ETH Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Biophysical land-use-climate interactions in low-emissions scenarios

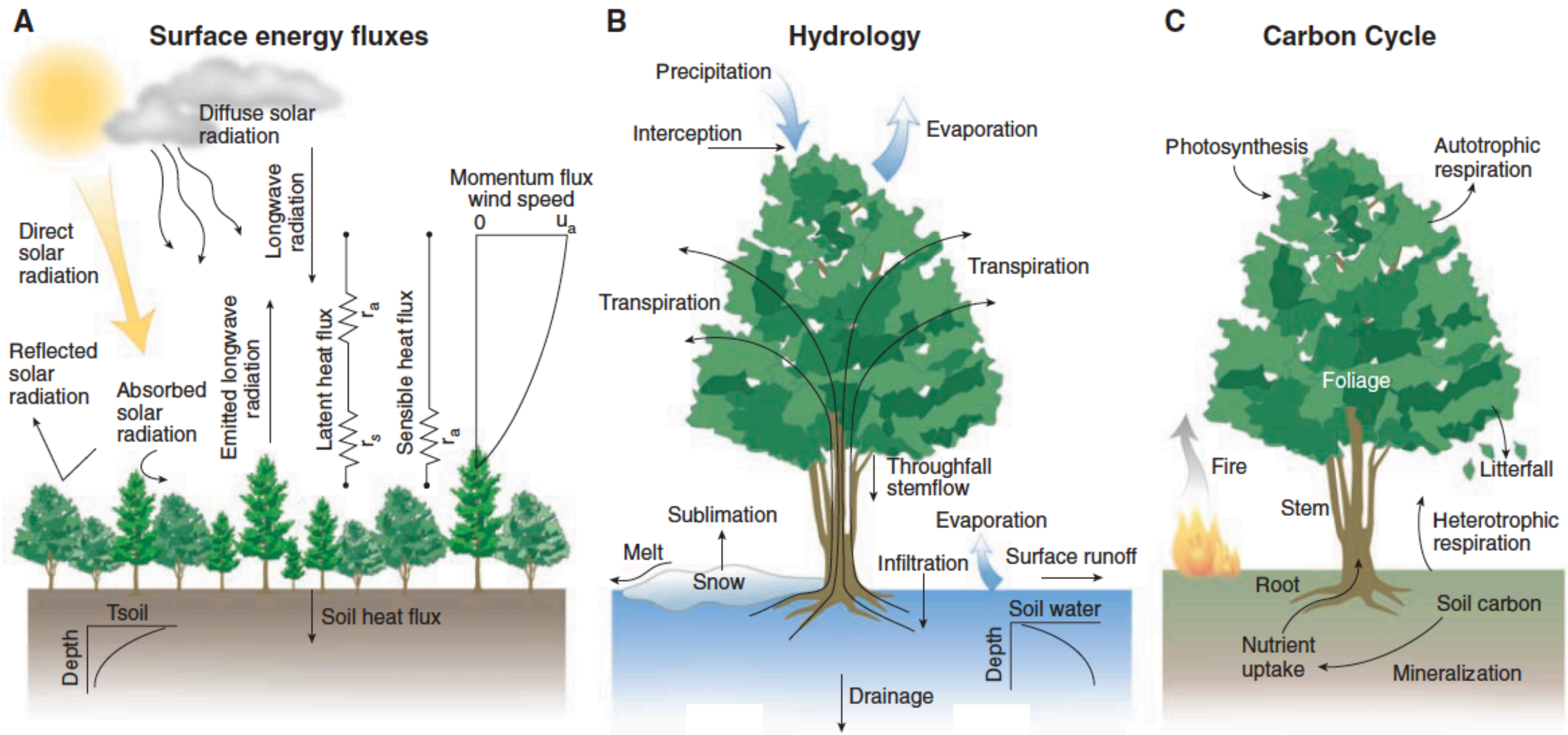
Sonia I. Seneviratne[1]

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

Acknowledgements: A. Hirsch, B. Guillod, L. Beusch, V. Brovkin, E. Davin, M. Donat, L. Gudmundsson, Q. Lejeune, S. Phipps, A. Pitman, C. Schleussner, W. Thiery, M. Vogel, R. Wartenburger, and D. van Vuuren

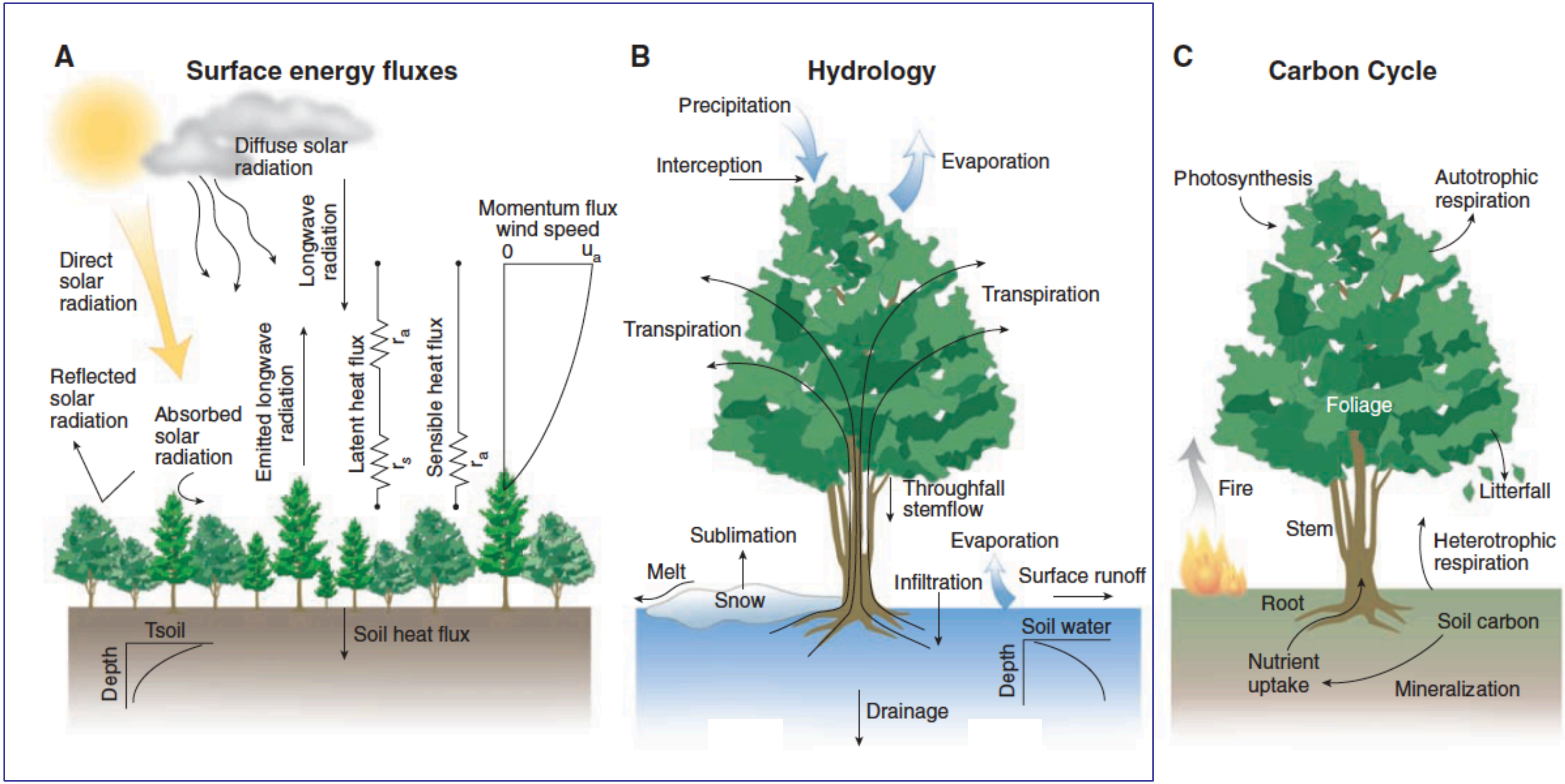
CIRAD/CLAND workshop «Albedo and climate change mitigation», December 3, 2020

Land use/cover effects on climate



(Bonan 2008, Science)

Biophysical effects (albedo, evapotranspiration)



