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CLIMATE CHANGE RESEARCH

IPRC Seminar 15. August 2016

Mitigation Delay Sensitivity: A new policy-relevant metric

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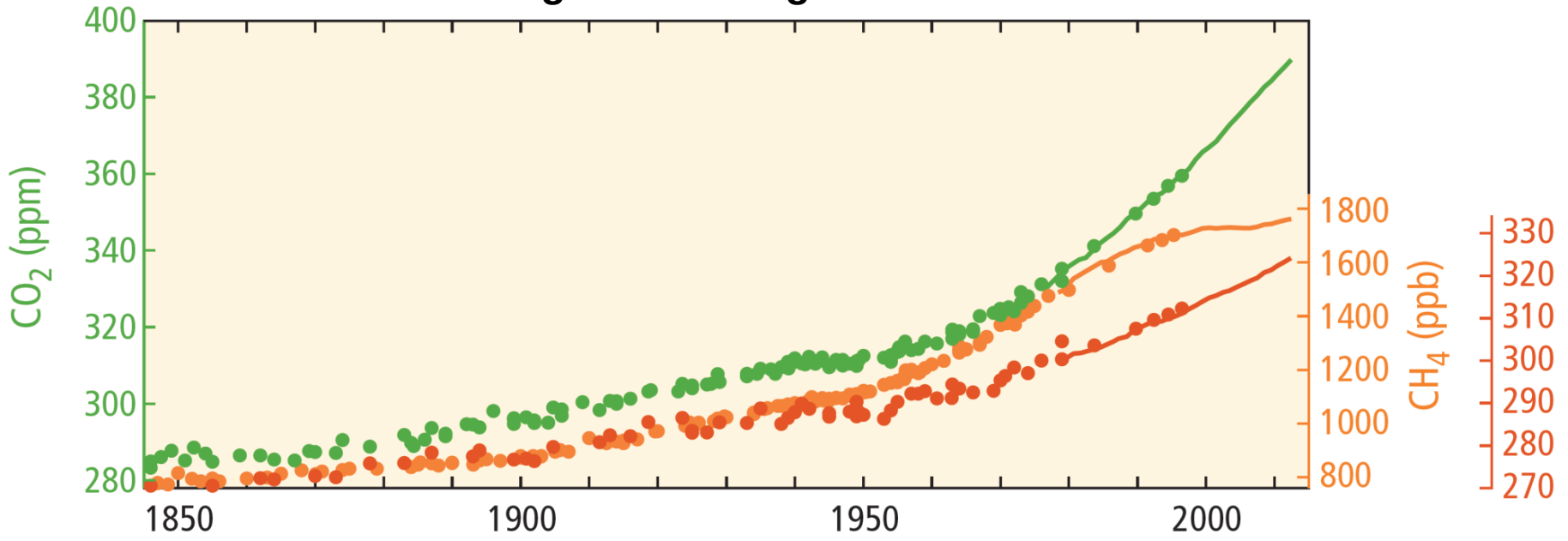
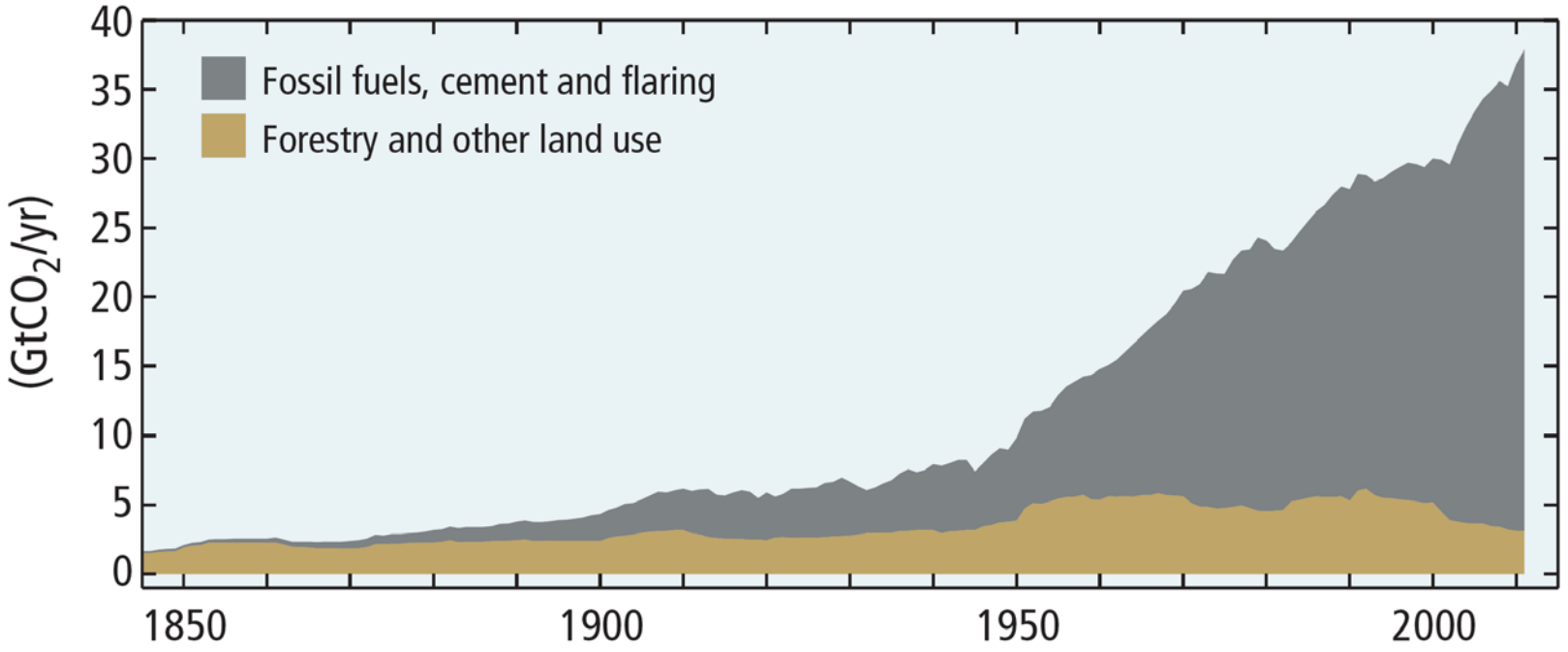
Global mean greenhouse gas concentrations



IPCC 2014 , Fig. SPM.1c

Changes since the industrial revolution

CO_2: +40%, CH_4: +150%, N_2O: +20%



IPCC 2014 , Fig. SPM.1d

Recent anthropogenic emissions of greenhouse gases are the highest in history.

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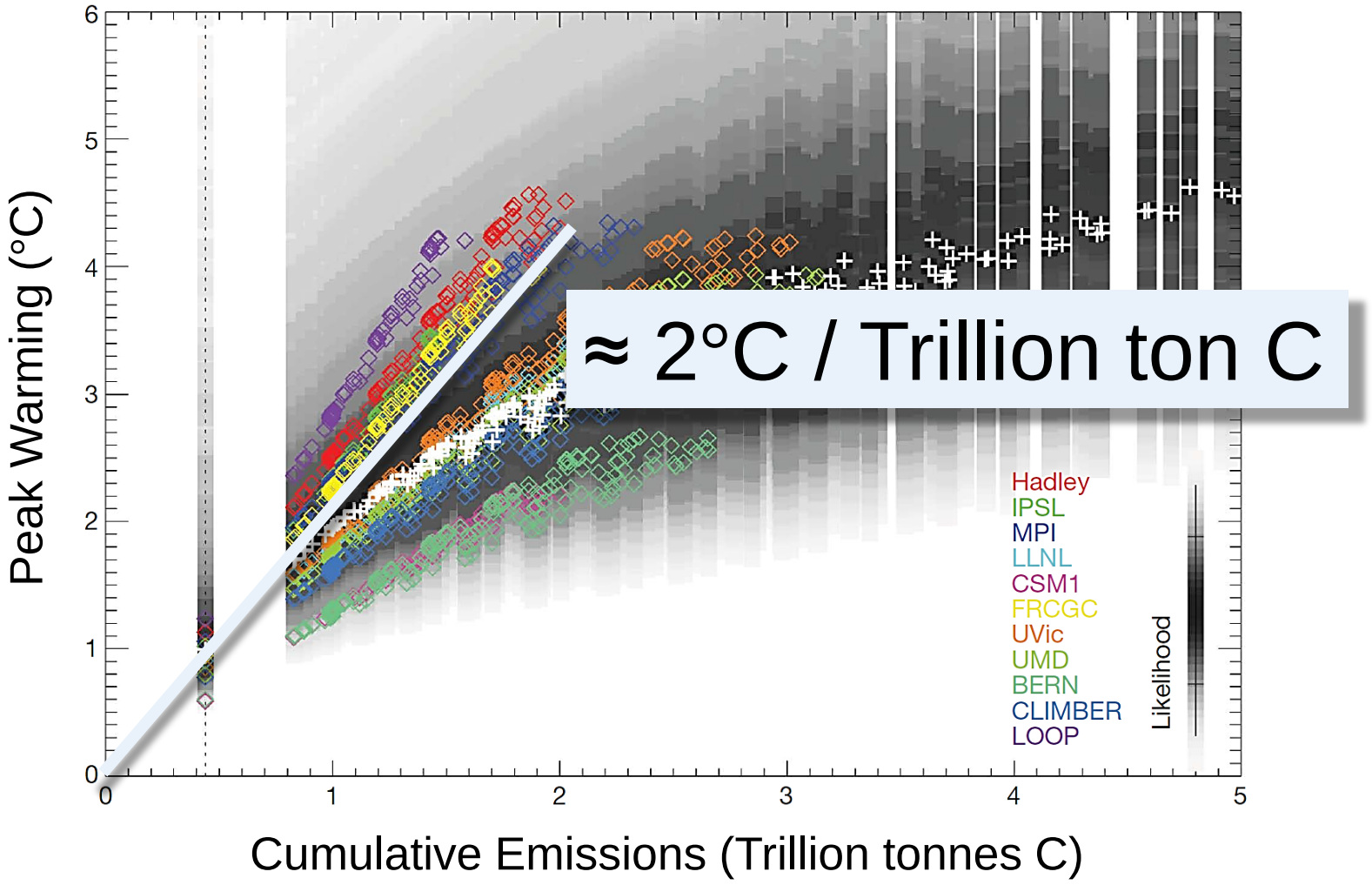
ECS	*The **equilibrium climate sensitivity*** [..] *is defined as the change in global mean surface temperature at equilibrium that is caused by a doubling of the atmospheric CO_2 concentration.*
TCR	*The **transient climate response*** [..] *is defined as the change in global mean surface temperature at the time when the atmospheric CO_2 concentration has doubled in a scenario of concentration increasing at 1% per year.*
TCRE	*The **transient climate response to cumulative carbon emissions*** [..] *is defined as the global mean surface temperature change per 1000 GtC emitted to the atmosphere.*

