Additional global warming caused by crossing critical thresholds within the Earth‘s cryosphere

Nico Wunderling

IRTG1740 – São Paulo

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Introduction

PhD student in IRTG1740 and FAPESP @ PIK & USP
(H. Barbosa, J.F. Donges & R. Winkelmann)

Stay in Brasil: Until 17.10.2018

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i. ***Climate models*: CLIMBER-2: Today**

ii. *Conceptual models*: Differential equations – Work in progress

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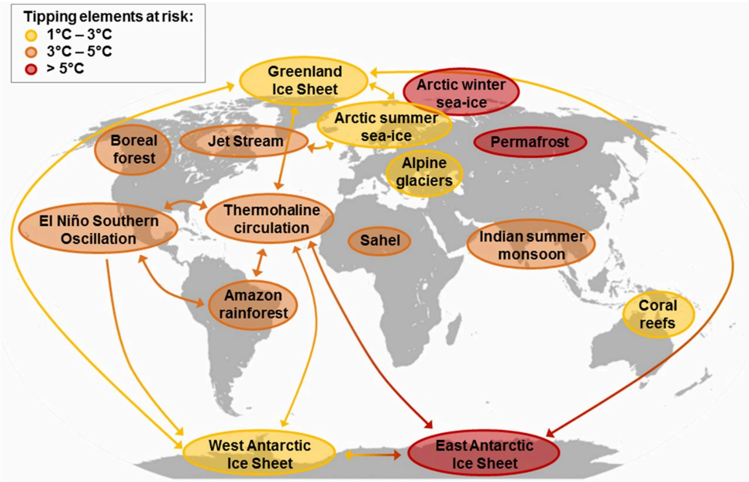
2)Further interests:

i. Networks of tipping elements

ii. Social tipping elements

iii. Climate history in South America (16-18th century)

Tipping elements in the Earth system can be grouped into clusters according to their temperature threshold



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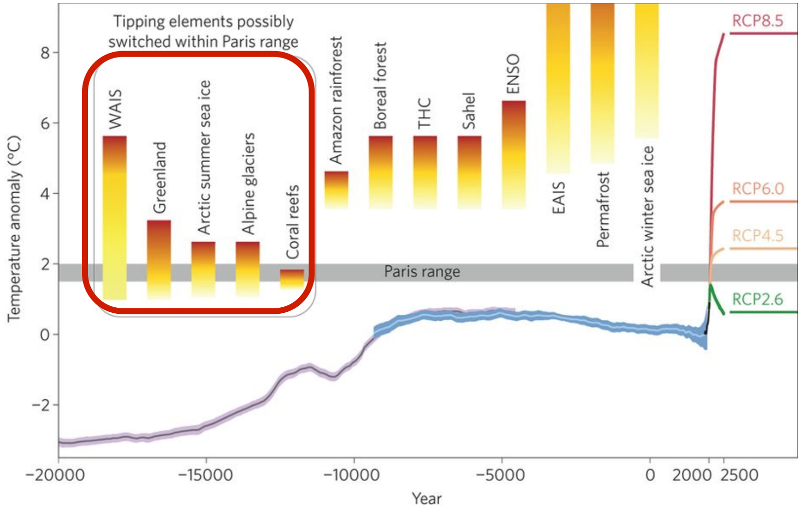

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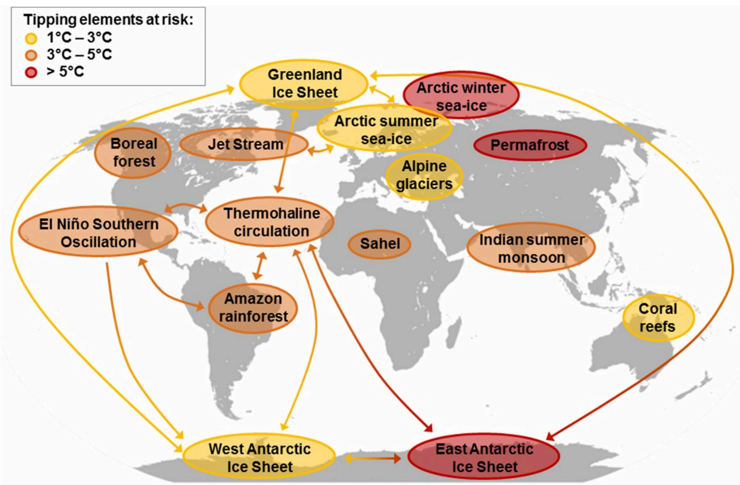

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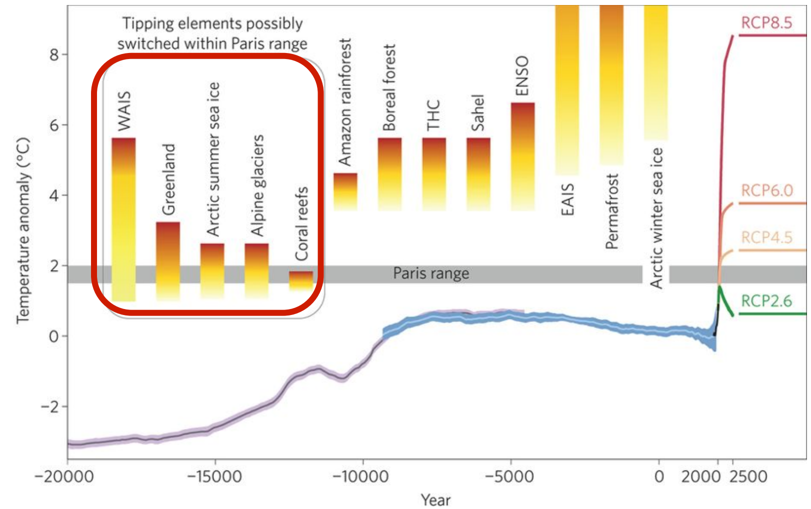

Schellnhuber et al.(2016), NCC

→ Some TEs are at risk of transgressing their critical threshold within the Paris range

Simple model $4 \cdot \gamma\sigma T^4 = S_0(1-\alpha) <=> T = \sqrt[4]{\frac{S_0(1-\alpha)}{4\gamma\sigma}} \Rightarrow \Delta T = 0.27 \pm 0.11°C$