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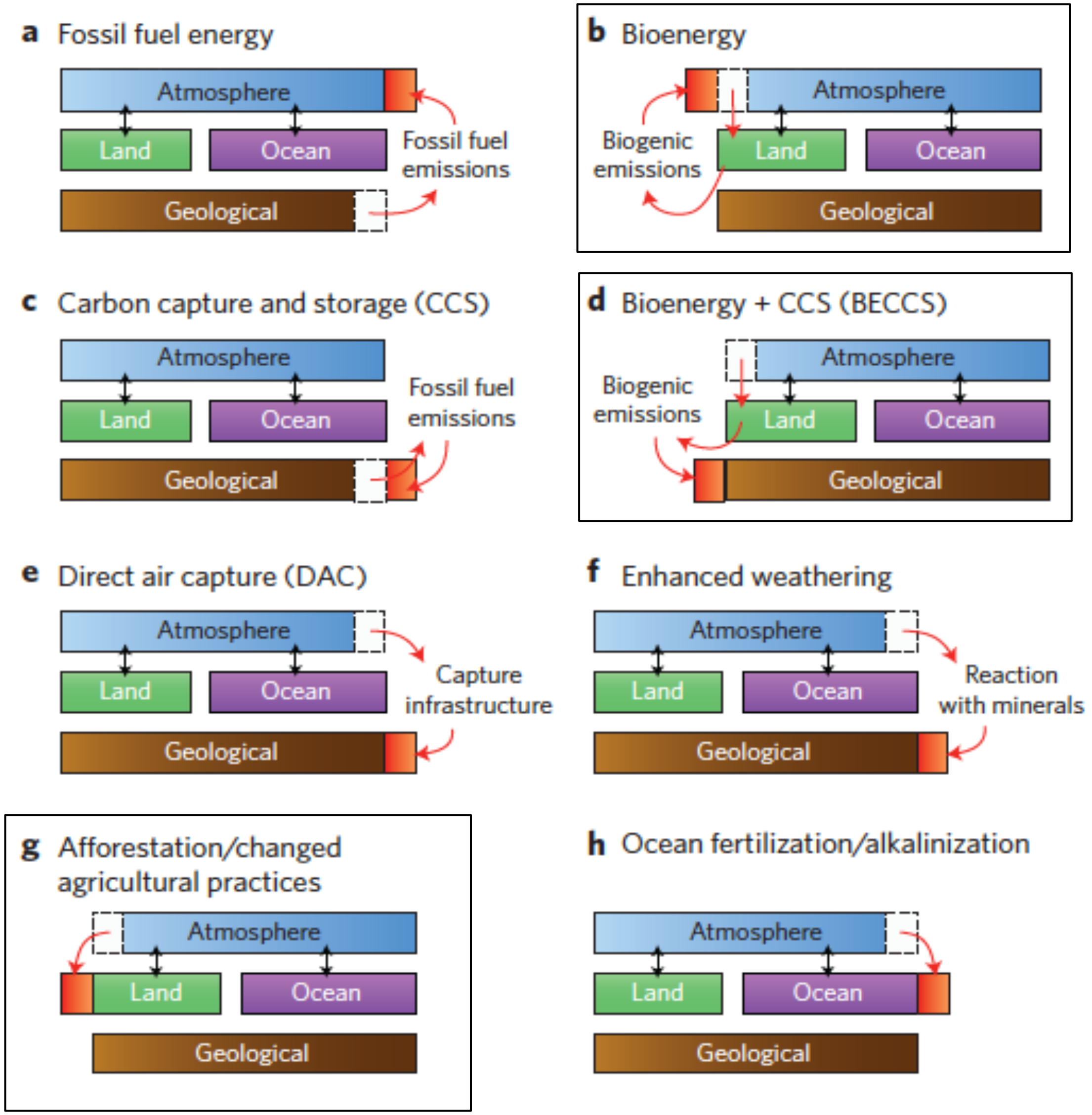
Land use change in low-emissions scenarios

Low-emissions scenarios from IPCC include extensive implementations of:

- **bioenergy use**
- **bioenergy with carbon capture and storage (BECCS)**
- **afforestation/ reforestation**

All +1.5ºC-compatible scenarios include at least some these measures *(IPCC SR15)*



(Smith et al. 2016, Nature Climate Change)

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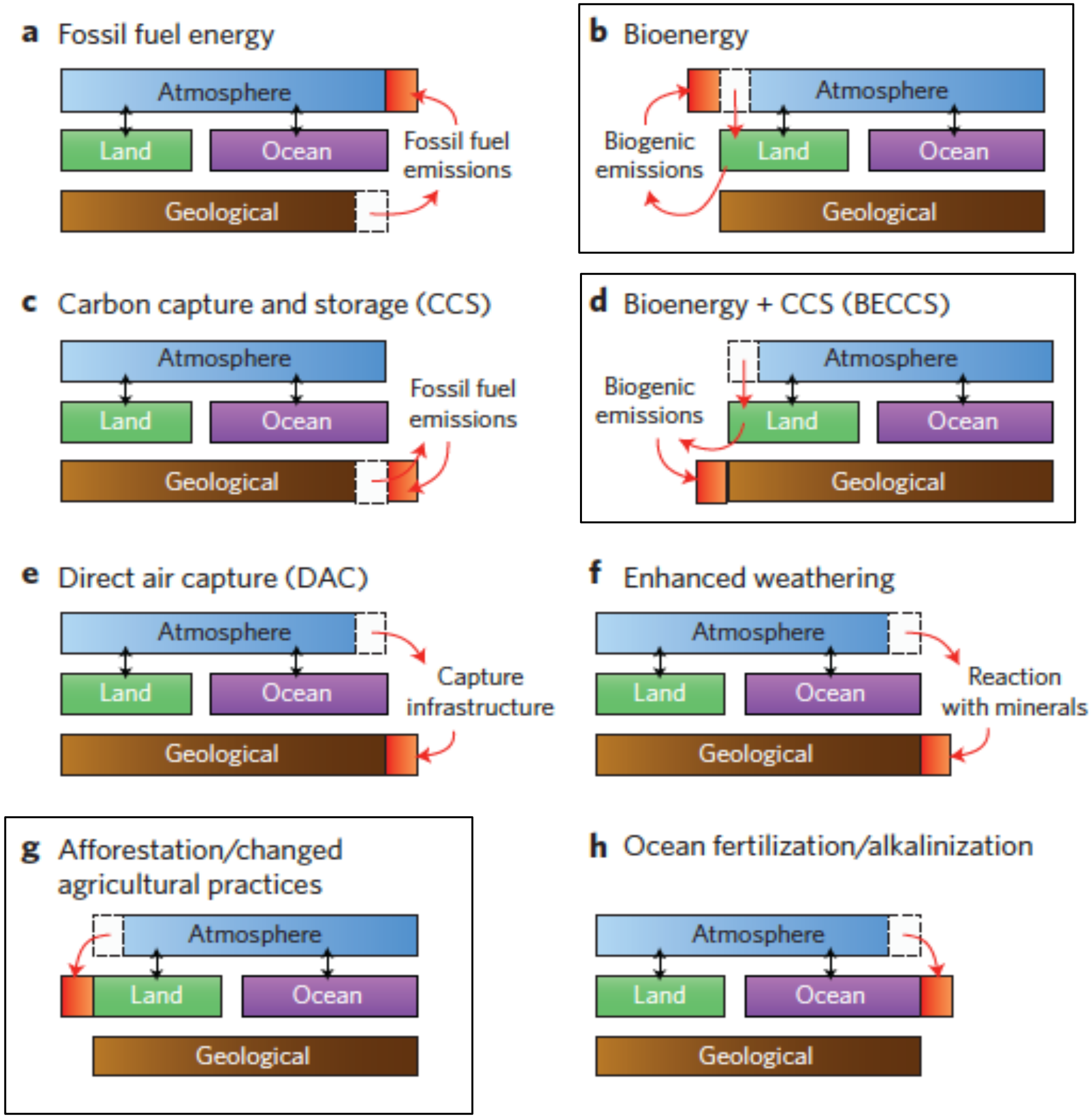
Issues:

- Biophysical feedbacks are not integrated!
- Are the projected land use changes resilient to climate change?



(Smith et al. 2016, Nature Climate Change)

Overview

AGU PUBLICATIONS

Earth's Future

RESEARCH ARTICLE
10.1002/2017EF000744

Biogeophysical Impacts of Land-Use Change on Climate Extremes in Low-Emission Scenarios: Results From HAPPI-Land

Annette L. Hirsch[1], Benoit P. Guillod[1,2], Sonia I. Seneviratne[1], Urs Beyerle[1], Lena R. Boysen[3], Victor Brovkin[3], Edouard L. Davin[1], Jonathan C. Doelman[4], Hyungjun Kim[5], Daniel M. Mitchell[6], Tomoko Nitta[5], Hideo Shiogama[7], Sarah Sparrow[8], Elke Stehfest[4], Detlef P. van Vuuren[4,9], and Simon Wilson[10,11]

[1]Institute for Atmospheric and Climate Science, Eidgenössische Technische Hochschule (ETH) Zurich, Zurich, Switzerland, [2]Institute for Environmental Decisions, Eidgenössische Technische Hochschule (ETH) Zurich, Zurich, Switzerland, [3]Land in the Earth System, Max Planck Institute for Meteorology, Hamburg, Germany, [4]PBL Netherlands Environmental Assessment Agency, Den Haag, The Netherlands, [5]Institute of Industrial Science, The University of Tokyo, Tokyo, Japan, [6]School of Geographical Sciences, University of Bristol, Bristol, UK, [7]Center for Global Environmental Research, National Institute for Environmental Studies, Tsukuba, Japan, [8]Oxford e-Research Centre (OeRC), University of Oxford, Oxford, UK, [9]Copernicus Institute for Sustainable Development, Utrecht University, Utrecht, The Netherlands,

Key Points:

- Land-use change (LUC) accounts for 20% change in temperature extremes for low-emission scenarios
- Multimodel results show projected temperature extremes depend on where and what land-based mitigation activities are pursued
- For some regions and models, LUC can affect temperature extremes as much as a half degree change in global mean temperature

Hirsch et al. 2018, Earth's Future

"HAPPI-Land" experiment
(based on IMAGE scenarios)

PHILOSOPHICAL TRANSACTIONS A

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Research

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Cite this article: Seneviratne SI *et al.* 2018 Climate extremes, land– climate feedbacks and land-use forcing at 1.5°C. *Phil. Trans. R. Soc. A* **376**: 20160450.
http://dx.doi.org/10.1098/rsta.2016.0450

Accepted: 31 January 2018

One contribution of 20 to a theme issue 'The Paris Agreement: understanding the physical and social challenges for a warming world of 1.5°C above pre-industrial levels'.

Climate extremes, land–climate feedbacks and land-use forcing at 1.5°C

Sonia I. Seneviratne[1], Richard Wartenburger[1], Benoit P. Guillod[1,2], Annette L. Hirsch[1], Martha M. Vogel[1], Victor Brovkin[3], Detlef P. van Vuuren[4,5], Nathalie Schaller[6], Lena Boysen[3], Katherine V. Calvin[7], Jonathan Doelman[4], Peter Greve[8], Petr Havlik[8], Florian Humpenöder[9], Tamas Krisztin[8], Daniel Mitchell[10], Alexander Popp[9], Keywan Riahi[8], Joeri Rogelj[1,8], Carl-Friedrich Schleussner[9,11], Jana Sillmann[6] and Elke Stehfest[4]

[1]Institute for Atmospheric and Climate Science, and [2]Institute for Environmental Decisions, ETH Zurich, 8092 Zurich, Switzerland

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

Review of expected effects.
Projected changes in land cover in +1.5ºC and +2ºC scenarios in Integrated Assessment Models.