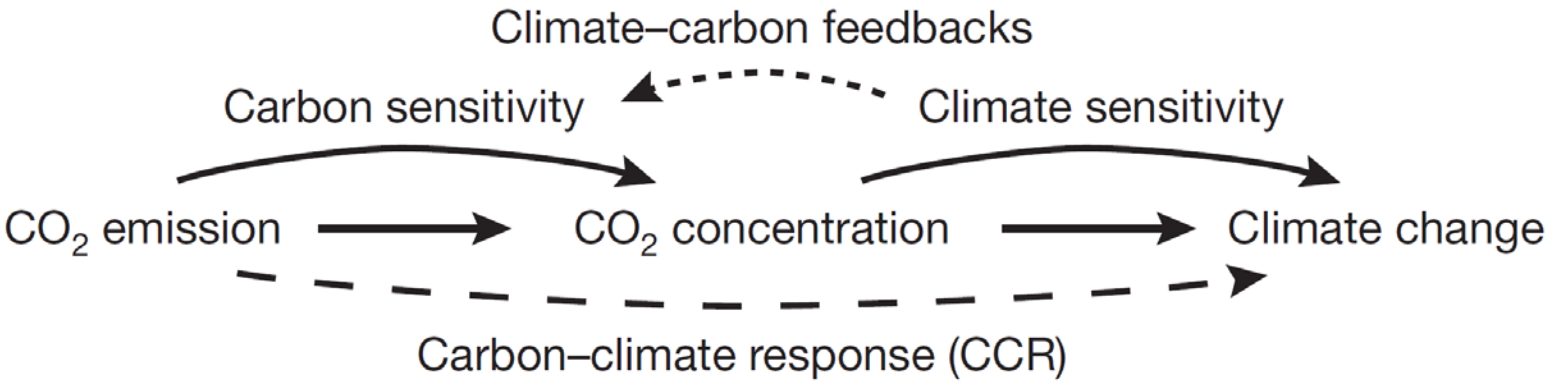
	IPCC TAR	IPCC AR4	IPCC AR5
ECS	Likely range: 1.5 to 4.5°C	*likely* range: 2.0 to 4.5°C *very unlikely* <1.5°C – best estimate about 3°C	***likely* range:** **1.5 to 4.5°C** ***extremely unlikely*** **<1.0°C** ***very unlikely*** **>6.0°C** –
TCR	Model range 1.1 to 3.1°C	*very likely* >1.0°C *very unlikely* >3.0°C	***likely* range:** **1.0 to 2.5°C** ***extremely unlikely*** **>3.0°C**

Cumulative emissions determine peak warming



(Allen et al., 2009)

Combination of GHG warming and ocean carbon uptake



(Matthews et al., 2009)

metrics of equilibrium responses

$$\Delta T(t) = \frac{a}{\lambda I_B}\left(1 - \frac{\varepsilon N(t)}{R(t)}\right)\left(1 + \frac{I_{Usat}(t)}{I_{em}(t)}\right) I_{em}(t)$$

physical disequilibrium | **chemical disequilibrium**

(Goodwin et al., 2014)

	IPCC TAR	IPCC AR4	IPCC AR5
ECS	Likely range: 1.5 to 4.5°C	*likely* range: 2.0 to 4.5°C *very unlikely* <1.5°C – best estimate about 3°C	***likely* range:** **1.5 to 4.5°C** ***extremely unlikely*** **<1.0°C** ***very unlikely*** **>6.0°C** –
TCR	Model range 1.1 to 3.1°C	*very likely* >1.0°C *very unlikely* >3.0°C	***likely* range:** **1.0 to 2.5°C** ***extremely unlikely*** **>3.0°C**
TCRE			***likely* range:** **0.8 to 2.5 °C / 1000 GtC**

