Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

INTERGOVERNMENTAL PANEL ON climate change

Climate change and extreme events: Why every year matters

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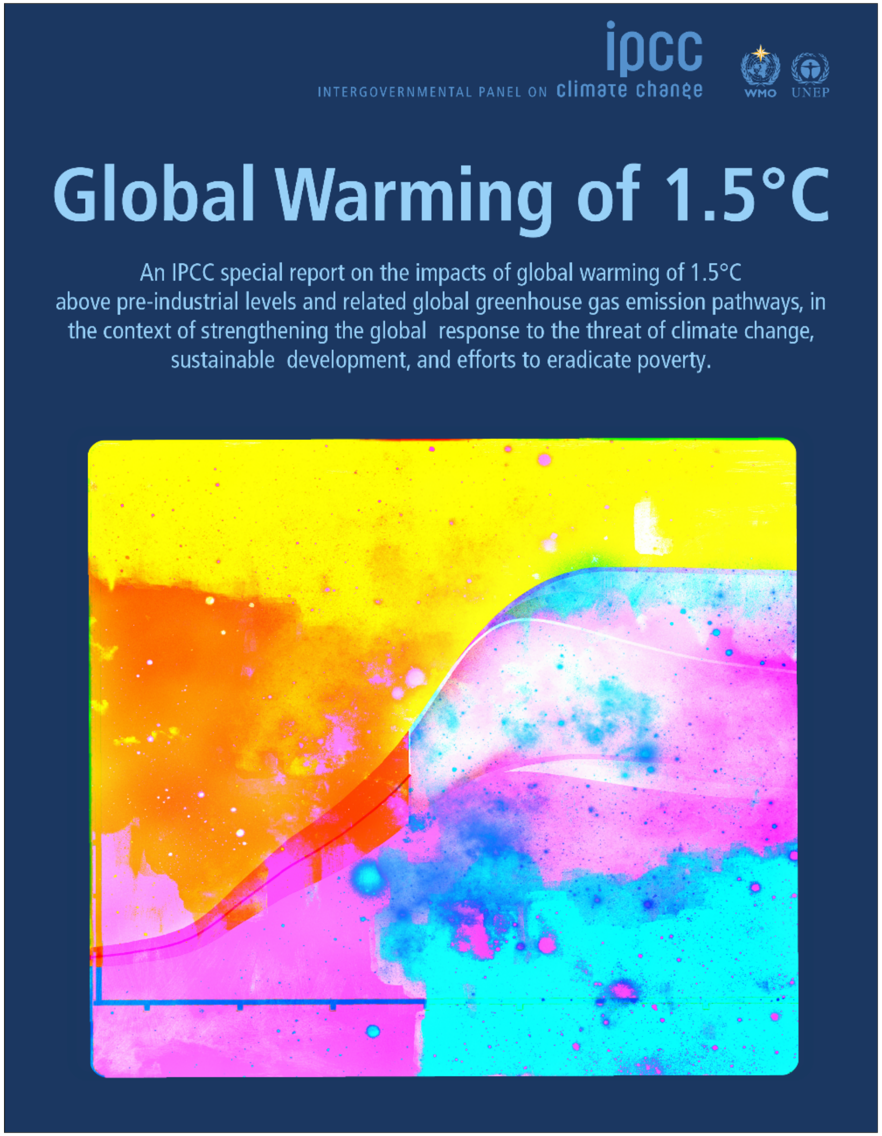
Bureau of meteorology, Australia; Annual R&D workshop
November 24, 2020

Outline

- The IPCC SR15 report
- Relating changes in global warming to regional climate extremes and impacts
- Climate changes at +1.5ºC vs +2ºC: Does half a degree matter?
- Regional climate sensitivity and role of land processes for temperature projections
- Emissions scenarios towards stabilization at +1.5ºC
- Conclusions

IPCC SR15 Report



IPCC SR15 report

Approved on Oct. 6, 2018

Upcoming: IPCC AR6 Report, 2021

Chapter 11: Weather and climate extremes in a changing climate

https://wg1.ipcc.ch/ar6.html

2015 Paris agreement: 1.5ºC and 2ºC limits

United Nations FCCC/CP/2015/L.9

Framework Convention on Climate Change

Distr.: Limited
12 December 2015

1. This Agreement, in enhancing the implementation of the Convention, including its objective, aims to strengthen the global response to the threat of climate change, in the context of sustainable development and efforts to eradicate poverty, including by:

(a) Holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change;

Where are we now?

Since pre-industrial times, human activities have caused approximately +1.1ºC* of global warming.

- Already seeing consequences for people, nature and livelihoods
- At current rate, we could reach +1.5ºC as soon as 2030
- Past emissions alone do not commit us to +1.5ºC although the window of opportunity is quickly closing

*****https://public.wmo.int/en/resources/united_in_science*

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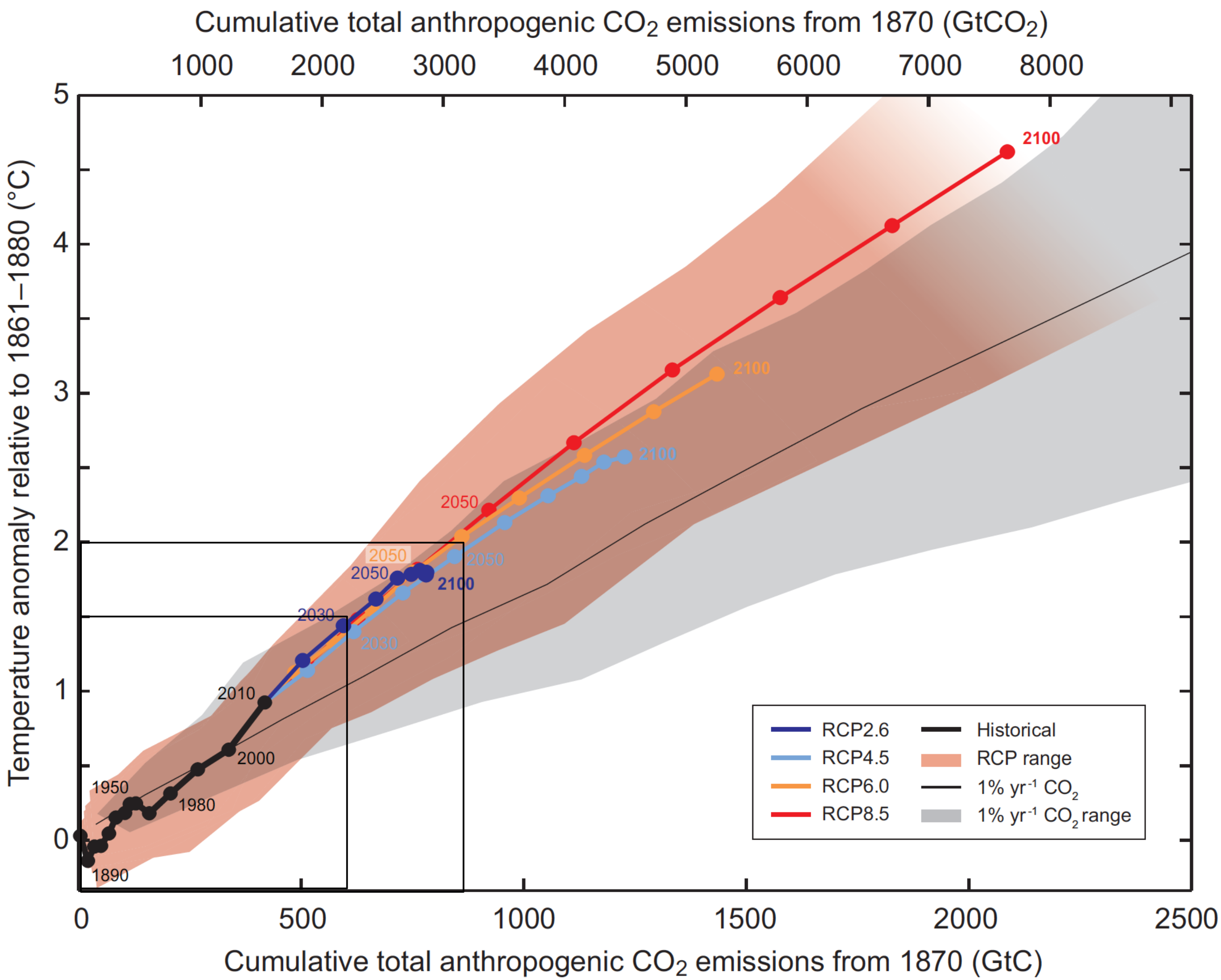
Link between cumulative CO_2 emissions and global T°

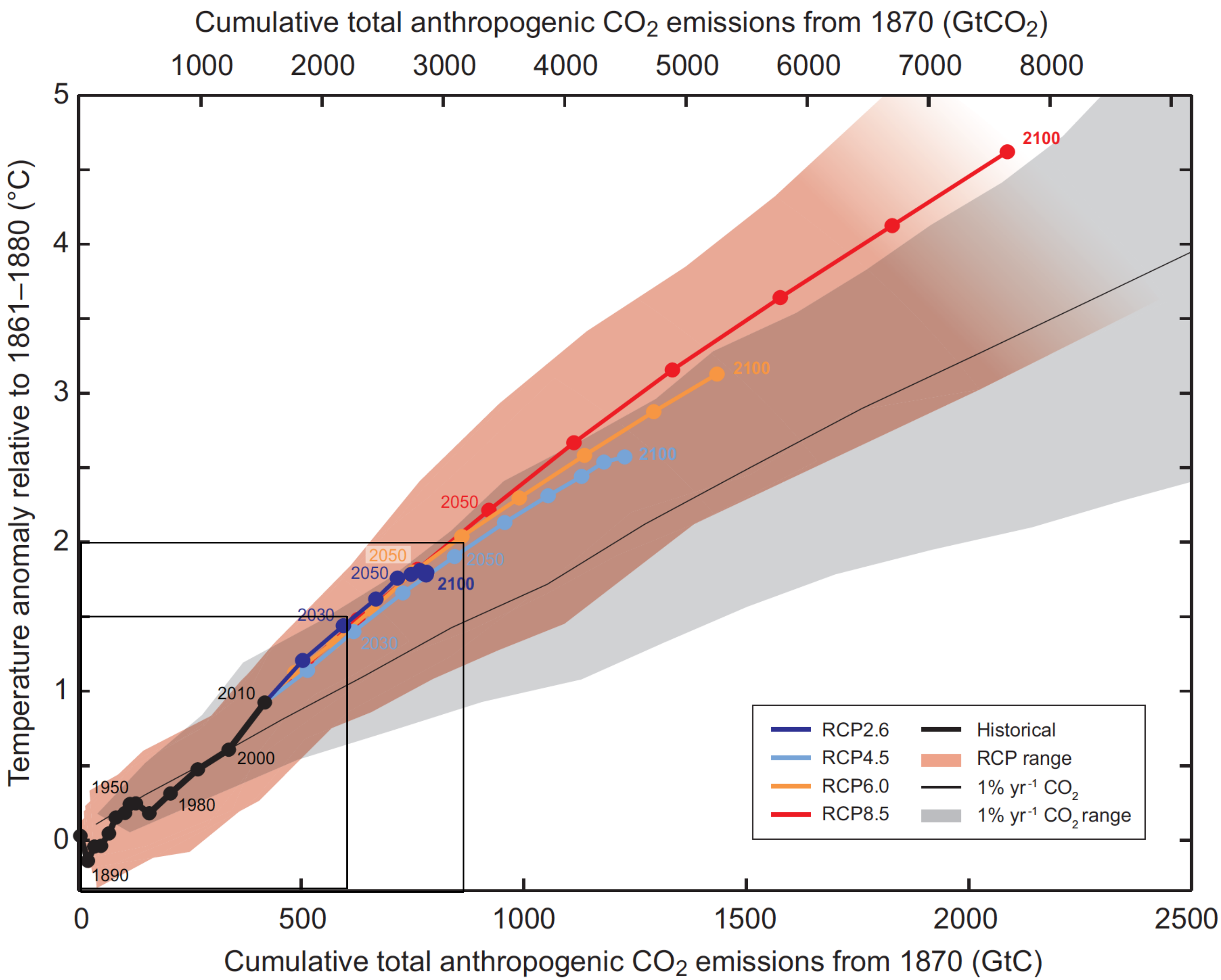


Direct link between cumulative CO_2 emissions and climate response

A global T° target can be linked to cumulative emissions target

(IPCC 2013)

Link between cumulative CO_2 emissions and global T°



Direct link between cumulative CO_2 emissions and climate response

A global T° target can be linked to cumulative emissions target

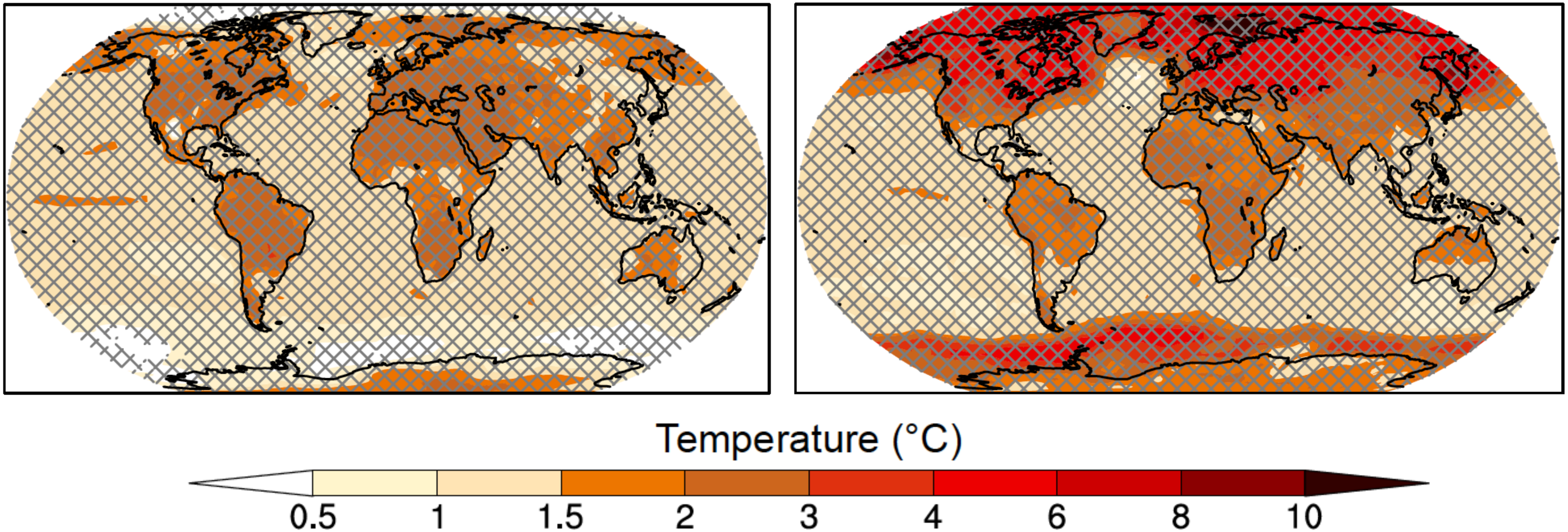
What are the implications for regional climate extremes?