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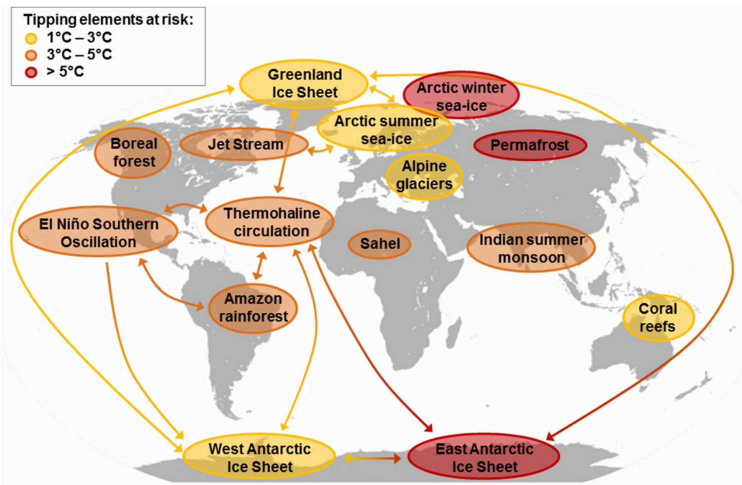

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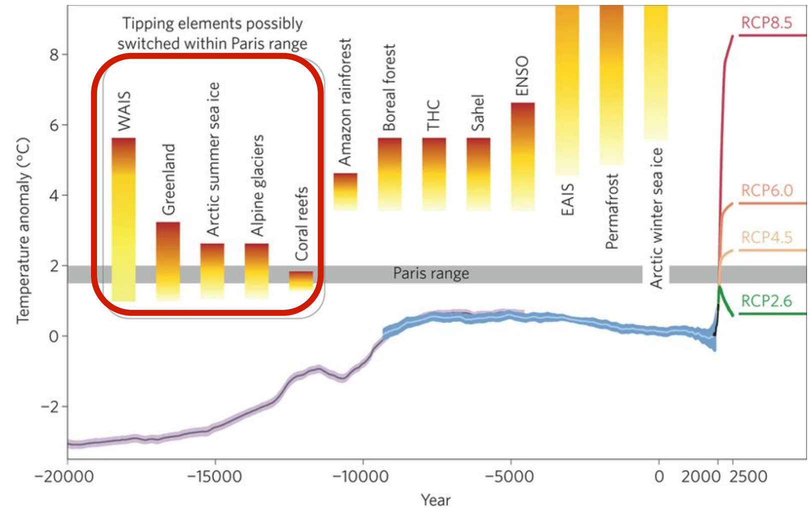

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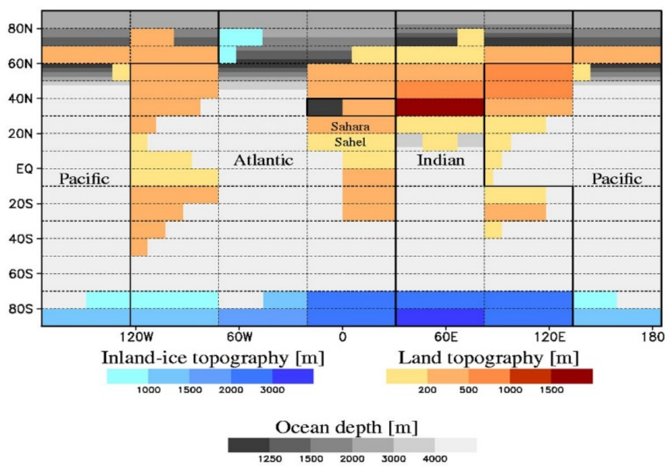
Research question:

How would the tipping of cryosphere elements affect the GMT? Which are the relevant feedbacks?

Climate model: CLIMBER-2

- CLIMBER-2: Earth system model of intermediate complexity (EMIC)
- Coarse spatial resolution → computationally efficient: > 3 000 eq. runs
- Ability to reconstruct drivers (fast climate feedbacks)



Petoukhov, et al.(2000), Climate Dynamics &
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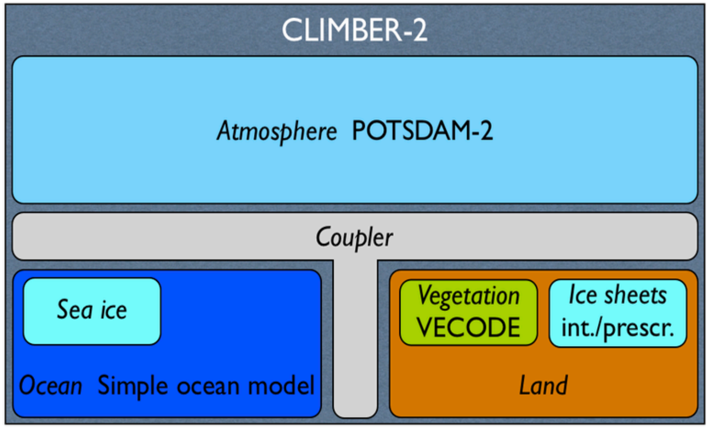

