I don't know, are you sure you want to do this?

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2 **Abstract.**   ...

1. Introduction

2. Sea level projections (PG)

2.1. Global sea level

Most climate models do not explicitly provide sea level as an output of the calculations. Rather, the IPCC AR5 report [*Stocker et al.*, 2013, ch. 13] combines the heat expansion of the ocean with temperature forced models for glacial melt, Greenland ice melt, and Antarctic ice melt and with land rise due to rebound from the last ice age. Judging from the supplementary material to *Stocker et al.* [2013, ch. 13], the uncertainty assessment is only based on the spread of the ensemble of temperature projections, not on the additional uncertainty in the ice models used.

We will instead use the empirical approach of Rahmstorf and collaborators [*Rahmstorf*, 2007; *Rahmstorf et al.*, 2011], employing the statistical modeling of *Bolin et al.* [2014] to relate global annual mean temperature anomalies [*Hansen et al.*, 2001] to global mean sea level anomalies [*Church and White*, 2011].

We then apply the estimated historical relationship to projected temperatures from the CMIP5 experiment [*Taylor et al.*, 2012] to obtain projected global annual mean sea level, taking into account the uncertainty in the statistical model as well as the spread of the temperature projection ensemble (see subsection 2.3).

2.2. Local sea level

In order to get from global sea level projections to local ones, it is important to note that sea level rise not is uniform over the globe. Glacial and land ice melting affect the

20 local sea level differently depending on where the melted ice is located. Another major

21 effect in Fennoskandia is the land rise due to isostatic rebound from the glaciers of the

22 last ice age. Again, we will use historical data to relate global sea level to isostatically

23 corrected local sea level using a time series regression model. Figure 1 shows uncorrected

24 and corrected Bergen sea level data, and the relationship between the corrected Bergen

25 data and the global sea level data. The time series regression uses an ARMA(1,1)-model

26 [*Box and Jenkins*, 1970].

27   The local sea level projections are then obtained by first relating projected temperature

28 to global sea level, and then relating the global sea level to the local one. Each climate

29 model temperature projection yields a different local sea level projection.

2.3. Uncertainty assessment

30   Following the approach of *Guttorp et al.* [2014] we assess the uncertainty in the local

31 sea level projections taking into account the variability between the climate projections

32 used, the uncertainties in the regressions of global mean temperature on global mean sea

33 level and of global on local sea level. We express the sea level projection uncertainty in

34 terms of a confidence band that is simultaneously of the intended level for all projection

35 years. This allows us, for example, to get a confidence band for the years when a given

36 sea level rise is obtained.

2.4. Limitations of the sea level projections

37   The main assumption is using historical relationships in statistical projections of the

38 type used in this paper is that there is no major change in how temperature relates to

39 sea level, globally and locally. Among the factors that may invalidate this approach are

changes in water storage on land (removing water from the oceans), excessive siphoning

of groundwater (resulting in land subsidence), changes in the rates of glacial and land

ice melt, and changes in Earth's gravitational field due to transfer of mass from land ice

to ocean water. For example, the rate of ice melt on Greenland may suddenly increase

substantially due to intense warming of both air and sea water. Our current climate

models are not able to resolve the ice processes sufficiently to include such so called

tipping points into the projections. Also, the IPCC scenarios do not include changes in

water usage [*van Vuuren et al.*, 2011].

3. Decision tools (KdB, MD, TT)

3.1. Timing of adaptation measures

We consider adaptation decision making related to the timing of proactive adaptation

measures. That is, the goal is to adapt to sea level rise before major damages occur. In a

cost-benefit framework, an investment should be delayed as long as the benefits of delay

(avoided investment costs) are greater than the associated costs (higher climate change

damages) [*Fankhauser et al.*, 1999].

Fankhauser et al. [1999] describe a deterministic framework where an adaptation in-

vestment of C^0 now (at time $n = 0$) leads to unmitigated damage of d_0^0 in period 0, and a

stream of partially mitigated damages d_t^0 in periods $t = 1, 2, \ldots$. If r is the discount rate,

the net present value damage, D^0, associated with this investment is

$$D^0 = C^0 + d_0^0 + \frac{d_1^0}{1+r} + \frac{d_2^0}{(1+r)^2} + \cdots \tag{1}$$

In comparison, postponing the adaptation investment to time period $n = 1$ would lead to

unmitigated damages in periods 0 and 1, and partially mitigated damages, d_t^1, thereafter.