Biophysical effects of LU changes: Links to CO_2 exchanges

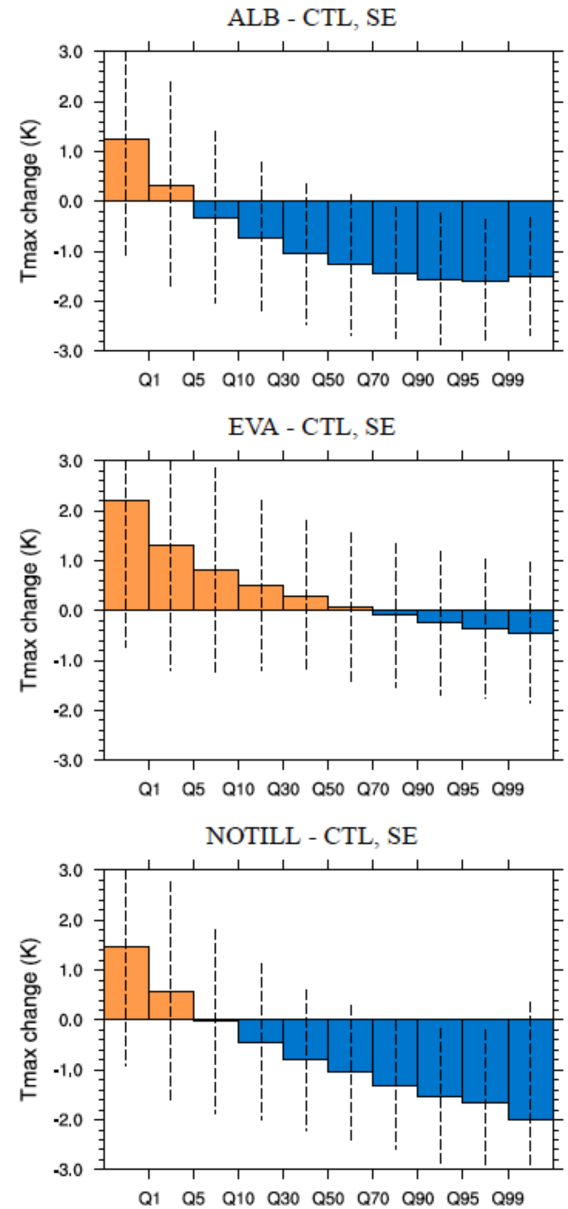
Substantial co-benefits (no-till farming)

Substantial trade-offs (e.g. afforestation)

Agricultural management and temperature extremes

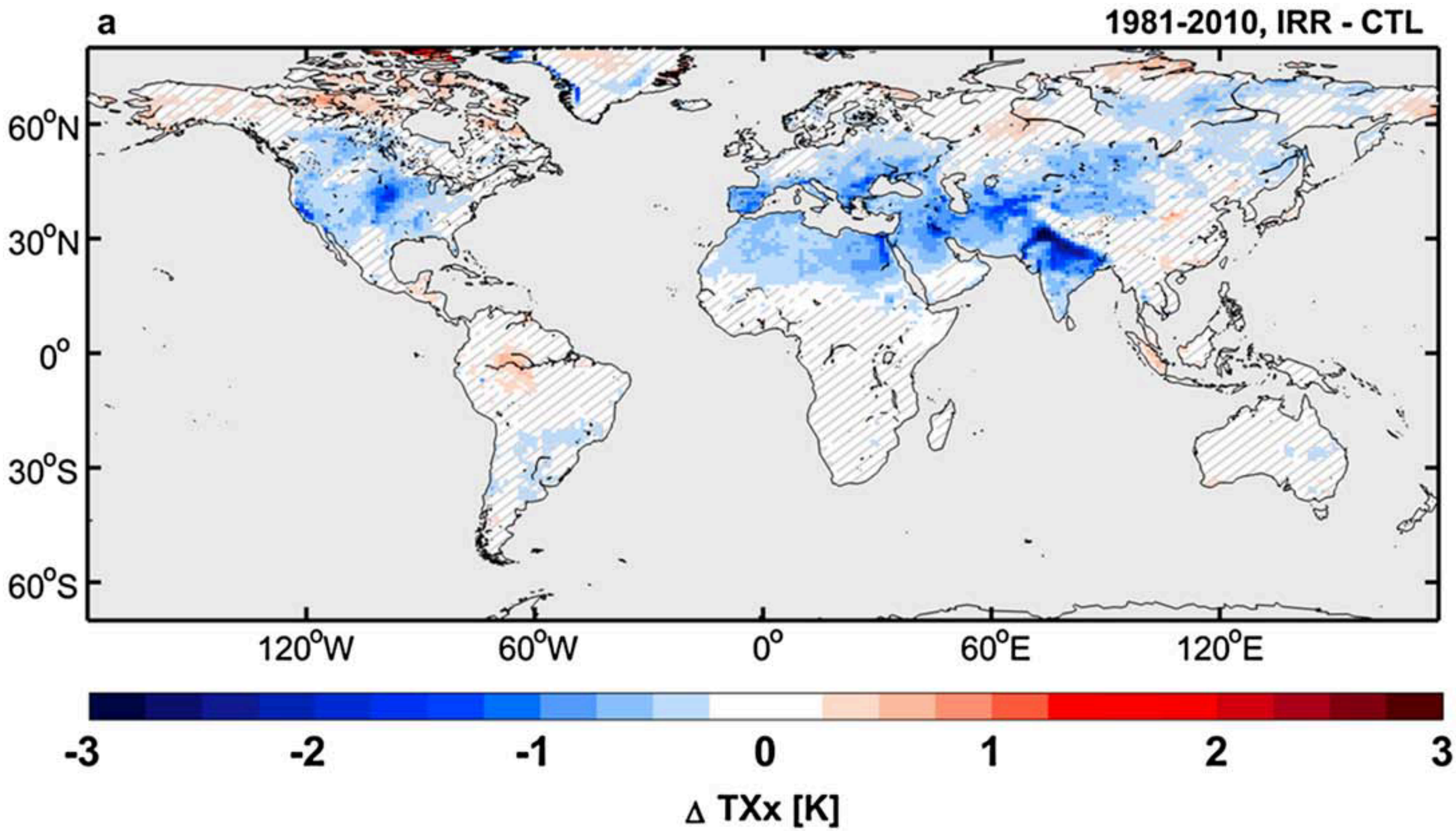
Impacts of no-till farming (albedo, evaporation) on regional temperature extremes:

Preferential cooling of hot extremes both from albedo and evaporation effects (up to 1-2C)!



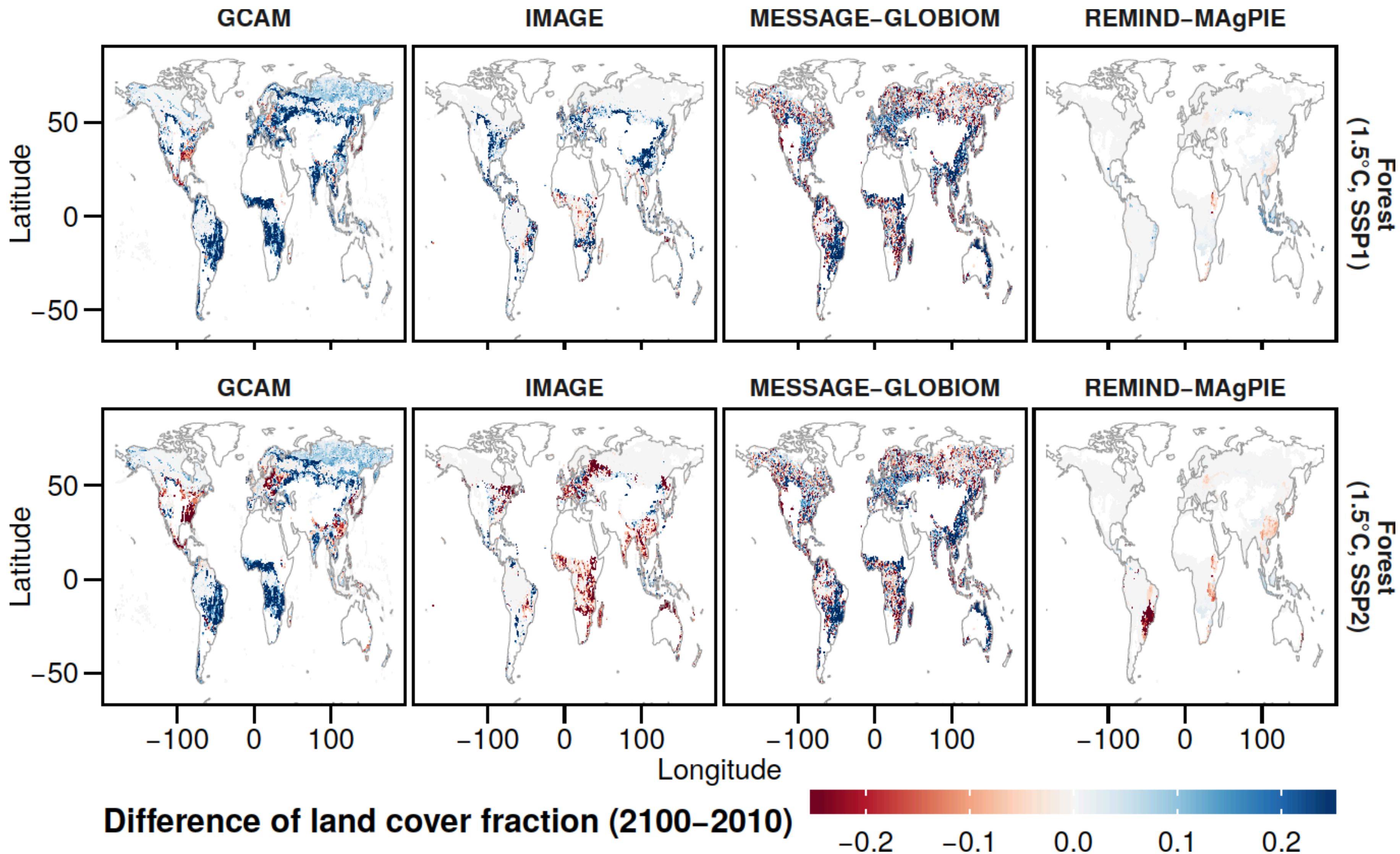
(Davin et al. 2014, PNAS)

