Nonlinearities in the Observational Ice-melt Record and Their Implications for Future Sea Level Rise

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1) Introduction

Sea level projections from different methods vary. This could be due to nonlinear behaviour in the relationship between ice melt and warming, which is often treated as linear in semi-empirical models.

We use a semi-empirical Earth systems model[1] to assess the impact of nonlinearities on projections of future sea level rise. For this study, we only focus on nonlinearities that are already present in the observational record - i.e., those that are already impacting sea level rise from ice melt.

2) Methods

$$\frac{d}{dt}GMSL_{total} = \underbrace{c_{thermal}\Delta OHC}_{1} + \Big(\underbrace{a\Delta T}_{2} + \underbrace{b\Delta T^2}_{3}\Big)\underbrace{\left(\frac{c\Delta T - \Delta GMSL_{ice}}{c\Delta T}\right)}_{4}$$

1) Process-based thermal expansion
2) Linear ice-melt component
3) Nonlinear ice-melt component
4) Maximum ice-melt constrained by LIG sea levels

We add a nonlinear term (3) to the relationship between warming and the rate of sea level rise within a large ensemble of historically constrained efficient earth systems model simulations.

3) Results and Conclusions

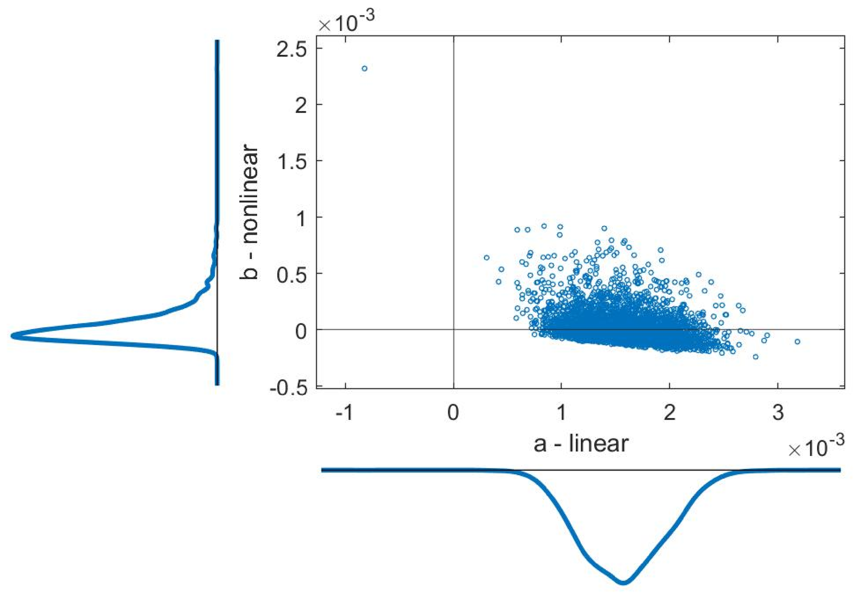

Fig1: Posterior distribution (after history matching protocol) of linear and nonlinear coefficients ('a' and 'b' respectively)

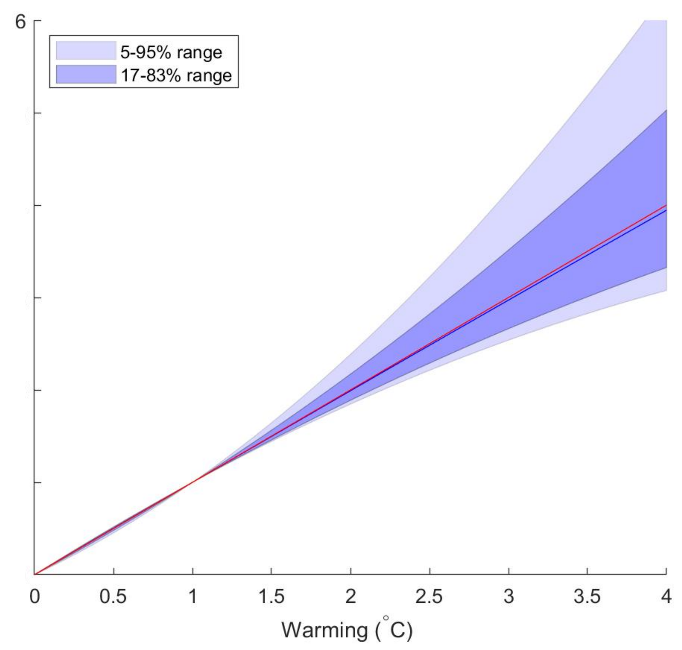

Fig2: Rate of sea level rise at a given amount of warming relative to current rate of rise. The red (1:1) line represents linearity.

