The following supplement accompanies the article

Sea level rise projections for northern Europe under RCP8.5

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Supplement.

This supplement contains additional material used in the regional sea level rise calculation, and uncertainty distributions for 36 cities (Fig. S4), as well as a detailed look at the uncertainty budget for London. We show how we emulate AR5 uncertainties, and the Dynamic Sea Level (Fig. S1), Glacial Isostatic Adjustment (Fig. S2), and the sea level fingerprints (Fig. S3) used in the calculation. We also show an alternative projection that does not include the expert uncertainty as expressed in the Bamber & Aspinall (2013) elicitation.

Emulating AR5 uncertainties

The uncertainties of the individual contributions to 21st century sea level as projected by AR5 are not independent (Church et al. 2013). Hence, the likely range of global mean sea level rise is wider than would be expected if the terms were independent. However, the AR5 does not provide detailed information on the uncertainty covariance of the projected sea level budget. We therefore have to make some assumptions on the uncertainty covariance structure in order to emulate the AR5 uncertainties. We model all terms in the AR5 budget as a multivariate normal distribution, with the exception of the ice sheet dynamics and land water contributions where the AR5 explicitly states that uniform distributions were used. In our emulation of the AR5 budget uncertainties we assume that the Glacier, Greenland and Antarctic surface mass balance and the steric uncertainties are equally correlated but with different variances. The AR5 ice sheet dynamical and land water terms are scenario independent, and we assume that these uncertainties were modelled as being independent of other terms in the budget. We derive the variance and mean value directly from the AR5 likely ranges of the individual components. Using the uncertainty covariance matrix in table S1 results in uncertainties that are consistent with AR5 for both the individual contributors and the global mean sea level. These assumptions allows us to draw random samples from the covariant distribution in a manner that closely emulates the AR5 sea level projections of the sea level budget.

Table S1: Uncertainty covariance matrix used to emulate AR5 RCP8.5 likely ranges of 21st century sea level rise (cm^2). The contributions from Land water, ice sheet rapid dynamic loss are modelled using independent uniform distributions.

	Steric	Glacier	Greenland SMB	Antarctica SMB
Steric	48	21	22	9
Glacier	21	79	28	11
Greenland SMB	22	28	91	12
Antarctica SMB	9	11	12	14

The AR5 (Church et al., 2013) were only able to provide likely ranges (17-83%) for the sea level distribution and not probe further into the tail of the uncertainty, due to primarily limitations in ice sheet modeling. AR5 states that collapse of marine-based sectors of the Antarctic ice sheet, if initiated, could cause global mean sea level to rise substantially above the likely range during the 21st century. We interpret this to mean that the range was determined from a distribution conditional on no collapse, and not from the full uncertainty distribution. The full uncertainty is however essential for adaptation planning, and thus we have to look to other sources. We take the ice sheet uncertainties from the expert elicitation of Bamber & Aspinall (2013) which, like the AR5, is a community assessment. A key motivation for using this particular elicitation is that it comes from the ice-sheet expert community, which has the needed expertise. To minimize the possibility of introducing investigator bias we use this assessment as provided, although we note that it does not relate specifically to RCP8.5 but corresponds to a less intense range of warming (see main text). This is similar to the AR5 where the estimated future Antarctic ice sheet dynamical contribution is also scenario independent.

Dynamic sea level change

We use DSL extracted for the IPCC AR5 (Church et al., 2013) from the following CMIP5 models (ACCESS1-0,ACCESS1-3,CNRM-CM5,GFDL-ESM2G,GISS-E2-R,IPSL-CM5A-LR,MPI-ESM-LR,MPI-ESM-MR,MRI-CGCM3,NorESM1-ME,NorESM1-M,inmcm4). We have excluded models that do not resolve the English Channel and the connection between the Baltic and the ocean. The DSL fields are shown in figure S1.