Present-day impacts of irrigation



(Thiery et al. 2017, JGR)

Land use changes in Integrated Assessment Models (1.5ºC)

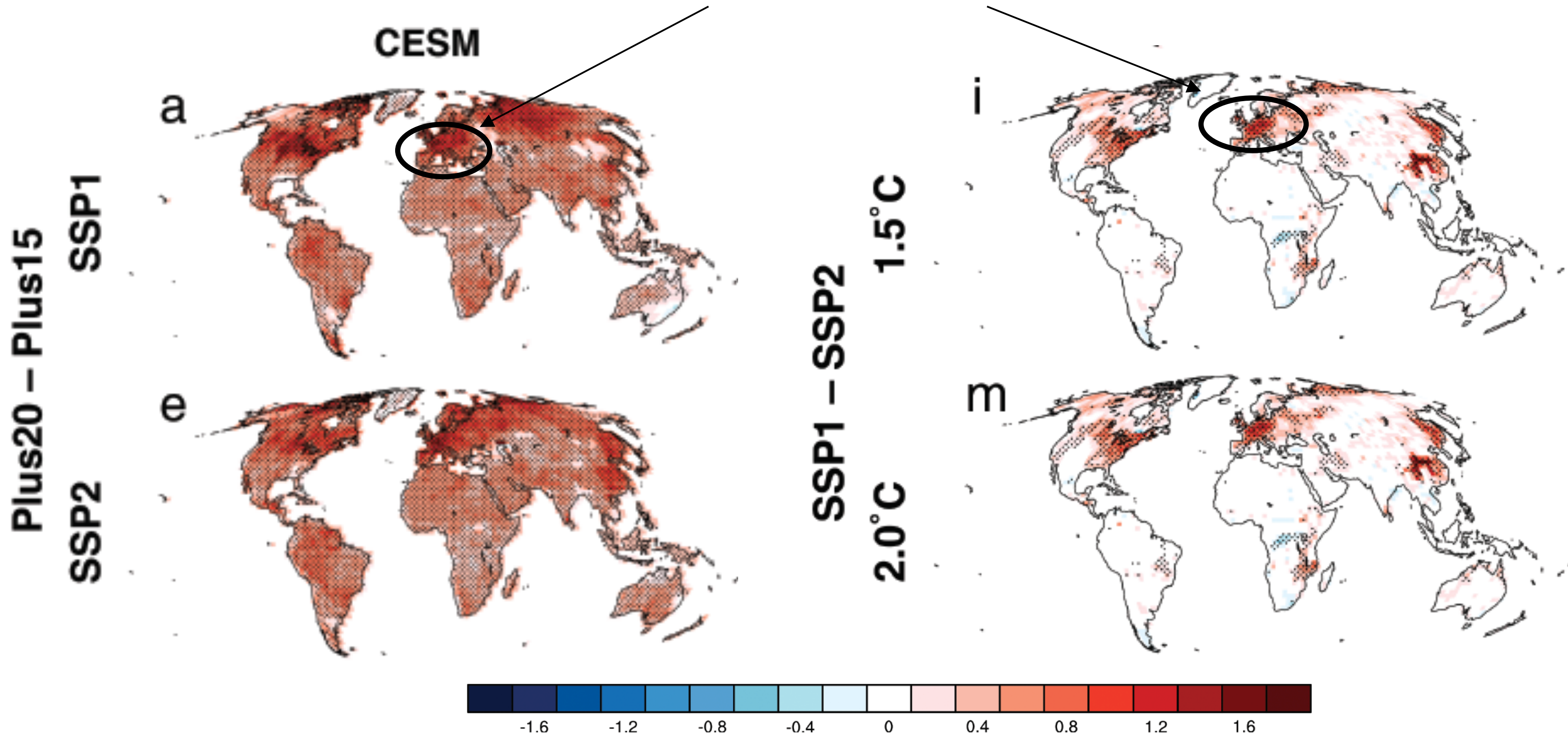


(Seneviratne et al. 2018, Phil. Trans. Roy. Soc. A)

Land use changes in Integrated Assessment Models (1.5ºC)

Differences in temperature of yearly hottest day (TXx) due to LU feedbacks based on IMAGE LU scenarios:

Regionally, differences in land use (SSP1,SSP2) can have as much impact as difference in global warming of 0.5ºC (2ºC,1.5ºC)



(Hirsch, Guillod, et al. 2018, Earth Future)

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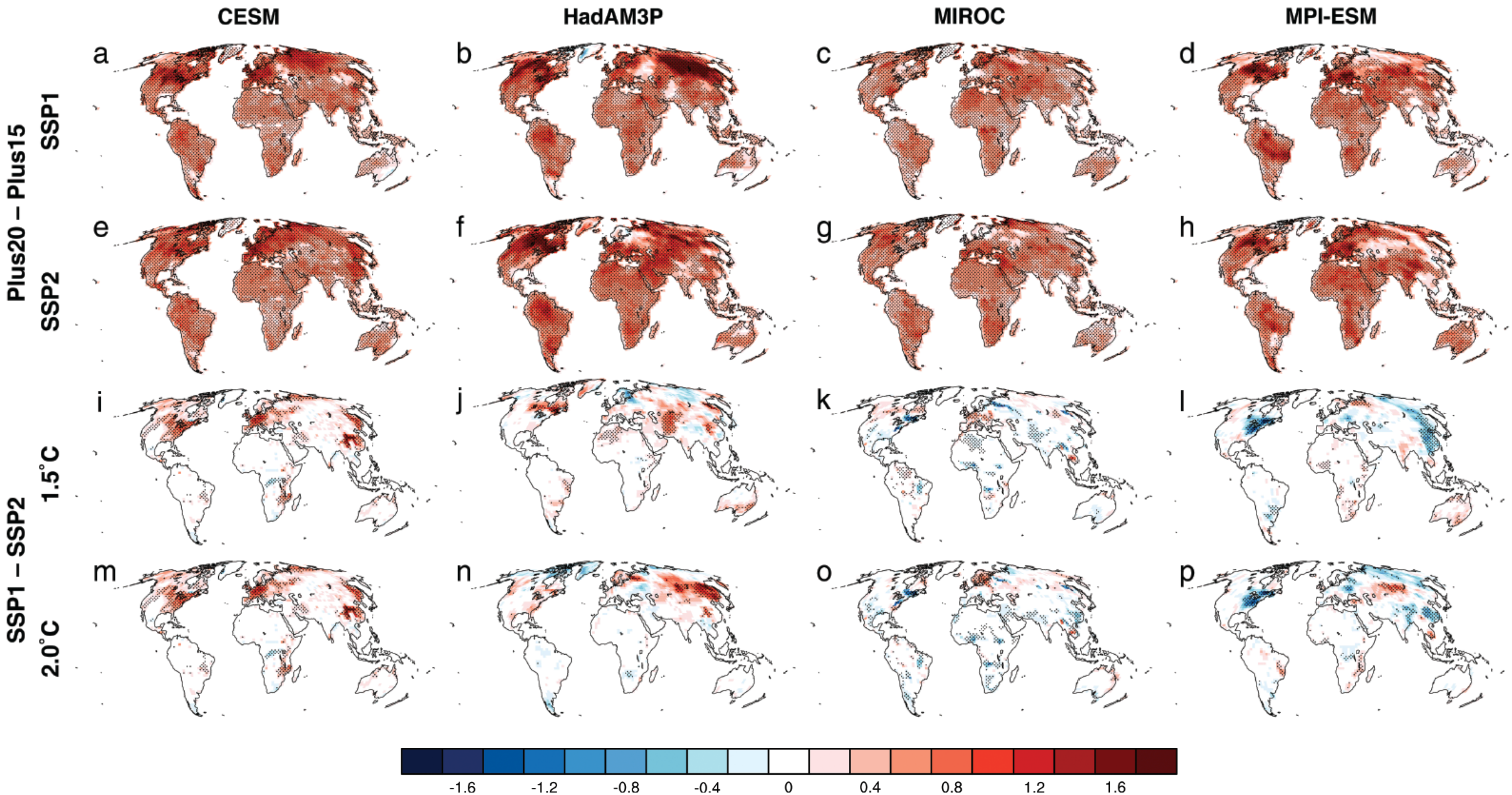

