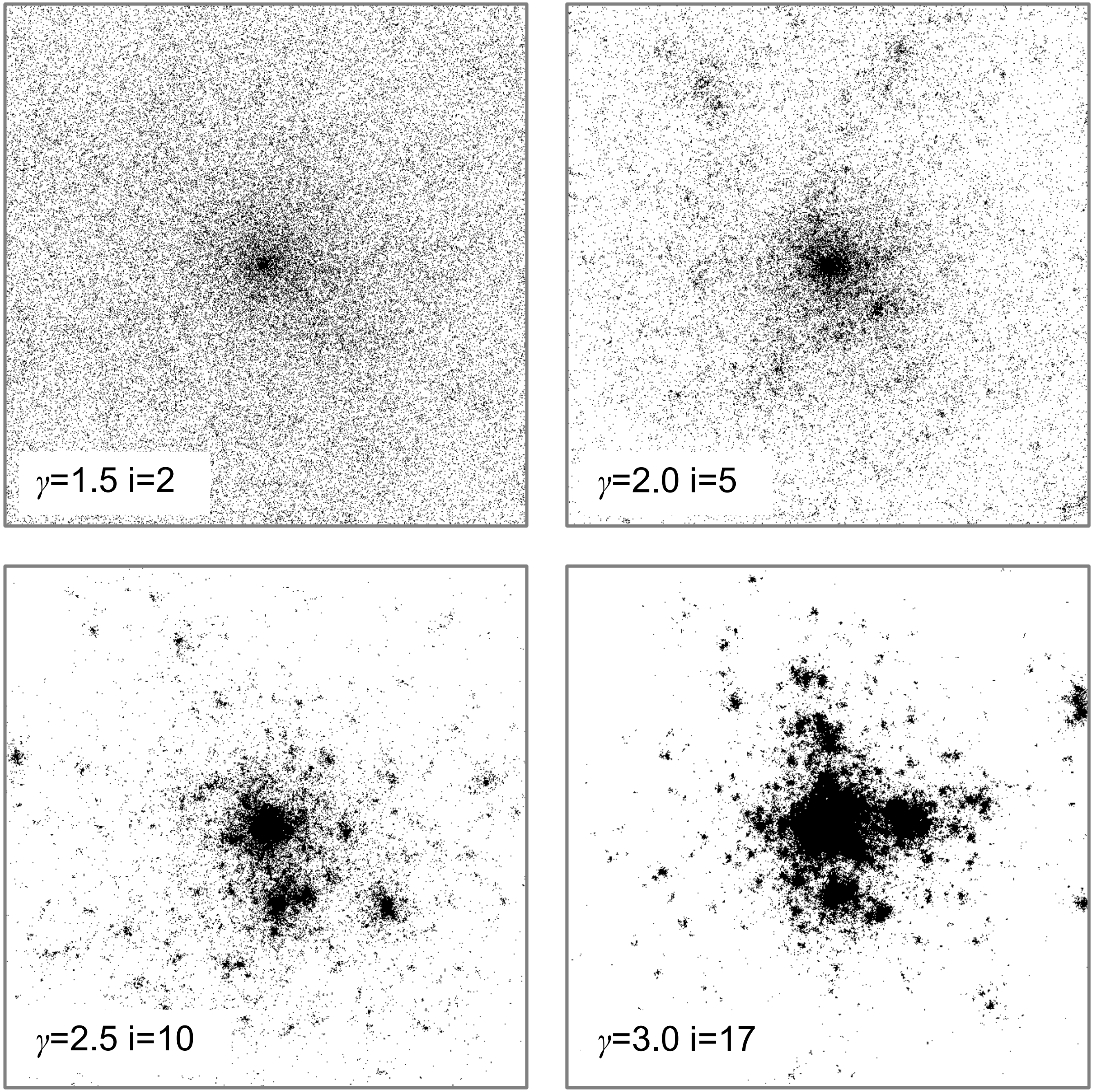
Example



Example .. end



Exponent

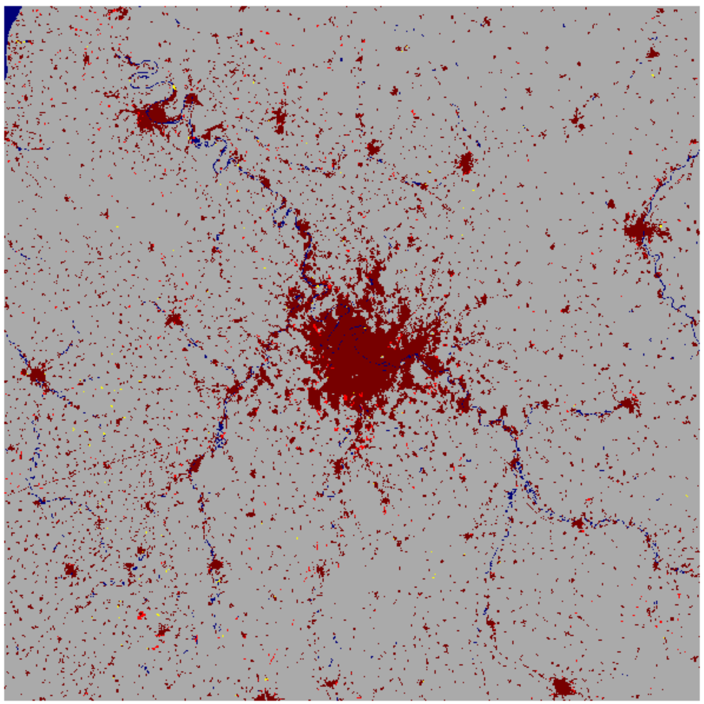


- small exponent fills faster
- large exponent more compact
- large exponent less rad. sym.