Project together with:
Ricarda Winkelmann, Jonathan Donges
& Matteo Willeit

PIK

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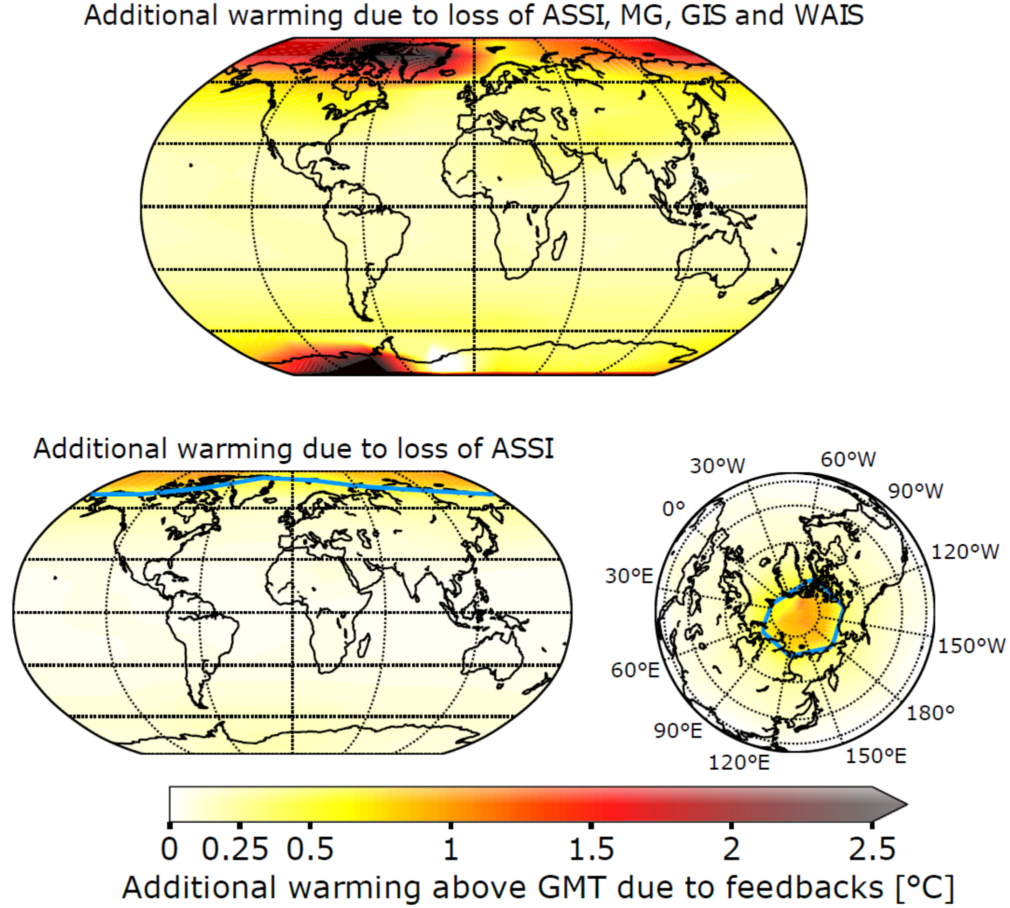
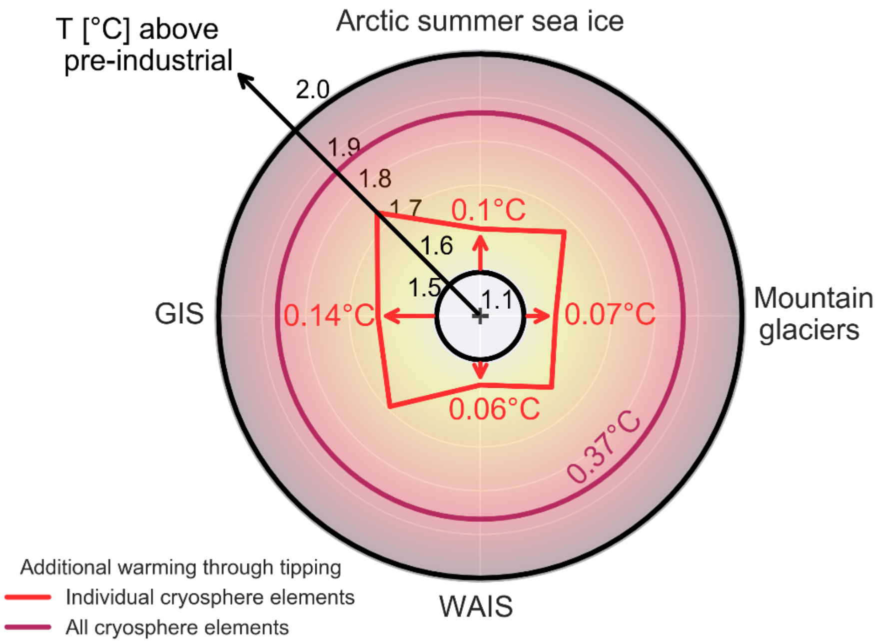
Regional warming due to feedbacks

Additional warming compared to 1.5°C above pre-industrial



GMT increase due to tipping of cryosphere elements



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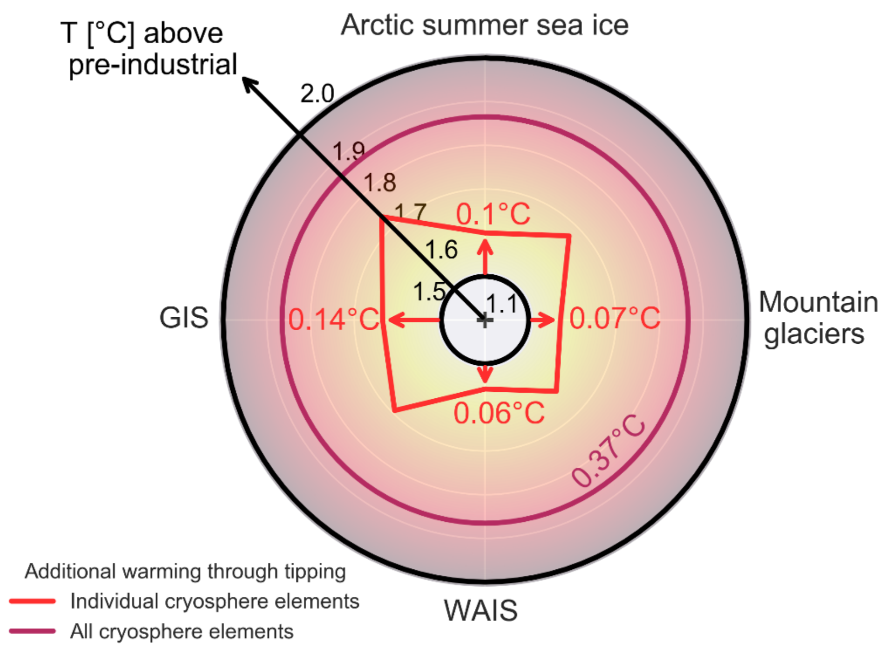

