Using global sea-level rise targets to find optimal temperature overshoot profile

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1. Introduction

In the Paris Agreement, the goal of keeping surface warming well below 2.0°C and pursuing efforts to limit surface warming to 1.5°C has been widely adopted by most countries.. However, when halting a surface warming below 2.0°C or to 1.5°C by 2100, a continuous rise of global sea level rise will remain several centuries or even for millennia and beyond (Schaeffer et al., 2012; Meehl et al., 2012; Clark et al., 2016). One possible interpretation of a successful climate policy for the next few decades could be that it should avoid global-warming induced impacts on climate, ecosystems and human societies not only within this century, but also for the next centuries and beyond. **Here, we perform a proof-of-concept study to introduce a constraint on SLR as a new climate target and compare the economic impact to that of a corresponding temperature target.**

2. Model and definition of climate targets

We have substantially augmented the climate physics of the optimizing climate-energy-economy model MIND (Model of Investment and Technological Development, Edenhofer et al., 2005; Neubersch et al., 2014), allowing for a much improved represented of ocean heat uptake and a connection between surface warming and land-ice melting. We introduce a global total SLR model with three components, one due to ocean thermal expansion, one due to the melt of Greenland ice-sheet (Fettweis et al., 2013) and Antarctic ice-sheet (Wigley, 2018), and one due to mountain glaciers and ice cap melting (Wigley and Raper, 2005). This has enabled us to investigate, for the first time, a sea-level rise climate target in an integrated-assessment framework, a target that is closer to coastal planning and associated adaption measures than a temperature target.

Our simple climate model and SLR model can reasonably simulate the climate response to atmospheric CO2 forcing as the IPCC AR5 state-of-the-art climate models projections (Fig. 1), and serve the task of climate target development in the integrated assessment framework.

Table 1: Definition of climate targets (bold=target variable, normal font=free variable)

Targets	SAT Maximum	SLR maximum	SLR rate maximum
T<=2.0°C	**2.0°C**	0.89m	5.1mm/yr
SLR<=0.89m	2.3°C	**0.89m**	5.6mm/yr
SLR rate<=5.1mm/yr	2.7°C	1.02m	**5.1mm/yr**
T<=1.5°C	**1.5°C**	0.75m	4.2mm/yr
SLR<=0.75m	1.8°C	**0.75m**	4.6mm/yr
SLR rate<=4.2mm/yr	2.1°C	0.89m	**4.2mm/yr**

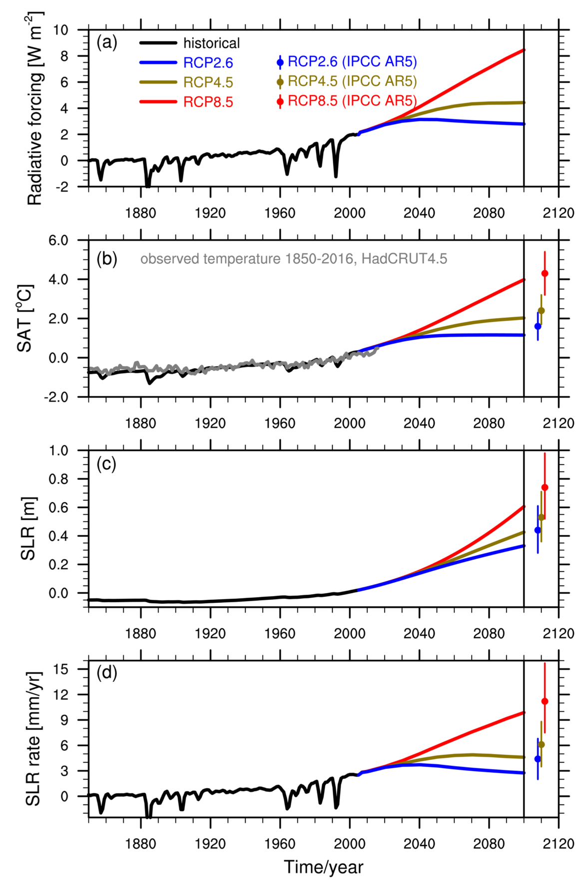

Figure 1: Historical evolution and future projections as simulated with our three-layer ocean model. (a) Effective radiative forcing from the IPCC AR5 Annex II sheet 1-2 for the historical period and sheet 6-8 for the future projected period, unit: W m⁻², (b) surface air temperature change, unit: °C, (c) total sea-level rise, unit: m, (d) total sea-level rise rate, unit: mm/yr. The grey line in (b) is the instrumental temperature record for 18502016 from HadCRUT4 data provided by the UK Met Office Hadley Centre. The dots with vertical line are projections from IPCC AR5.