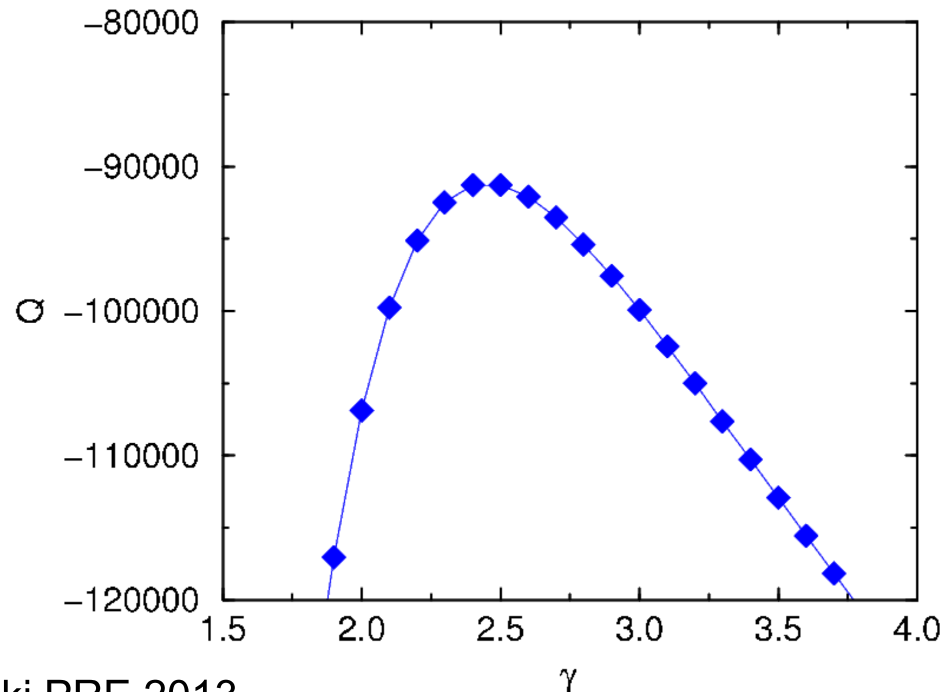
Gravitational city model: benchmarks

(i)	City **size** distribution	partly (excluding largest cluster)
(ii)	City **growth**	no
(iii)	**Fractality**	yes