Main results:

1. Additional global warming: 0.37±0.03°C => commitment up to 25% higher than due to combustion of fossil fuels only (simple model: 0.27 ± 0.11°C)
2. Climate warming self-amplifying in such scenarios

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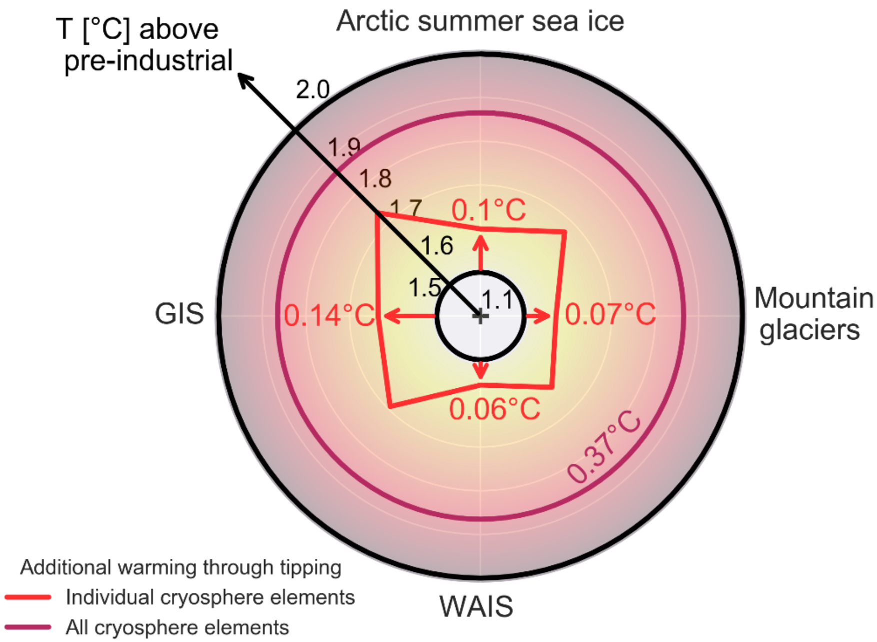

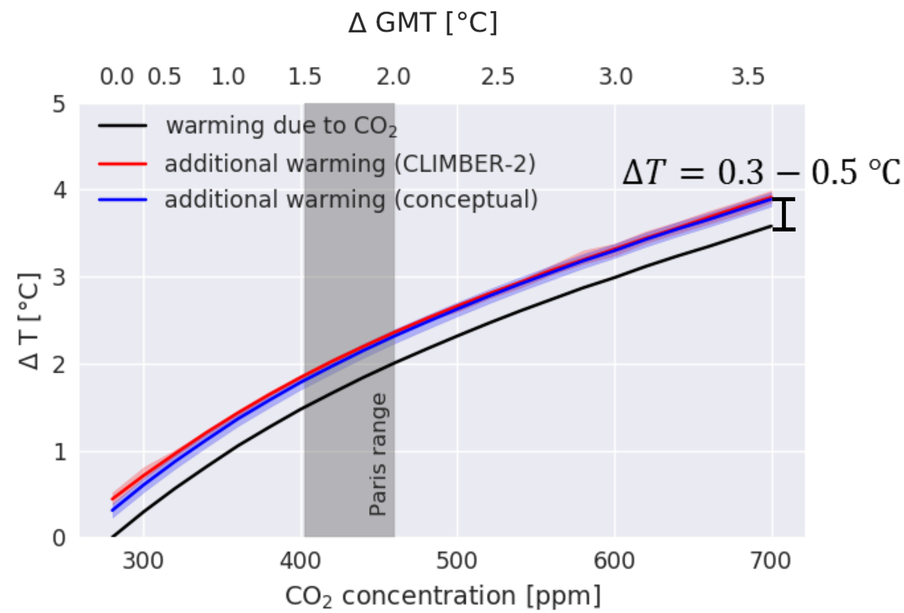

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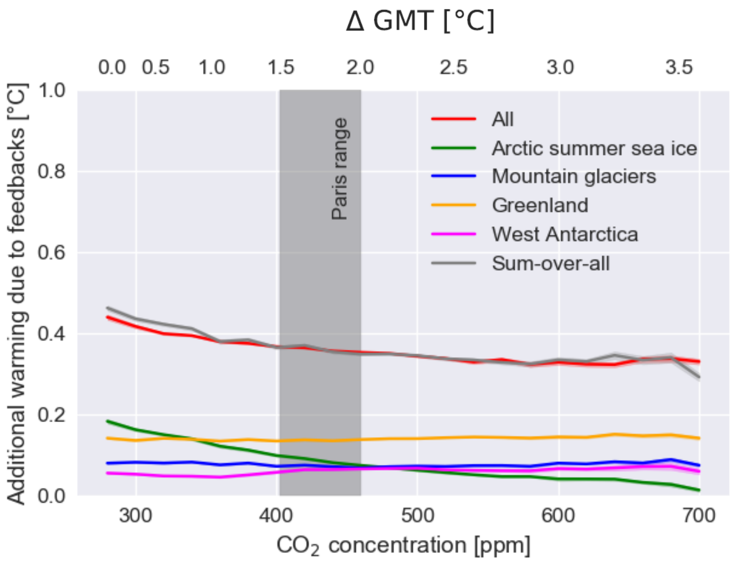
Linearity of additional warming due to critical transition of tipping elements



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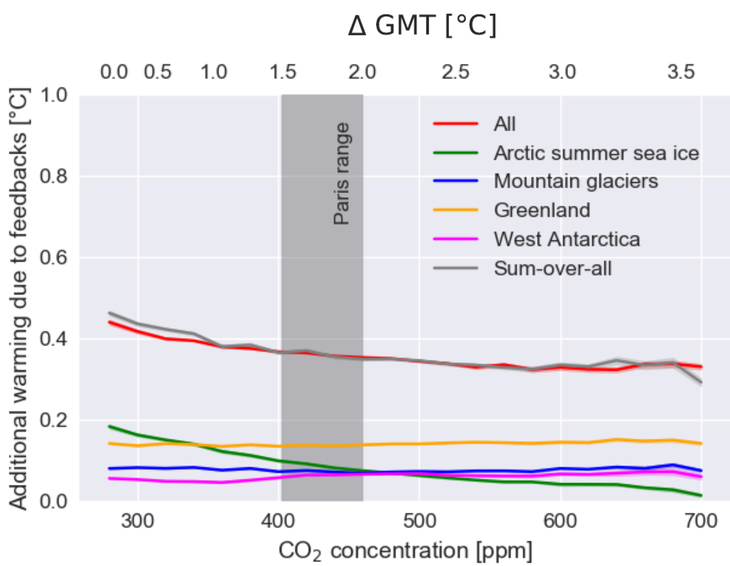