60 The delay would be preferable if

$$C^0 - \frac{C^1}{(1+r)} > (d_0^1 - d_0^0) + \frac{d_1^1 - d_1^0}{1+r} + \frac{d_2^1 - d_2^0}{(1+r)^2} + \cdots$$

62 Here, the expression on the left describes the benefits of the delay while the expression

63 on the right describes the cost of the delay. In the simplest case, there is no change

64 in investment costs ($C^0 = C^1 = C$) and the delay has no lasting effects beyond period

65 1 ($d_t^1 = d_t^0$ for $t > 1$). In this case, the comparison is between the expected return r

66 earned on the captial while implementation is delayed and one addtional time period of

67 unmitigated damage,

$$rC > d_1^1 - d_1^0.$$

3.2. Limitations of the decision framework

4. Case studies

4.1. Data (PG)

4.2. Timing of adaptation measures (KdB, TT)

69 A case study focusing on and comparing different cities in Norway.

4.3. Selection of adaptation measures(?) (MD)

70 A case study focusing on Denmark.

5. Conclusions

Extremes in Large Datasets" (ClimateXL). The source code for the analysis is implemented in the statistical programming language R (`http://www.R-project.org`) and is available on GitHub at `http://github.com/eSACP/...`.

References

Bolin, D., P. Guttorp, A. Januzzi, M. Novak, H. Podschwit, L. Richardson, C. Sowder, A. Särkkä, and A. Zimmerman (2014), Statistical prediction of global sea level from global temperature, *Statistica Sinica*, *25*, 351–367.

Box, G., and G. Jenkins (1970), *Time series analysis: Forecasting and control*, Holden-Day.

Church, J., and N. White (2011), Sea-level rise from the late 19th to the early 21st century, *Surveys in Geophysics*, *32*, 585–602.

Fankhauser, S., J. Smith, and R. S. J. Tol (1999), Weathering climate change: some simple rules to guide adaptation decisions, *Ecological Economics*, *30*, 67–78.

Guttorp, P., D. Bolin, A. Januzzi, D. Jones, M. Novak, H. Podschwit, L. Richardson, A. Särkkä, C. Sowder, and A. Zimmerman (2014), Assessing the uncertainty in projecting local mean sea level from global temperature, *Journal of Applied Meteorology and Climatology*, *53*, 2163–2170.

Hansen, J., R. Rued, M. Sato, M. Imhoff, W. Lawrence, D. Easterling, T. Peterson, and T. Karl (2001), A closer look at United States and global surface temperature change, *J. Geophys. Res.*, *106*, 23,947–23,963.

Rahmstorf, S. (2007), A semi-empirical approach to projecting future sea-level rise, *Science*, *315*, 368–370.

Rahmstorf, S., M. Perrette, and M. Vermeer (2011), Testing the robustness of semi-empirical sea level projections, *Climate Dynamics*, *39*, 861–875.

Stocker, T., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P. Midgley (2013), *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Pabel on Climate Chang*, Cambridge University Press.

Taylor, K., R. Stouffer, and G. Meehl (2012), An overview of CMIP5 and the experiment design, *Bull. Amer. Meteor. Soc.*, *93*, 485–498.