Gravitational city model:
Estimating exponent in real data



Paris 2000-2006

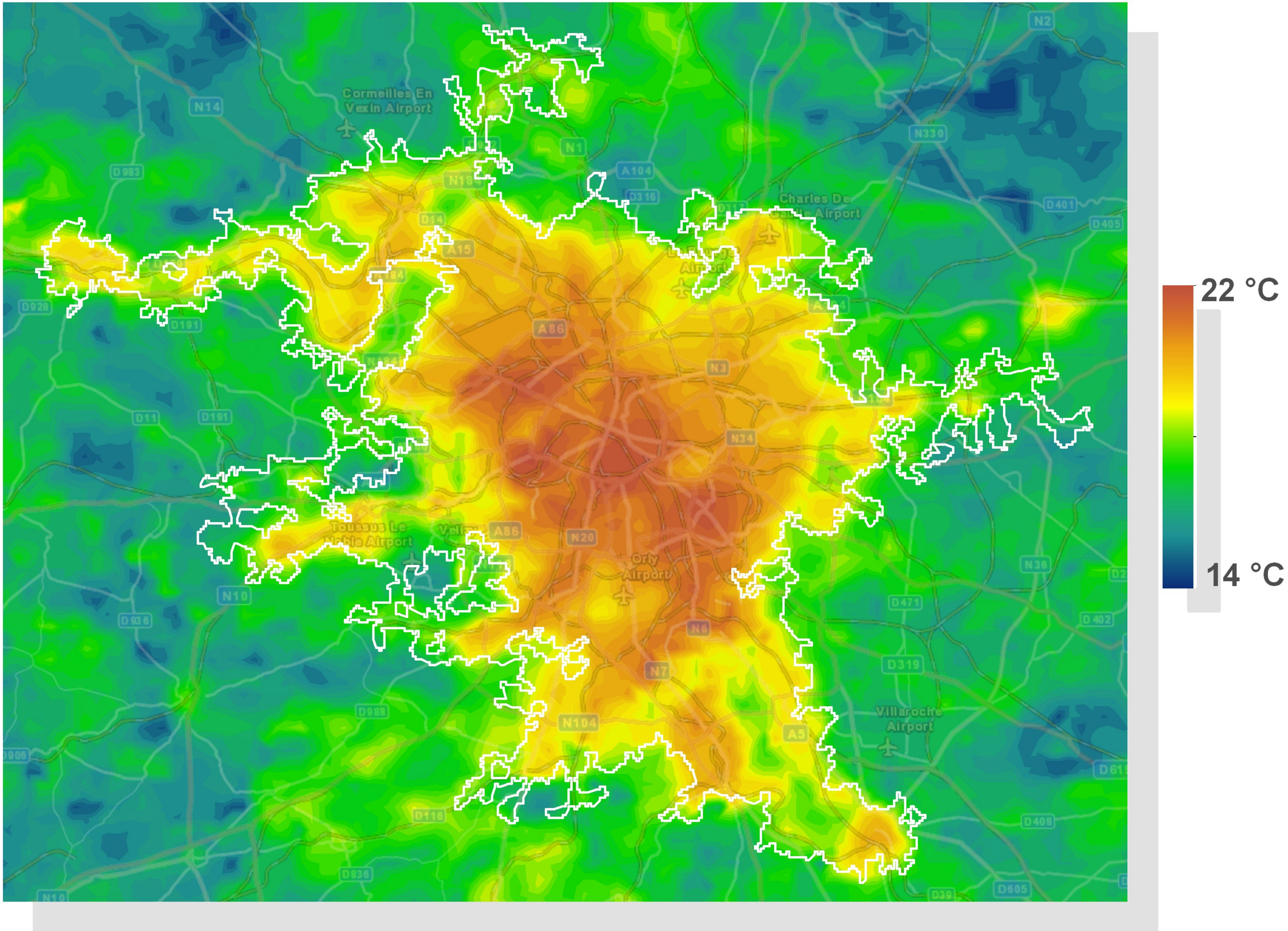


log-likelihood

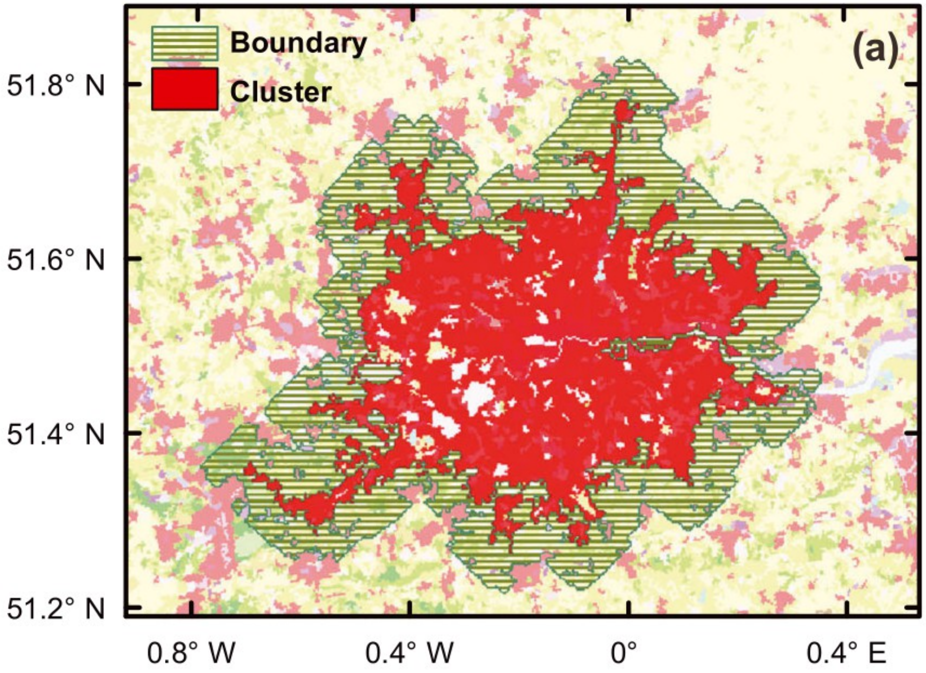
Rybski PRE 2013

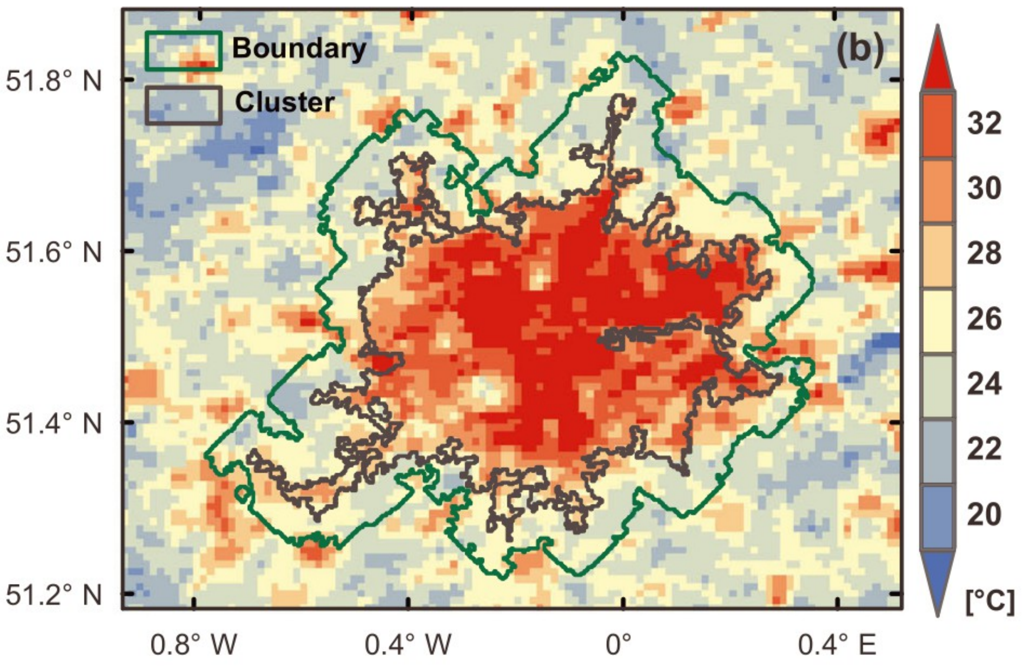
Examples of impact studies