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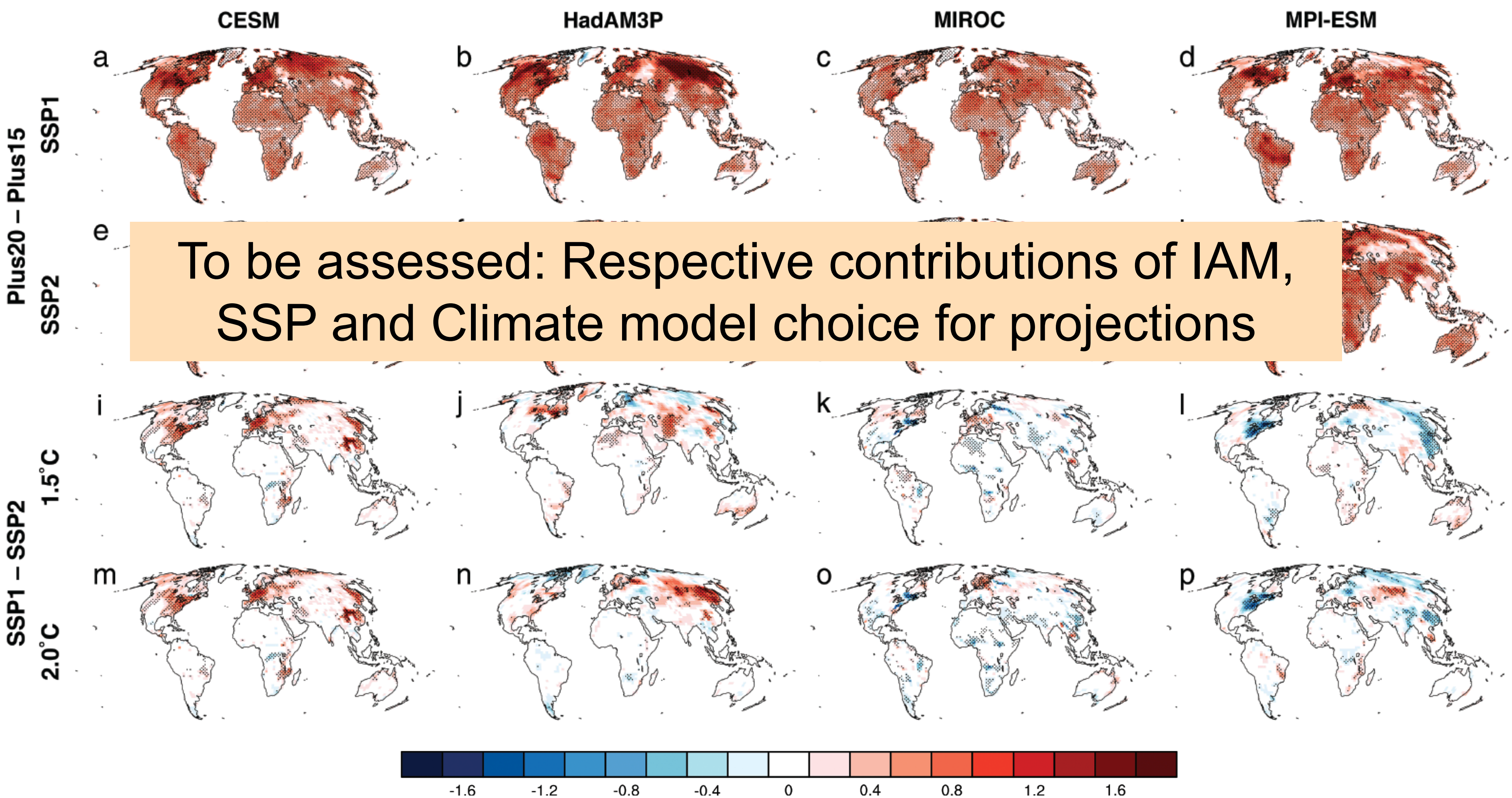
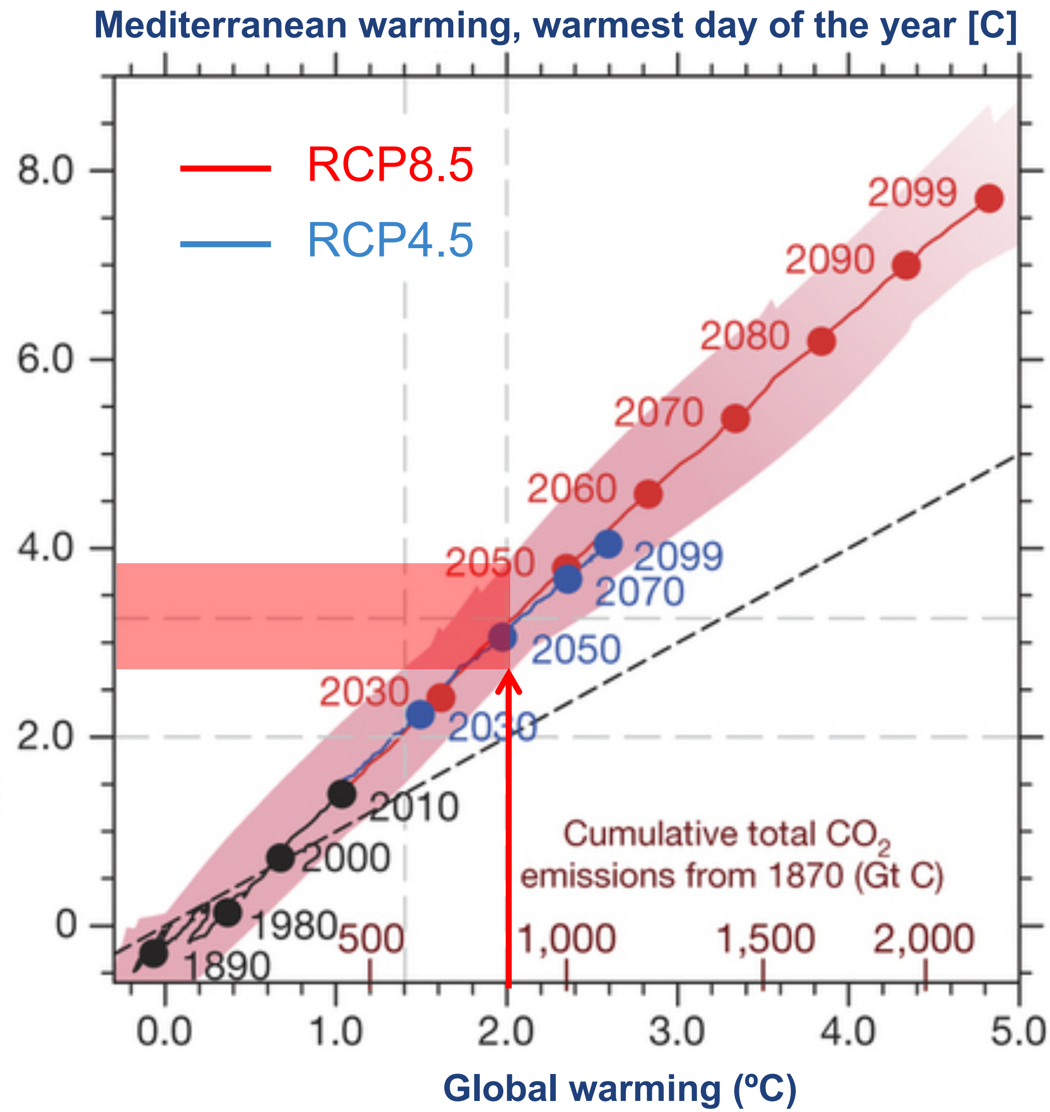


To be assessed: Respective contributions of IAM, SSP and Climate model choice for projections

(Hirsch, Guillod, et al. 2018, Earth Future)

Regional extremes vs global climate change

Why is LU so relevant for regional changes in temperature extremes?



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

(Seneviratne et al. 2016, Nature)

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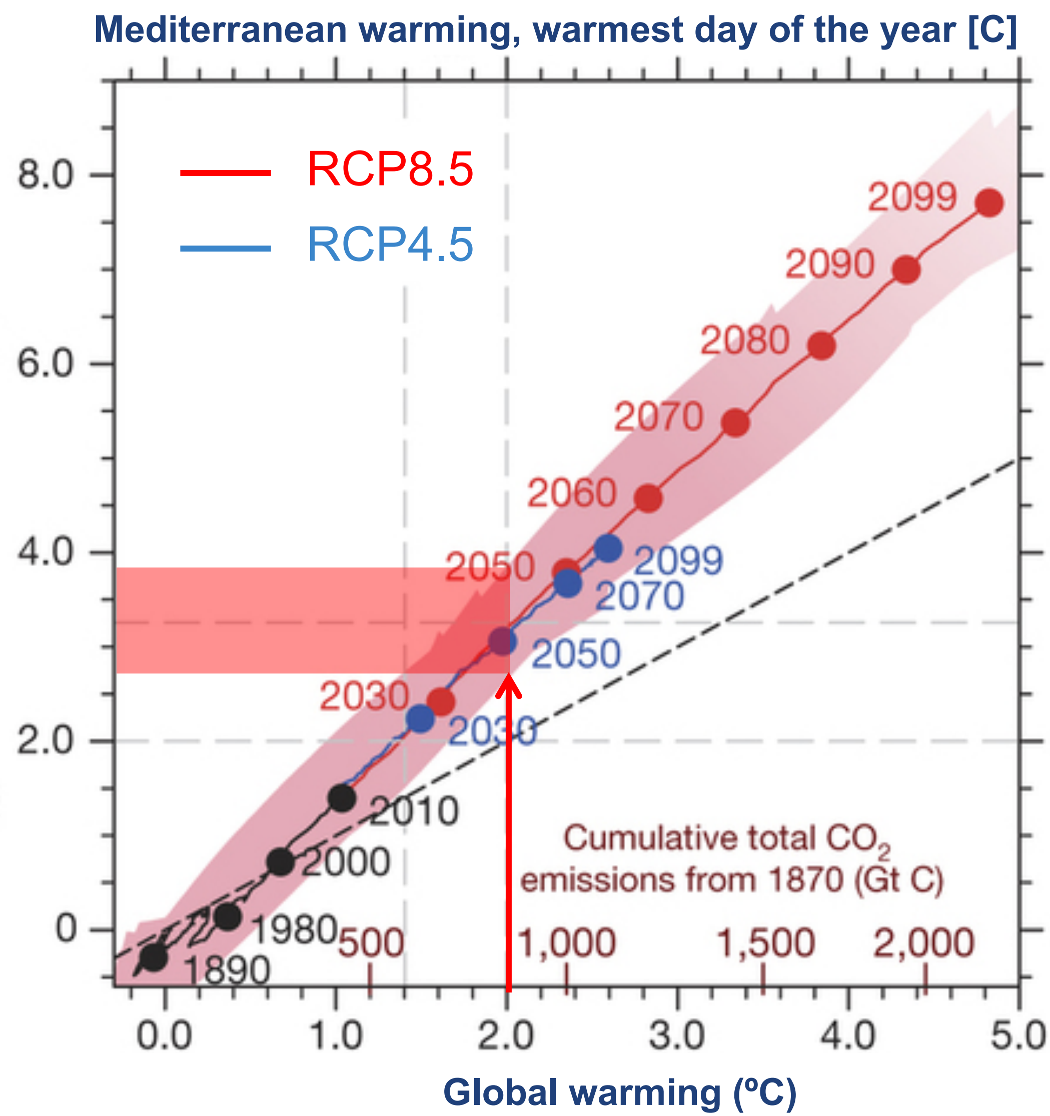