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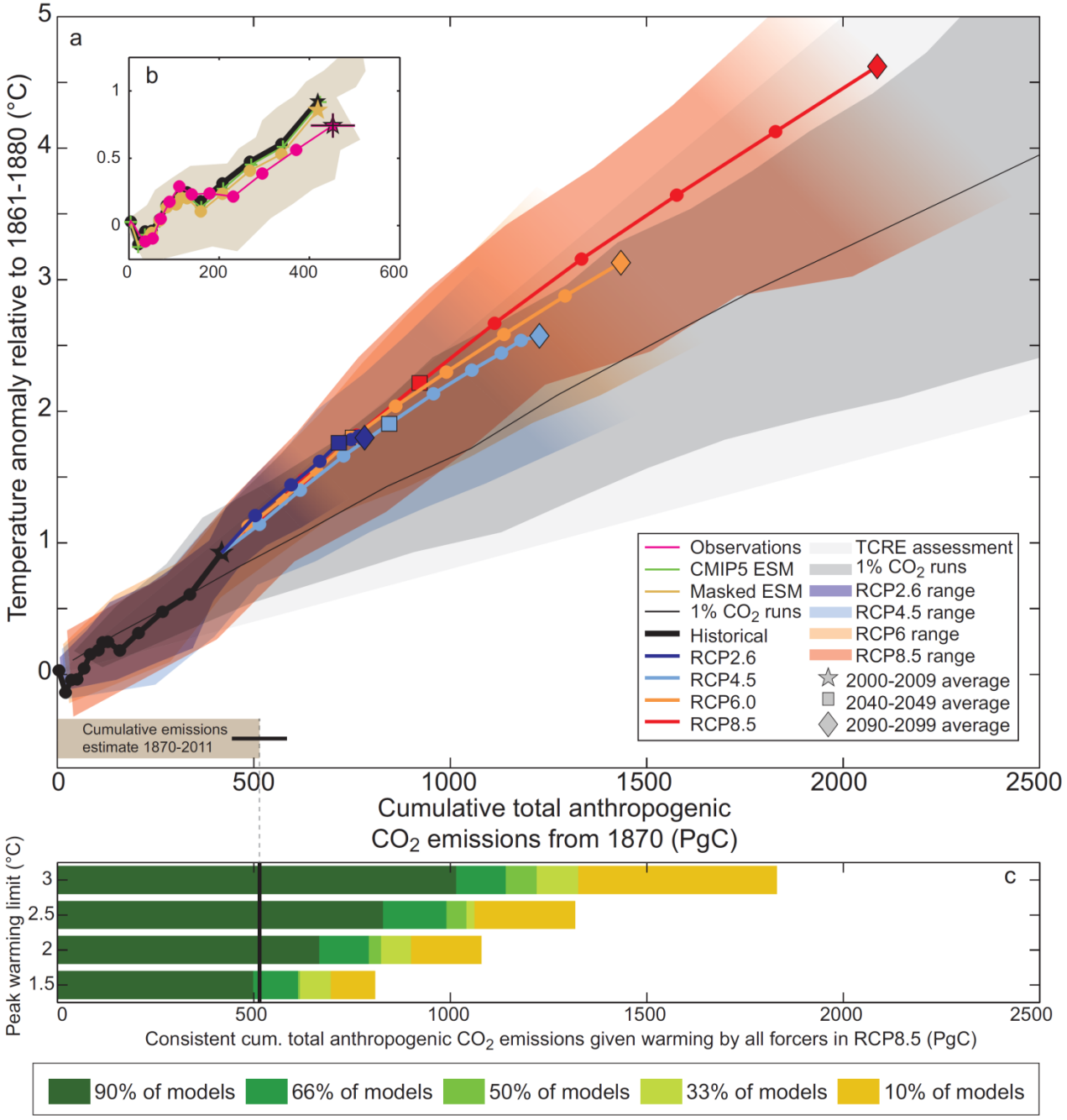
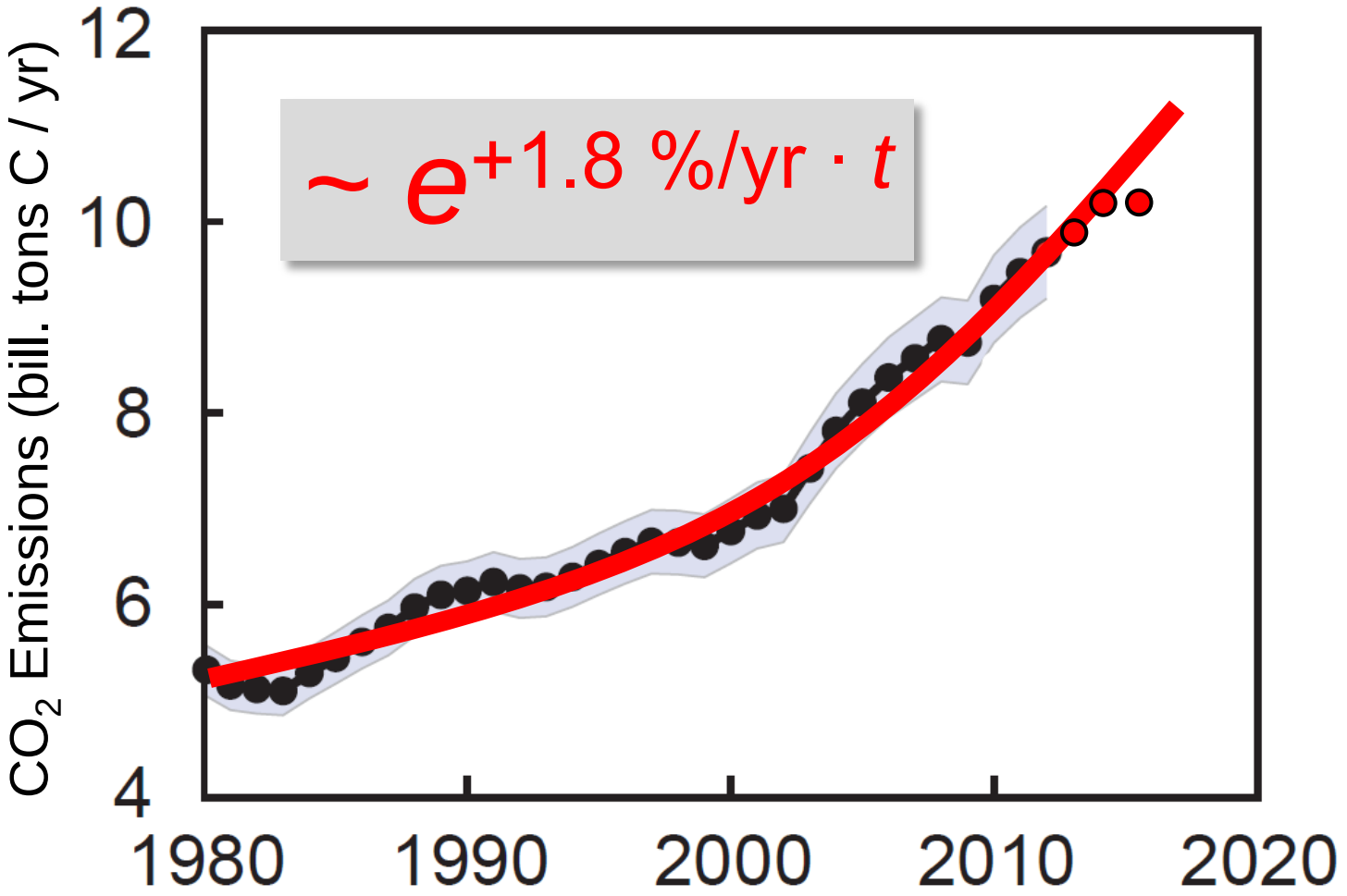


IPCC 2013, TFE.8, Fig. 1

The closing door of climate targets



(modified from Le Queré et al., 2015)

2°C scenarios assuming no net negative emissions

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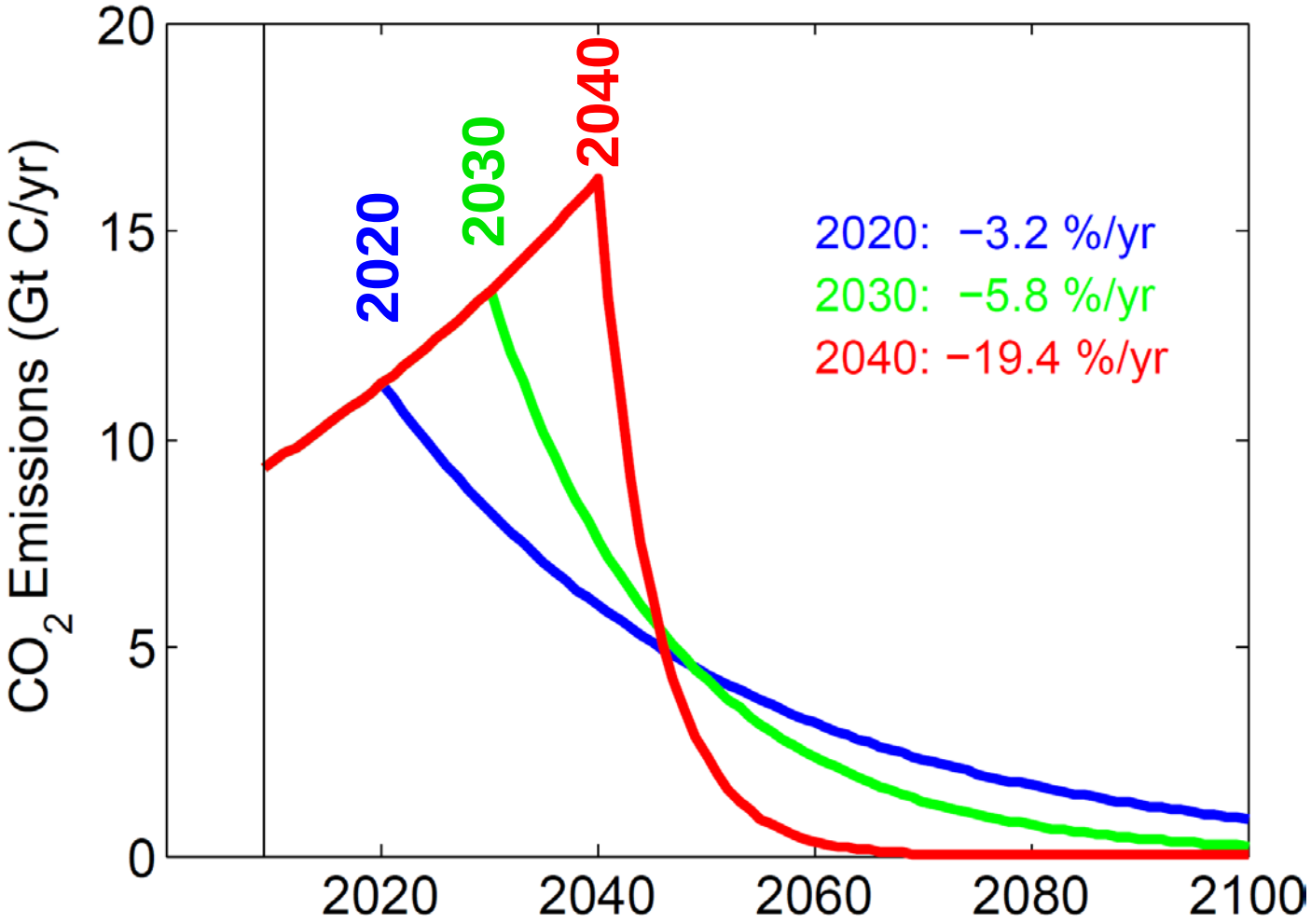

(Stocker, 2013)