Cities have their own climate: e.g. Paris



Urban Heat Island: Zhou, GRL, 2013

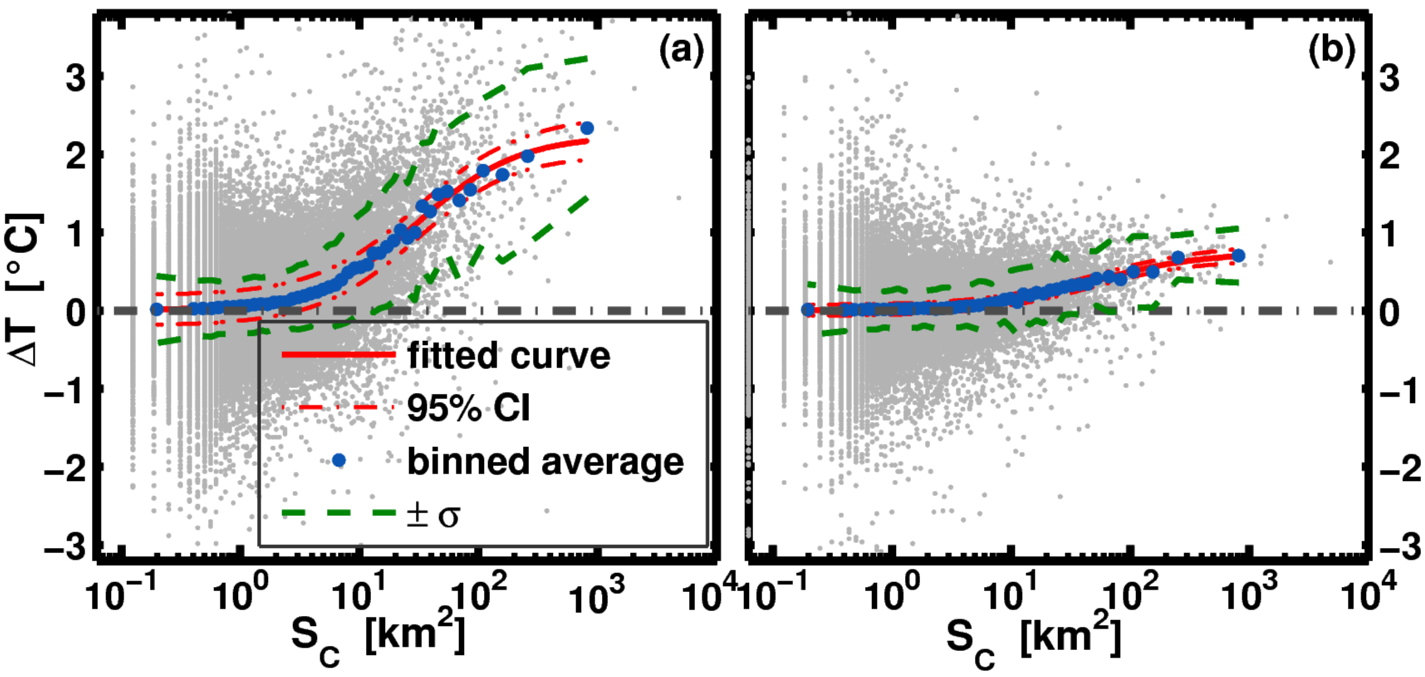




Land cover
Corine
250m

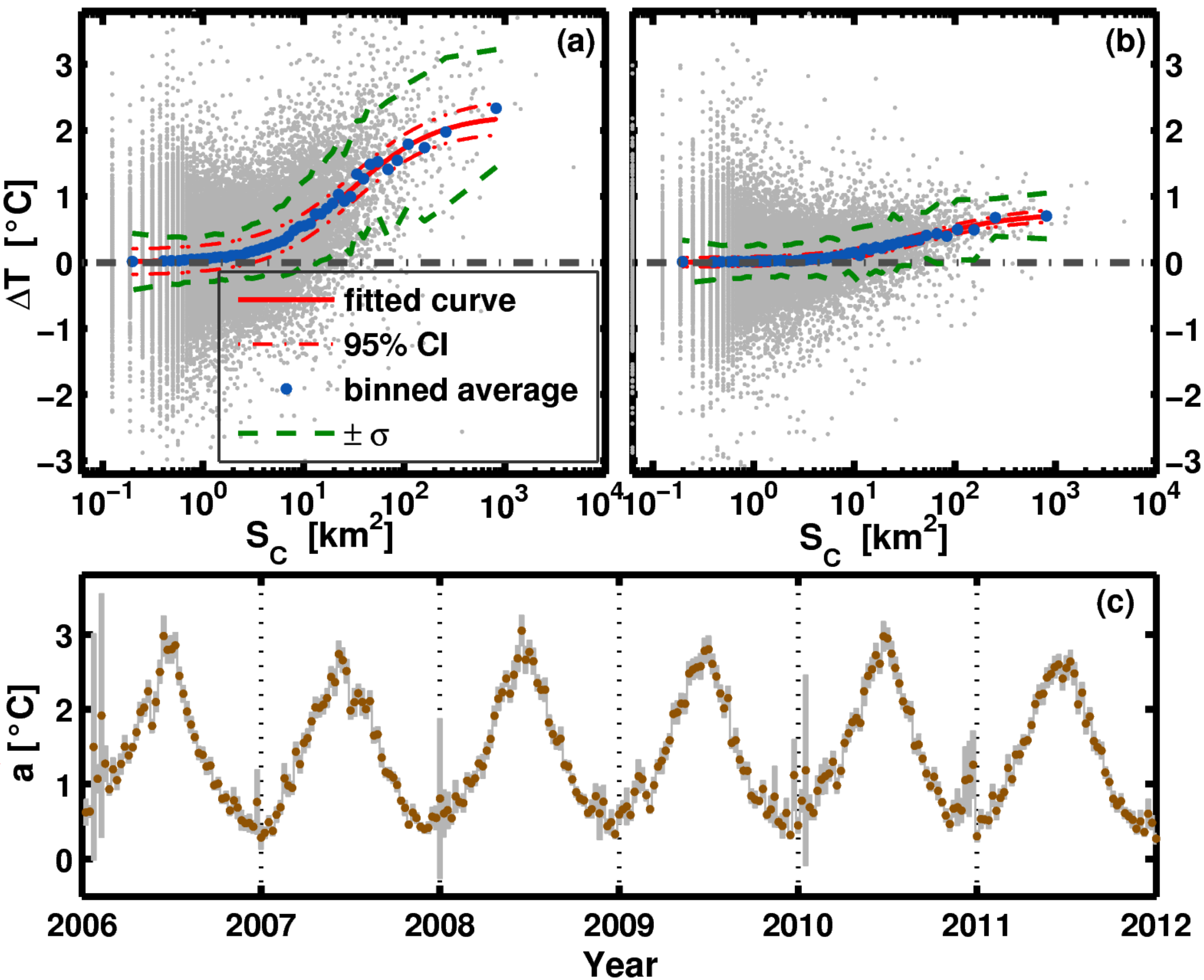
Surface temperature
Modis
1000m

Urban Heat Island: Zhou, GRL, 2013



Size dependence (Europe, 130000 city clusters)