- Stronger warming of extremes in land hot spots vs global temperature
- Robust and almost linear scaling, mostly independent of emissions scenario! *(see also Wartenburger et al. 2017, GMD)*

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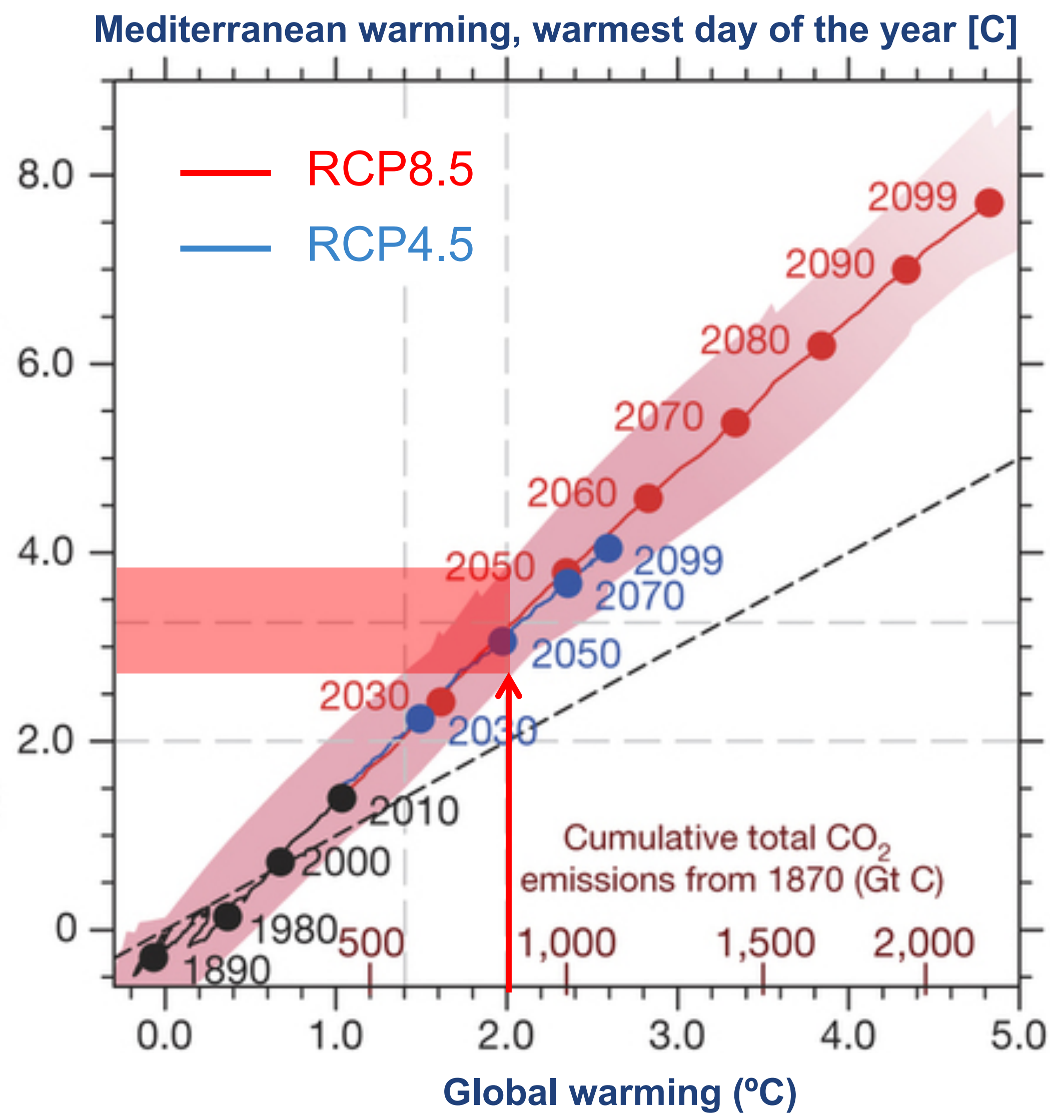


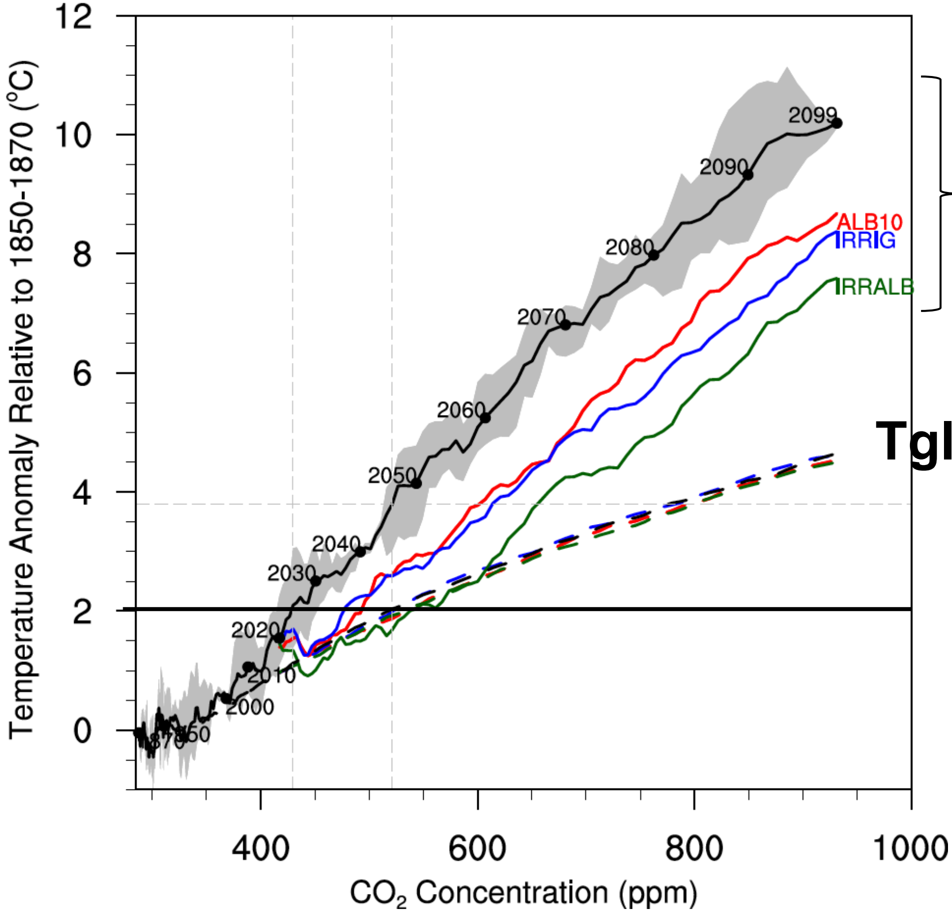
- Stronger warming of extremes in land hot spots vs global temperature
- Robust and almost linear scaling, mostly independent of emissions scenario! *(see also Wartenburger et al. 2017, GMD)*
- *Much of the additional warming is due to land processes (projected drying) (see Vogel et al. 2017, GRL)*

(Seneviratne et al. 2016, Nature)

Biophysical effects of land use changes: Projections

Effects of albedo changes (+0.1) and irrigation on regional temperature extremes (CESM simulations)

Central North American warming, hottest day of the year [C]



TXx (hottest day of year): Reference run and Land use scenarios (albedo increases, irrigation, and combination)

Tglob

(Hirsch et al. 2017, JGR)