Determinants of Peak Warming

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Peak Warming:

$$\Delta T = TCRE \cdot C_{\infty}$$

Cumulative CO_2 Emissions:

$$C_{\infty} = \int E(t)dt$$

$$\Delta T = TCRE \cdot C_{\infty}(r, t_1, s)$$

Start Time of CO_2 emission reduction

Rate of CO_2 emission rise (r) and fall (s)

Emissions reductions: The later, the stronger

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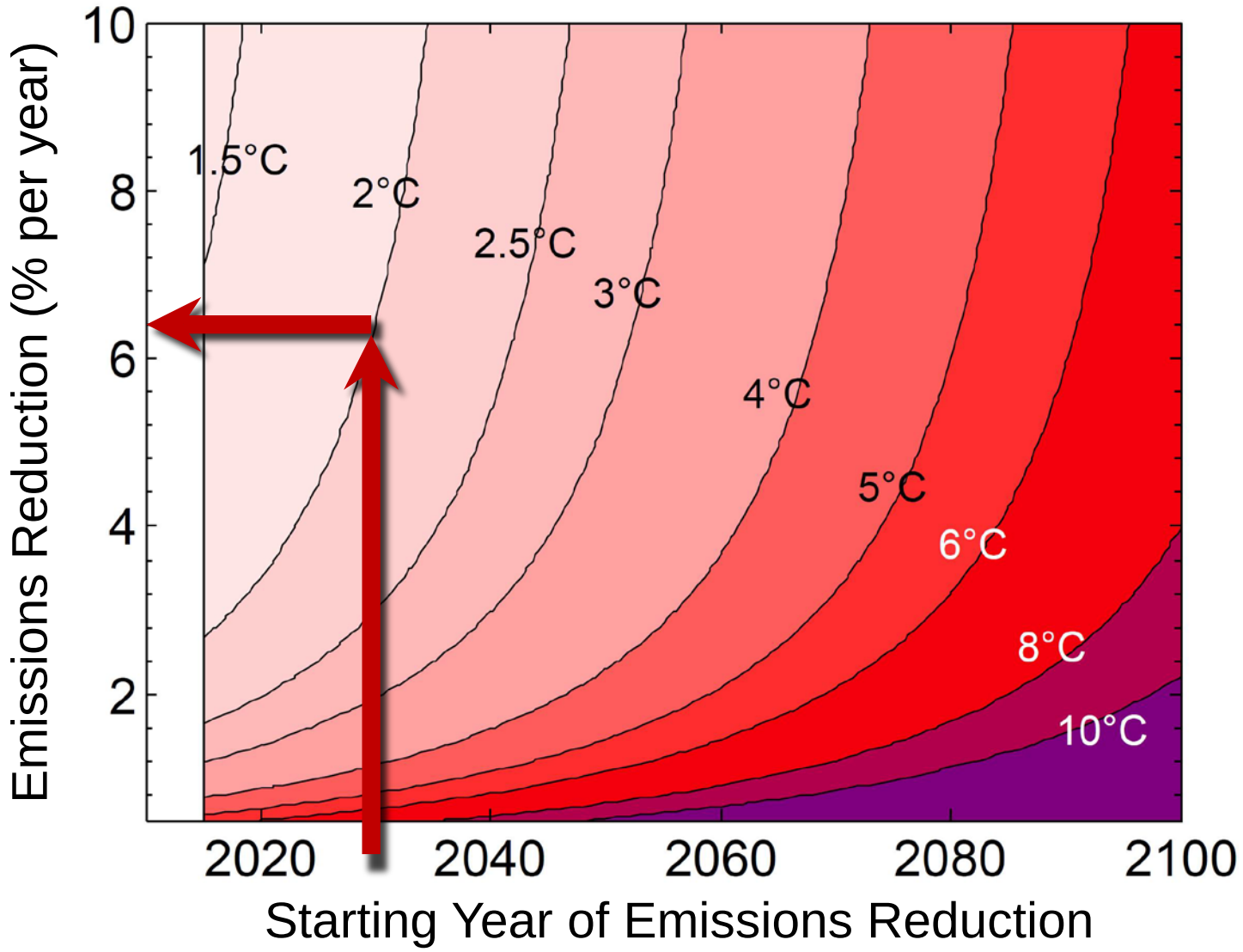
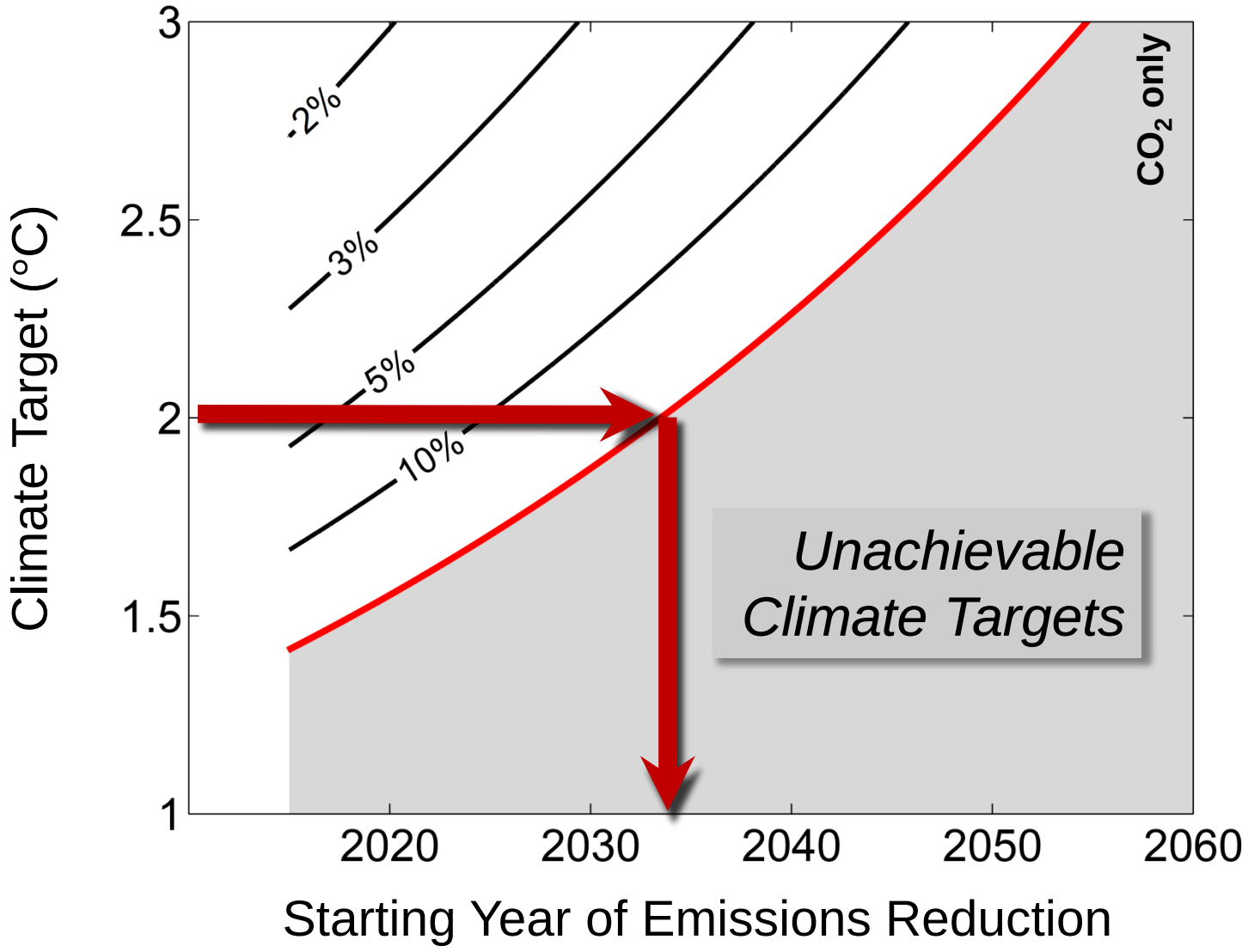