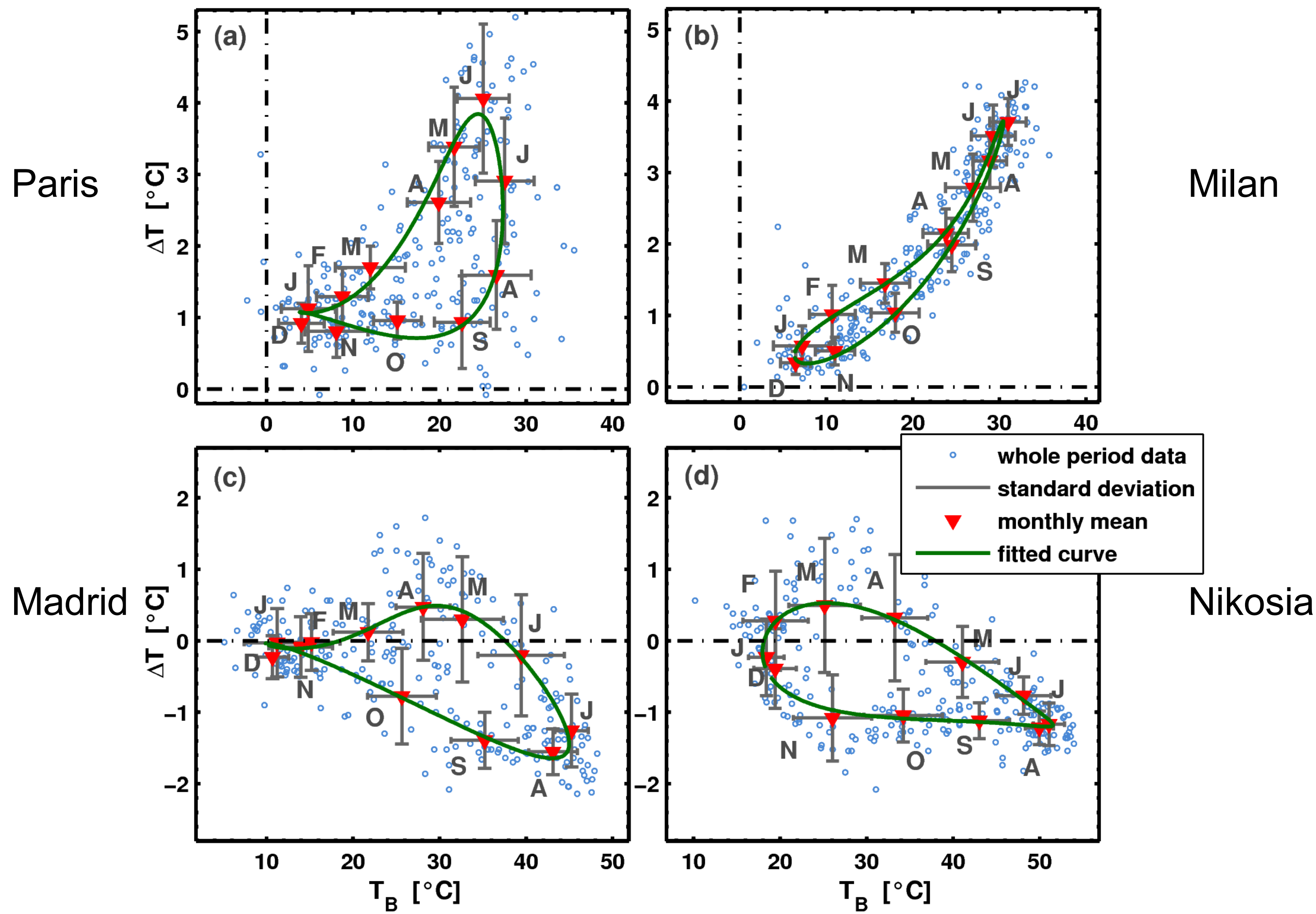
Urban Heat Island: Zhou, GRL, 2013



sigmoid
asymptotic

Size dependence (Europe, 130000 city clusters)

Urban Heat Island: Zhou, GRL, 2013



Dependence on background temperature (new seasonality)

Storm damages: Prahl, GRL, 2012

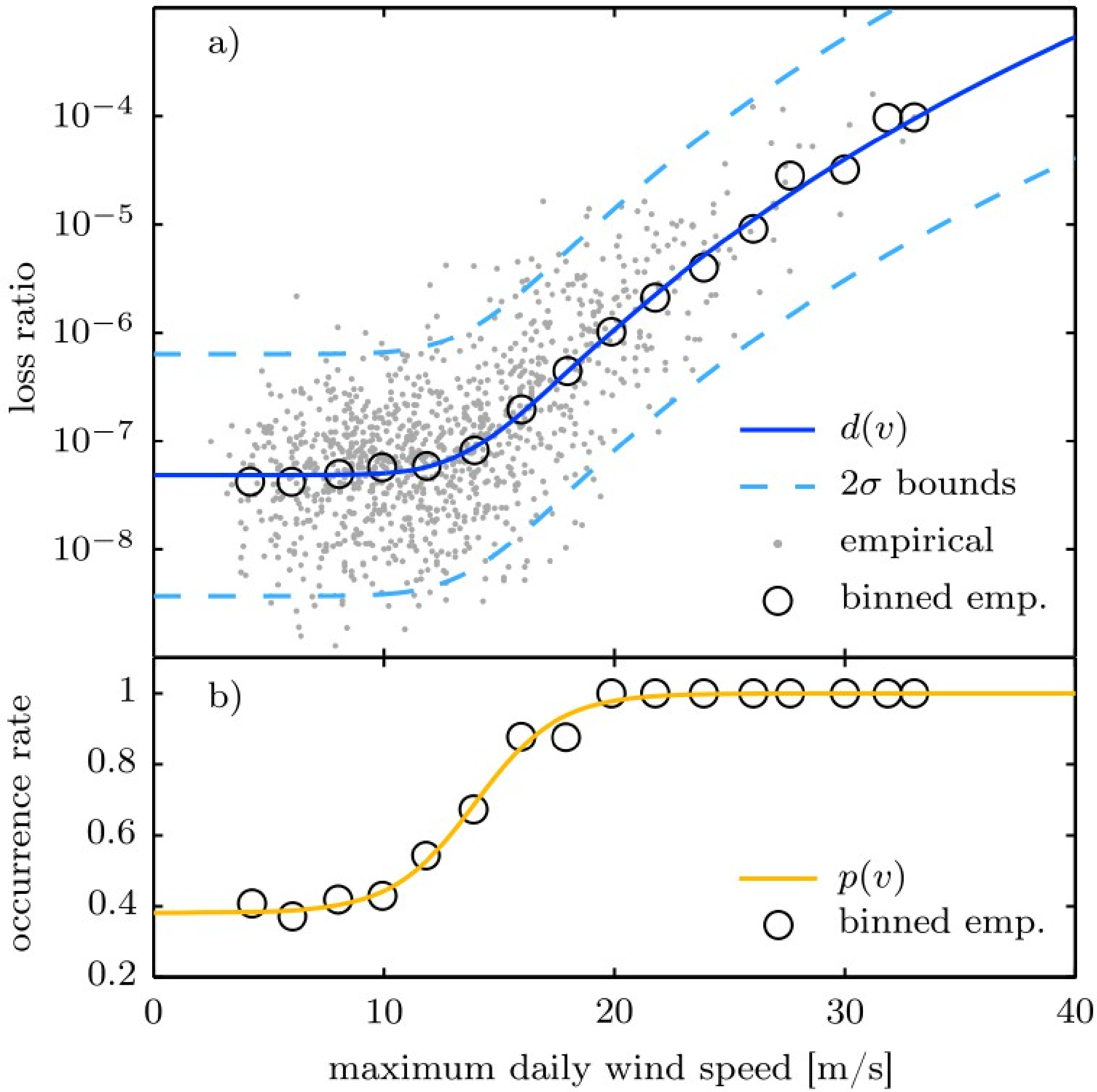


Figure 1. Example of damage function and occurrence probability for an arbitrary district. (a) The damage function $d(v)$ is plotted against the maximum daily wind speed v. Confidence bounds of $\pm 2\sigma$ are shown by dashed lines. Grey points represent daily loss data. (b) The fitted occurrence probability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