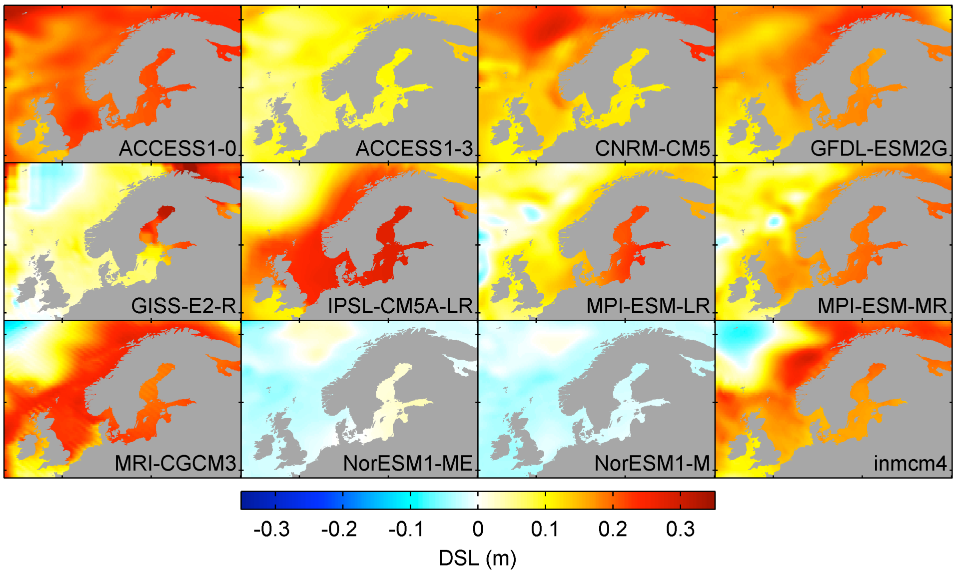

Figure S1: Dynamic sea level change between the periods 1986-2005 and 2081-2100.

Glacial Isostatic Adjustment

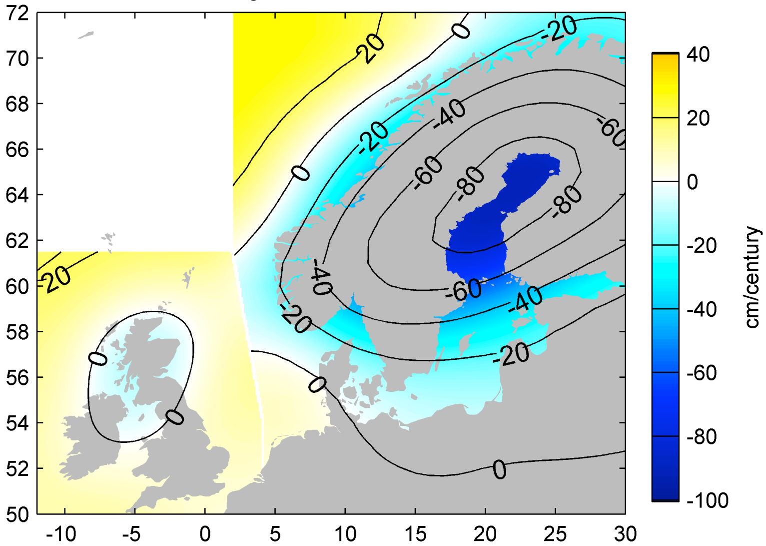

Figure S2: Two models of glacial isostatic adjustment for the British Isles (Bradley et al., 2011) and the Baltic region (Hill *et al., 2*010). Blue shades indicates a relative sea level drop.