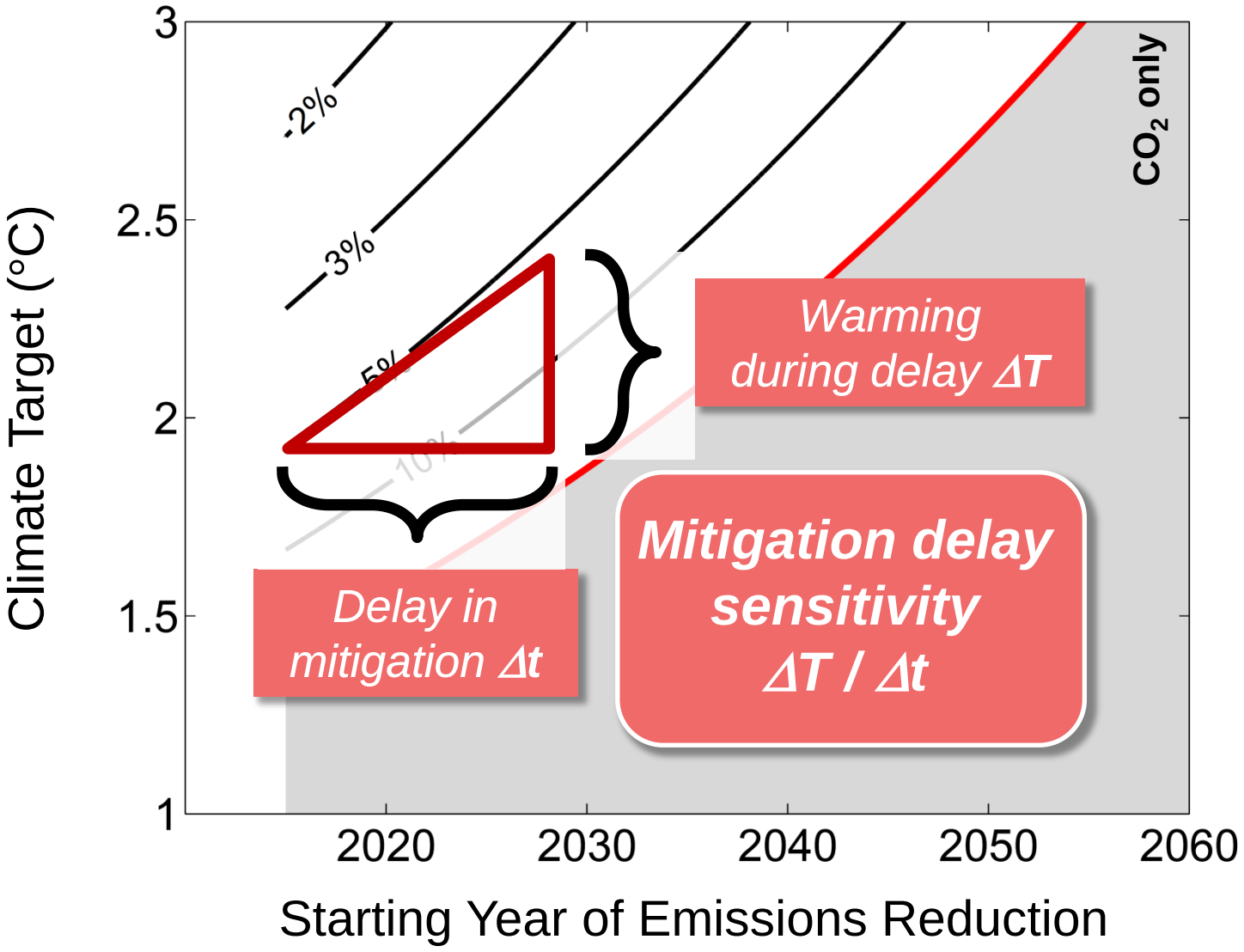
(Stocker, 2013)

The closing door of climate targets



(updated from Stocker, 2013)

The closing door of climate targets



(updated from Stocker, 2013)

Mitigation delay: Peak temperature rises fast

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Peak Warming:

$$\Delta T = TCRE \cdot C_{\infty}$$

Mitigation Delay Sensitivity:

$$\frac{d\Delta T}{dt_1} = TCRE \cdot \frac{d}{dt_1} C_{\infty}(r, t_1, s)$$

$$\frac{d\Delta T}{dt_1} \approx r \cdot \Delta T$$

Rate of CO_2 **Emission** Increase

Peak warming rises at the rate of emissions

Mitigation delay: Peak temperature rises fast

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20th century warming:	≈ 0.08 °C per decade
1951 to 2012 warming:	≈ 0.12 °C per decade
1998 to 2012 warming:	≈ 0.05 °C per decade

Mitigation Delay Sensitivity

$\Delta T / \Delta t \approx 0.4$ °C per decade

(Pfister & Stocker, 2016)

Committed peak warming rises 2.5 to 6 times faster than observed warming

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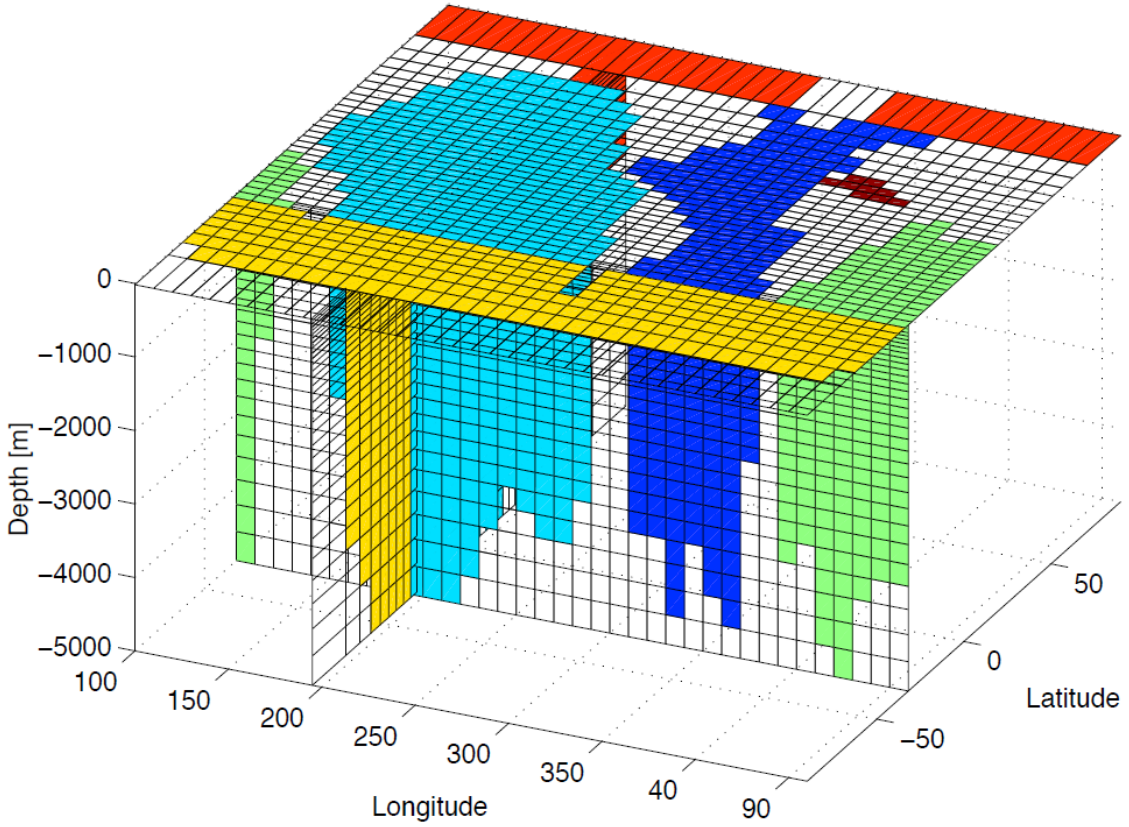
Bern3D Model:

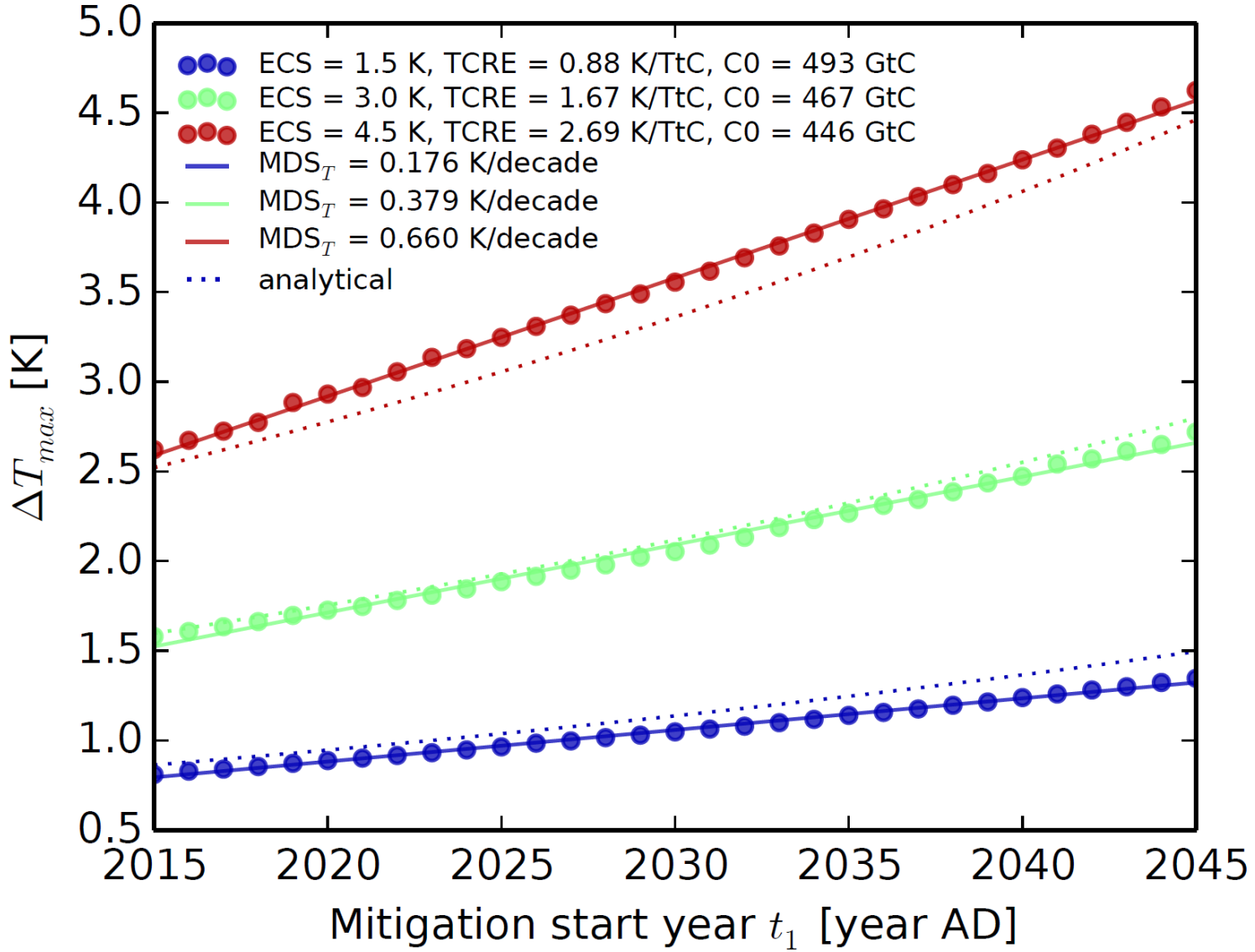
carbon cycle
N_2, Ar, Kr, Xe
^{13}C, ^{14}C
^{39}Ar
^{143}Nd, ^{144}Nd
^{231}Pa, ^{230}Th



(Ritz et al., 2011, Ritz 2013)

- very long integrations (Ritz et al., 2011; Clark et al., 2016)
- massive ensembles (Steinacher et al., 2013, Steinacher & Joos, 2016)

MDS: global mean temperature



(Pfister & Stocker, 2016)

MDS: steric sea level rise

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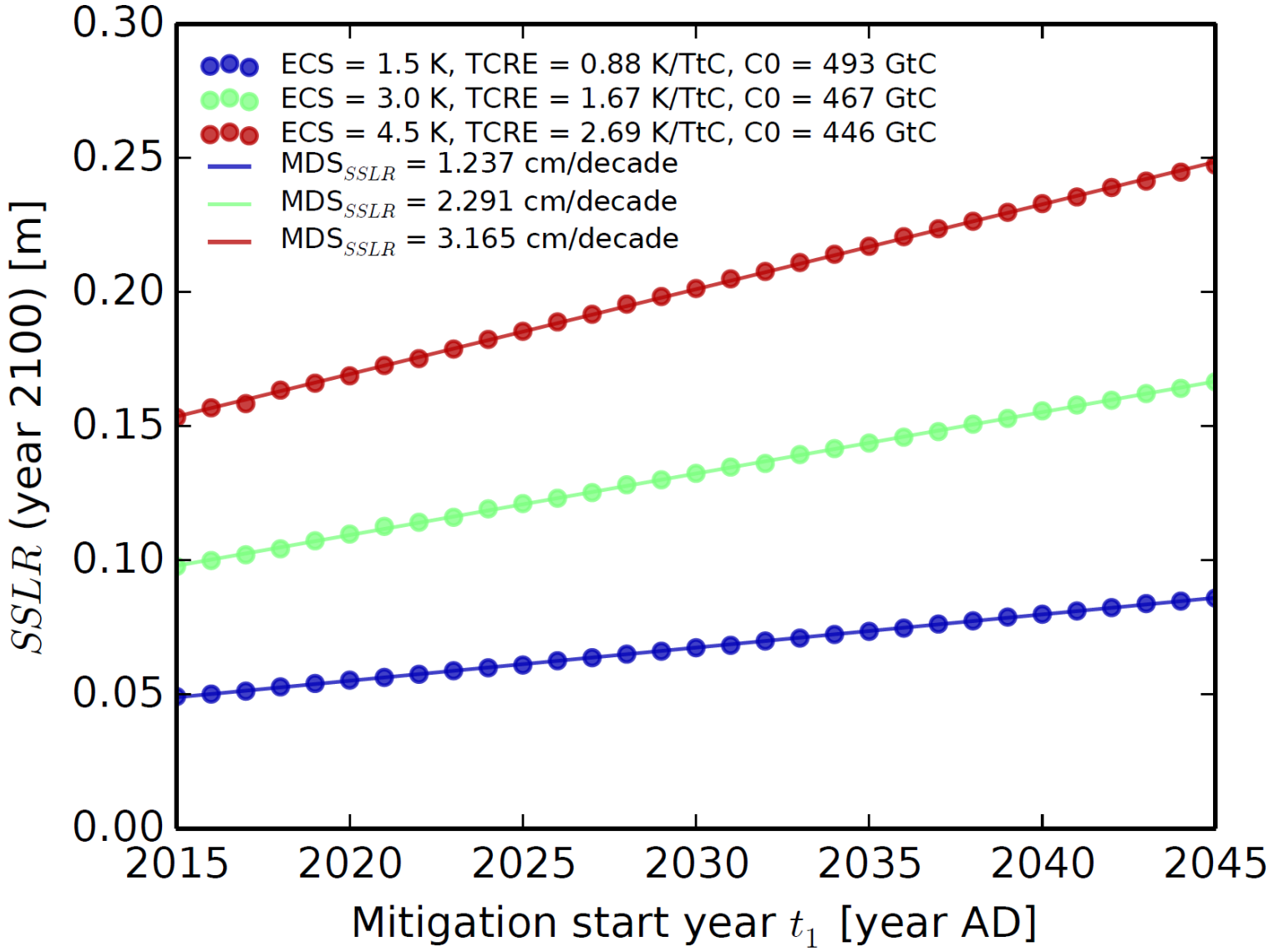