Storm damages: Prahl, GRL, 2012

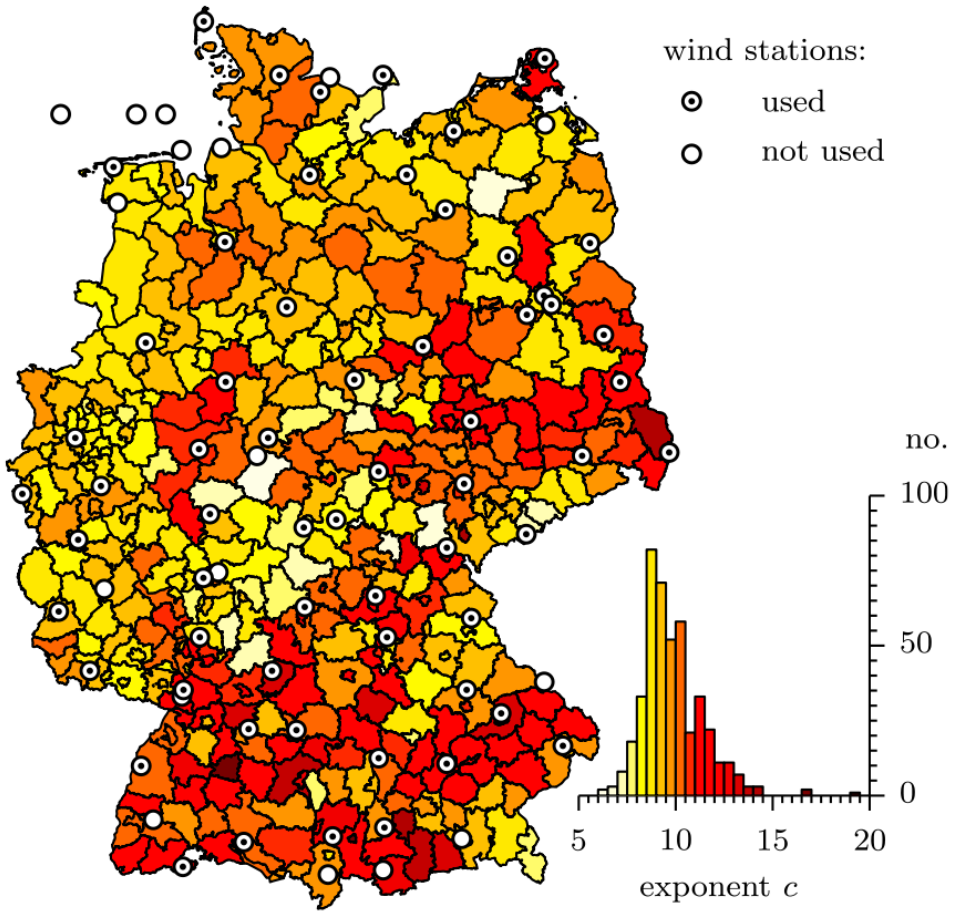


Figure 2. Spatial distribution of exponent c and DWD wind stations. The color code indicates the local values of c, summarized in the histogram inset. Markers indicate DWD wind stations that were used for calculations or excluded due to inhomogeneities or missing data.