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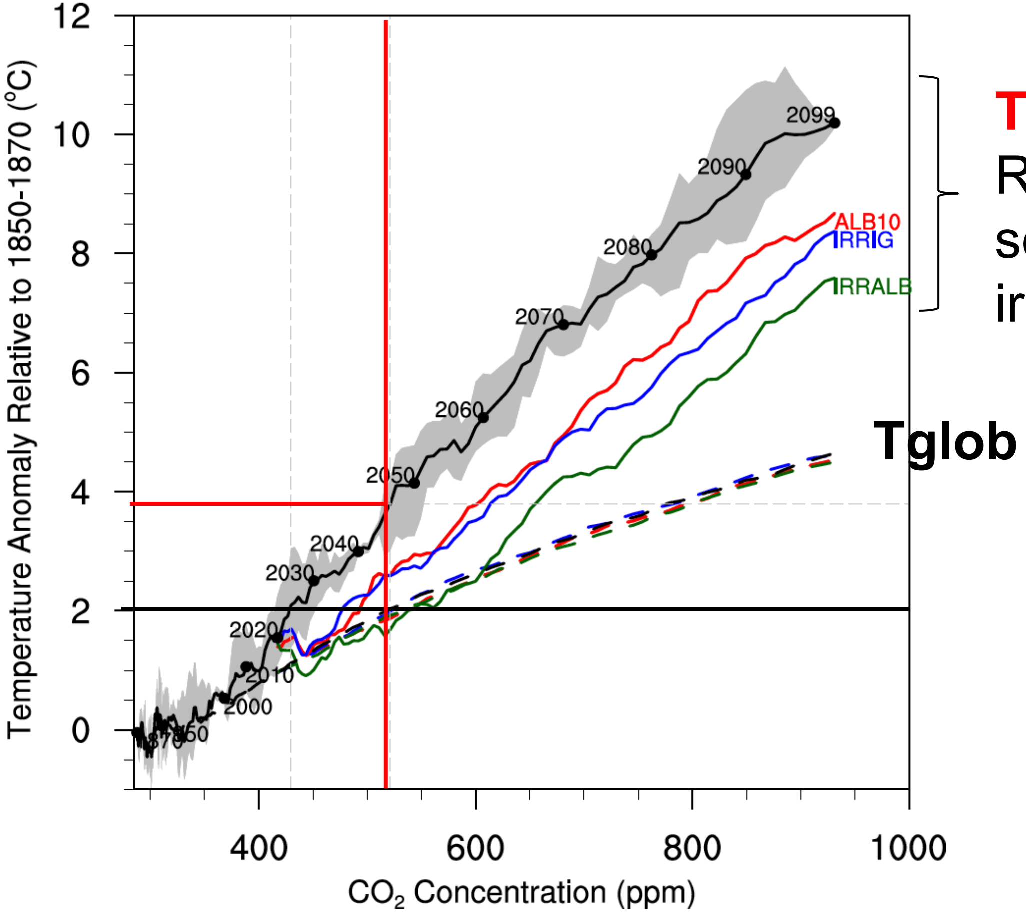

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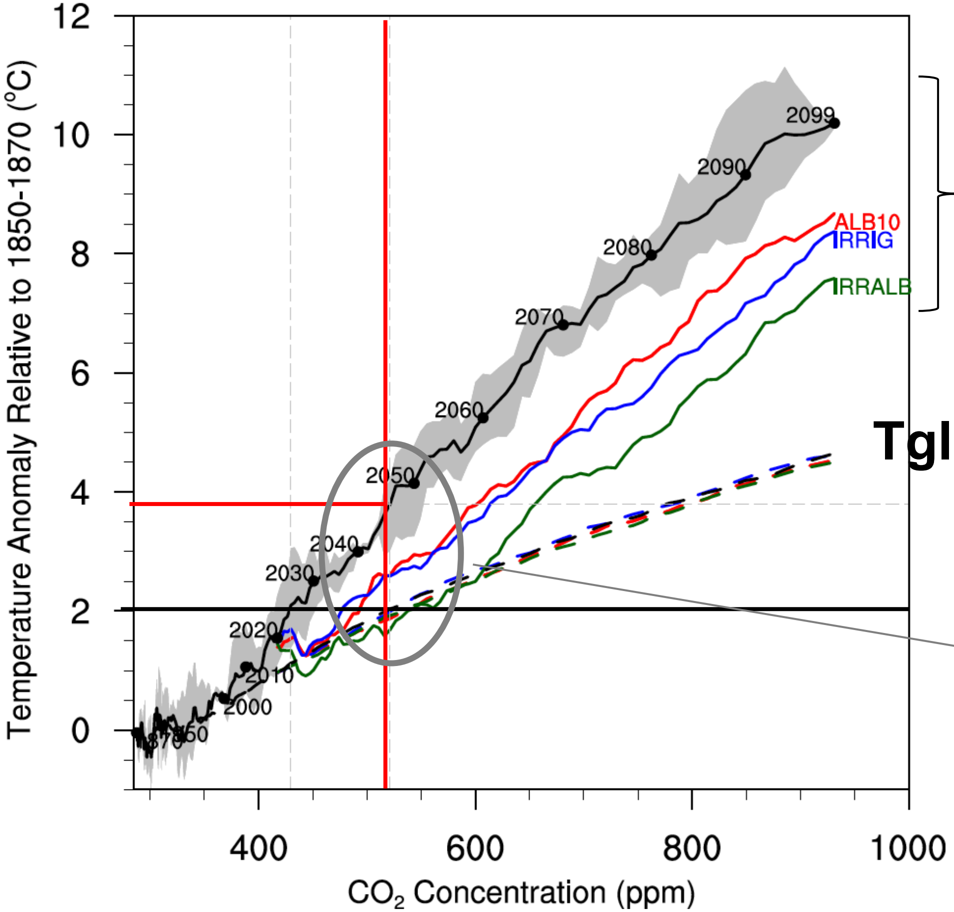

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Land use effects are particularly relevant for low-emissions scenarios!

(Hirsch et al. 2017, JGR)

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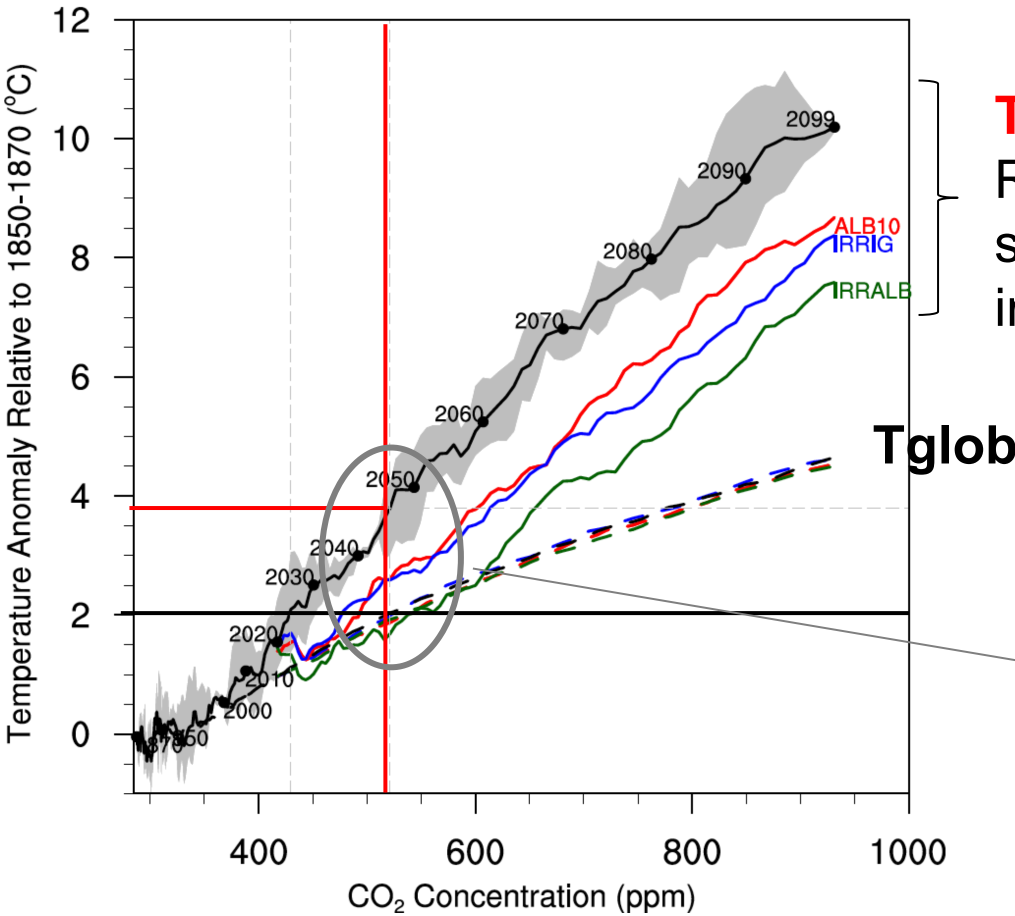


TXx (hottest day of year): Reference run and Land use scenarios (albedo increases, irrigation, and combination)

Land use effects are particularly relevant for low-emissions scenarios!

But not included in Integrated Assessment Models…

(Hirsch et al. 2017, JGR)

If land albedo and other biophysical land use effects are so effective, could we consider them to intentionally modify climate? (“climate-effective land management”, “land radiative management”)

Land radiative management / Climate-effective land management

nature geoscience
PERSPECTIVE
https://doi.org/10.1038/s41561-017-0057-5

Land radiative management as contributor to regional-scale climate adaptation and mitigation

Sonia I. Seneviratne[1*], Steven J. Phipps[2,3], Andrew J. Pitman[4], Annette L. Hirsch[1], Edouard L. Davin[1], Markus G. Donat[2], Martin Hirschi[1], Andrew Lenton[5], Micah Wilhelm[1] and Ben Kravitz[6]

Considering potential effects of changes in albedo (but irrigation also relevant!)