van Vuuren, D. P., J. Edmonds, M. Kainuma, K. Riahi, A. Thomson, K. Hibbard, G. C. Hurtt, T. Kram, V. Krey, J.-F. Lamarque, T. Masui, M. Meinshausen, N. Nakicenovic, S. J. Smith, and S. K. Rose (2011), The representative concentration pathways: an overview, *Clim. Change*, *109*, 5–31.
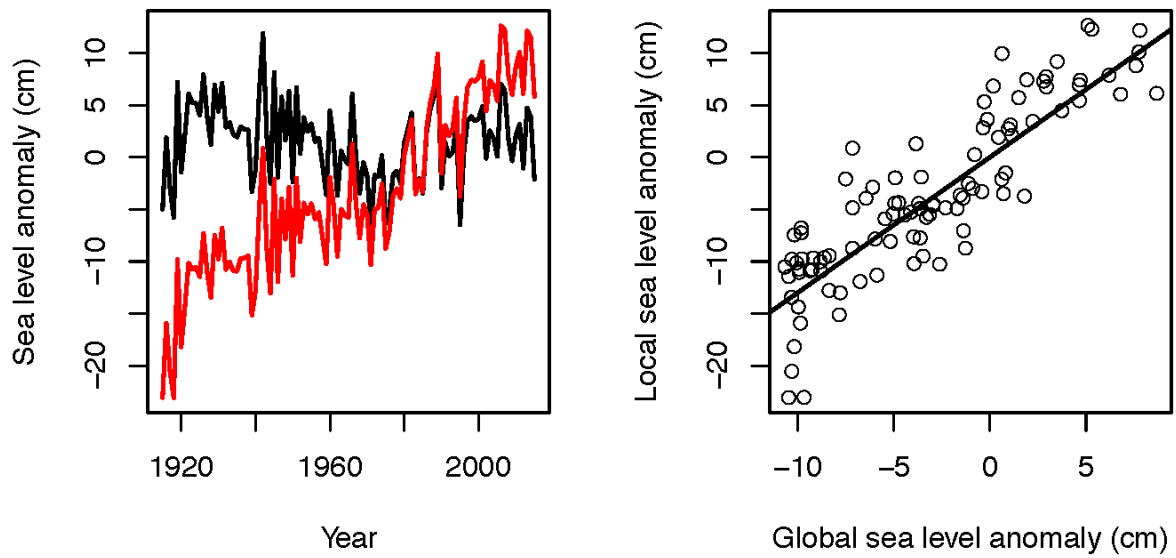
Figure 1. The left figure shows raw (black)and gia-corrected (red) sea level data from Bergen, The right figure relates the gia-corrected Bergen sea level to the global sea level series of *Church and White* [2011]. The straight line is the time series regression line.
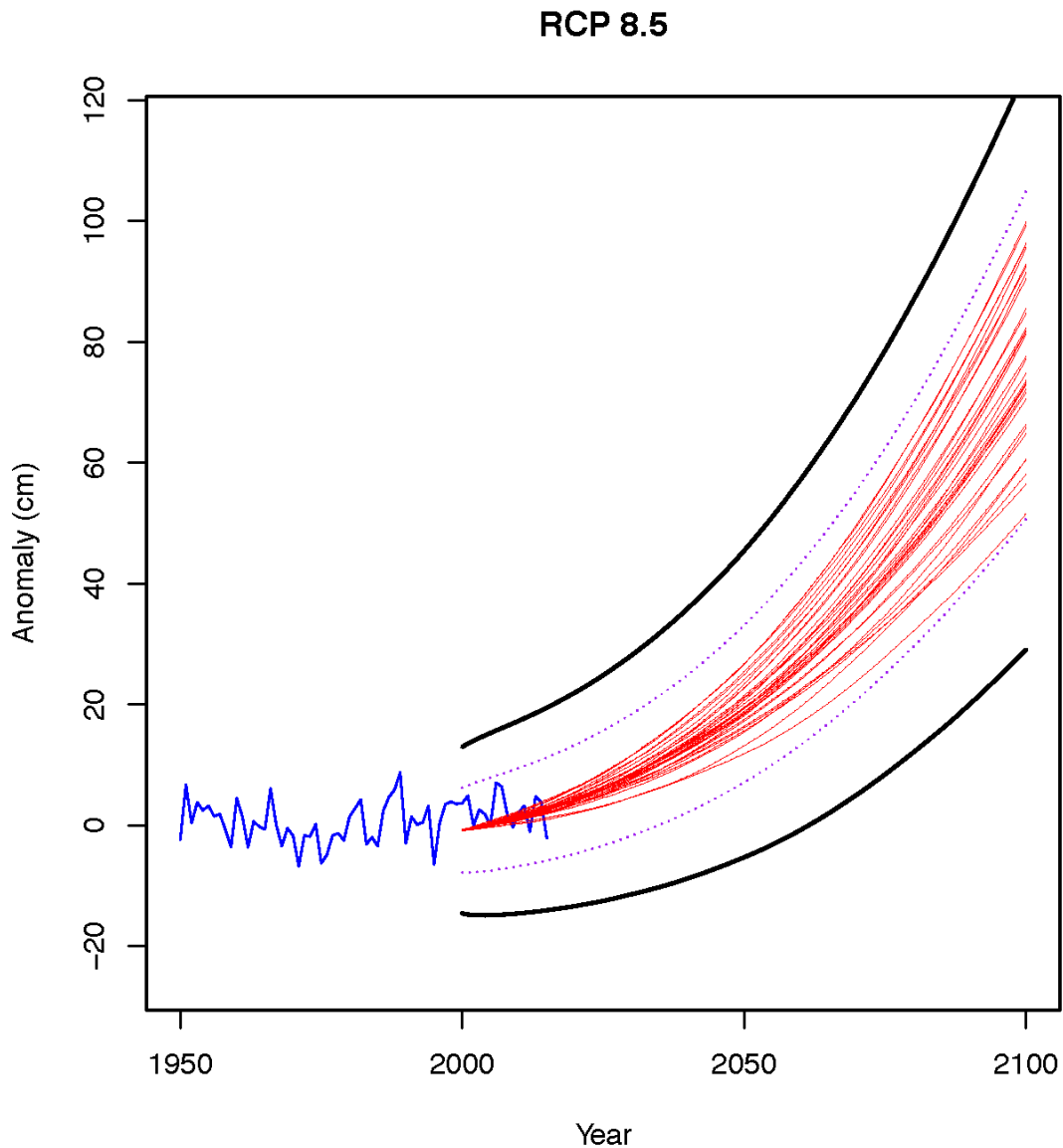
Figure 2.   Simultaneous 90% confidence set (thick black lines) for Bergen sea level projections for the years 2000-2100 using RCP8.5. The sea level data are shown in blue and end in 2015. The thin red lines are the projections without uncertainty based on each of the climate models. The dashed purple lines connect pointwise confidence intervals for each year.