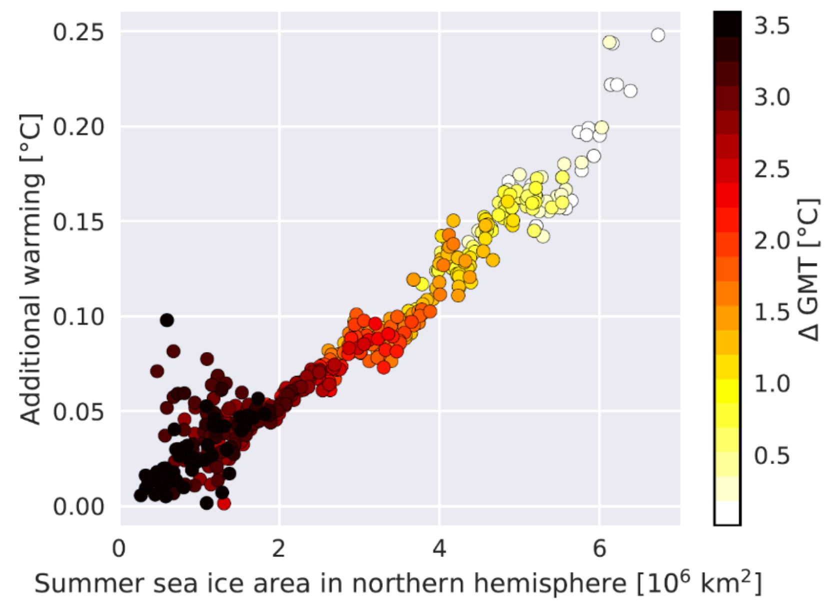

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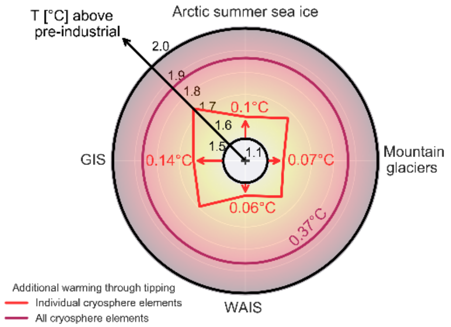
Contributions from fast climate feedbacks



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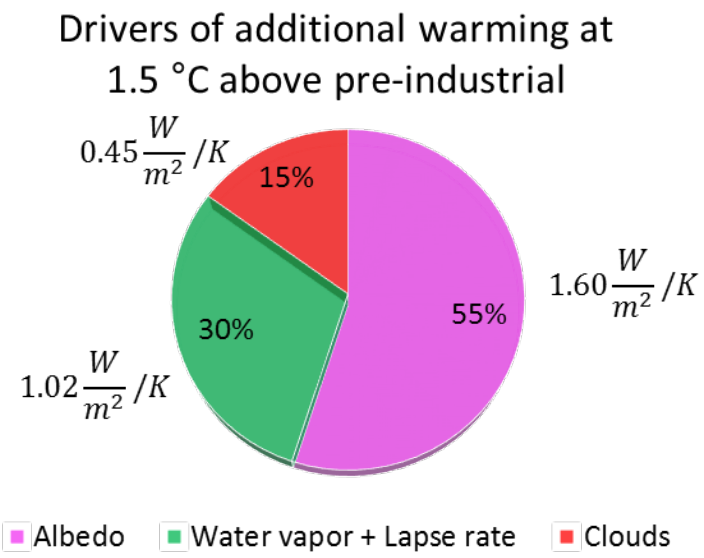

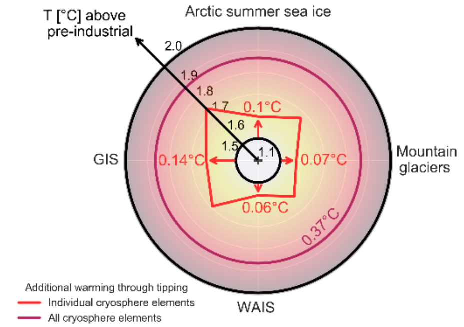

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3. **Lapse rate**: Change of vertical temperature profile
4. **Clouds**: Rearrangement of clouds