Fingerprints

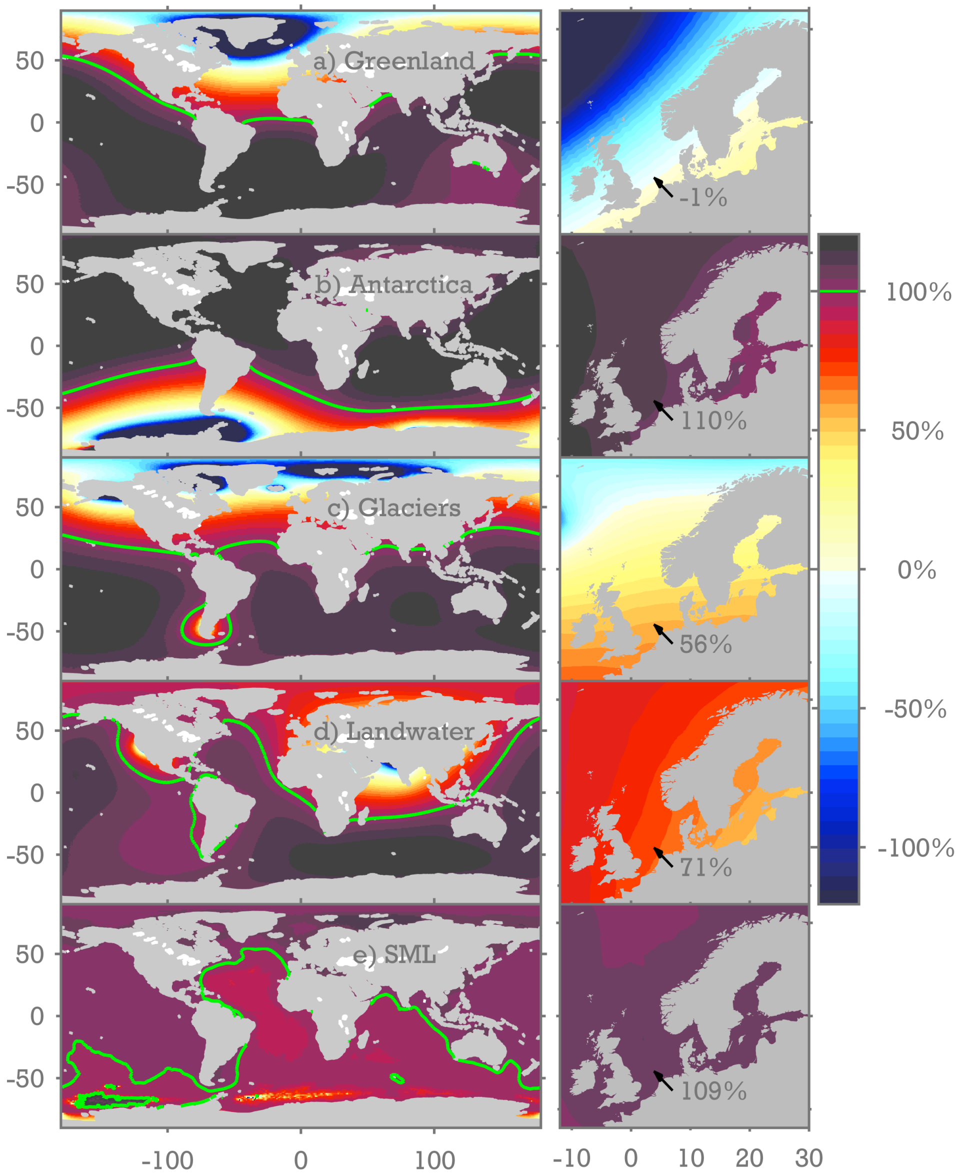

Figure S3: The spatial fingerprint of sea level rise expressed as a percentage of the global mean sea level contribution from the dominant terms in the sea level budget. a,b: from Bamber & Riva, 2010; c,d: calculated based Radic & Hock (2011), and Wada et al., (2012) projections. The Shelf Mass Loading (SML) fingerprint is expressed as a percentage of the global mean ocean expansion plus the local change in dynamic sea level (Richter et al., 2013).

Fingerprint uncertainties in the region of interest arise primarily from uncertainties in future loading patterns. These are hard to quantify formally, and here we gauge the uncertainties by comparing alternative estimates in the literature. The relative proximity of Greenland means that the uncertainty in the Greenland fingerprint is considerable, and here we adopt a standard uncertainty in F_{GrIS} of 0.15 based on the alternative fingerprints presented in Bamber & Riva (2010) and Kopp et al. (2014). The uncertainty in the Antarctic fingerprint is much smaller as Northern Europe is a considerable distance away. We adopt a standard uncertainty on F_{AIS} of 0.02 (in our region of interest) by comparing the fingerprints presented in Bamber & Riva (2010), Kopp et al. (2014), and Mitrovica et al. (2011). For the glacier fingerprint (F_{GIC}) we adopt a standard uncertainty of 0.15 based on Bamber & Riva (2010) and Kopp et al. (2014). The average land-water fingerprint (F_{LW}) is calculated from the Wada et al. (2012) projections for A2 projections from two climate models, and we adopt a standard uncertainty of 0.05 based on the deviation of these two fingerprints in our region of interest. The spread in the Shelf Mass Loading fingerprints (F_{SML}) between scenarios considered in Richter et al. (2014) is about 0.02 in the region of interest, but as these were all calculated from a single climate model, we allow for an uncertainty of 0.05.