3. Temperature targets versus sea-level targets

- **The 2.0°C target** shows stabilized surface warming of 2.0°C after year 2070 (Fig. 2a). The CO2 emission increases until 2050 and then decreases sharply to about 3.4GtC/yr by 2070 (Fig. 3a). After 2070, the external forcing due to anthropogenic CO2 emission is compensated by ocean heat uptake and continuously increases SLR while surface warming is halting at 2.0°C (Fig. 2b,c).
- **The SLR target (SLR<=0.89m)** allows surface warming overshooting within the 21st century, but after the middle of the next century surface warming is smaller than the 2.0°C target (Fig. 2a). The SLR target largely slows down the SLR rate after 2200 by about 18% (Fig. 2c). With the same amount of cumulative carbon emission as 2.0°C target, the SLR target allows more emission in the short term, but requires zero emission in the long term(Fig. 3a,b).
- **The SLR rate target (SLR rate<=5.1mm/yr)** could slow down surface warming, but has no upper limit for long-term climate change (Fig. 2a,b).
- Results from the 1.5°C target and equivalent sea-level targets are similar to Fig. 2 and Fig. 3 except for a rescaling of numbers.

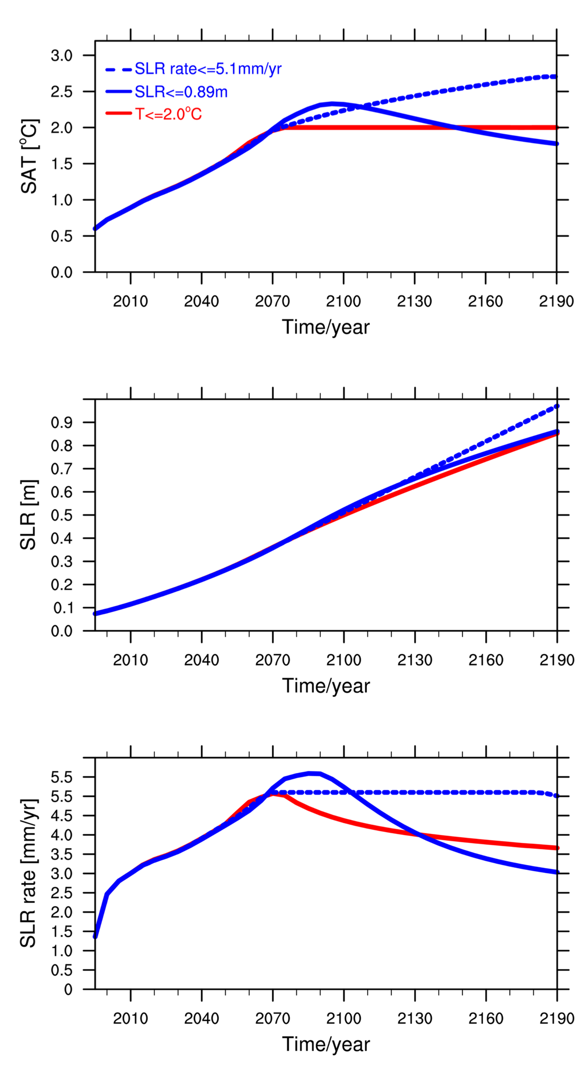

Figure 2: Climate responses for all climate targets. (a) surface temperature change, (b) global sea-level rise, and (c) global sea-level rise rate for the 2.0ºC target and all corresponding sea-level targets.