(IPCC 2013)

Scaling relationships for regional extremes

Change in temperature of hottest days (TXx) at 1.5°C GMST warming

Change in temperature of coldest nights (TNn) at 1.5°C GMST warming

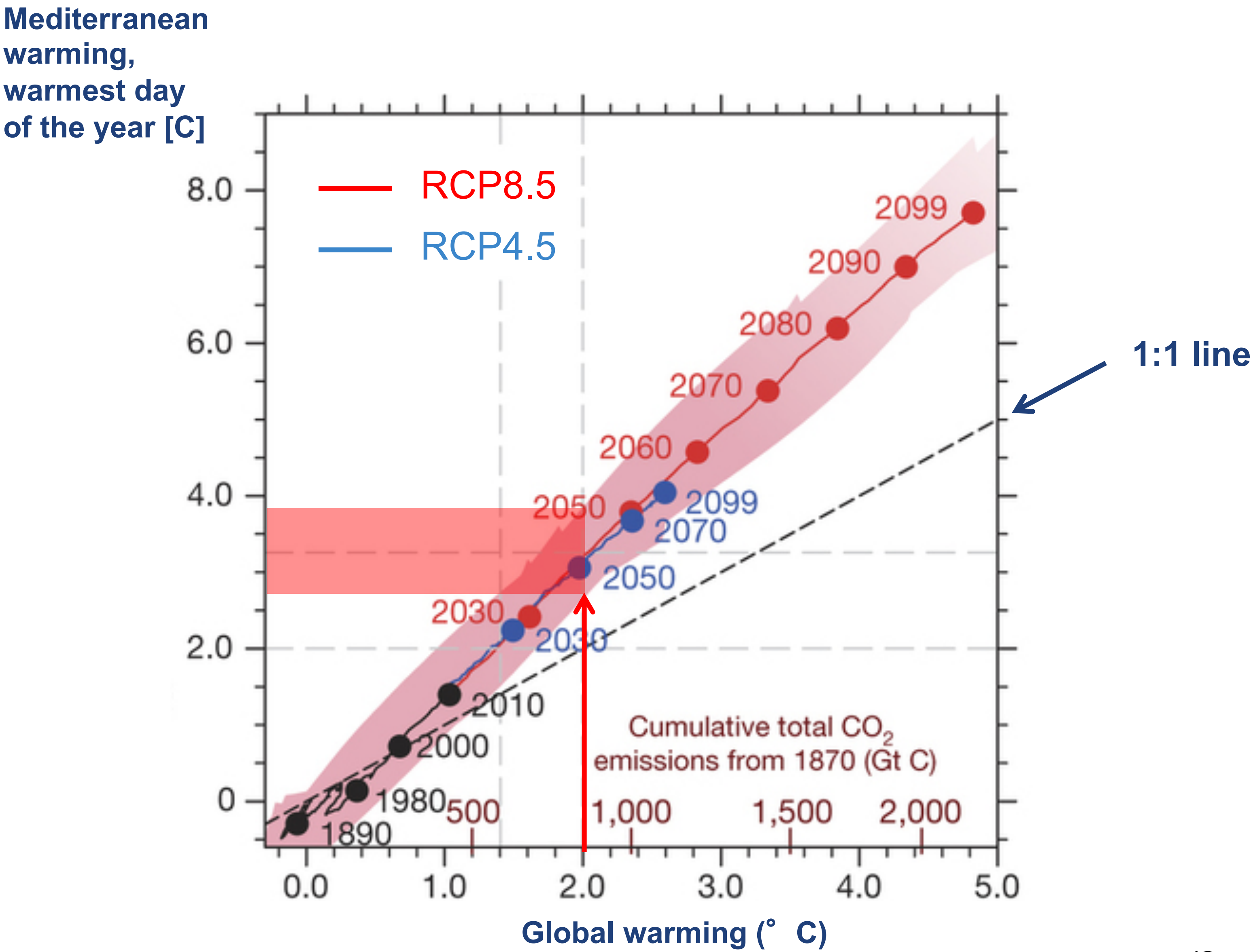


Does a +1.5ºC global warming implies a +1.5ºC warming everywhere and all the time?

No! Stronger warming of land extremes compared to global temperature due to soil moisture and snow feedbacks

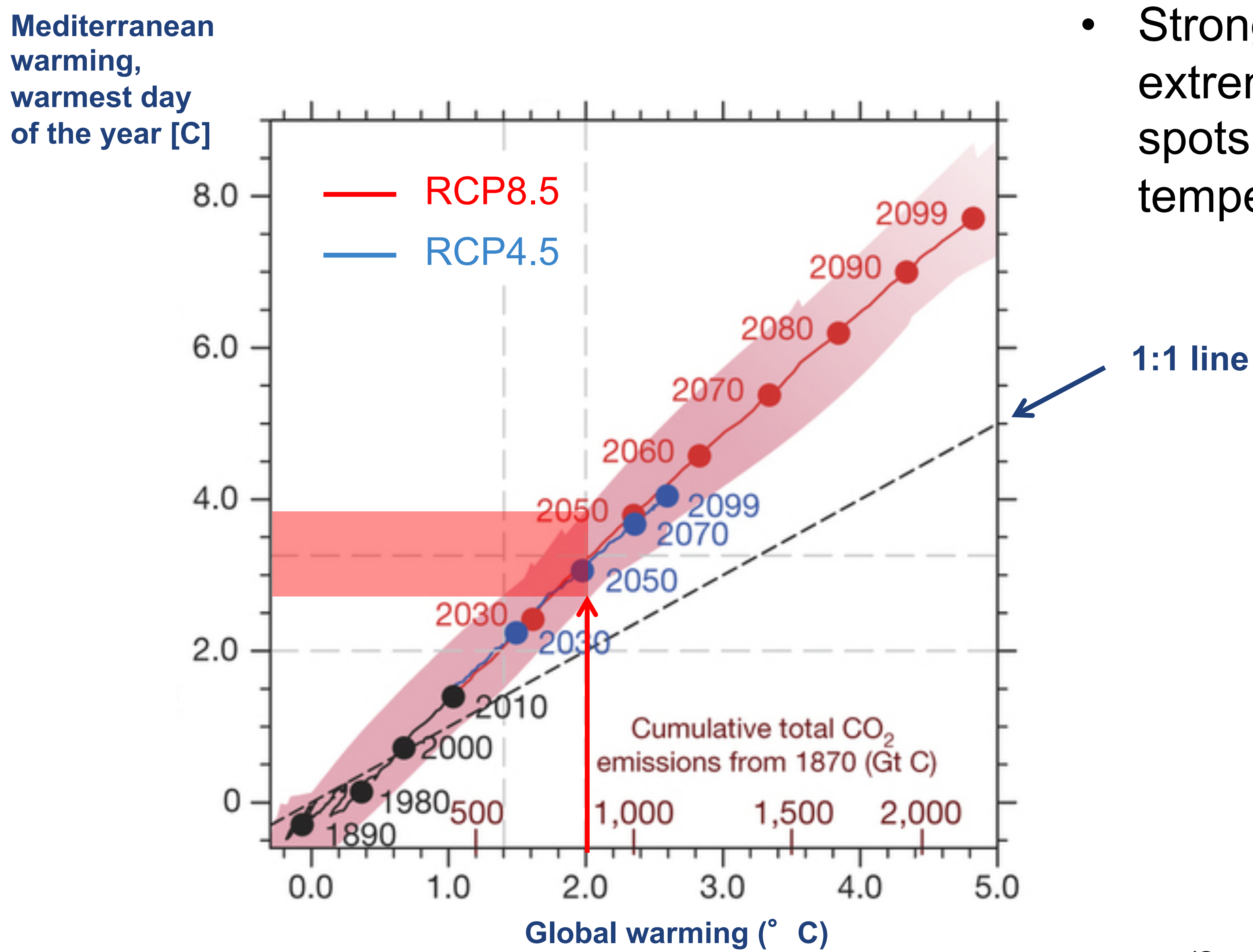
(IPCC SR15, Chapter 3)

Regional extremes vs global climate change



(Seneviratne et al. 2016, Nature)

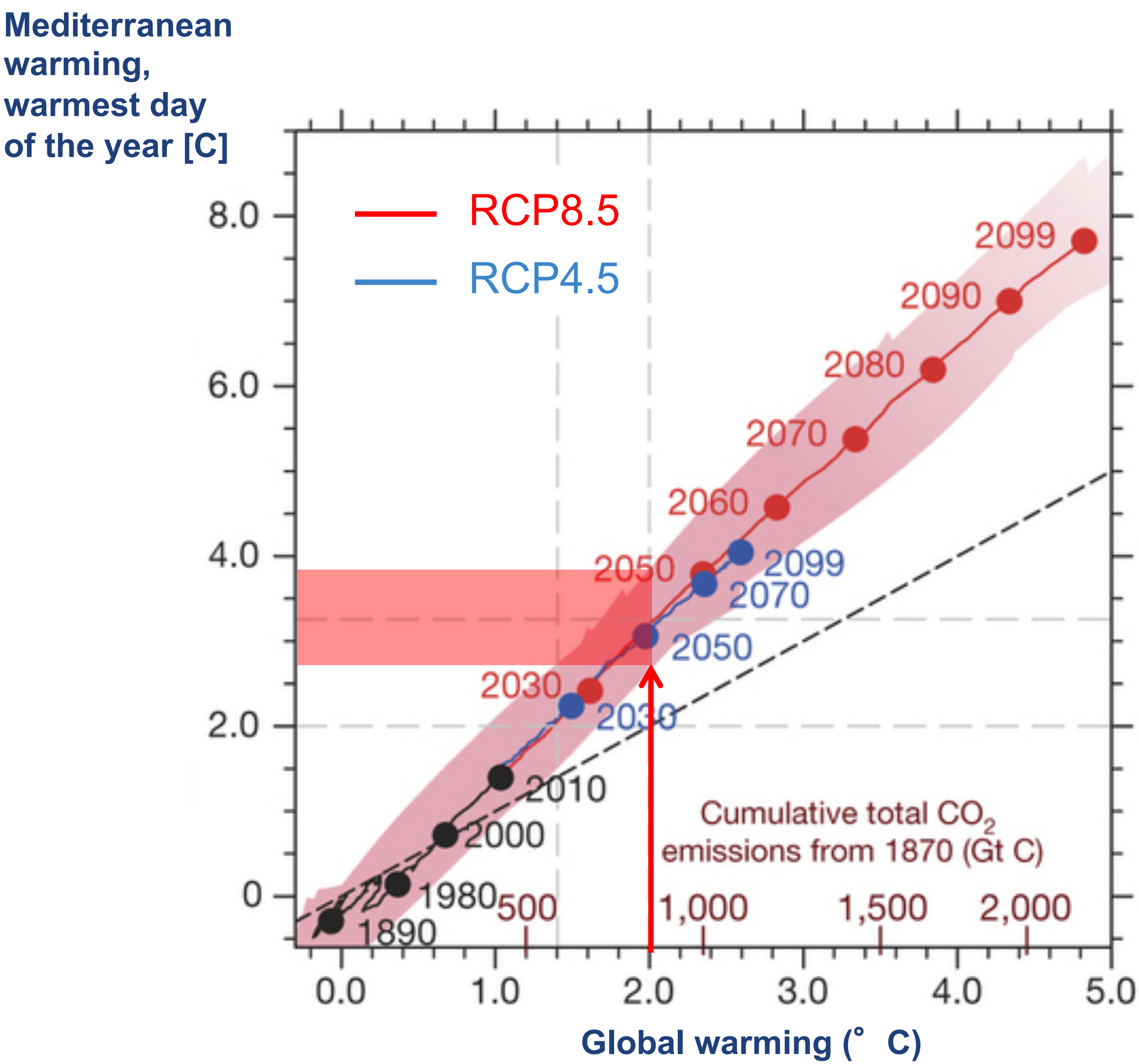
Regional extremes vs global climate change



- Stronger warming of extremes in land hot spots vs global temperature

(Seneviratne et al. 2016, Nature)

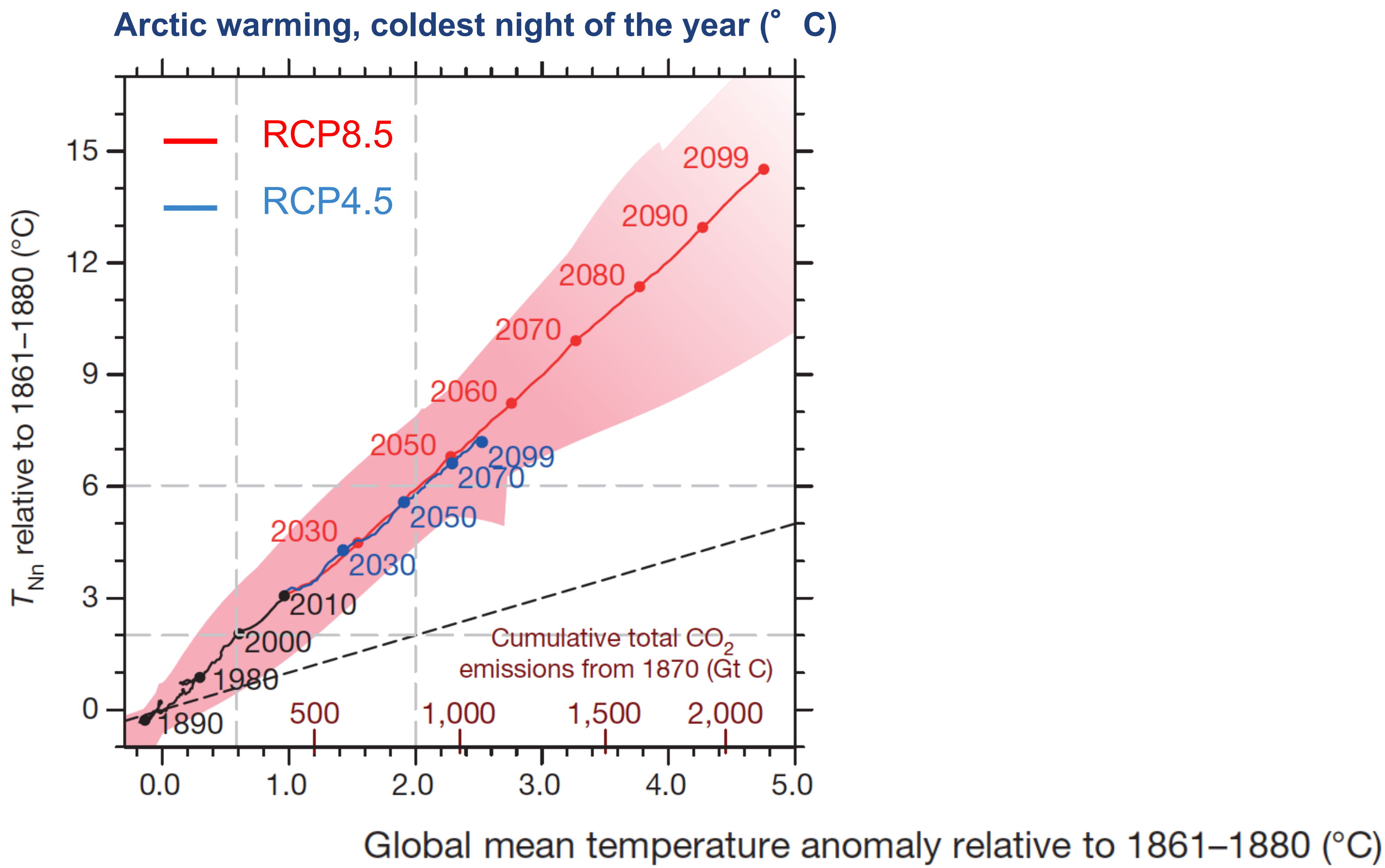
Regional extremes vs global climate change



- Stronger warming of extremes in land hot spots vs global temperature
- Robust and almost linear scaling, mostly independent of emissions scenario!
  (see also Wartenburger et al. 2017, GMD)

(Seneviratne et al. 2016, Nature)

Also scaling found for warming of minimum temperatures and changes in heavy precipitation