Regional sea level rise projections for cities

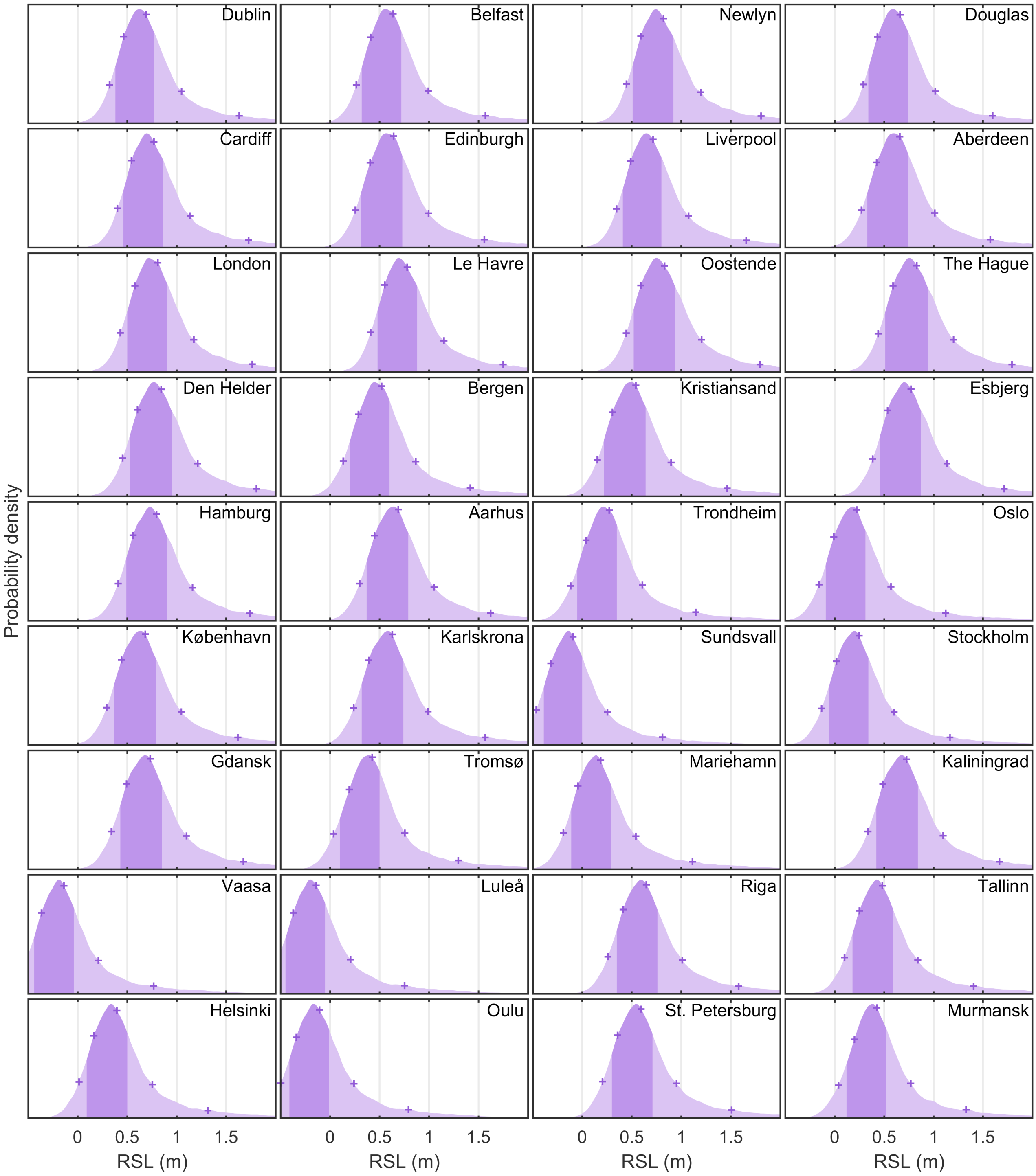

Figure S4: Projected regional sea level rise over the 21st century and uncertainty distributions for cities in Northern Europe under RCP8.5. The 5,17,50,83,95th percentiles are marked with crosses and listed in table S2. Darker shading indicates the 17-83% range when using AR5 for all components in the budget (i.e. excluding Bamber and Aspinall, 2013).