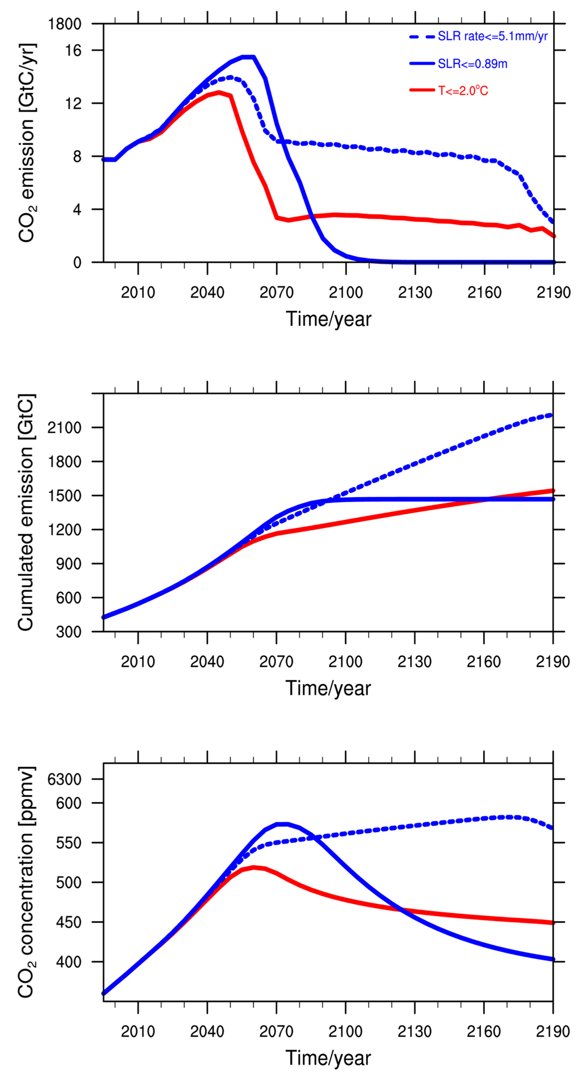

Figure 3: Carbon emissions and concentrations for all climate targets. (a) carbon emissions, (b) cumulative carbon emissions, and (c) atmospheric CO2 concentration for the 2.0ºC target and all corresponding sea-level targets.

4. Mitigation cost of temperature targets and sea-level targets

SLR targets while leading to temperature overshoots, lead to lower maximum consumption losses and mitigation cost. SLR targets allow for higher emissions at the earlier period but require much stronger emissions reduction in the later period. Hence, the targets for SLR taken from the results of temperature targets over the period out to year 2200 lead to lower mitigation cost.

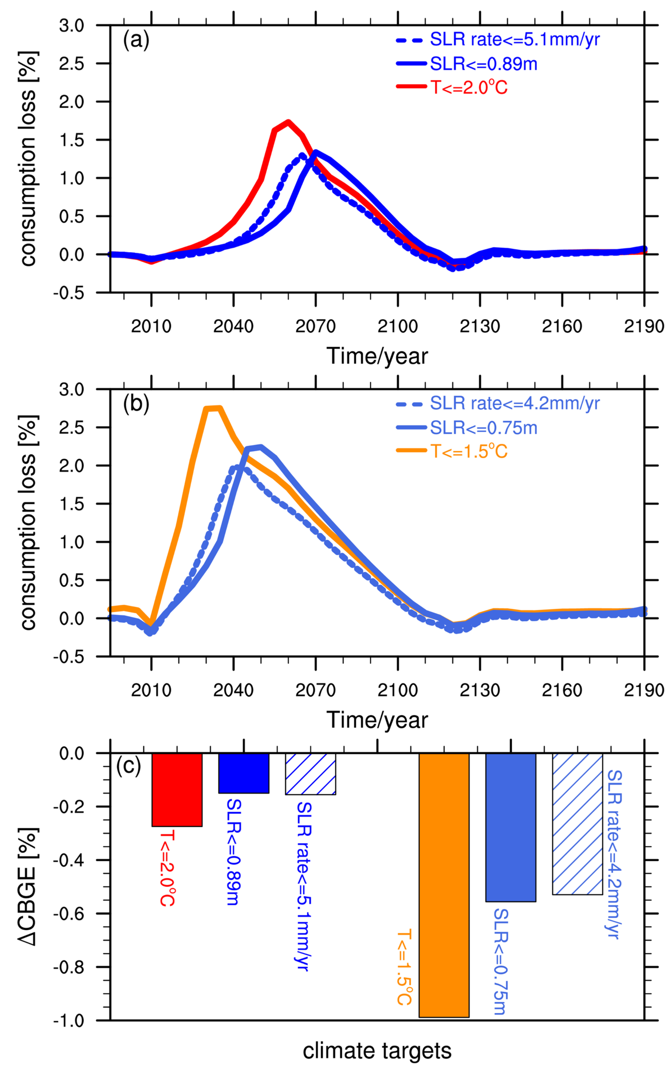

Figure 4: Mitigation costs for all climate targets. Consumption loss for (a) the 2.0ºC target and all corresponding sea-level targets, and (b) the 1.5ºC target and all corresponding sea-level targets. (c) BGE loss for all climate targets. BGE gives the change in initial consumption that is necessary to reach the difference in welfare assuming equal consumption growth in both the defined climate target and the BAU scenario

5. Sensitivity of choice of sea-level target

With the same mitigation cost as the corresponding temperature target, the SLR target limits surface warming in compliance with the original temperature target to an accuracy better than 0.1°C in the short term, and brings surface warming below the targeted temperature and reduces SLR in the long-term. Overall, SLR targets are sufficient to limit climate change in both the short and the long term, and are also sufficient to suggest a mitigation strategy with a minimized mitigation cost. (Figure 5).