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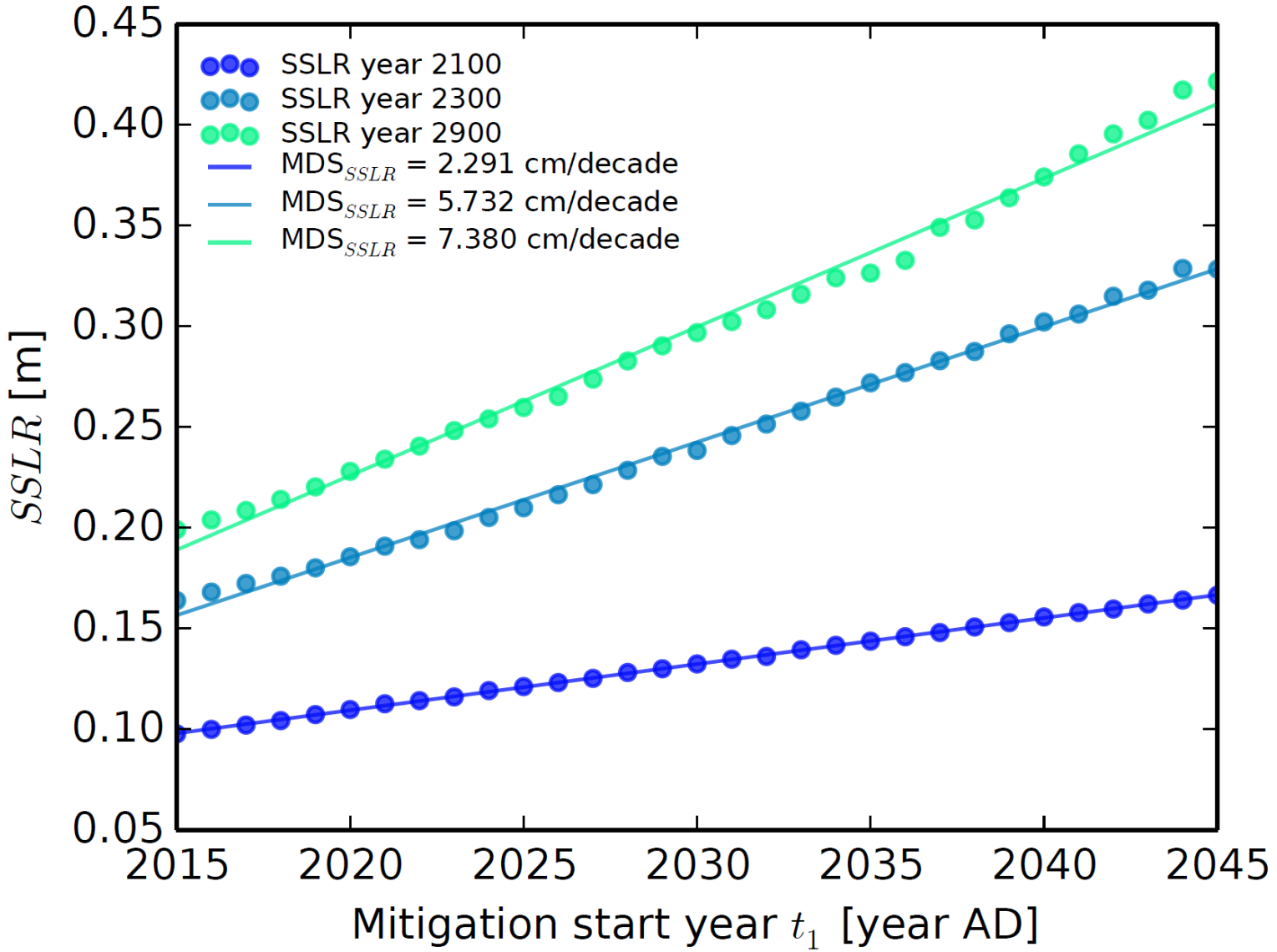
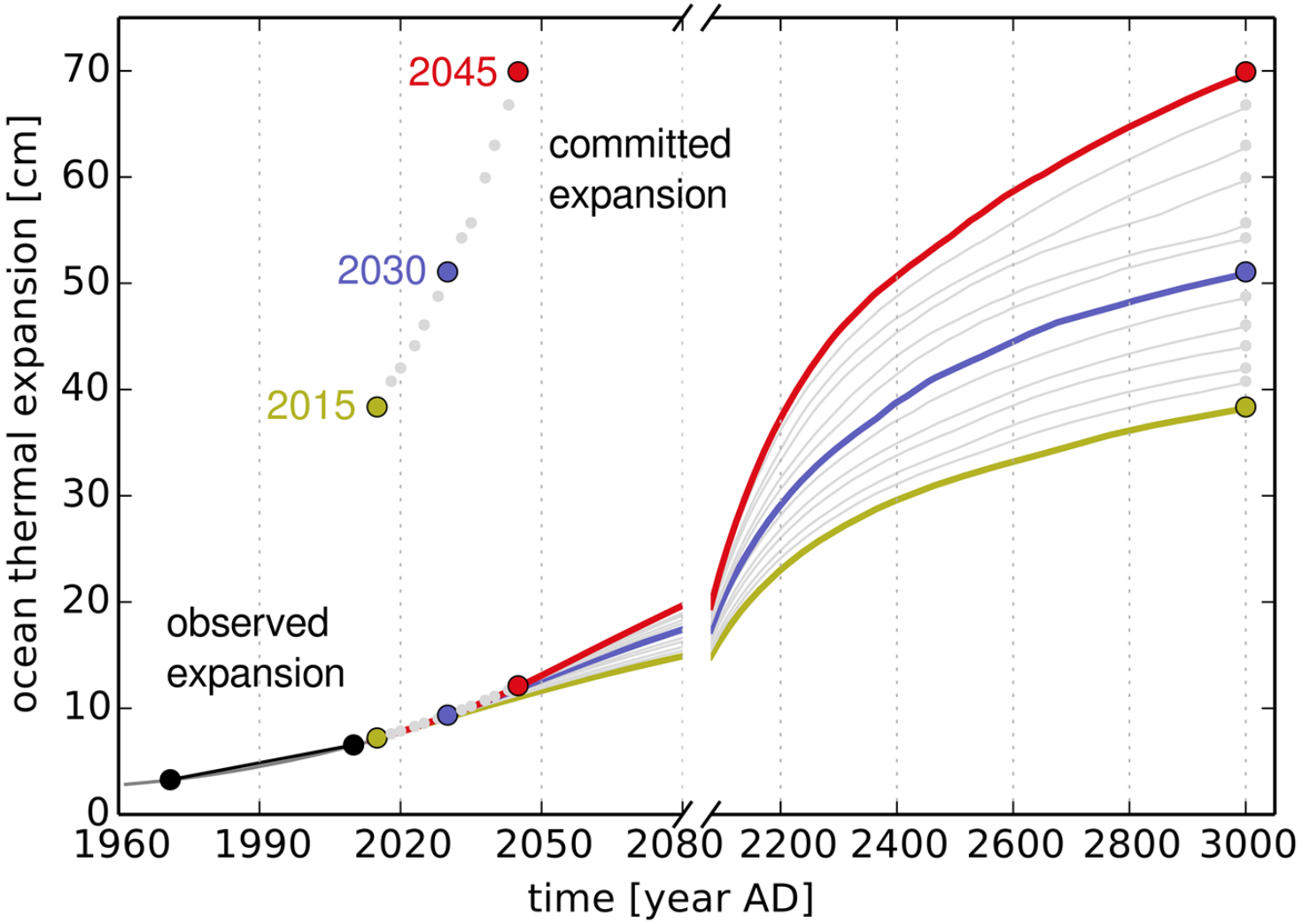
MDS: steric sea level rise



(Pfister & Stocker, 2016)

MDS: steric sea level rise



(based on Pfister & Stocker, 2016)

Mitigation delay: Committed steric sea level rises fast

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20th century total sea level rise: ≈ 17 mm per decade

1971 to 2010 total sea level rise: ≈ 20 mm per decade

1971 to 2010 steric sea level rise: ≈ 8 mm per decade

Mitigation Delay Sensitivity

$MDS_{SSLR3000} \approx 100$ mm per decade

Committed steric sea level rise increases 7 to 25 times faster than observed sea level rise