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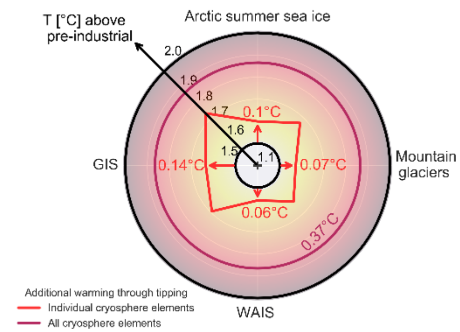
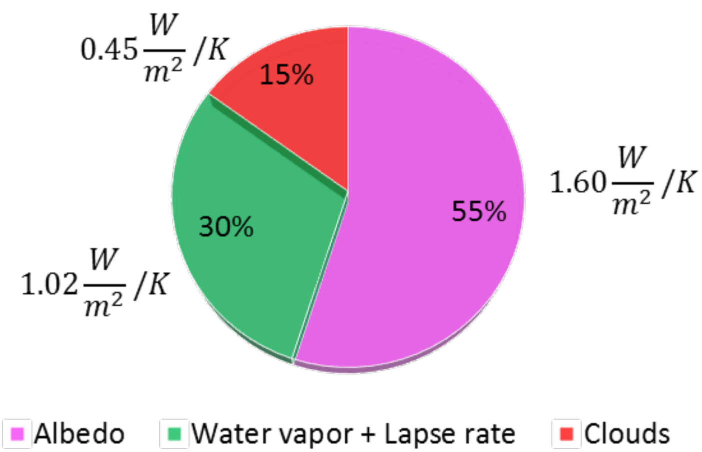
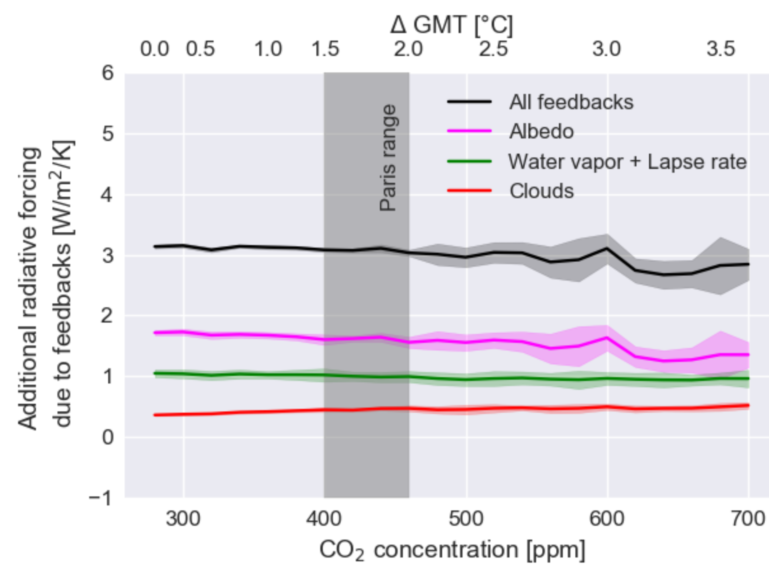


Drivers of additional warming at 1.5 °C above pre-industrial





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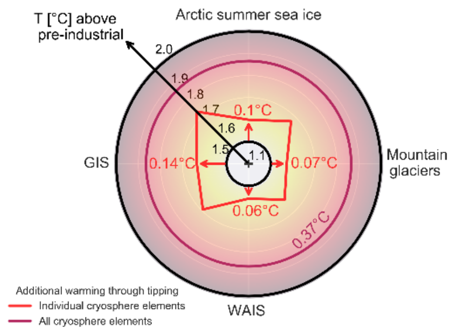

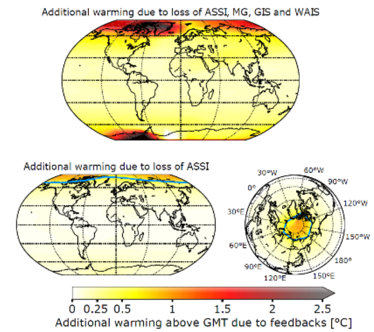

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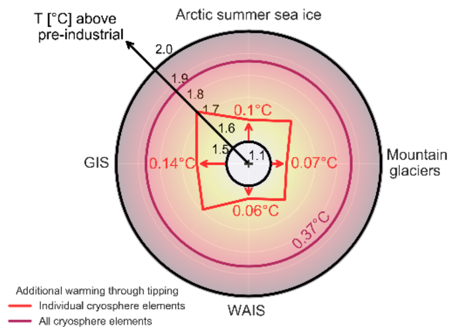

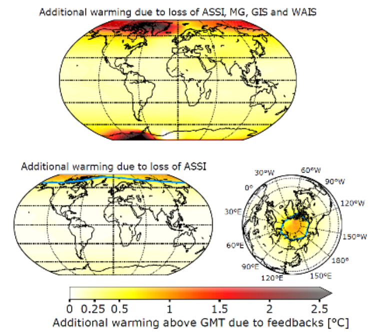

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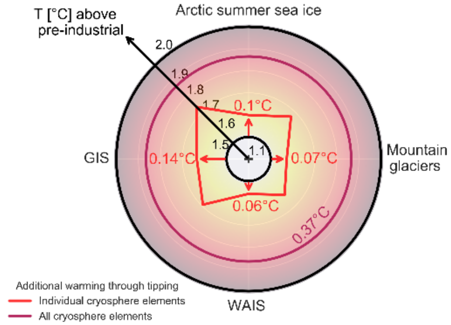

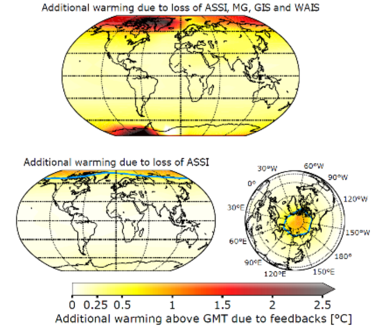

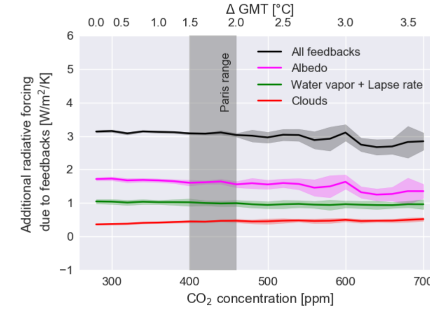

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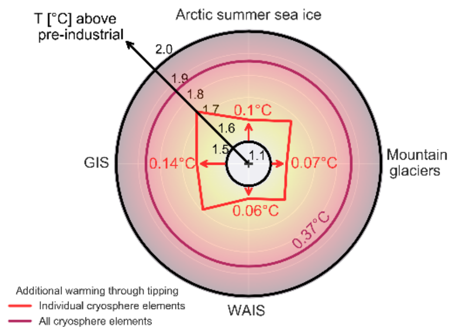