Storm damages: Prahl, GRL, 2012

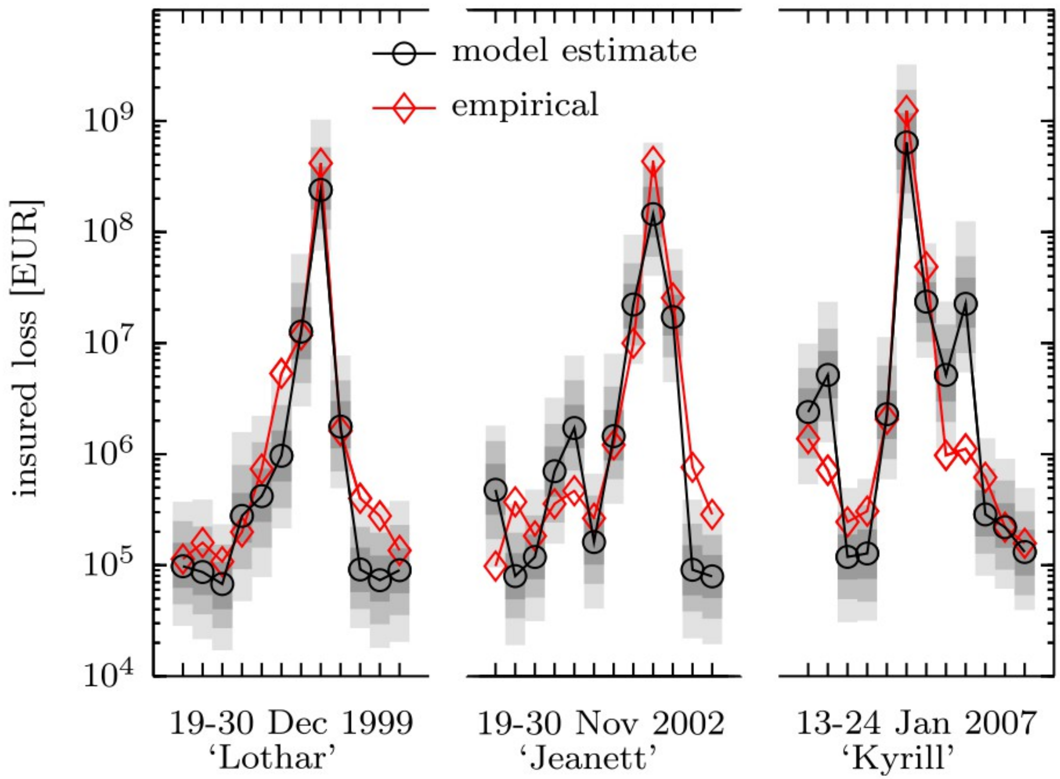
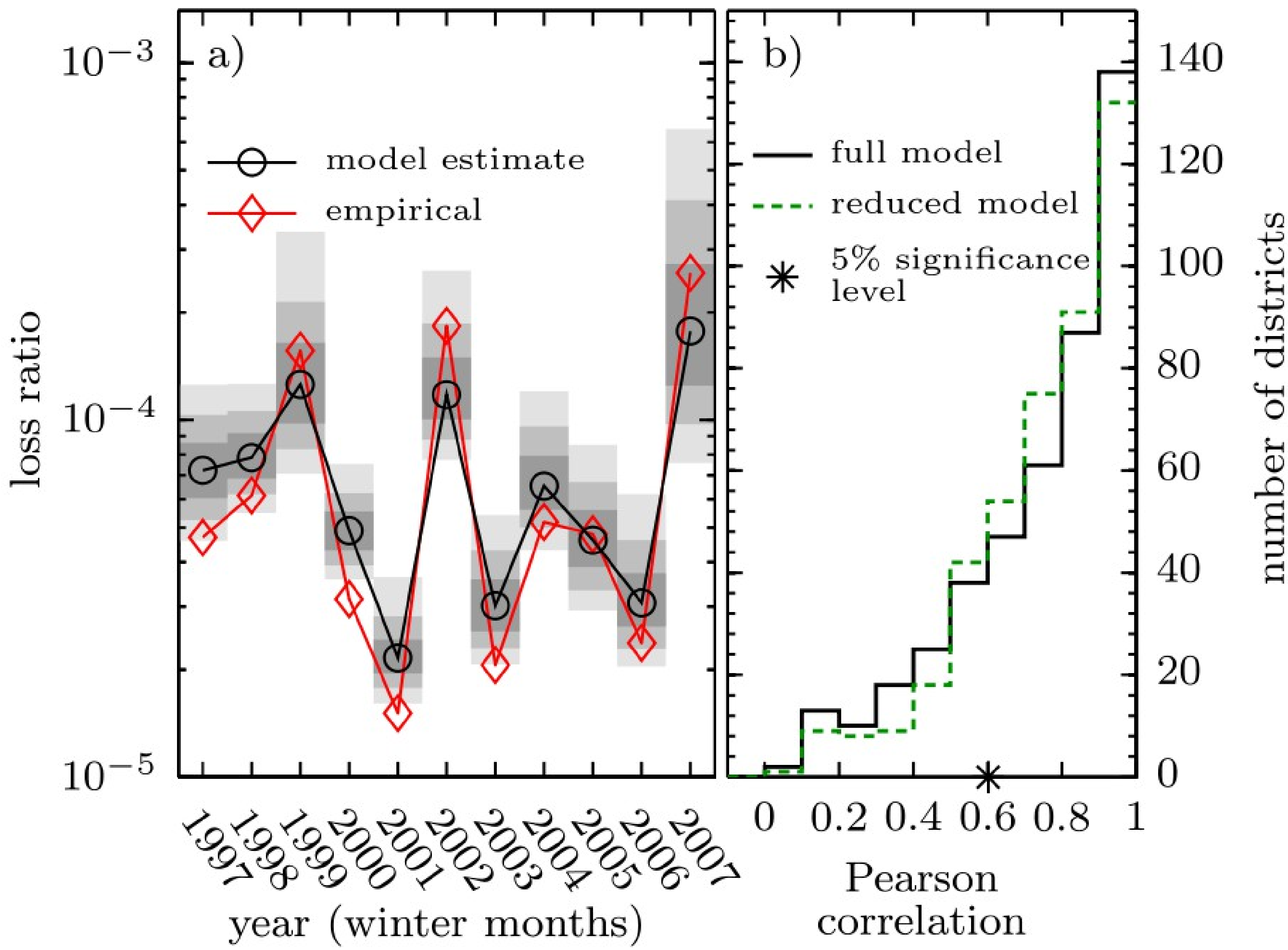
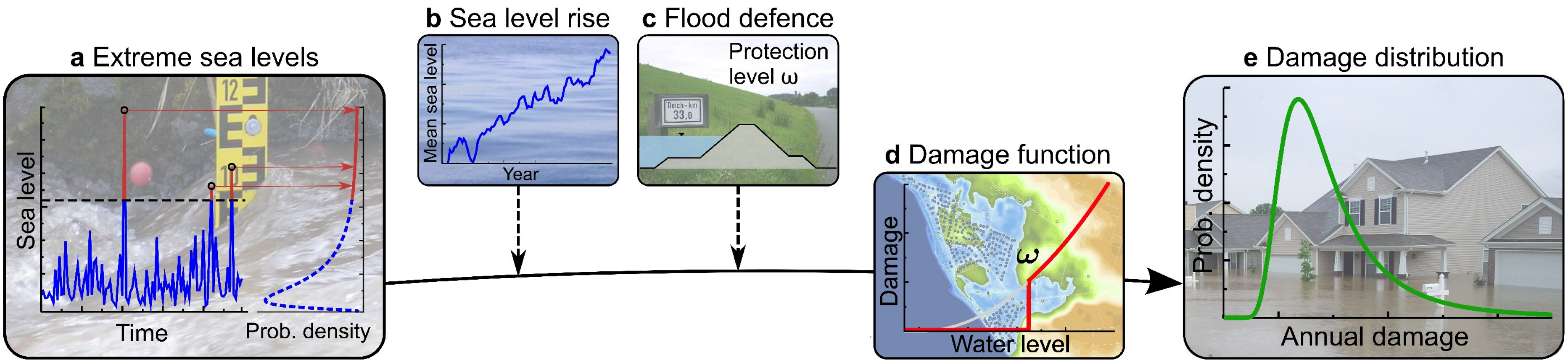


Figure 4. Out-of-sample calculations for daily German absolute losses during three severe winter storms ('Lothar', 'Jeanett', and 'Kyrill'). Circles denote the median of the damage distribution and diamonds empirical values. 50%, 80%, and 95% confidence bounds are shaded from dark to light grey, respectively.

Storm damages: Prahl, GRL, 2012



Coastal flood damages



M. Boettle, 2014

study sea-level rise via extremes
required:
- gauge data (a)
- damage function (d)

Coastal flood damages: Boettle, nhess, 2011

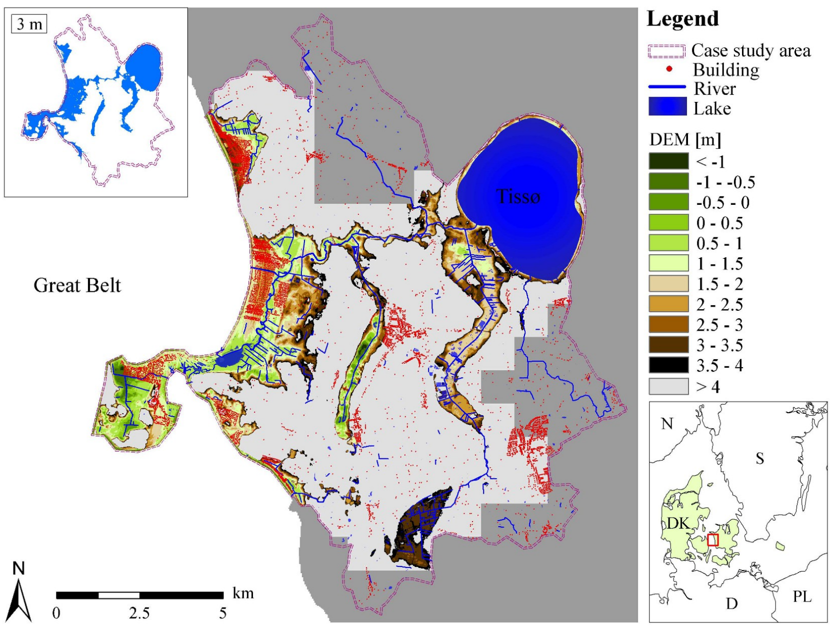


Fig. 1. Map of the case study area and location within Northern Europe. The elevation according to the available DEM is colour coded (light grey represents elevations above 4 m) and buildings are indicated by red dots. The dark grey area delineates land for which no elevation data is available and the white area in the east is the sea. The inset in the upper left corner indicates the inundated area for a 3 m sea level referred to DVR90 (no aggregation, 4 nearest neighbours). The inset in the lower right shows the country contours and the cut-out represents the major map. DEM owned by BlomInfo A/S, Denmark.