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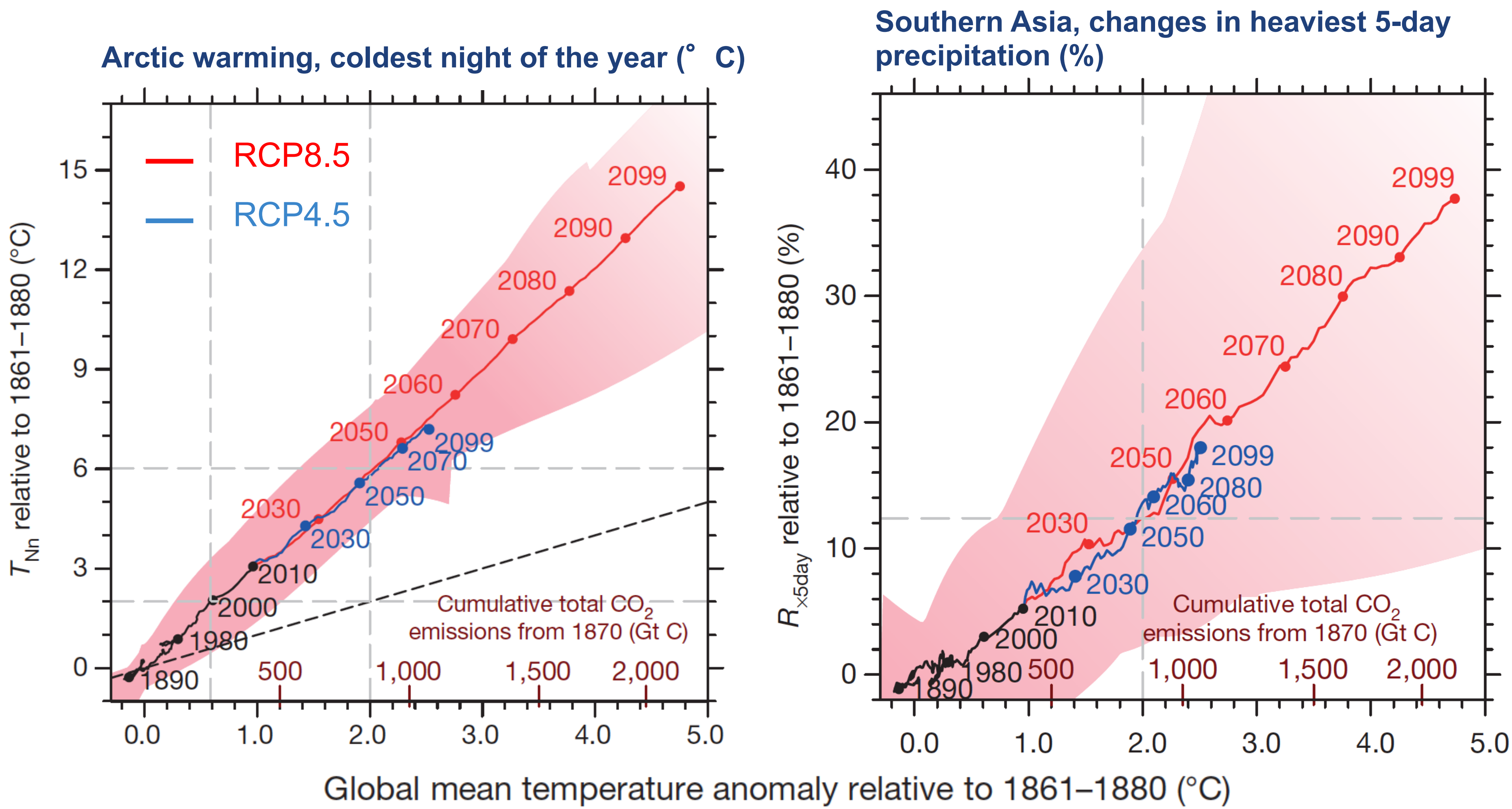

(Seneviratne et al. 2016, Nature)

Regional extremes vs global climate change

We can use global warming levels as a new "dimension of integration" (instead of scenarios & time framework)

- +1.5ºC scenarios: Stabilization at ca. 1.5ºC between ~2030-2050
- Failed mitigation: Warming up to +3ºC (countries' current commitments) or even >+4-5ºC by 2100 (no mitigation)
- Focus on global warming levels makes the link between adaptation and mitigation

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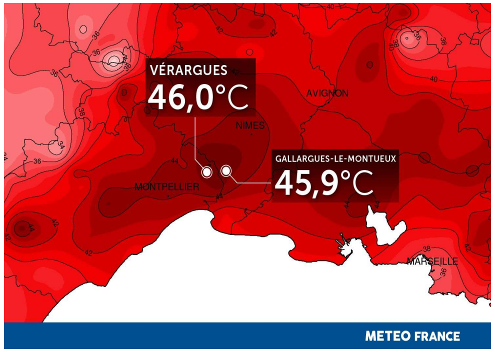
A world at ~ +1ºC: Recent extreme events

The probability of these events was made higher due to human-induced climate change

Europe 2018

Japan 2018

California, 2018 & 2020



France, 2019

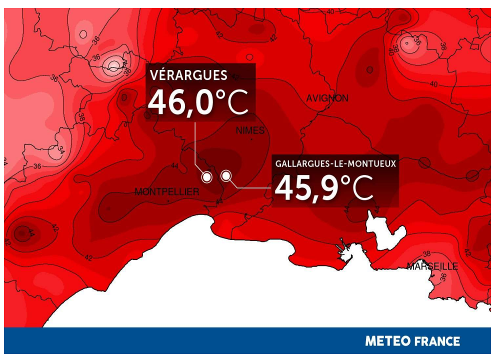
Australia, 2019-2020

Siberia, 2020

A world at ~ +1ºC: Recent extreme events

The probability of these events was made higher due to human-induced climate change

Human-induced global heating and its consequences are happening now, not in the distant future!

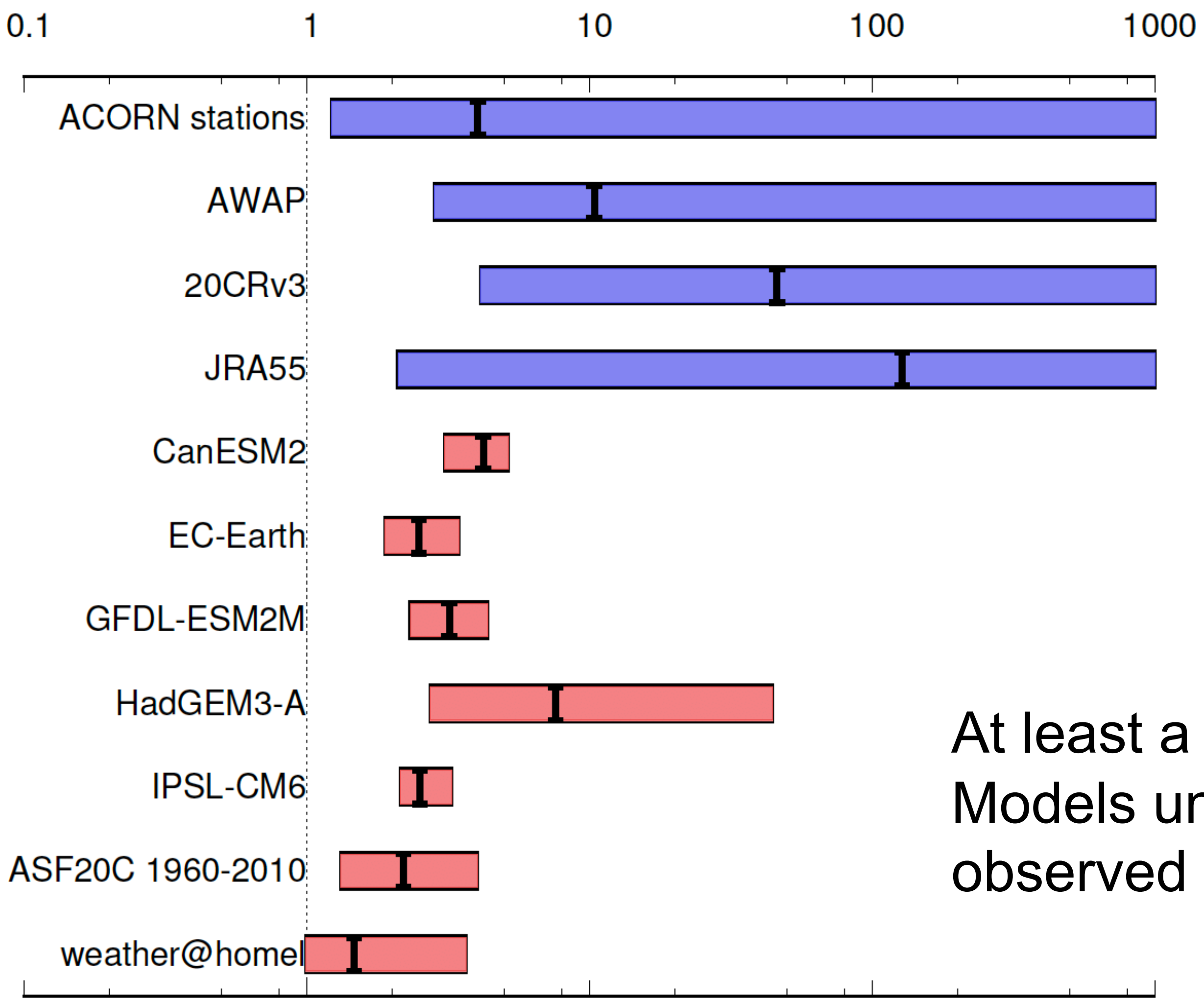


France, 2019

Australia, 2019-2020

Siberia, 2020

Probability ratio of temperature anomaly, 2019 vs 1900

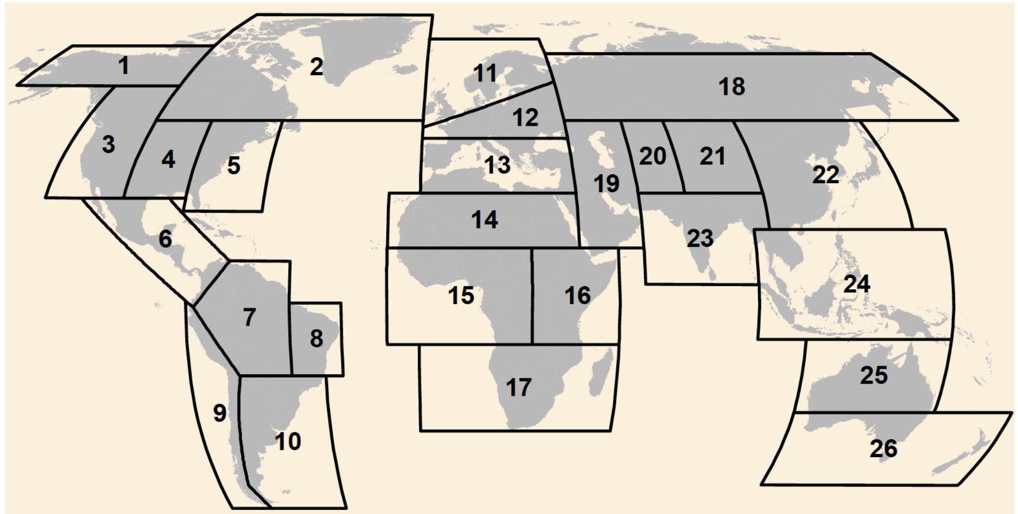


At least a factor 2
Models underestimate the observed warming

Van Oldenborgh et al., in review, NHESS: https://nhess.copernicus.org/preprints/nhess-2020-69/

Is a +1.5ºC climate substantially different from +2ºC?

Yes!



(IPCC SREX, 2012)

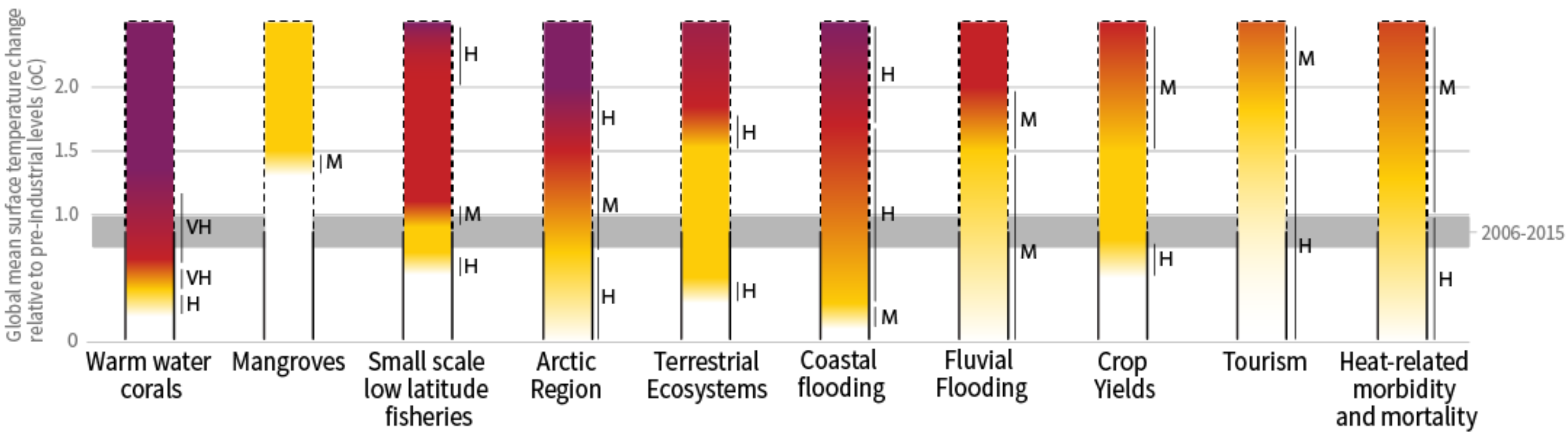
	ALA	AMZ	CAM	CAS	CEU	CGI	CNA	EAF	EAS	ENA	MED	NAS	NAU	NEB	NEU	SAF	SAH	SAS	SAU	SEA	SSA	TIB	WAF	WAS	WNA	WSA
TXx	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
TNn	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Rx5day	+	+	+	+	+	+	+	+	+	+	+	+	-	-	+	-	-	+	+	+	+	+	+	-	+	+
CDD	-	+	+	+	+	-	+	-	-	+	+	-	+	+	+	+	+	+	+	-	+	-	-	+	-	+

significant difference in between the distributions of ΔI_{reg} for $\Delta T_{glob} = 1.5^{\circ}C$ and $\Delta T_{glob} = 2^{\circ}C$
no significant difference in between the distributions of ΔI_{reg} for $\Delta T_{glob} = 1.5^{\circ}C$ and $\Delta T_{glob} = 2^{\circ}C$

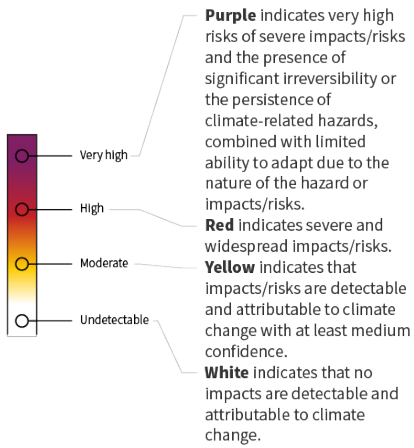
(adapted from Wartenburger et al. 2017, GMD)

Impacts: Some critical thresholds above +1.5ºC

Impacts and risks for selected natural, managed and human systems



Confidence level for transition:
L=Low,
M=Medium,
H=High and
VH=Very high



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Summary: Impacts at +1.5ºC vs +2ºC

Jason Florio / Aurora Photos

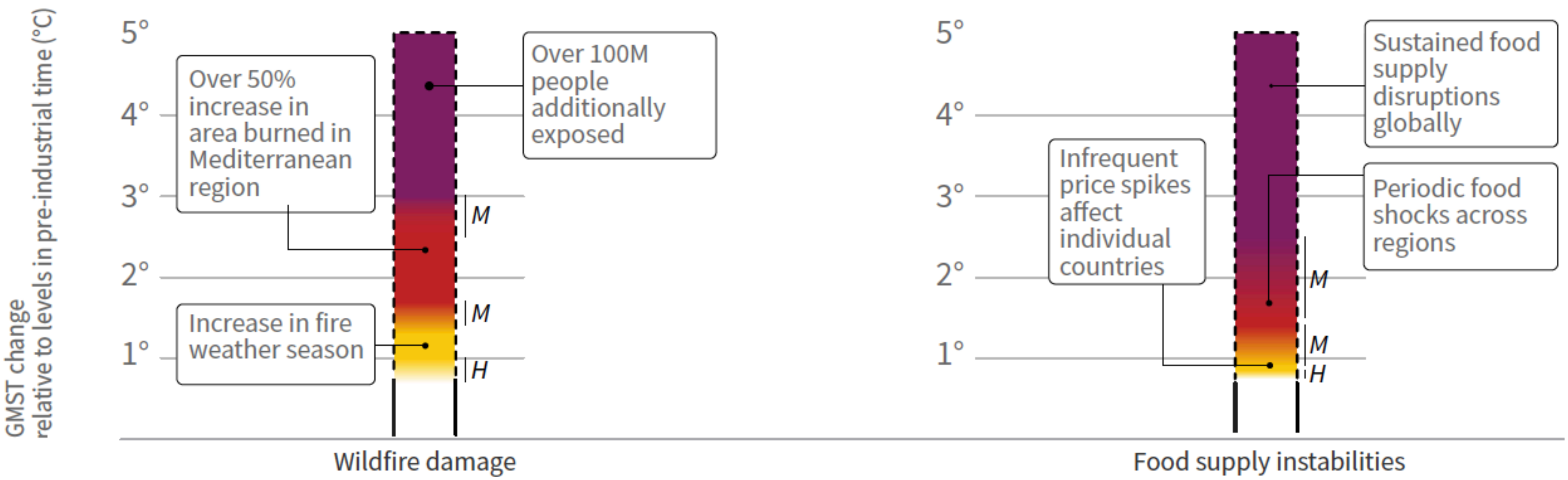
Impacts of global warming of 1.5ºC

At +1.5ºC compared to +2ºC:

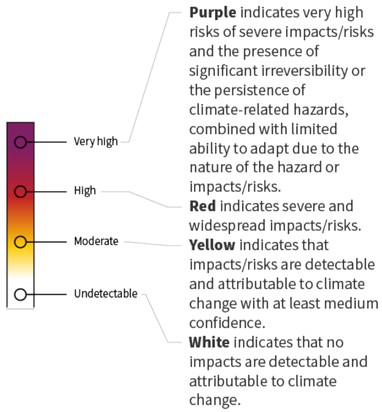
- Less extreme weather where people live, including extreme heat and rainfall
- 10 million fewer people exposed to risk of rising seas
- Some irreversible changes are avoided (loss of coral reefs, sea level rise, loss of some terrestrial species)

ipcc INTERGOVERNMENTAL PANEL ON climate change WMO UNEP

New evidence from IPCC special report on land



Risks of wildfire damages and food supply instabilities increase from moderate to high at +1.5ºC



(IPCC, SRCCL, 2019)

Effects of human-induced climate change on wildfires

24 SEP 2020 • 11 MIN READ

September Update: Climate change increases the risk of wildfires

Update: strengthened evidence that #climatechange increases the frequency and/or severity of fire weather around the world. Land management alone cannot explain recent increases in #wildfire because increased fire weather from climate change amplifies fire risk where fuels remain available.

https://news.sciencebrief.org/wildfires-sep2020-update/

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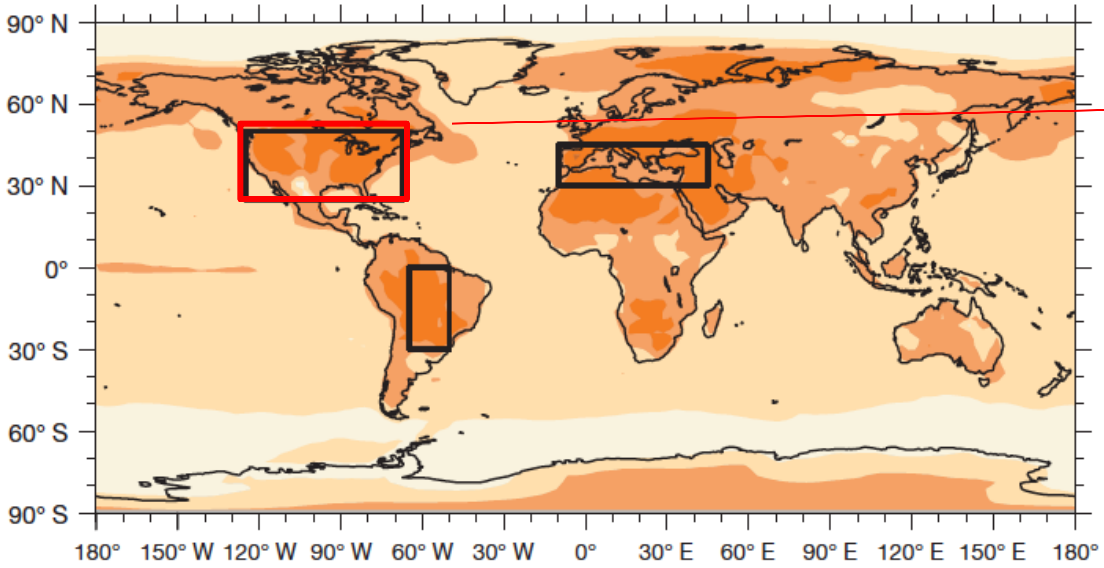
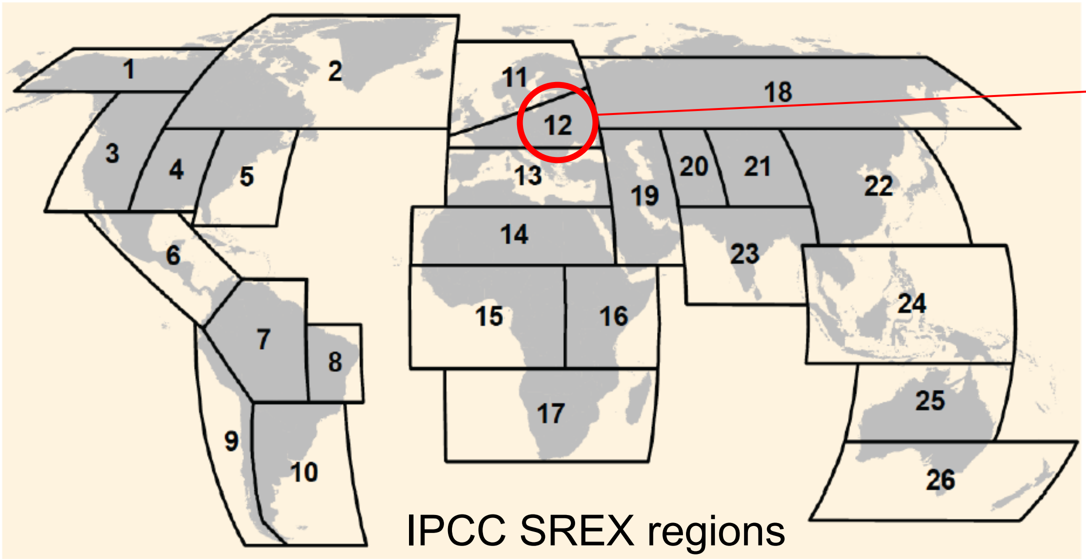
Complex regional scaling for T°: Example from 2 regions



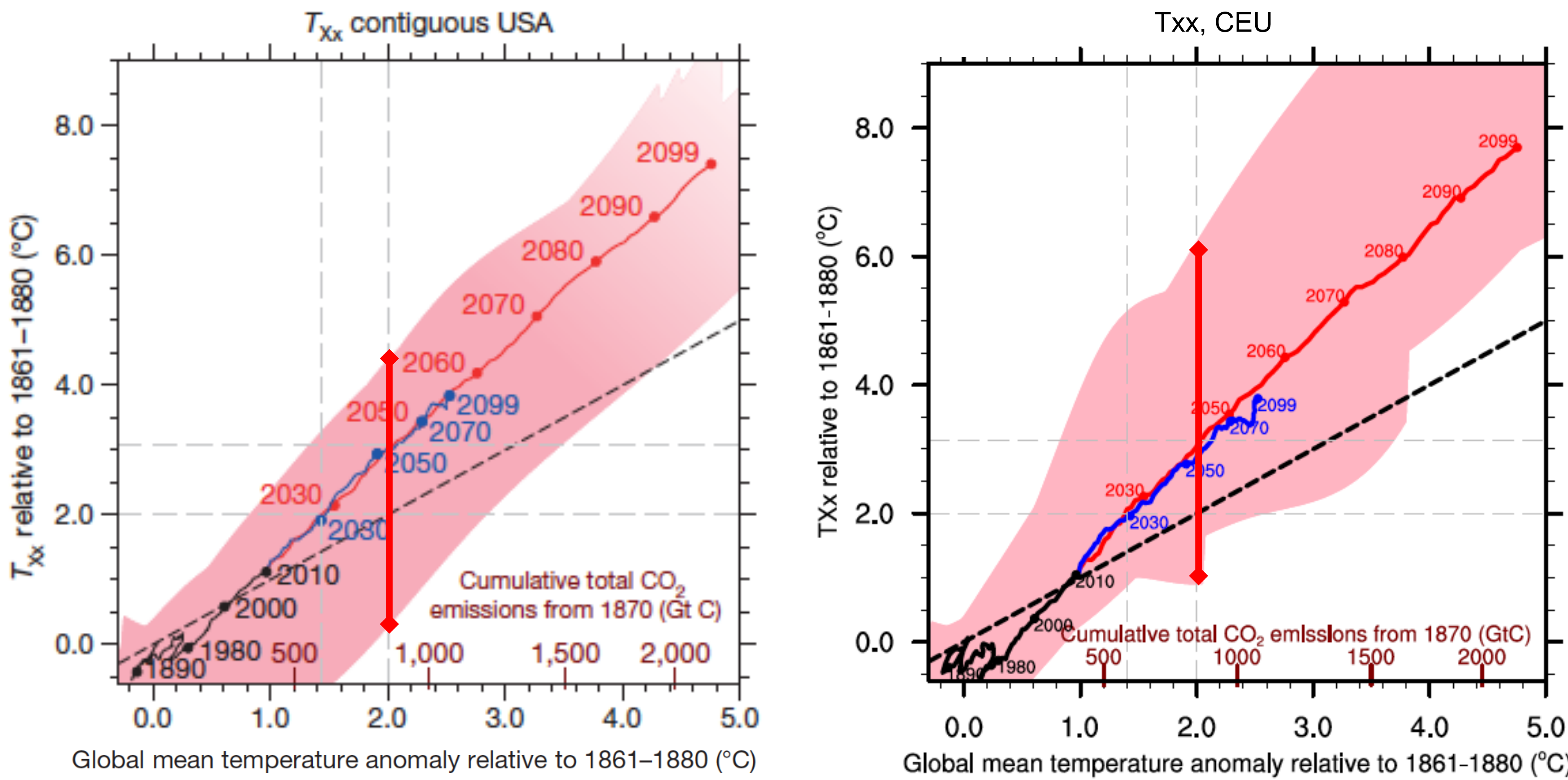
Contiguous US



IPCC SREX regions

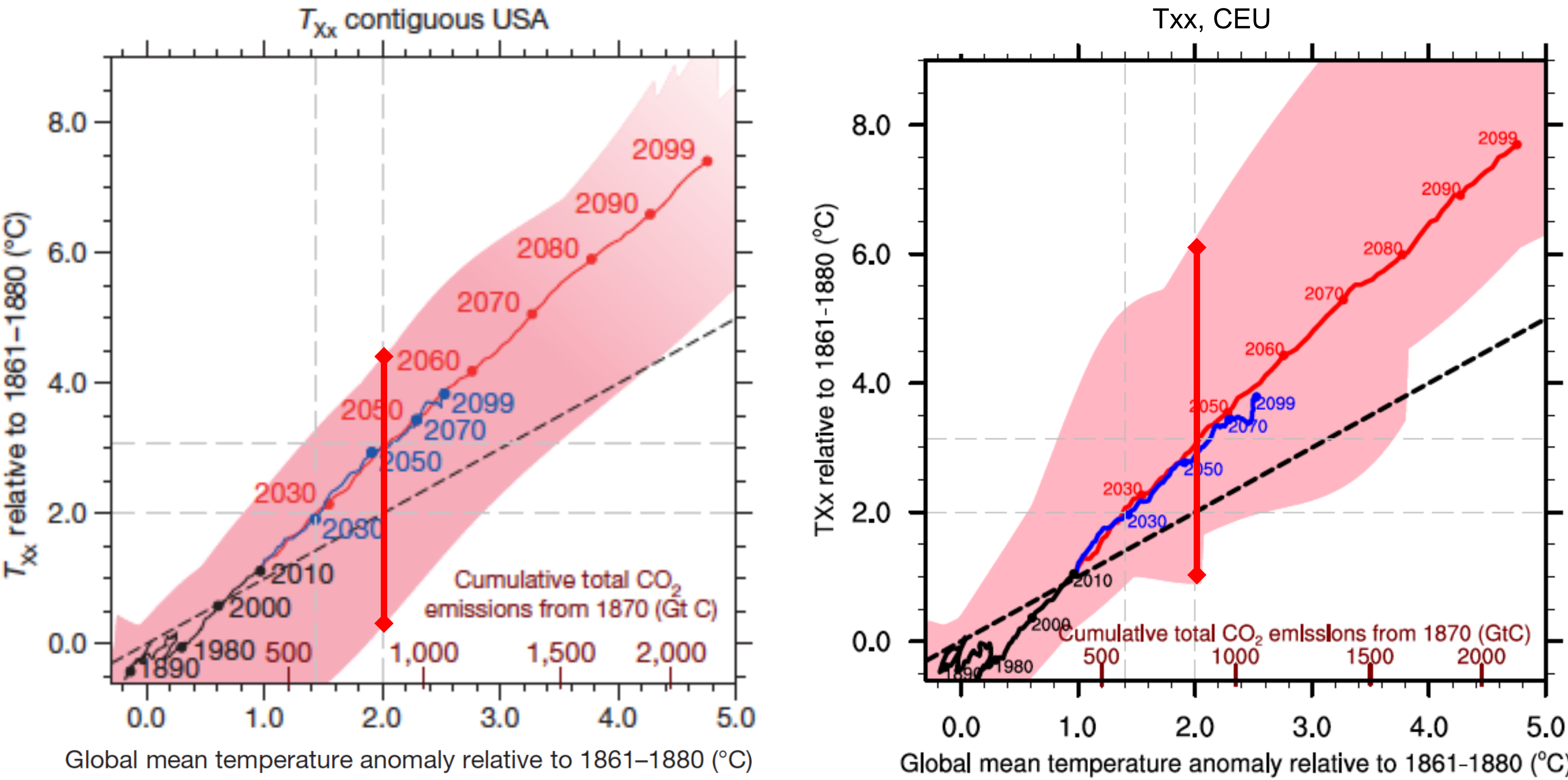
Central Europe

Complex regional scaling for T°: Example from 2 regions



(Seneviratne et al. 2016, Nature)

Complex regional scaling for T°: Example from 2 regions



NB: Regions with large spread in regional responses are found in locations of known large soil moisture-temperature feedbacks *(e.g. Mueller and Seneviratne 2012, PNAS; Seneviratne et al. 2013, GRL)*

(Seneviratne et al. 2016, Nature)

Introducing Regional Climate Sensitivity

Uncertainties in projections do not only depend on global climate sensitivity but also on the regional response as function of global warming, the "regional climate sensitivity"

Earth's Future

RESEARCH ARTICLE
10.1029/2019EF001474

Special Section:
CMIP6: Trends, Interactions, Evaluation, and Impacts

Regional Climate Sensitivity of Climate Extremes in CMIP6 Versus CMIP5 Multimodel Ensembles

Sonia I. Seneviratne[1] and Mathias Hauser[1]

[1]Institute for Atmospheric and Climate Science, Department of Environmental Systems Science, ETH Zurich, Zurich, Switzerland