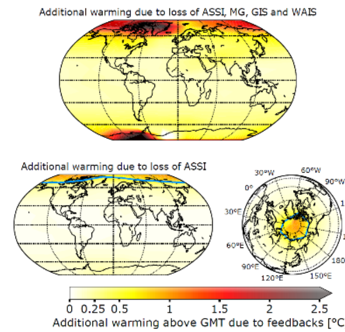

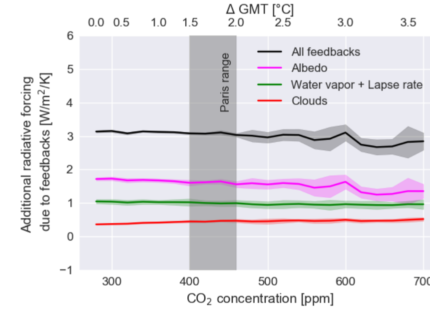

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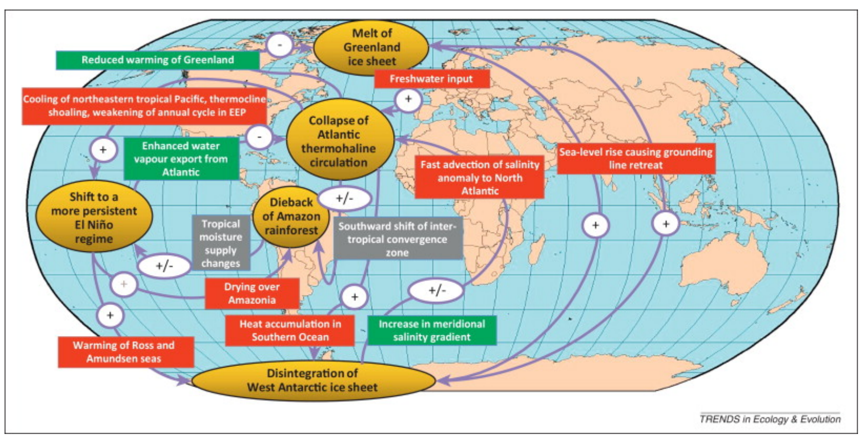
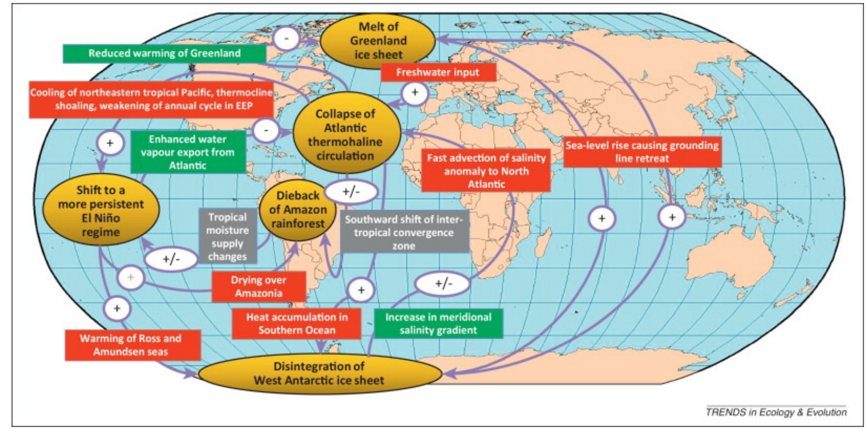
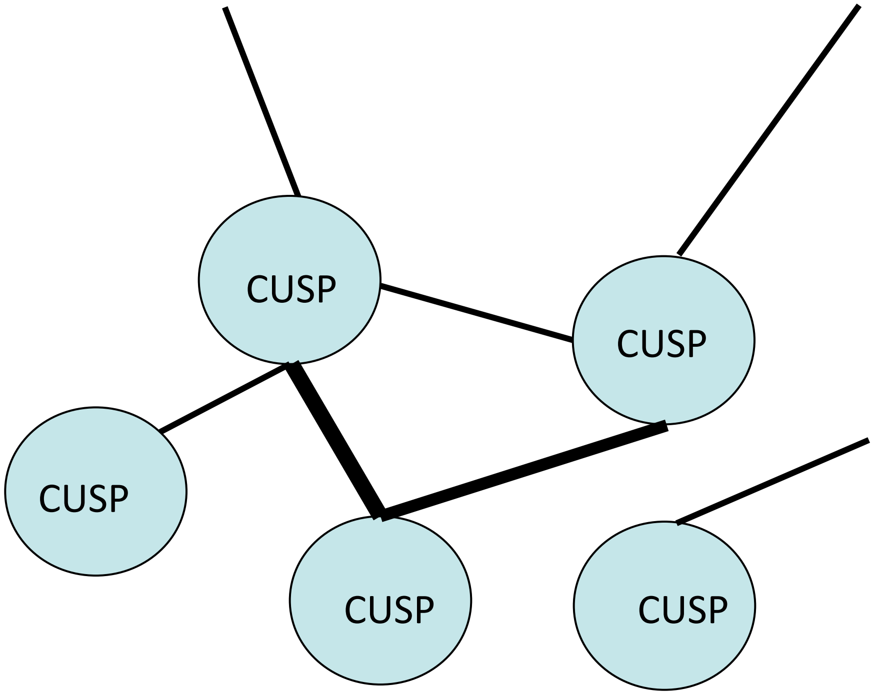


Lenton & Williams (2013), Trends in ecology & evolution

Direct and indirect coupling => Are tipping cascades possible?

OUTLOOK:
Conceptual tipping points on networks





Simplified approaches to capture climate TEs, e.g., using the CUSP equation:

$$\frac{dx_i}{dt} = -a_i x_i^3 + b_i x_i + c_i + \sum_{\substack{ij \\ i\neq j}} d_{ij} x_i$$

Key literature

1. Lenton, T.M., Held, H., Kriegler, E., Hall, J.W., Lucht, W., Rahmstorf, S. and Schellnhuber, H.J., 2008. Tipping elements in the Earth's climate system. Proceedings of the national Academy of Sciences, 105(6), pp.1786-1793.
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3. Schellnhuber, H.J., Rahmstorf, S. and Winkelmann, R., 2016. Why the right climate target was agreed in Paris. Nature Climate Change, 6(7), p.649.
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5. Ganopolski, A., Petoukhov, V., Rahmstorf, S., Brovkin, V., Claussen, M., Eliseev, A. and Kubatzki, C., 2001. CLIMBER-2: a climate system model of intermediate complexity. Part II: model sensitivity. Climate Dynamics, 17(10), pp.735-751.
6. Kriegler, E., Hall, J.W., Held, H., Dawson, R. and Schellnhuber, H.J., 2009. Imprecise probability assessment of tipping points in the climate system. Proceedings of the national Academy of Sciences, 106(13), pp.5041-5046.
7. Lenton, T.M. and Williams, H.T., 2013. On the origin of planetary-scale tipping points. *Trends in ecology & evolution*, *28*(7), pp.380-382.