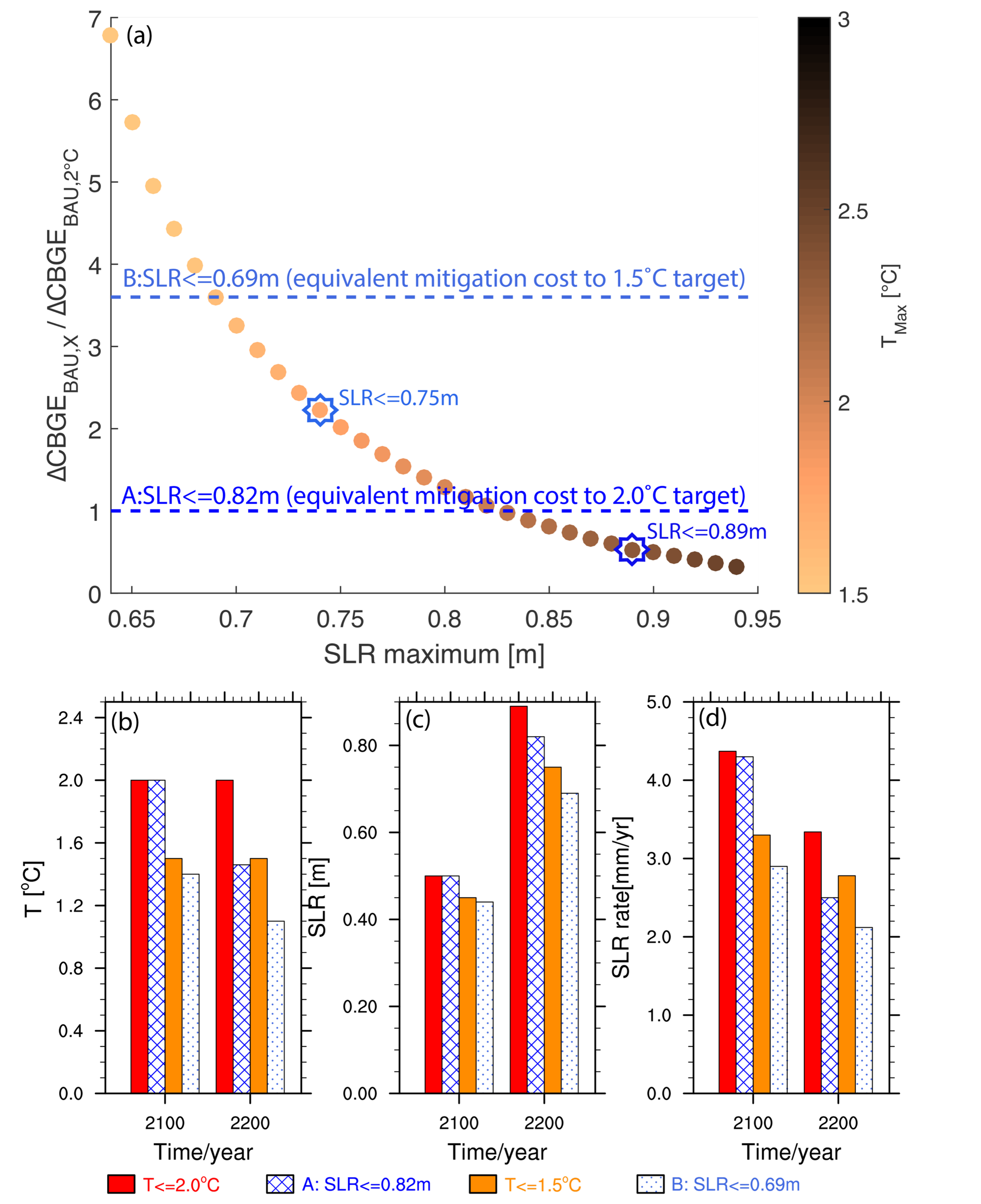

Figure 5: Characteristics of different SLR targets. (a) Normalized BGE loss and surface temperature change maximum for limiting global SLR at different level from 0.64 m to 0.94 m until 2200. (b) Surface temperature change, (c) global sea-level rise and (d) global sea-level rise rate at years 2100 and 2200 for temperature targets and SLR targets of equivalent mitigation cost.

6. Discussions and conclusions

- We emphasize a key effect of carbon emissions pathways on future SLR. The goal of limiting surface warming or limiting cumulative carbon emission to a certain level is not enough to limit future risk caused by SLR, because the shape of carbon emissions pathway will largely influence future SLR after 21st century.
- We find that a global SLR target will provide a more sustainable and more cost-efficient solution to limit both short-term and long-term climate change for stakeholders who primarily care about SLR among all global warming impact categories compared to a temperature target with the same SLR by 2200.
- We find that the SLR target can provide a temperature overshoot profiles through a physical constraint rather than arbitrarily defining an overshoot range of temperature as acceptable.
- SLR targets can be viewed as a re-interpretation of the 2.0°C and 1.5°C targets and can provide a rational justification of a certain temperature overshoot for stakeholders who primarily care about SLR.
- Our present framework with re-interpretation of the widely agreed temperature targets can in principle be transferred from SLR targets to other impact-related targets, and can be used to identify a more sustainable path towards meeting the Paris Agreement.

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