Median behaviour is linear, but superlinear interactions could cause sea level rise up to 6x faster than present for 4x level of warming (95th percentile) - outweighing the magnitude of sublinear interactions.

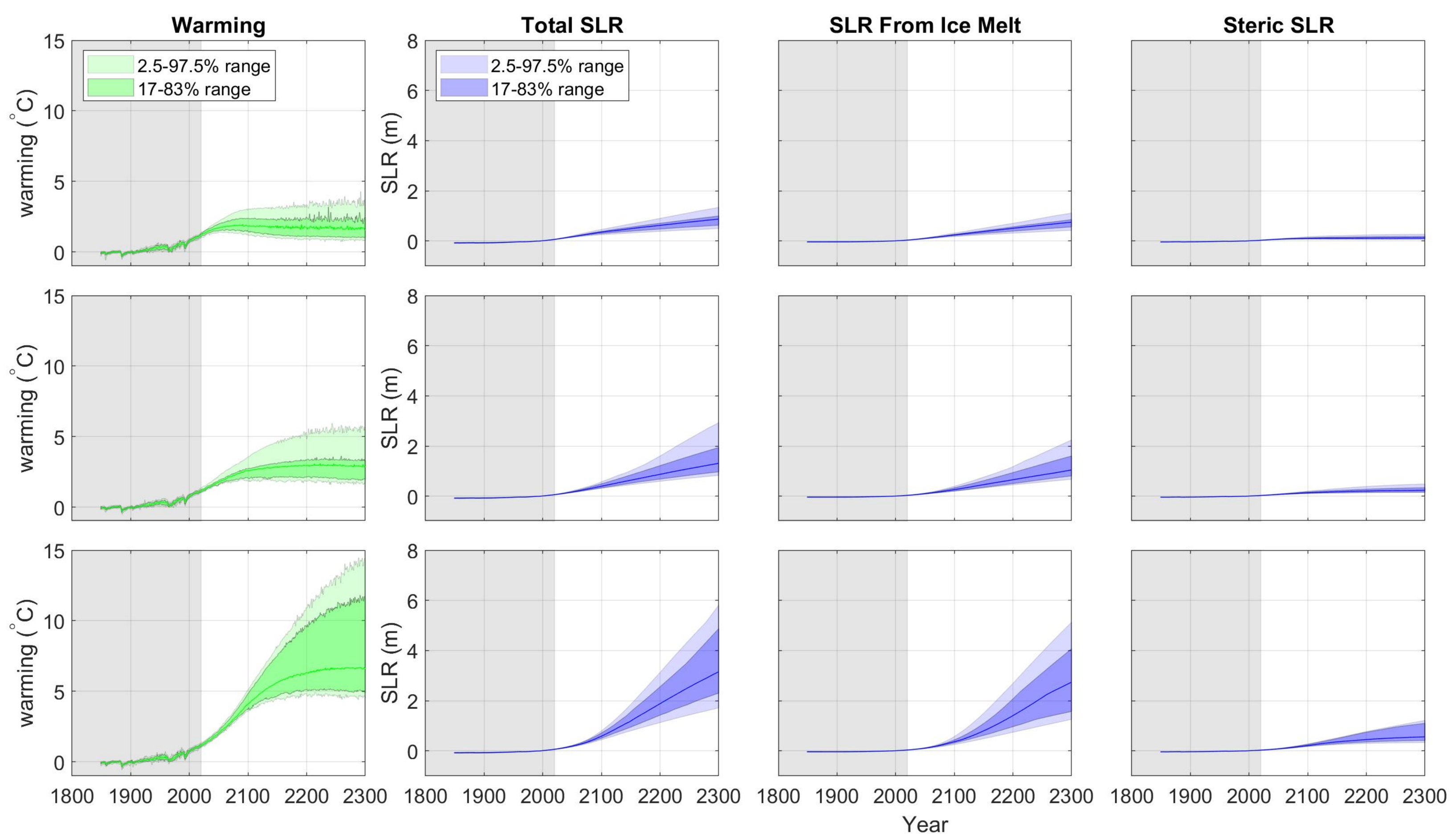

Fig3: Projections of warming (green) and total, ice and steric sea level rise (blue) for SSPs 126, 245 and 585 (top, middle and bottom rows respectively)

Projections including a nonlinear element are similar in the median to those without a nonlinear element, but there is a greater upward skew due to the upward skew in the distribution of values for the nonlinear coefficient 'b'.

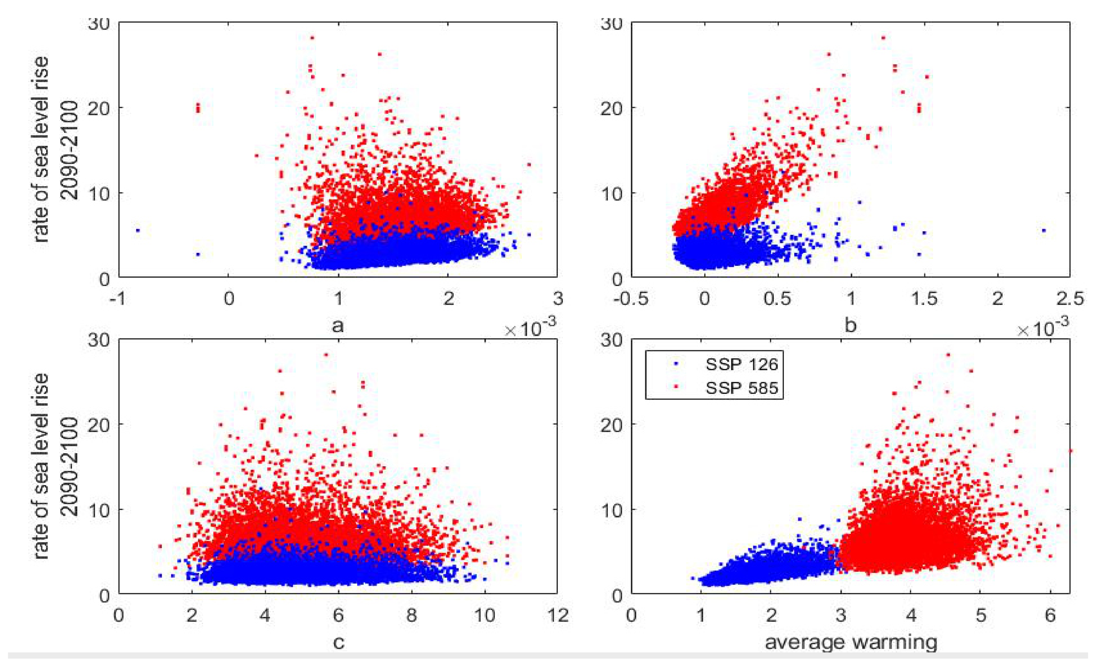

Fig4: Impact on uncertainty in rate of sea level rise by 2100 by a- linear behaviour, b- nonlinear behaviour, c- linear and nonlinear in combination, d-warming.

time period, scenario	r squared		
	a	b	dT
2010-2020	0.24	0.27	0.05
2090-2100 low emissions	0.01	0.09	0.6
2090-2100 high emissions	0.18	0.39	0.07

Table 1: Correlation coefficient for a, b and warming versus the rate of sea level rise

Observationally consistent nonlinearities dominate uncertainty in the rate of end-of-century sea level rise for high-emissions scenarios (SSP585), whereas warming dominates for low-emission scenarios (SSP126). This provides further incentive to limit warming by the end of the century.