Plain AR5 RSL projection

In this section, we show the regional sea level rise distribution for RCP8.5 using only the AR5 projections for the major components of the sea level budget: AIS, GrIS, GIC, LW, and T. That is, when we do not utilize the Bamber & Aspinall (2013) ice-sheet expert elicitation in our projection. We do not recommend using these projections for adaptation planning, as the AR5 projected ranges exclude the possibility of a collapse of marine based sectors of the Antarctic ice sheet. These projections do not therefore consider the full uncertainty (see discussion in main text, and figure S4).

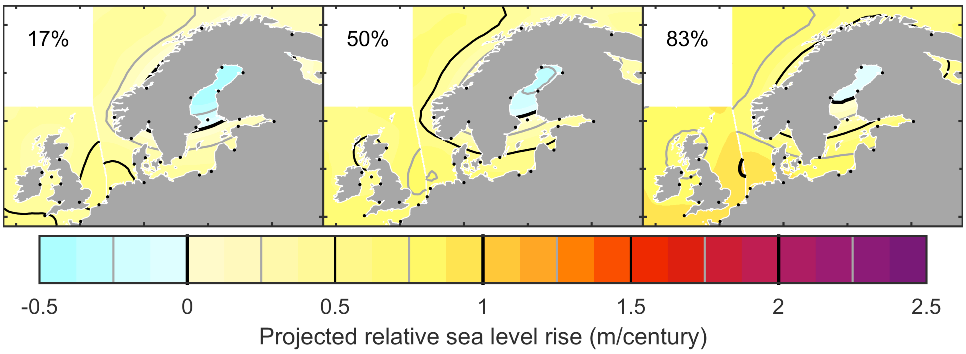

Figure S5: An alternative 21st century regional sea level rise projection using the AR5 RCP8.5 projections. These do not consider the full uncertainty, as the AR5 projections are conditional on no collapse of marine based sectors of the Antarctic ice sheet.

Relative contributions to RSL

The uncertainties in the sea level budget means there is no unique relative sea level budget and no unique way to describe their relative contributions. E.g. a smaller Antarctic contribution can be compensated by a greater steric contribution. We list the relative contributions to the relative sea level budget for London in table S2.

Table S2: Uncertainties the contributions to 21st century GMSL, and in the contributions to London RSL under RCP8.5. Names refer to terms in equations 1 and 2.

	5%	17%	50%	83%	95%	Mode	Mean	Std.dev
T (m)	0.20	0.25	0.32	0.38	0.43	0.33	0.32	0.07
GIC (m)	0.03	0.09	0.18	0.26	0.32	0.19	0.18	0.09
GrIS (m)	0.08	0.10	0.14	0.22	0.32	0.12	0.16	0.08
AIS (m)	-0.05	-0.02	0.09	0.41	0.97	-0.02	0.21	0.34
LW (m)	-0.04	-0.01	0.05	0.11	0.13		0.05	0.05
GMSL (m)	0.45	0.58	0.80	1.20	1.83	0.70	0.92	0.44
London								
LSL=RSL-GIA (m)	0.41	0.54	0.74	1.10	1.69	0.69	0.84	0.40
RSL (m)	0.43	0.58	0.81	1.17	1.76	0.72	0.90	0.41
DSL (m)	-0.03	0.02	0.13	0.18	0.21	0.11	0.11	0.08
GIA (m)	-0.10	-0.04	0.06	0.16	0.23	0.08	0.06	0.10
F_{SML}(T+DSL) (m)	0.26	0.35	0.47	0.57	0.63	0.49	0.46	0.11
F_{GIC}GIC (m)	0.02	0.05	0.10	0.16	0.22	0.09	0.11	0.06
F_{GrIS}GrIS (m)	-0.04	-0.02	0.00	0.03	0.05	0.01	0.00	0.03
F_{AIS}AIS (m)	-0.06	-0.02	0.10	0.44	1.06	-0.02	0.23	0.37
F_{LW}LW (m)	-0.03	-0.01	0.04	0.08	0.10		0.04	0.04
F_{SML}T (m)	0.22	0.27	0.34	0.41	0.46	0.34	0.34	0.08
F_{SML}DSL (m)	-0.03	0.02	0.13	0.20	0.22	0.12	0.12	0.08

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