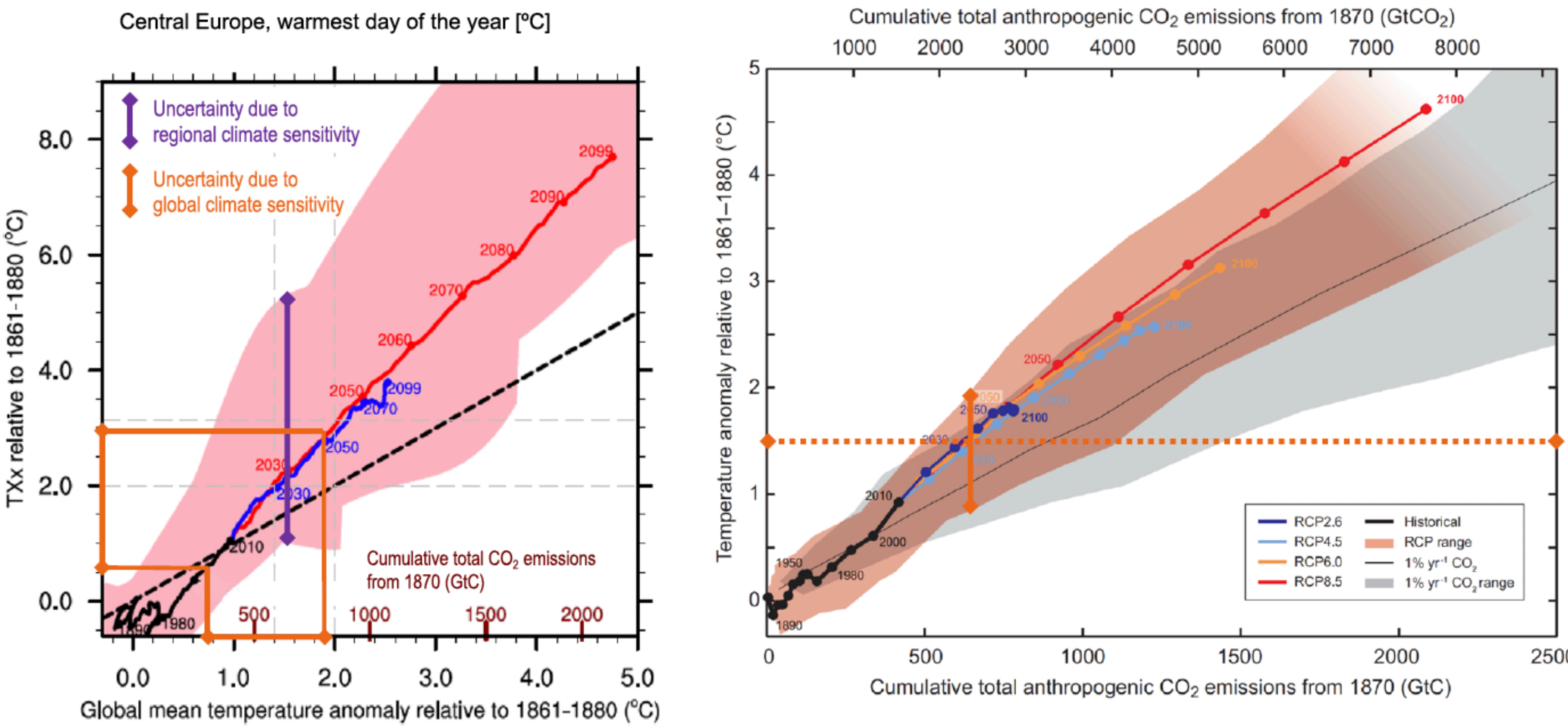
Key Points:
- Changes in climate extremes as a function of global warming are quasilinear and determine a "regional climate sensitivity" in CMIP5 and CMIP6
- The regional climate sensitivity of climate extremes is found to be very similar in CMIP5 and CMIP6,

Abstract We analyze projected changes in climate extremes (extreme temperatures and heavy precipitation) in the multimodel ensembles of the fifth and sixth Coupled Model Intercomparison Projects (CMIP5 and CMIP6). The results reveal close similarity between both ensembles in the regional climate sensitivity of the projected multimodel mean changes in climate extremes, that is, their projected changes as a function of global warming. This stands in contrast to widely reported divergences in global (transient

(Seneviratne and Hauser 2020, Earth's Future)

Introducing Regional Climate Sensitivity

Uncertainties in projections do not only depend on global climate sensitivity but also on the regional response as function of global warming, the "regional climate sensitivity"



(Seneviratne and Hauser 2020, Earth's Future)

Introducing Regional Climate Sensitivity

Let's define **regional climate sensitivity** as follows:

$$\frac{dX}{dT_{glob}}$$

X: variable, possibly also climate extreme (e.g. TXx)

$$\frac{dX}{dCO_2} = \frac{dX}{dT_{glob}} \frac{dT_{glob}}{dCO_2}$$

RCS (regional transient climate sensitivity)

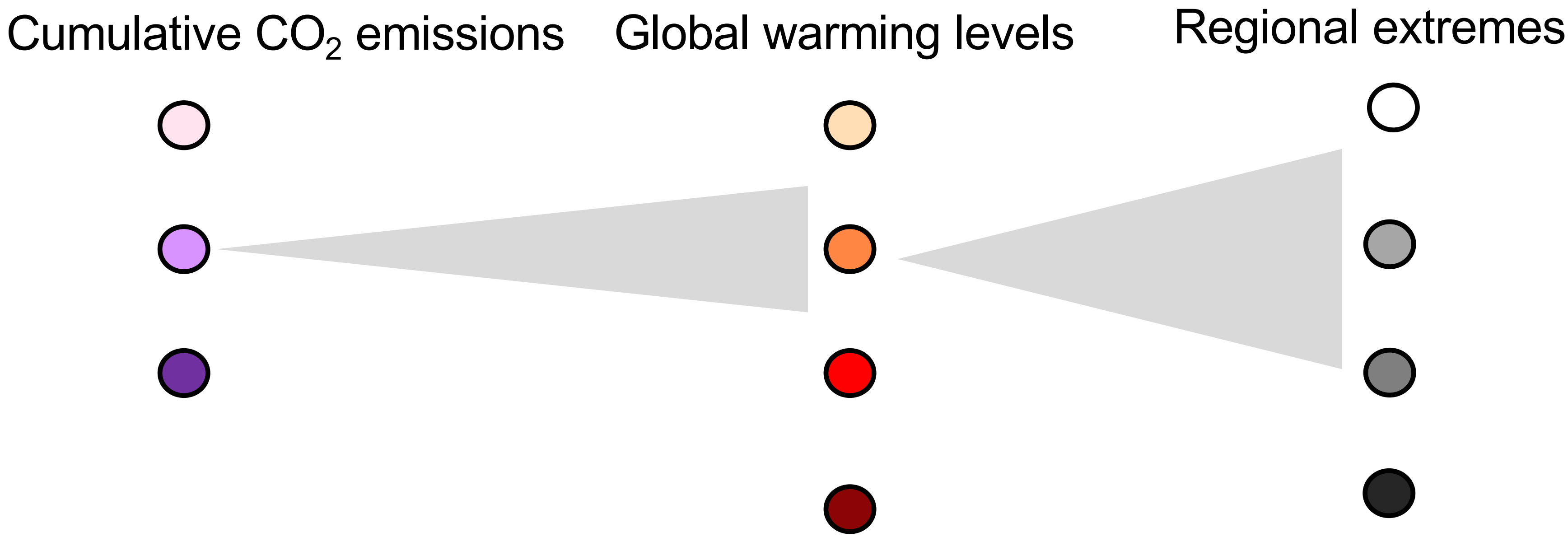
GCS (global transient climate sensitivity = TCRglob)

We can compare the contributions of RCS and GCS

Introducing Regional Climate Sensitivity

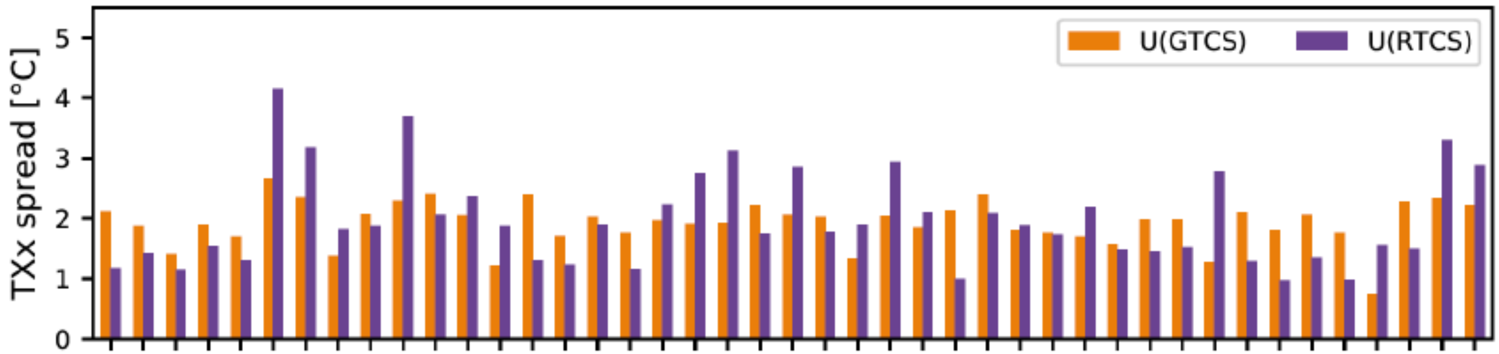
Regional projections can be split in two components:

- Changes in global warming at a given forcing (transient climate response; "global climate sensitivity", GCS)
- Regional changes at a given global warming level ("regional climate sensitivity", RCS)

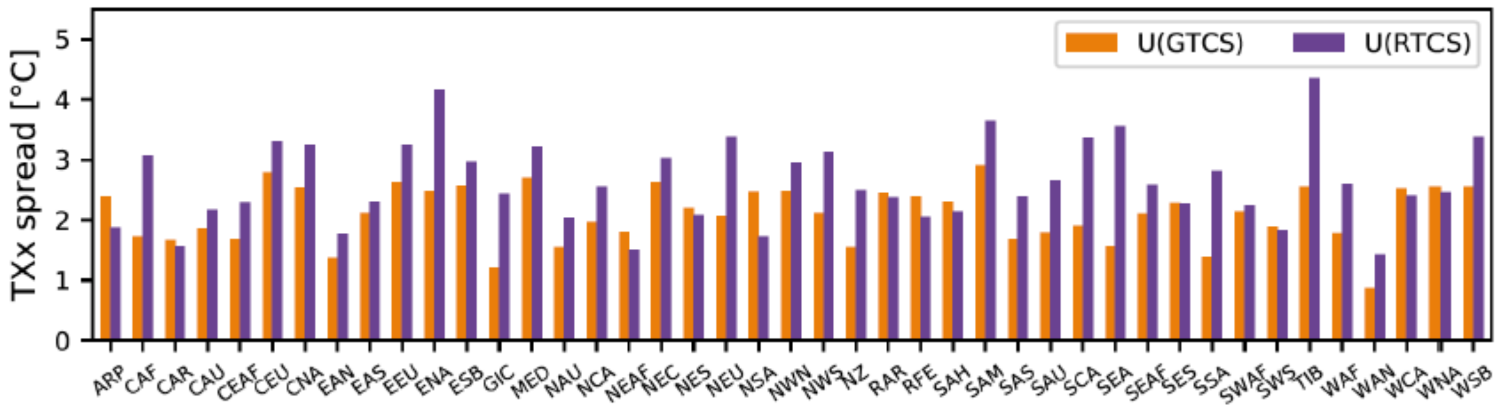


Introducing Regional Climate Sensitivity

(c) CMIP5: $U_{GTCS(1.5°C)}$ vs $U_{RTCS(1.5°C)}$ for TXx projections



(d) CMIP6: $U_{GTCS(1.5°C)}$ vs $U_{RTCS(1.5°C)}$ for TXx projections



CMIP6 vs CMIP5: The multi-model mean shows very similar RTCS in both ensembles, but…

RCS is a large contributor inter-model spread on regional scale and the dominant one compared to GCS in CMIP6!

NB: Comparison for response at +1.5ºC

(Seneviratne and Hauser 2020, Earth's Future)

MESMER regional ESM emulator

Lea Beusch

Earth Syst. Dynam., 11, 139–159, 2020
https://doi.org/10.5194/esd-11-139-2020

Earth System Dynamics
Open Access EGU

Emulating Earth system model temperatures with MESMER: from global mean temperature trajectories to grid-point-level realizations on land

Lea Beusch, Lukas Gudmundsson, and Sonia I. Seneviratne
Institute for Atmospheric and Climate Science, ETH Zurich, Zurich, Switzerland

- What?
  - Create plausible stochastic realizations of grid-point level land temperature field time series at a yearly resolution based on a single training run = a computationally cheap «initial-condition ensemble»

- Why?
  - Improve climate information in Integrated Assessment or Impact Models at a negligible computational cost

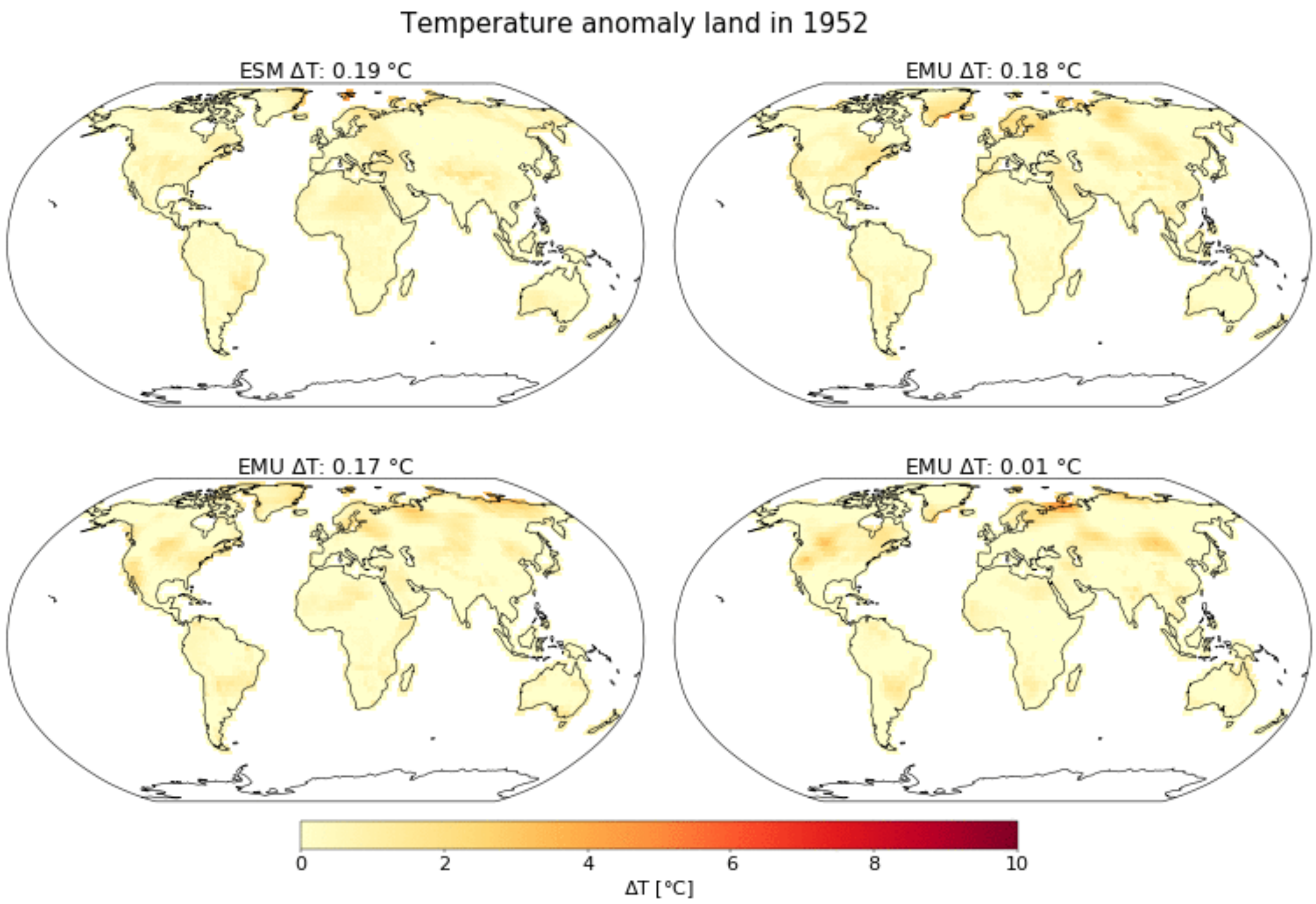
- How?

$$T_{s,t} = f\left(T_t^{glob}\right) + \eta_{s,t}$$

$T_{s,t}$: Temperature at grid point s and time t
T^{glob}_t: Global mean temperature
$\eta_{s,t}$: Local residual temperature variability

(Beusch et al. 2020, ESD)