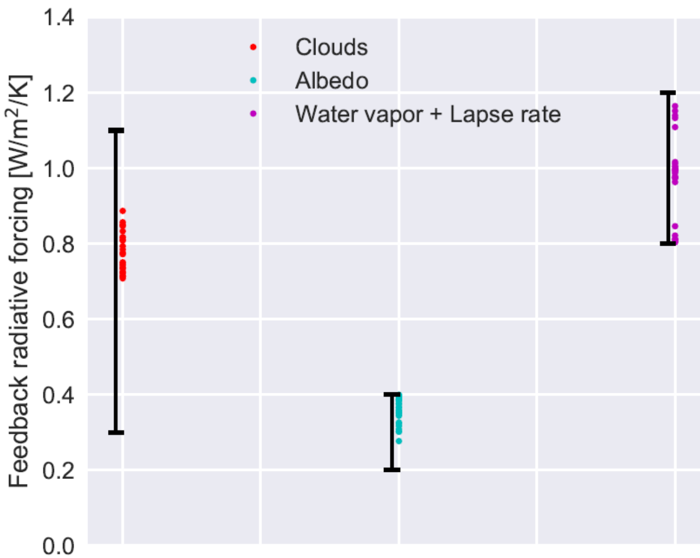
Back Up slides

Calibration of CLIMBER-2 – Part I (feedbacks)

Model Set-up

Calibration: $2xCO_2$ radiative feedback forcing scenarios from GCMs

(Soden & Held (2006))

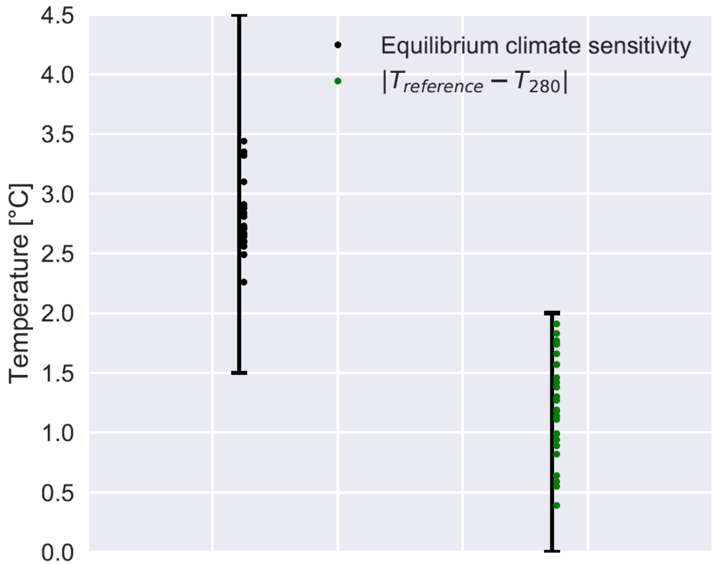


Parameter	Varied range (Mean)
Γ_0: Temp. lapse rate parameter	$4.7 - 5.2\ (5.0) \cdot 10^{-3}$
Γ_1: Temp. lapse rate parameter	$3.6 - 4.4\ (4.0) \cdot 10^{-5}$
Γ_2: Temp. lapse rate parameter	$0.7 - 1.3\ (1.0) \cdot 10^{-3}$
a_q: Temp. lapse rate parameter	$25 - 35\ (30) \cdot 10^{-3}$
OD_1: Cloud optical depth parameter	$9.5 - 10.5\ (10.0)$
OD_2: Cloud optical depth parameter	$7.5 - 8.5\ (8.0)$
C_t: Tropopause height parameter	$0.765 - 0.785\ (0.775)$
A_{CO21}: Integral transmission of atm.	$0.3 - 0.65\ (0.5)$
c_1: Cloudiness height parameter	$0.180 - 0.186\ (0.183)$
α_{snow}: Diffusive new snow albedo	$0.85 - 1.0\ (0.95)$

Calibration of CLIMBER-2 – Part II (climate sensitivity)

Model Set-up

Calibration: $2xCO_2$ radiative feedback forcing scenarios from GCMs



Equilibrium climate sensitivity:
Temperature sensitivity per coubling of CO_2

$|\boldsymbol{T_{reference}} - \boldsymbol{T_{280}}|$:
Pre-industrial temperature difference between the reference run ($T_{reference}$) and the comparison run (T_{280}) should be below $\pm$2°C

Alle feedback strengths at 1.5 °C above pre-industrial

	LR + WV	Clouds	Albedo	All feedbacks
Arctic summer sea ice	$1.05^{+0.21}_{-0.18}$	$0.57^{+0.09}_{-0.13}$	$2.42^{+0.17}_{-0.17}$	$4.05^{+0.16}_{-0.21}$
Greenland ice sheet	$1.08^{+0.17}_{-0.13}$	$0.52^{+0.04}_{-0.09}$	$1.69^{+0.11}_{-0.10}$	$3.29^{+0.09}_{-0.06}$
West Antarctic ice sheet	$1.04^{+0.15}_{-0.19}$	$0.67^{+0.24}_{-0.13}$	$2.08^{+0.27}_{-0.20}$	$3.8^{+0.4}_{-0.4}$
Mountain glaciers	$1.14^{+0.23}_{-0.26}$	$0.60^{+0.21}_{-0.22}$	$2.1^{+0.4}_{-0.3}$	$3.80^{+0.25}_{-0.27}$
All elements	$1.02^{+0.30}_{-0.15}$	$0.45^{+0.07}_{-0.07}$	$1.60^{+0.16}_{-0.24}$	$3.08^{+0.05}_{-0.05}$

Drivers of additional warming: For each cryosphere element separately and together