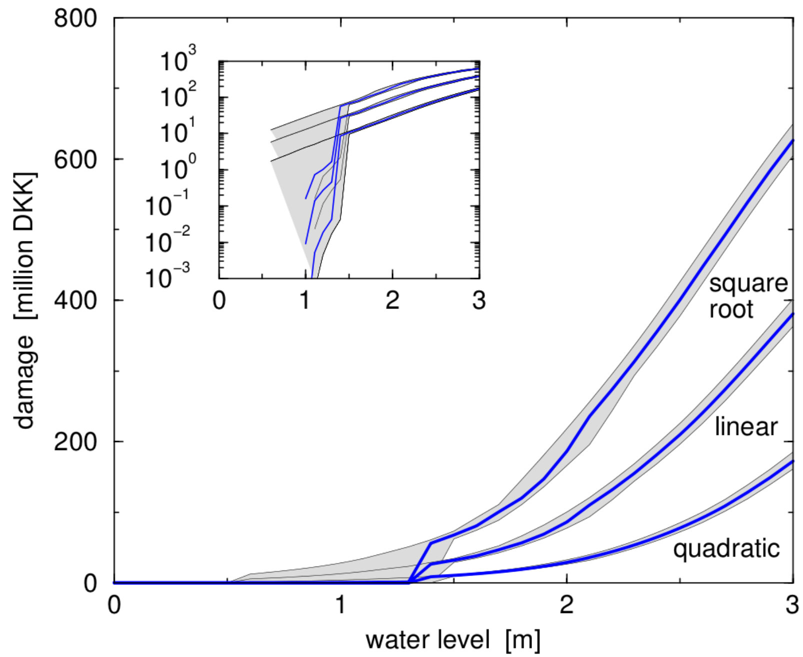


Fig. 6. Macroscopic damage functions assuming different building damage functions. The estimated direct monetary damage is plotted against the water level, whereas the central blue line corresponds to the non-coarse-grained case (using 4 nearest neighbours). The grey bands represent the range between highest and lowest of all 14 combinations. We assume square root, linear, or quadratic building damage functions (from top), Eqs. (1), (3), and (4), see Fig. 2. The result for the linear building damage functions is the same as in Fig. 5. The inset shows the curves in semi-logarithmic scale.

Coastal flood damages: sea level rise

		as a function of			
		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	$\omega^{-1/\xi}$	
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	$\xi = 0$:	$\sim e^{\mu/\sigma}$	$\sim \sigma^\gamma$	$\sim \omega^\gamma e^{-\omega/\sigma}$	Gumbel
	$\xi < 0$:	$\sim \mu^{\gamma-1/\xi}$	$\sim \sigma^\gamma$	$\overset{\omega \to x_{\max}}{\sim} (x_{\max} - \omega)^{-1/\xi}$	
	$\xi > 0$:	$\overset{\mu \to \mu_{\max}}{\sim} (\mu_{\max} - \mu)^{-1/\xi}$	$\sim \sigma^\gamma$	$\sim \omega^{\gamma-1/\xi}$	
STD_{D_i}	$\xi = 0$:	~ 1	$\sim \sigma^\gamma$	$\sim \omega^{\gamma-1}$	
	$\xi < 0$:	$\sim \mu^\gamma$	$\sim \sigma^\gamma$	$\overset{\omega \to x_{\max}}{\sim} x_{\max} - \omega$	
	$\xi > 0$:	$\overset{\mu \to \mu_{\max}}{\sim} \mu_{\max} - \mu$	$\sim \sigma^\gamma$	$\sim \omega^\gamma$	
STD_D	$\xi = 0$:	$\sim e^{0.5\mu/\sigma}$	$\sim \sigma^\gamma$	$\sim \omega^\gamma e^{-0.5\omega/\sigma}$	
	$\xi < 0$:	$\sim \mu^{\gamma-0.5/\xi}$	$\sim \sigma^\gamma$	$\overset{\omega \to x_{\max}}{\sim} (x_{\max} - \omega)^{-0.5/\xi}$	
	$\xi > 0$:	$\overset{\mu \to \mu_{\max}}{\sim} (\mu_{\max} - \mu)^{-0.5/\xi}$	$\sim \sigma^\gamma$	$\sim \omega^{\gamma-0.5/\xi}$	

Publications (*et al.* are ...)

City Clustering:
city size: H.D. Rozenfeld et al., AER, 2011
city growth: H.D. Rozenfeld et al., PNAS, 2008

Auerbach's legacy:
D. Rybski, Env Plan A, 2013

Gravitational city model:
D. Rybski et al., Phys Rev E, 2013

Urban Heat Island statistics:
B. Zhou et al., Geophys Res Lett, 2013

Storm damages:
B. Prahl et al., Geophys Res Lett, 2012

Coastal floods & sea-level rise:
M. Boettle et al., Water Resour Res, 2013
M. Boettle et al., submitted, 2014

Ramses project

RAMSES
Science for cities in transition

RAMSES stands for
Reconciling **A**daptation, **M**itigation and **S**ustainable Development for citi**ES**

The main aim of this research project is to deliver much needed quantified evidence of the impacts of climate change and the costs and benefits of a wide range of adaptation measures, focusing on cities. RAMSES will engage with stakeholders to ensure this information is policy relevant and ultimately enables the design and implementation of adaptation strategies in the EU and beyond. The project will focus on climate impacts and adaptation strategies pertinent to urban areas due to their high social and economic importance.

http://www.ramses-cities.eu/

The work leading to these results has received funding from the European Community's Seventh Framework Programme under Grant Agreement No. 308497 (Project RAMSES - Reconciling Adaptation, Mitigation and Sustainable Development for Cities).

COOPERATION

Thank you for your attention

http://diego.rybski.de/

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