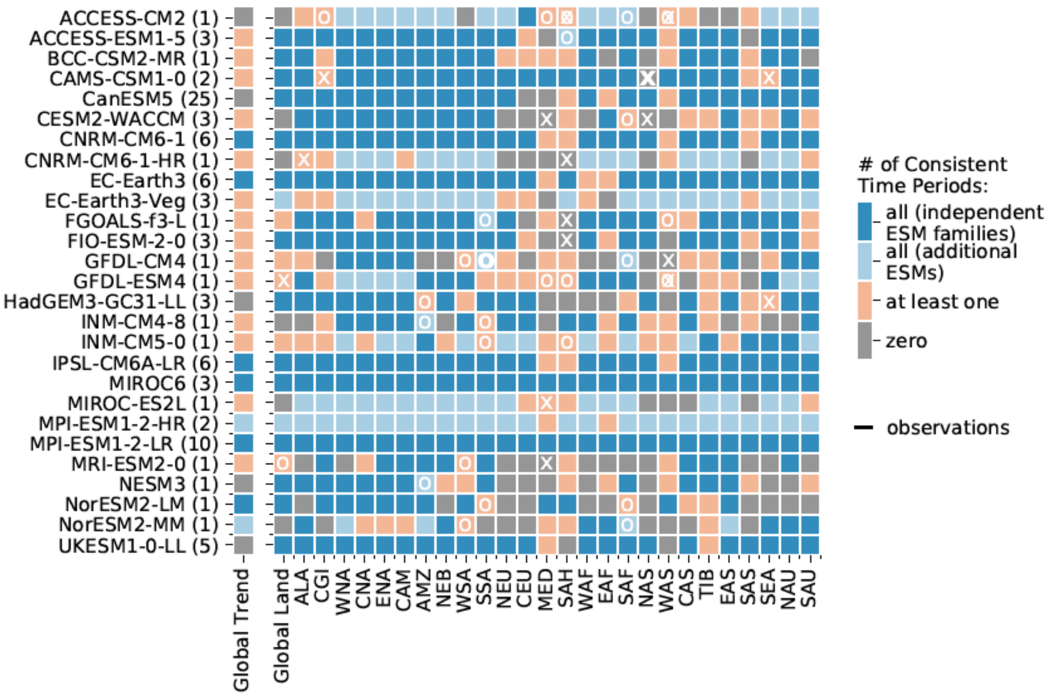
MESMER regional ESM emulator

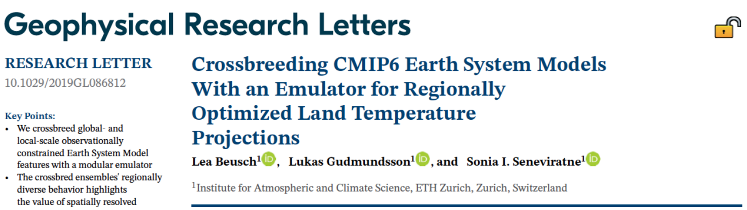


So far: representation of yearly temperature at grid-cell scale

(Beusch et al. 2020, ESD)

"Crossbreeding" of global and regional responses




Geophysical Research Letters

RESEARCH LETTER
10.1029/2019GL086812

Key Points:
- We crossbreed global- and local-scale observationally constrained Earth System Model features with a modular emulator
- The crossbred ensembles' regionally diverse behavior highlights the value of spatially resolved

Crossbreeding CMIP6 Earth System Models With an Emulator for Regionally Optimized Land Temperature Projections

Lea Beusch[1], Lukas Gudmundsson[1], and Sonia I. Seneviratne[1]

[1]Institute for Atmospheric and Climate Science, ETH Zurich, Zurich, Switzerland

- Separate assessment of global warming trends vs regional scaling: **Some models performing poorly on global scale present some good regional features and vice versa**. Best performing models on both global and regional scale: MIROC, MPI-ESM1-2-LR

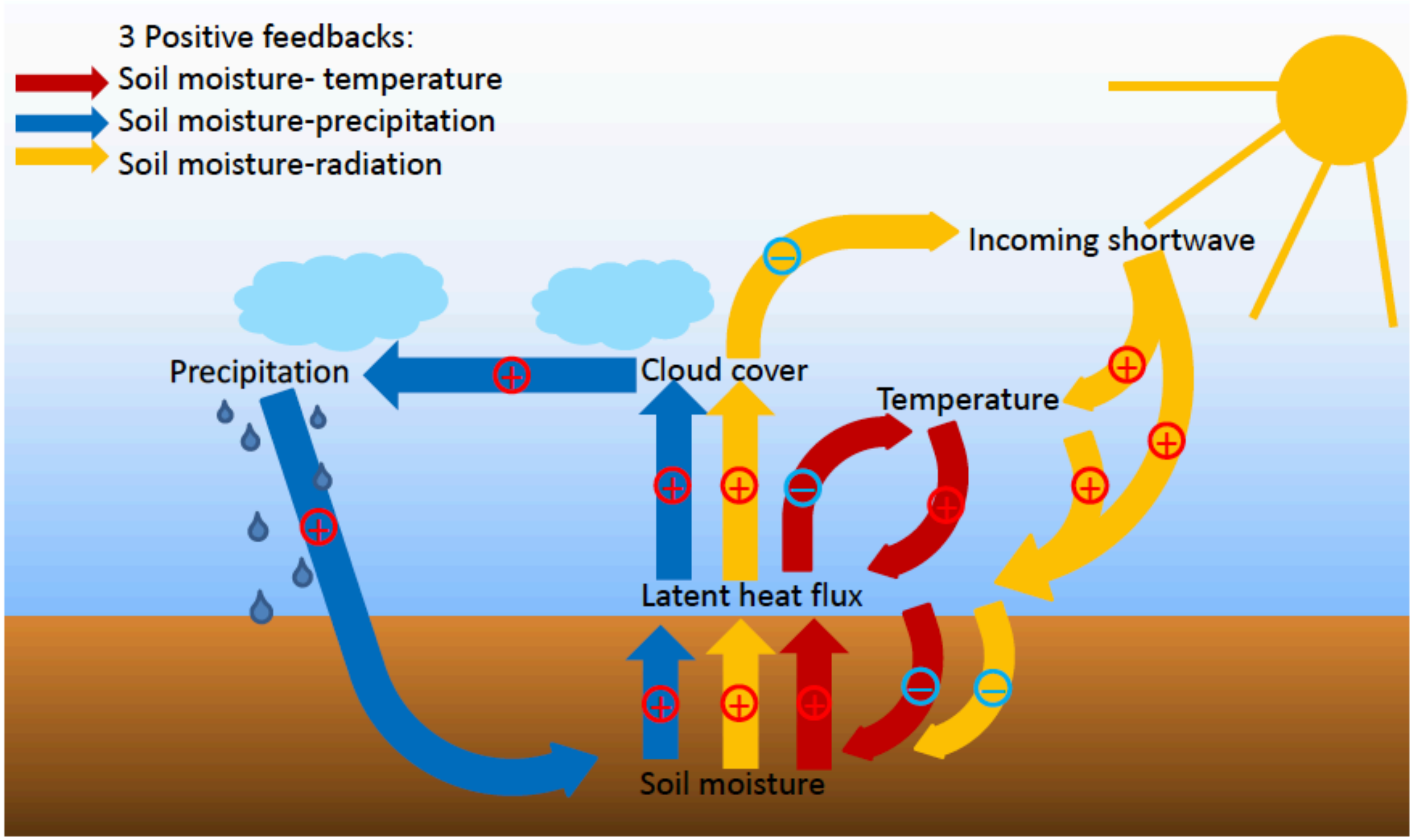
- **Idea:** Combine best global-scale features with best regional-scale features to derive "constrained cross-bred ensembles"

(Beusch et al. 2020, GRL)

Can we reduce uncertainties in regional climate sensitivity?

E.g. use of observational constraints…

Role of soil moisture – temperature feedbacks



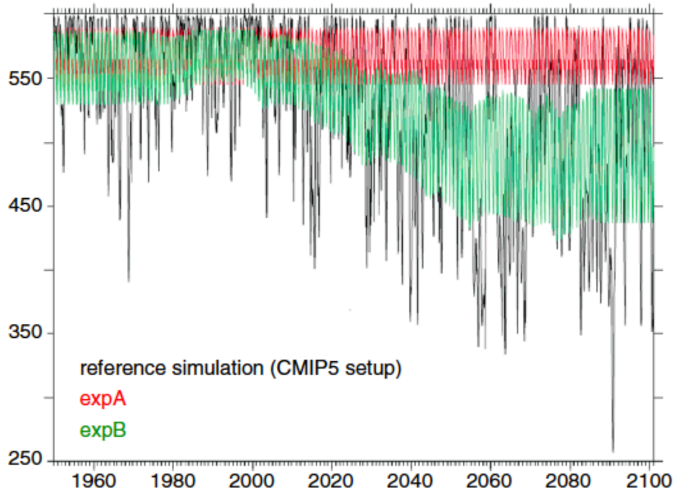
Martha Vogel

(Vogel et al. 2018, ESD)

➔ *evidence in projections: Seneviratne et al. 2006, Nature; Diffenbaugh et al. 2007, GRL; Seneviratne et al. 2013, GRL*

➔ *observational evidence: Hirschi et al. 2011, Nature Geoscience; Quesada et al. 2012, Nature Climate Change; Mueller and Seneviratne 2012, PNAS; Miralles et al. 2014, Nature Geoscience*

Soil moisture – temperature feedbacks: Projections



SM20C

SMtrend

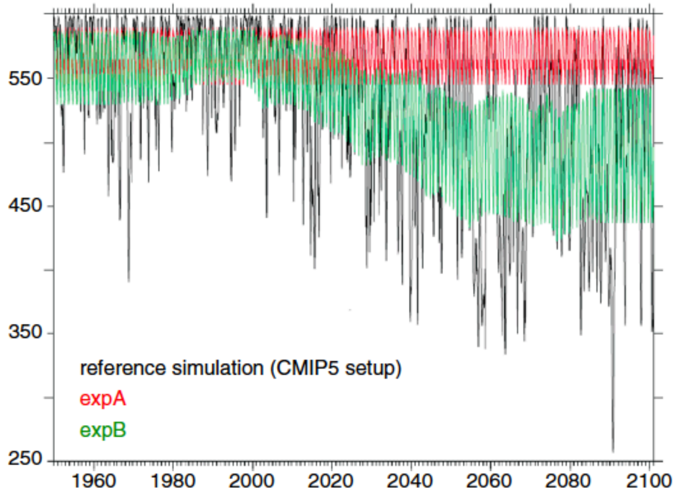
CTL

GLACE-CMIP5 experiments:

(Seneviratne et al. 2013, GRL)

Prescribed soil moisture to present-day levels in projections to assess impact of soil moisture changes for projections

Soil moisture – temperature feedbacks: Projections



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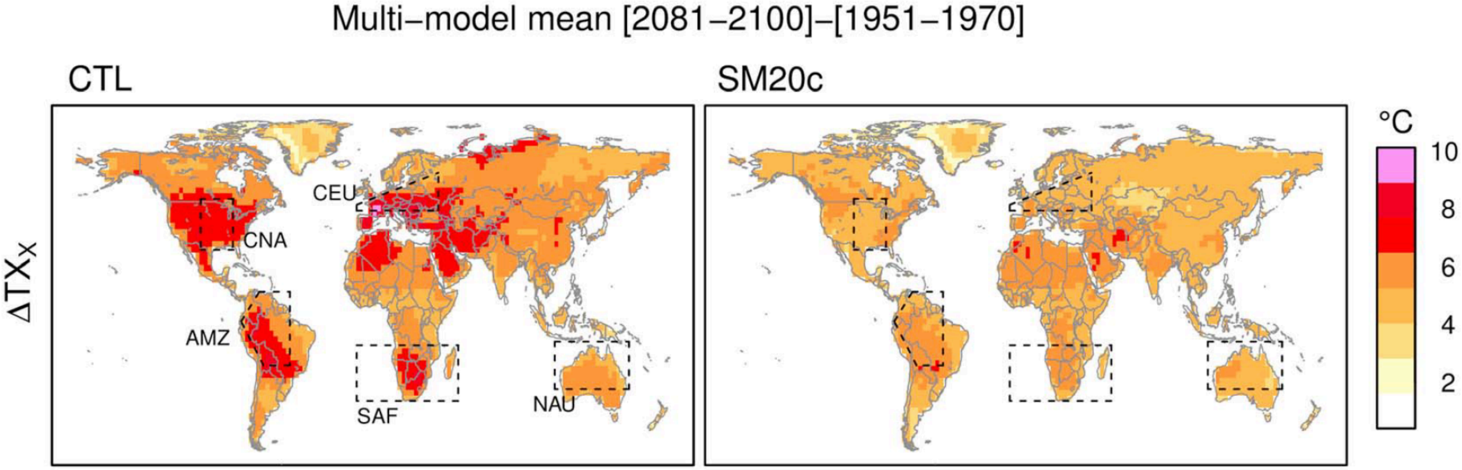
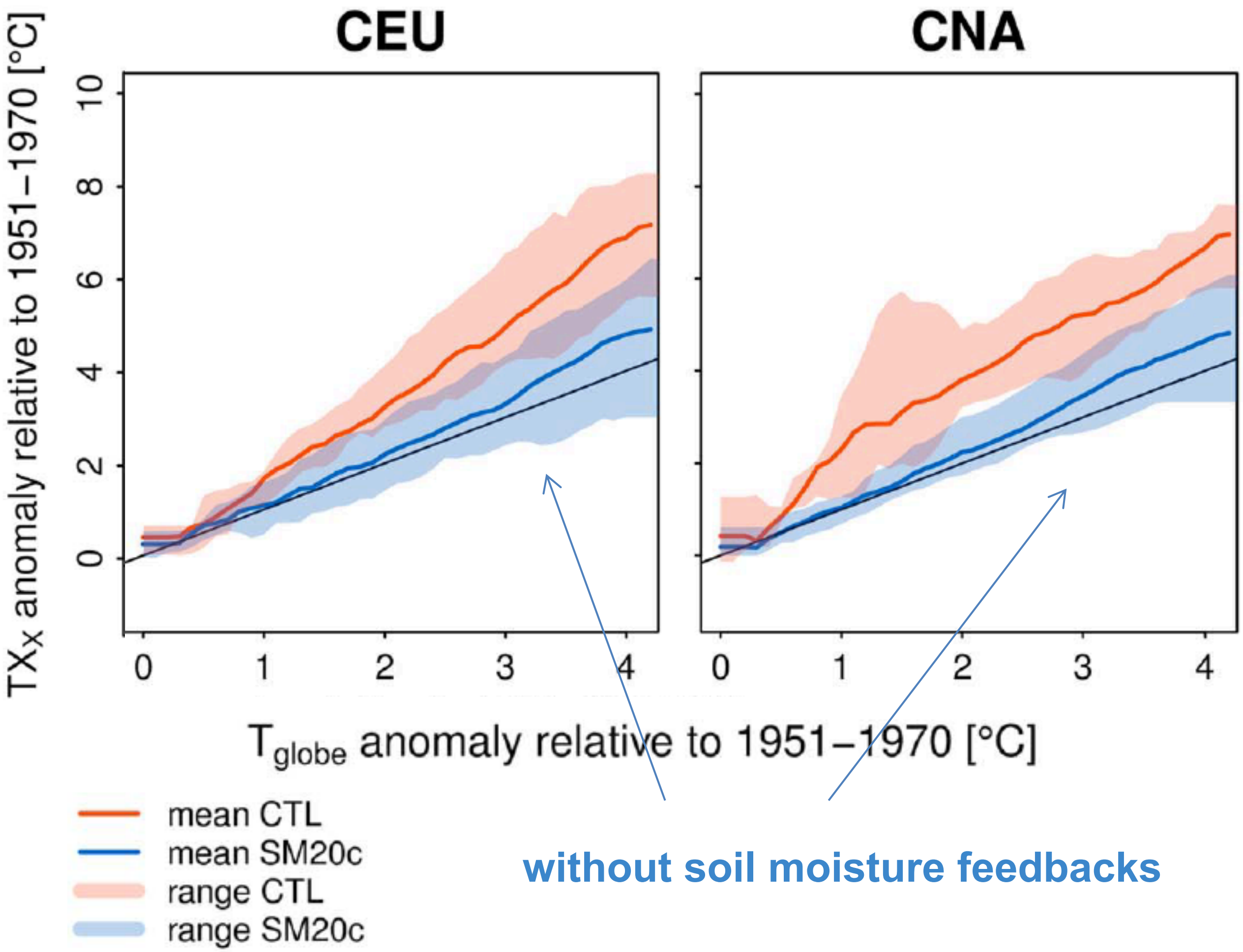