Aragonite saturation state Ω_A

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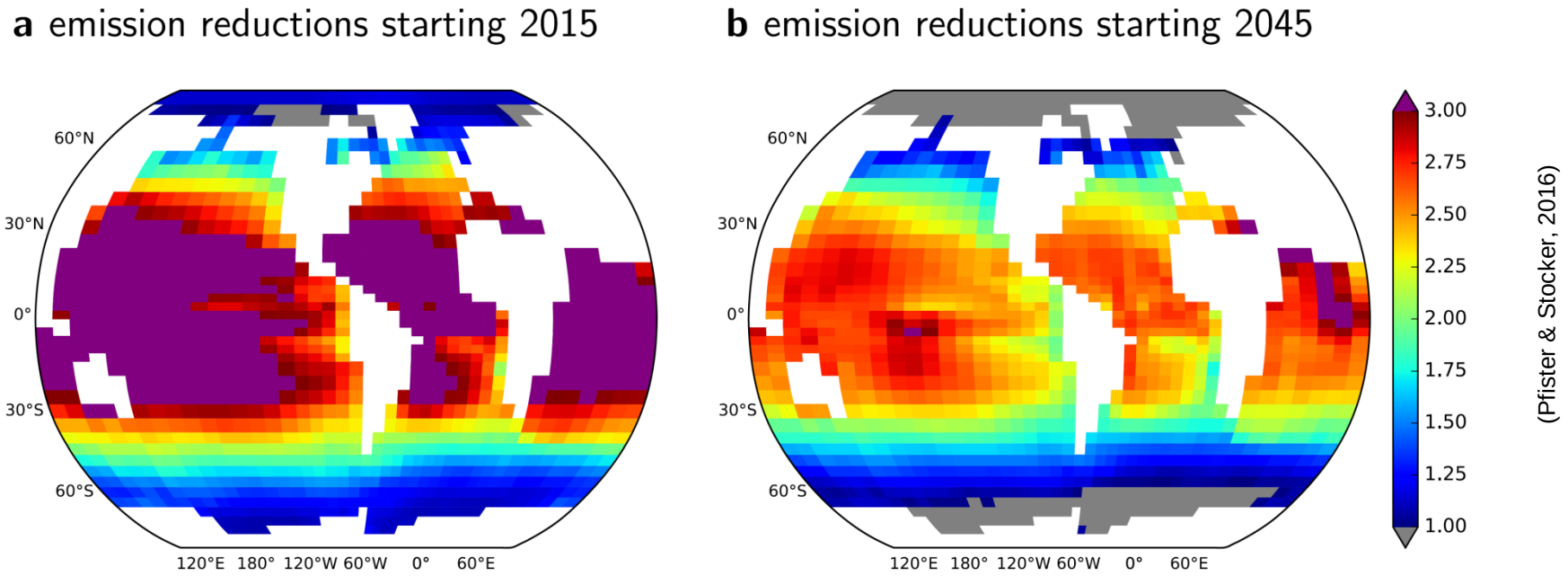
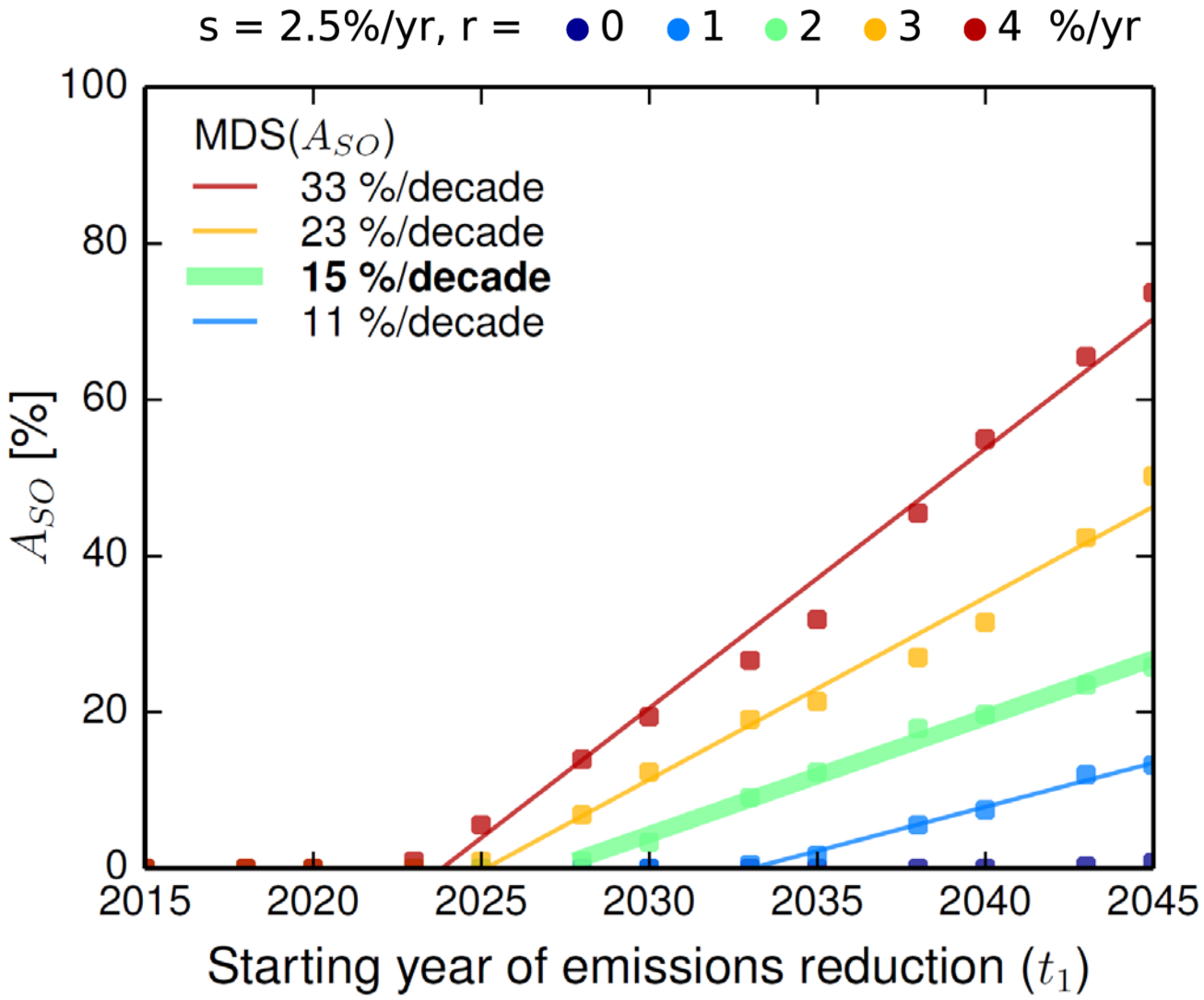


(Pfister & Stocker, 2016)

- aragonite undersaturation starts in the high latitudes and moves equatorwards
- measure for polar undersaturation: A_{SO} = fraction of Southern Ocean surface area with $\Omega_A < 1$.

Aragonite saturation state Ω_A



(Pfister & Stocker, 2016)

Aragonite saturation state Ω_A

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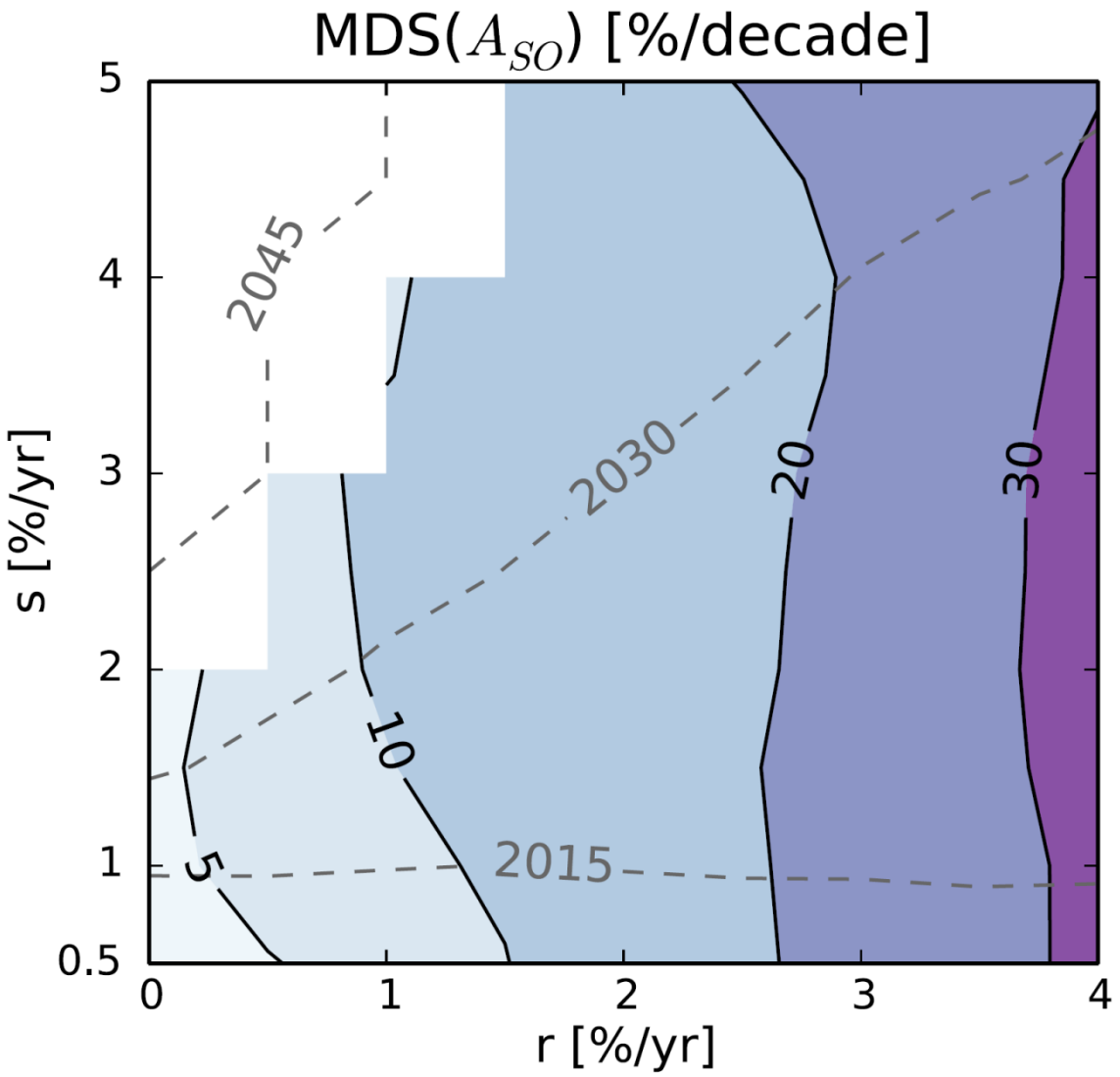

(Pfister & Stocker, 2016)

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Conclusions (1/2):

- **Mitigation Delay Sensitivity** (MDS) combines the coupled climate-carbon cycle response of the Earth System with a specific mitigation policy
- MDS conveys **useful policy information** concerning the penalty of delay in terms of a specific target variable
- MDS provides easily accessible **information about the urgency** of the climate change problem

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Conclusions (2/2):

- Based on the **observed global emissions**, MDS could be adapted to include constant emissions for $t < t_1$.
- The **effect of instabilities in the climate system** is not considered by MDS (e.g., disintegration of ice masses)
- MDS could be extended to **regional climate change** increasing the effectiveness of communicating climate change risks