Mean drying of the soil is explaining added warming in extremes in several land regions

(Vogel et al. 2017, GRL)

Soil moisture – temperature feedbacks: Projections

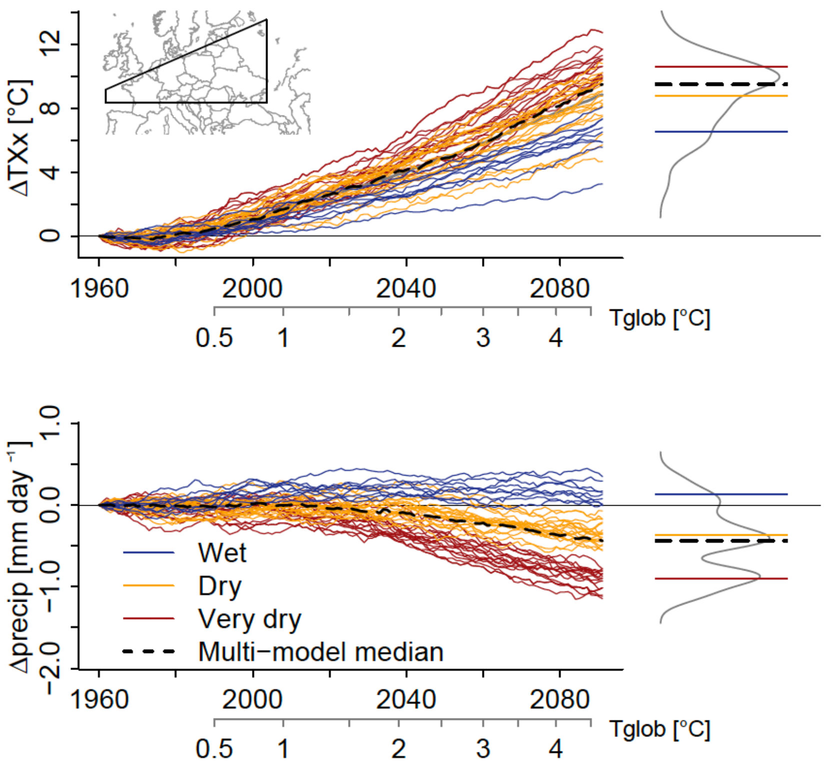
Scaling for GLACE-CMIP5 experiments

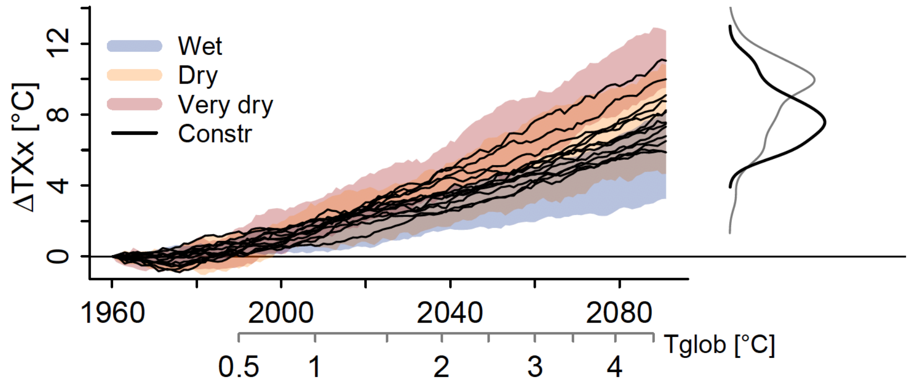


Soil moisture-temperature feedbacks are the main driver for the projected temperature extremes amplification in mid-latitudes!

(Vogel et al. 2017, GRL)

Observational constraints for projections





(Vogel et al. 2018, ESD)

- Trimodal distribution of CMIP5 projections in Central Europe ("wet", "dry" and "very dry" models)
- Observational constraint decreases range of projections
- *NB: CMIP6 show RCS closer to observational constraints, but still large spread (Seneviratne and Hauser 2020, Earth's Future)*

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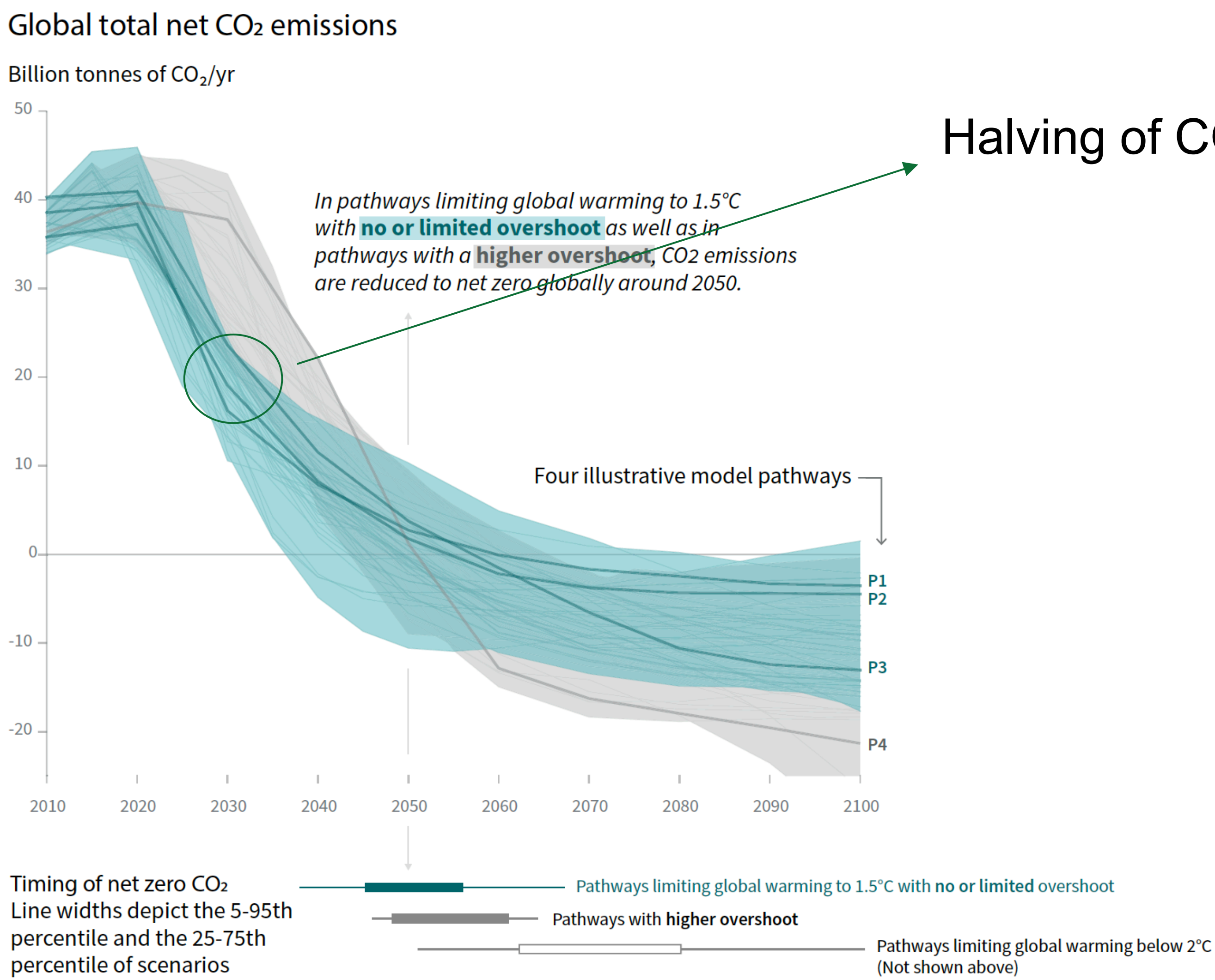
Net-zero CO_2 emissions are needed to stabilize temperature warming (no more burning of fossil fuels: coal, oil, gas)

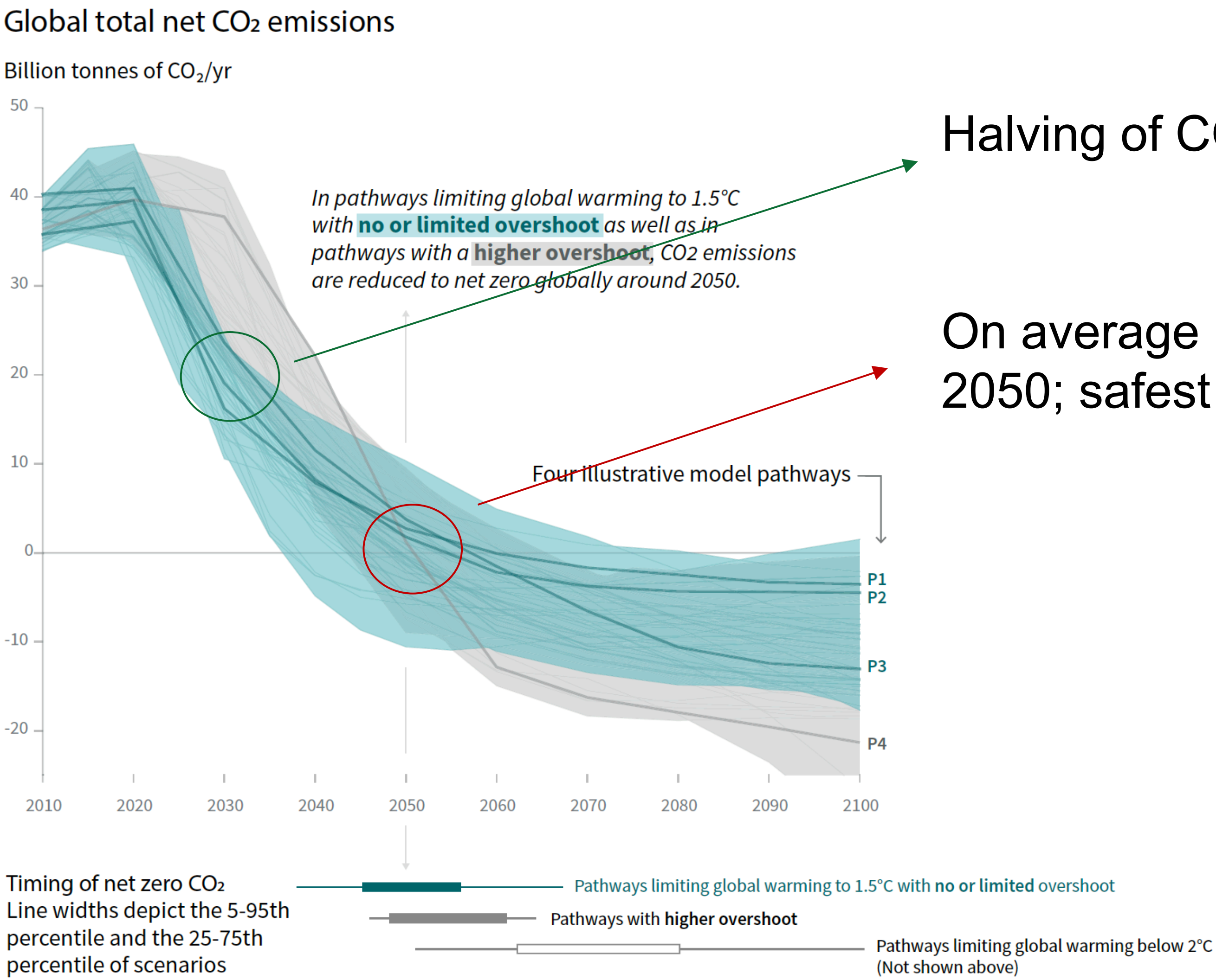


Halving of CO_2 emissions until 2030

(IPCC SR15, SPM.3a)

Emissions scenarios

Net-zero CO_2 emissions are needed to stabilize temperature warming (no more burning of fossil fuels: coal, oil, gas)

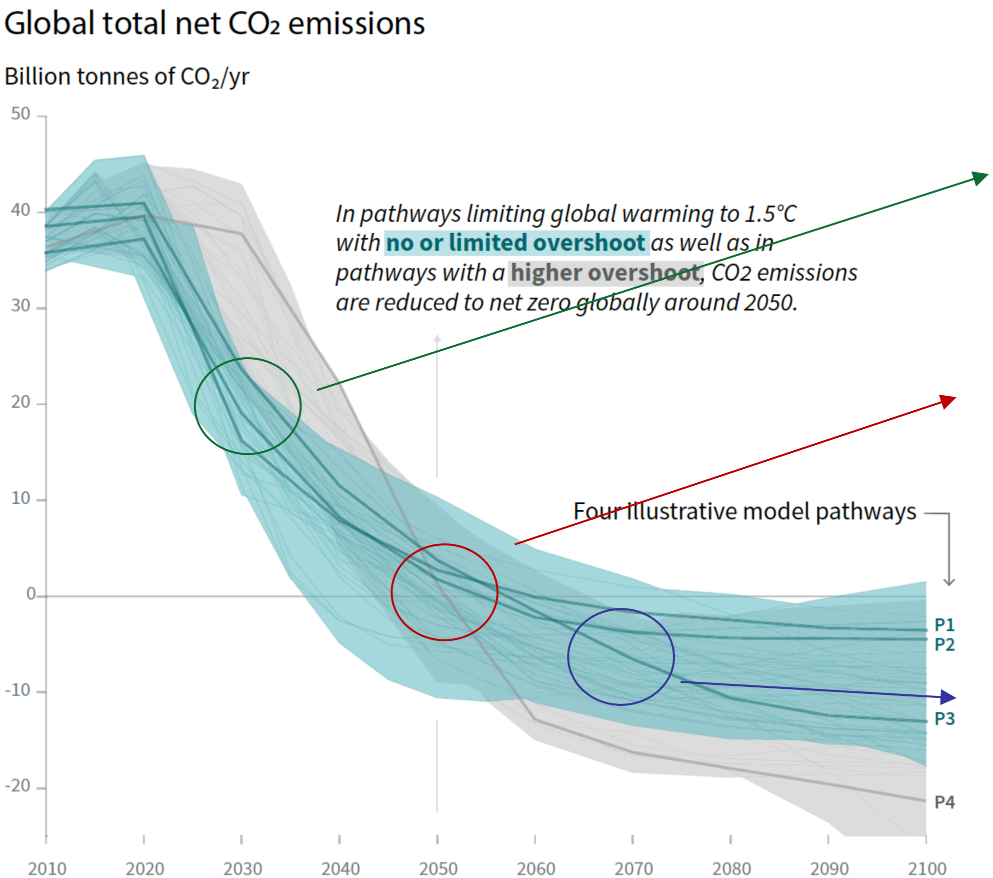


Halving of CO_2 emissions until 2030

On average net-zero CO_2 emissions in 2050; safest option, net-zero in 2040

(IPCC SR15, SPM.3a)

Net-zero CO_2 emissions are needed to stabilize temperature warming (no more burning of fossil fuels: coal, oil, gas)



Timing of net zero CO_2
Line widths depict the 5-95th percentile and the 25-75th percentile of scenarios

Pathways limiting global warming to 1.5°C with **no or limited** overshoot

Pathways with **higher overshoot**

Pathways limiting global warming below 2°C
(Not shown above)

Halving of CO_2 emissions until 2030

On average net-zero CO_2 emissions in 2050; safest option, net-zero in 2040

About 10% carbon dioxide removal, also after reaching net-zero (carbon capture and storage combined with intense *bioenergy (crops, wood)* use; afforestation)

(IPCC SR15, SPM.3a)

Land-based carbon dioxide removal vs extremes

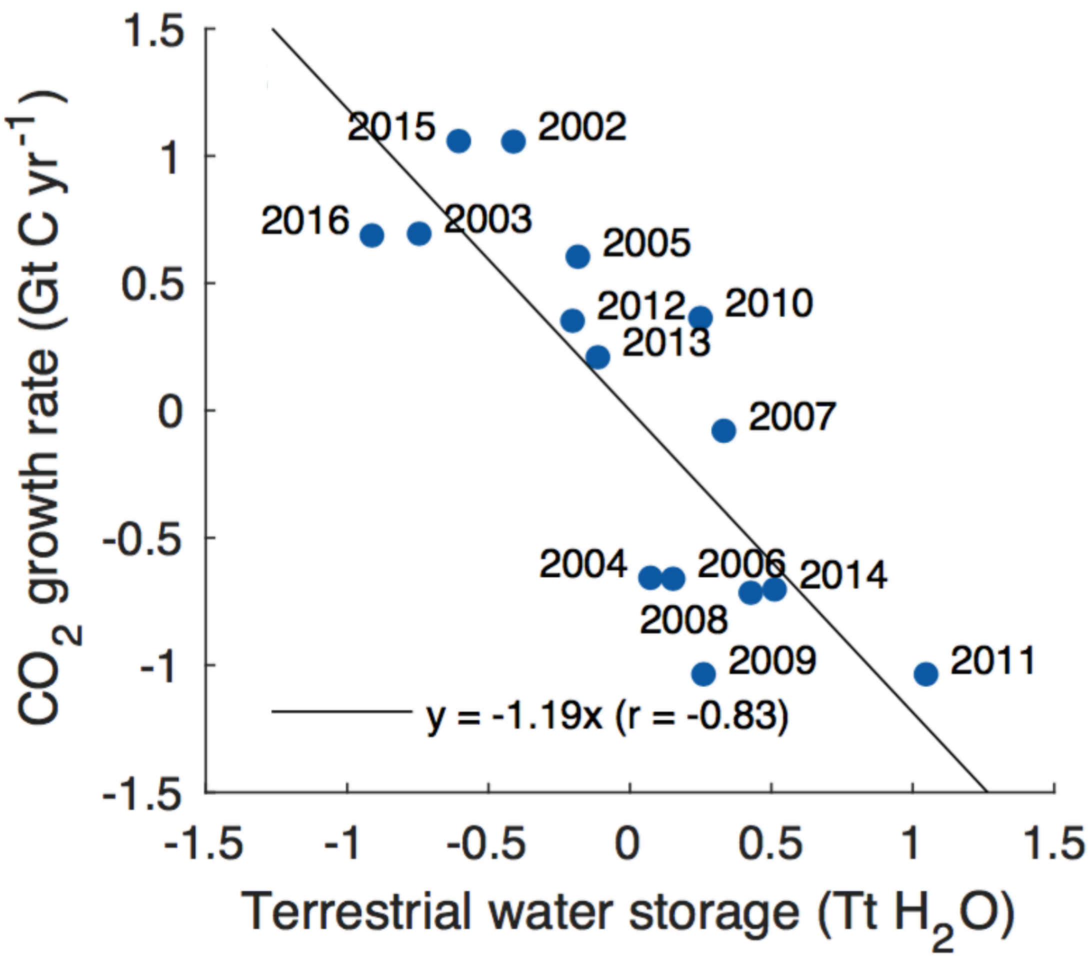
- Afforestation
- Bioenergy with carbon capture and storage

Land-based carbon dioxide removal vs extremes

- Afforestation
- Bioenergy with carbon capture and storage

- How about extremes? (not included in integrated assessments models deriving emissions scenarios); could be too optimistic

Further concerns

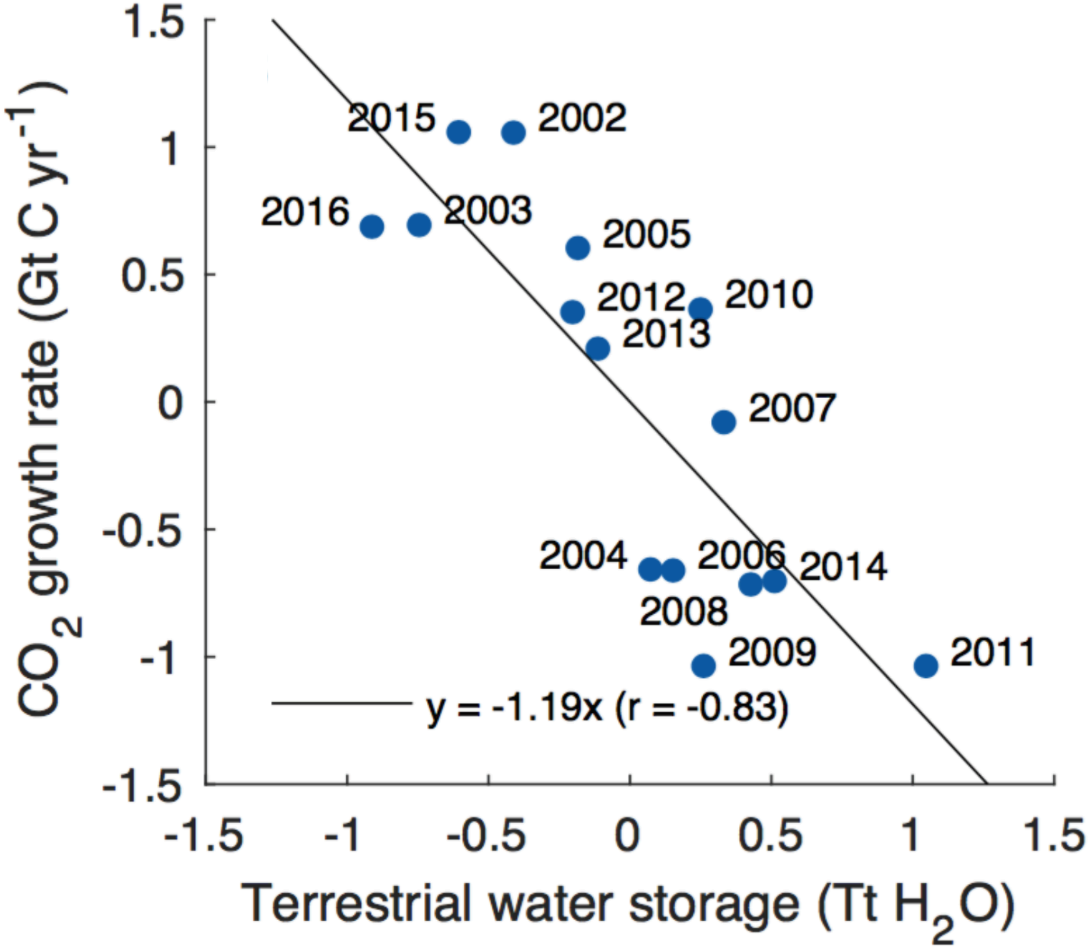


Effects of soil moisture/droughts on global carbon cycle

Observational evidence: Identified global-scale effect of land water storage on CO_2 growth rate!

(Humphrey et al. 2018, Nature)

Further concerns



Effects of soil moisture/droughts on global carbon cycle

Observational evidence: Identified global-scale effect of land water storage on CO_2 growth rate!

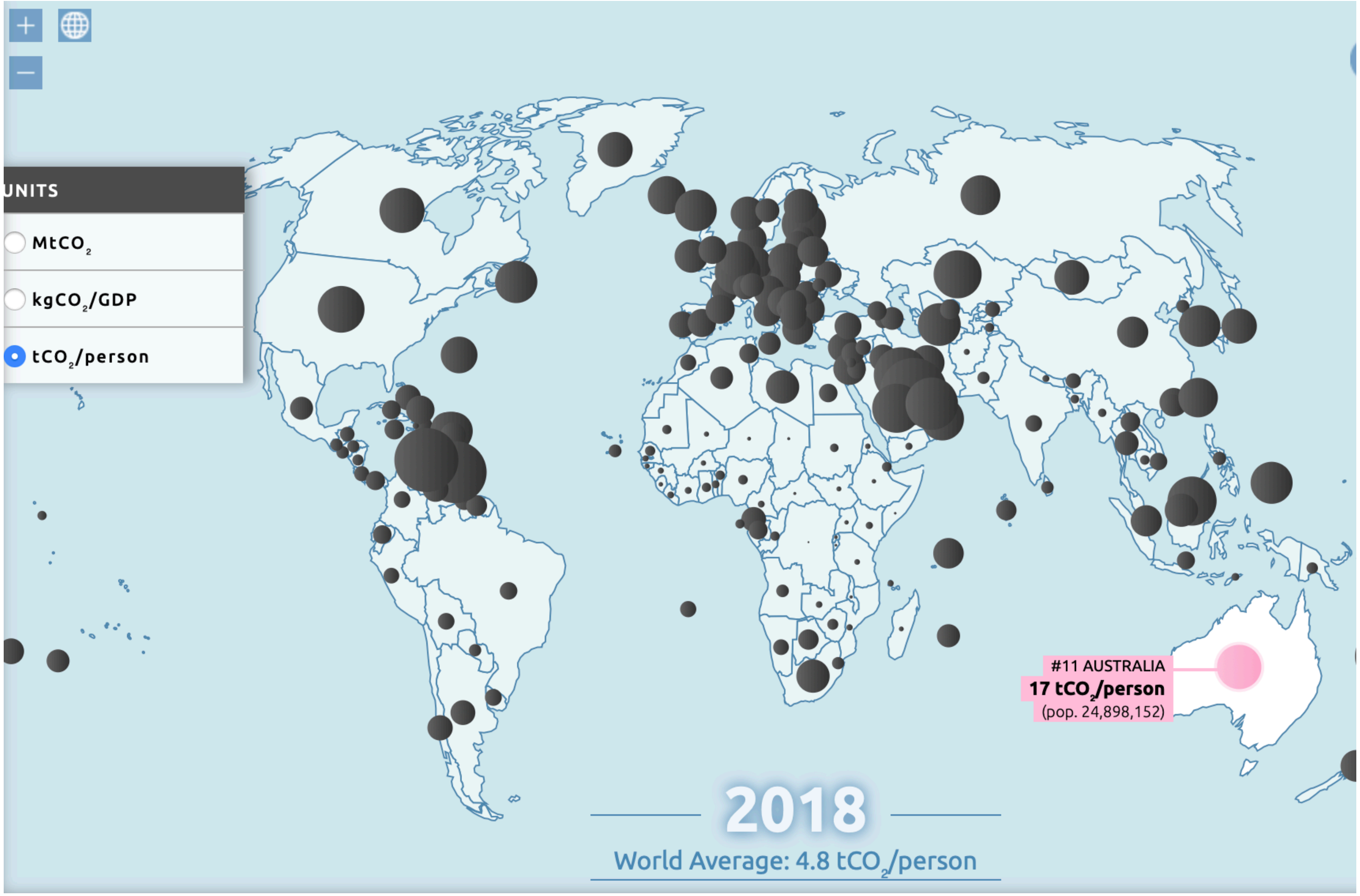
Possible enhancing feedback: Underestimated in current climate models...

(Humphrey et al. 2018, Nature)

Summary, emissions scenarios:

- Drastic and unprecedented changes required:
  - Halving of CO_2 emissions until 2030
  - Net-zero CO_2 emissions until 2040-2050 (about ~90% decrease and ~10% carbon dioxide removal)
  - Scenarios might be too optimistic, in particular about the ~10% carbon dioxide removal

Australian CO_2 emissions



Australian emissions:

17 tCO_2/person (3-4 times larger than global average)

Main sources:

Coal:
7.1 tCO_2/person
Oil:
5.8 tCO_2/person
Gas:
3.1 tCO_2/person

globalcarbonatlas.org

Outline

- The IPCC SR15 report
- Relating changes in global warming to regional climate extremes and impacts
- Climate changes at +1.5°C vs +2°C: Does half a degree matter?
- Regional climate sensitivity & role of land processes for temperature projections
- Emissions scenarios towards stabilization at +1.5°C
- Conclusions

Conclusions and outlook

- **Half a degree matters:** Limiting global warming to +1.5ºC would avoid widespread increases in extremes: hot extremes, but also heavy precipitation in several regions and drought in some regions

We are already experiencing important impacts of global warming (at +1.1ºC)

Conclusions and outlook

- **Half a degree matters:** Limiting global warming to +1.5ºC would avoid widespread increases in extremes: hot extremes, but also heavy precipitation in several regions and drought in some regions

- **Every year matters:** We need to decrease our CO_2 emissions by an additional 5% every year for next 10 years… If we wait any longer, we lose any chance of stabilizing temperature at +1.5ºC

Conclusions and outlook

- **Half a degree matters:** Limiting global warming to +1.5ºC would avoid widespread increases in extremes: hot extremes, but also heavy precipitation in several regions and drought in some regions

- **Every year matters:** We need to decrease our CO_2 emissions by an additional 5% every year for next 10 years… If we wait any longer, we lose any chance of stabilizing temperature at +1.5ºC

- **Australia is strongly threatened by climate change impacts** (heatwaves, potential droughts, fire risk, impacts to coral reefs, sea level rise) … **and also a key CO_2 emitter**

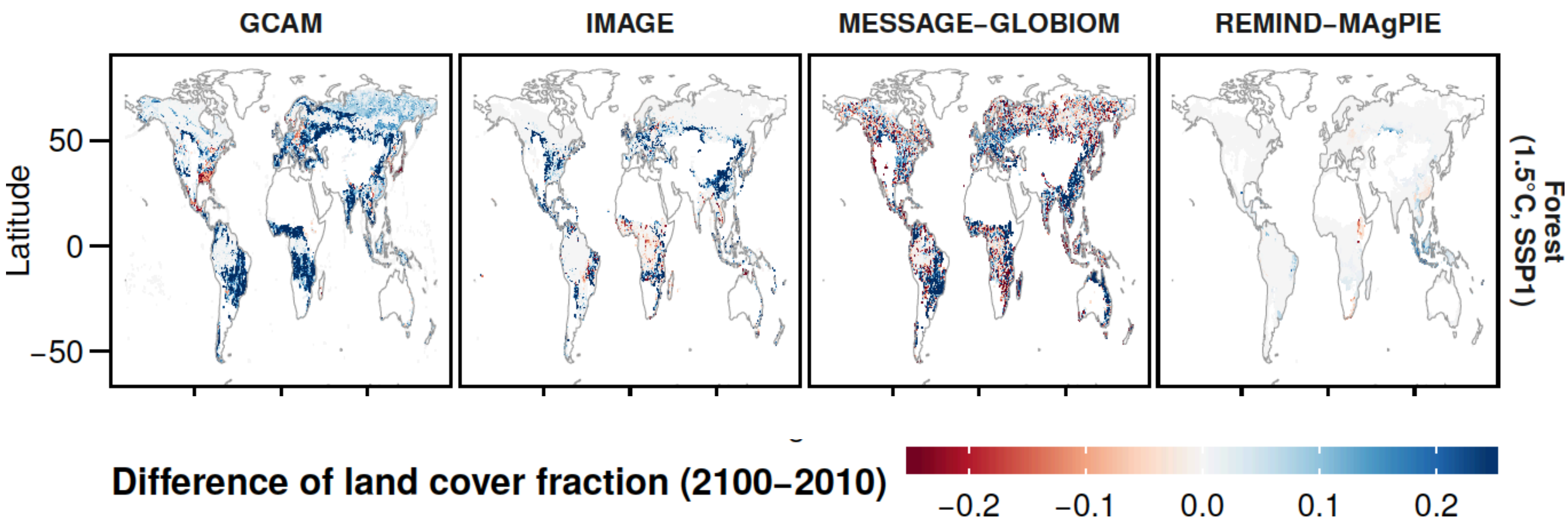
- **Biggest challenge of our times. A fraction of COVID19 recovery funding could put us on track towards +1.5ºC in coming years.**

ipcc
INTERGOVERNMENTAL PANEL ON climate change

EVERY ACTION MATTERS
EVERY BIT OF WARMING MATTERS
EVERY YEAR MATTERS
EVERY CHOICE MATTERS

Land use changes in Integrated Assessment Models (1.5ºC)

Could some of these increases in forest cover not be realized?



(Seneviratne et al. 2018, Phil. Trans. Roy. Soc. A)