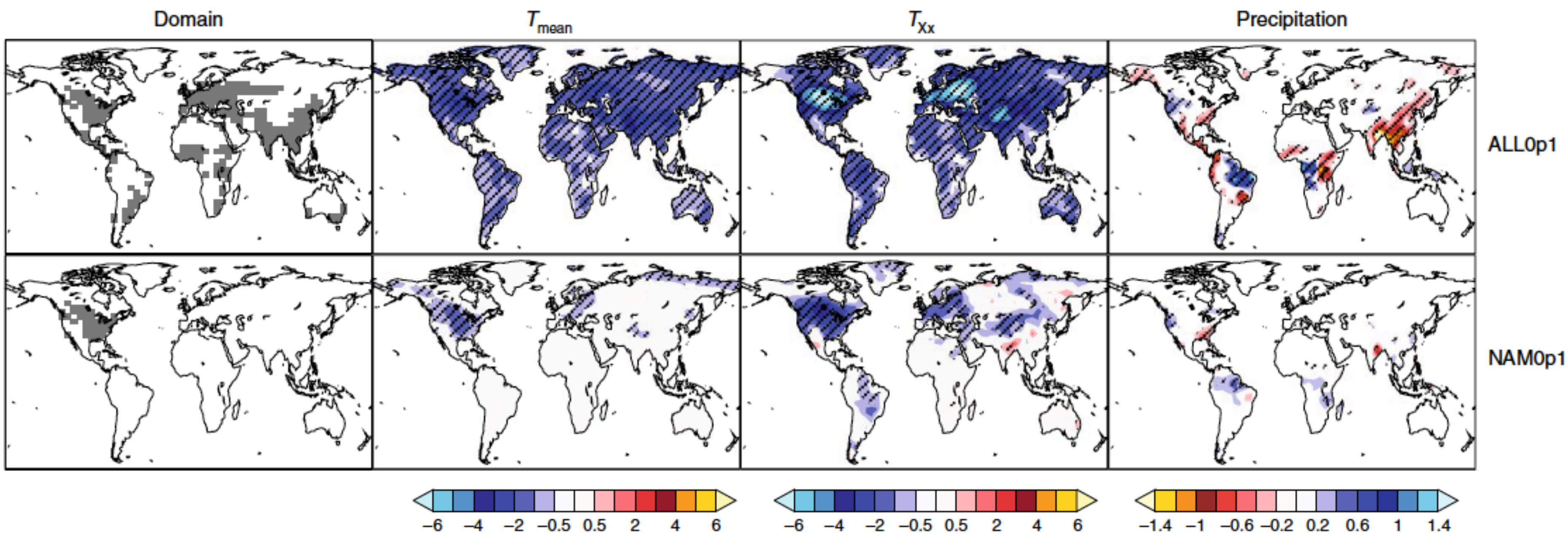
Table 1 | Approaches relevant to LRMreg in agricultural and urban areas

	No-till farming (albedo changes from retaining crop residues)	Crop phenology and timing of practices (for example, double cropping	Biogeoengineering (cropping with natural, selected, or genetically modified reflective varieties)	Greenhouses	Urban albedo (white roofs, higher reflectivity of paving)
Impact on land albedo	Approx. +0.05 to +0.20 in the case of crops with high reflectivity residues (for example, wheat)[15,20,21]; less efficient for other crops.	Not quantified, probably similar to no-till farming in regions with tillage; depends on crop albedo, and background bare soil albedo, may also vary during crop growth[24].	Approx. +0.02 to + 0.15 (including crop dependent variations in glaucousness, trichomes, canopy morphology)[17,18,42,66].	Approx. +0.05 (winter) to +0.15 (summer)[26].	Approx. +0.1 to +0.15 as average increase over the urban areas[16,18,19] (locally: approx. +0.15 over roofs and +0.25 over pavement[19]).

(Seneviratne et al. 2018, Nature Geoscience)

Land radiative management / Climate-effective land management

- +0.1 in albedo cools down hot extremes (4xCO_2 simulations)
- Negative effects possible (e.g. precipitation decrease in SE Asia)
- Effects mostly regionally constrained (e.g. less impact on monsoon precipitation if no changes in albedo in SE Asia)
- Realism? … Probably better than sulfate aerosol injections, but also limitations and concerns; no mitigation.



(Seneviratne et al. 2018, Nature Geoscience)

Land radiative management / Climate-effective land management

Table 2 | Comparison of LRMreg and SRMglob with respect to common concerns over climate engineering

Concern	SRMglob	LRMreg
Regional climate trade-offs	Substantial regional climate trade-offs[8,77,78]. Reduction of monsoon precipitation[79] and major regional overshooting in temperature extremes and precipitation (Supplementary Fig. 3) if aiming at cancelling global temperature response.	Signal mostly regional in scope as long as LRMreg is applied over single regions (Figs. 1 and 2). Application not as effective in all regions, and possible negative effects (weakening of monsoon) if applied in Southeast Asia (Fig. 1).
Environmental side effects	Possible ozone depletion from sulfate aerosol injections[13,80].	In the case of agriculture-based LRMreg, implementation needs to be weighed against other demands for land use[56] No reported side environmental effects of increased reflectivity of buildings or pavement[19].
Risk for cross-boundary conflicts	Large, because of creation of 'winners' and 'losers'[81] and possibility for single country to affect climate in other countries.	Limited because of mostly regional impact, provided deployment is kept regional in scope (Fig. 1).
Testing	Not tested[9,82]; prior volcanic eruptions proposed as analogies[4,81].	Approaches (see Table 1) are generally related to existing agricultural or urban implementations. Testing of relevant techniques available at local to subregional scale (in particular for modified urban albedo[19,76]), but no large-scale testing and assessment with specific focus on LRMreg questions. Monitoring on larger scale in the case of partial deployment would be possible without major investments (existing measurement networks and satellite retrievals).
Reversal	Deployment could be stopped quickly, but environmental effects could be long-lived (ozone depletion). Rapid increase in surface temperature if stratospheric sulfate injections were stopped abruptly, possibly leading to even larger impacts ('termination effect')[52-54].	Over agricultural areas, crops are renewed every year. Reversal possible. No expectation of an abrupt response because of required timescales of implementation on the ground.
Continued detrimental effects of CO_2 concentrations on environment (for example ocean acidification[1,55])	Not addressed (unabated, or possibly increased[83]).	Not addressed.
Moral hazard[7]	Exists for arguments in favour of strong deployment to reduce global mean temperature.	Less critical because of smaller/negligible global impact.

(Seneviratne et al. 2018, Nature Geoscience)

Are wide-spread modifications of land use/land cover to modify climate a safe bet (either through carbon-cycle or biophysical effects)?

…e.g. "trillion trees project"

Trump says US to join one trillion trees initiative

21 JAN 2020 / 19:33 H.

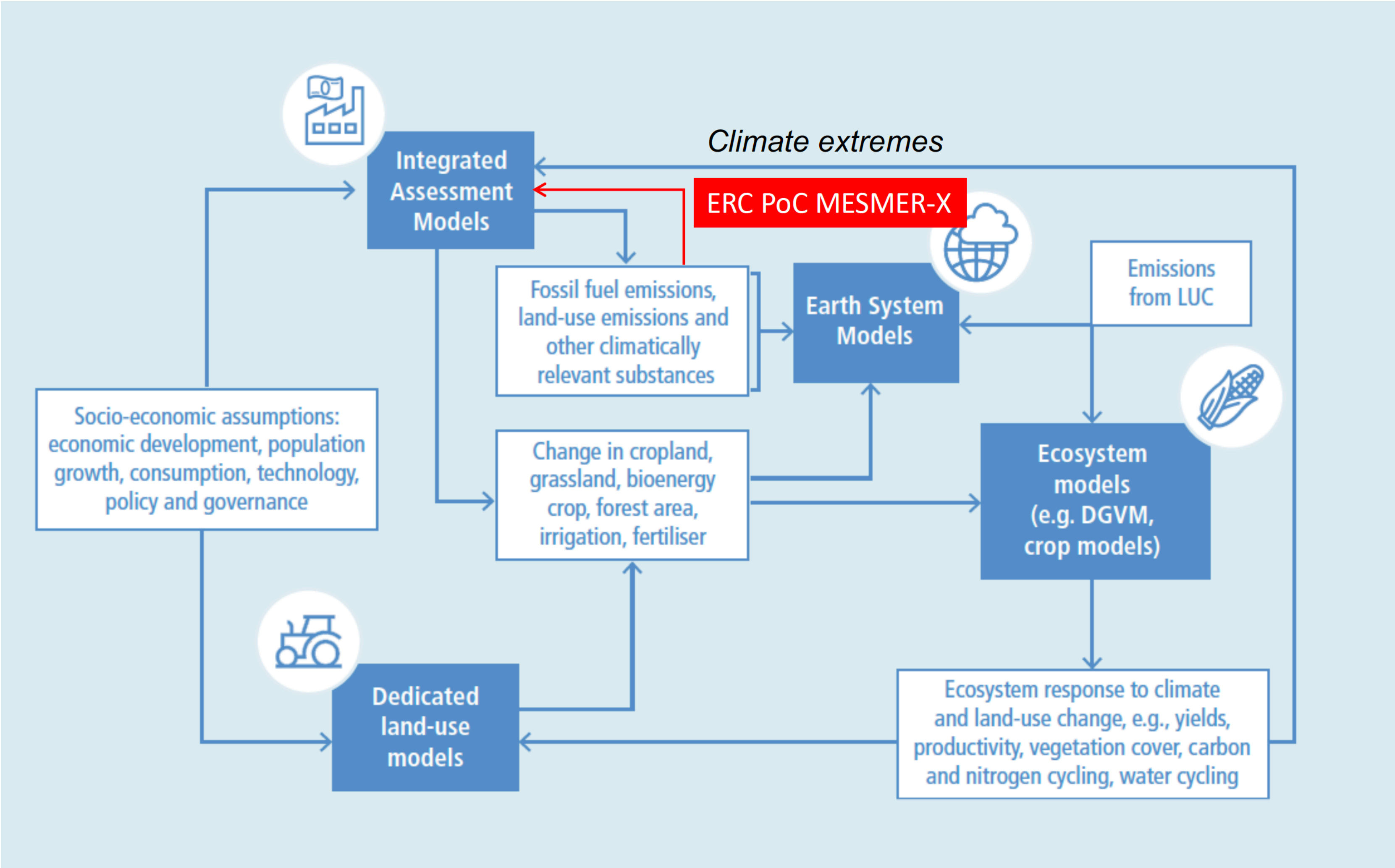
Land-based carbon dioxide removal vs extremes

- Afforestation
- Bioenergy with carbon capture and storage

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

ERC Proof-of-Concept MESMER-X project

(2021-2022)



ESM emulator: Speeding up ESM-IAM interface

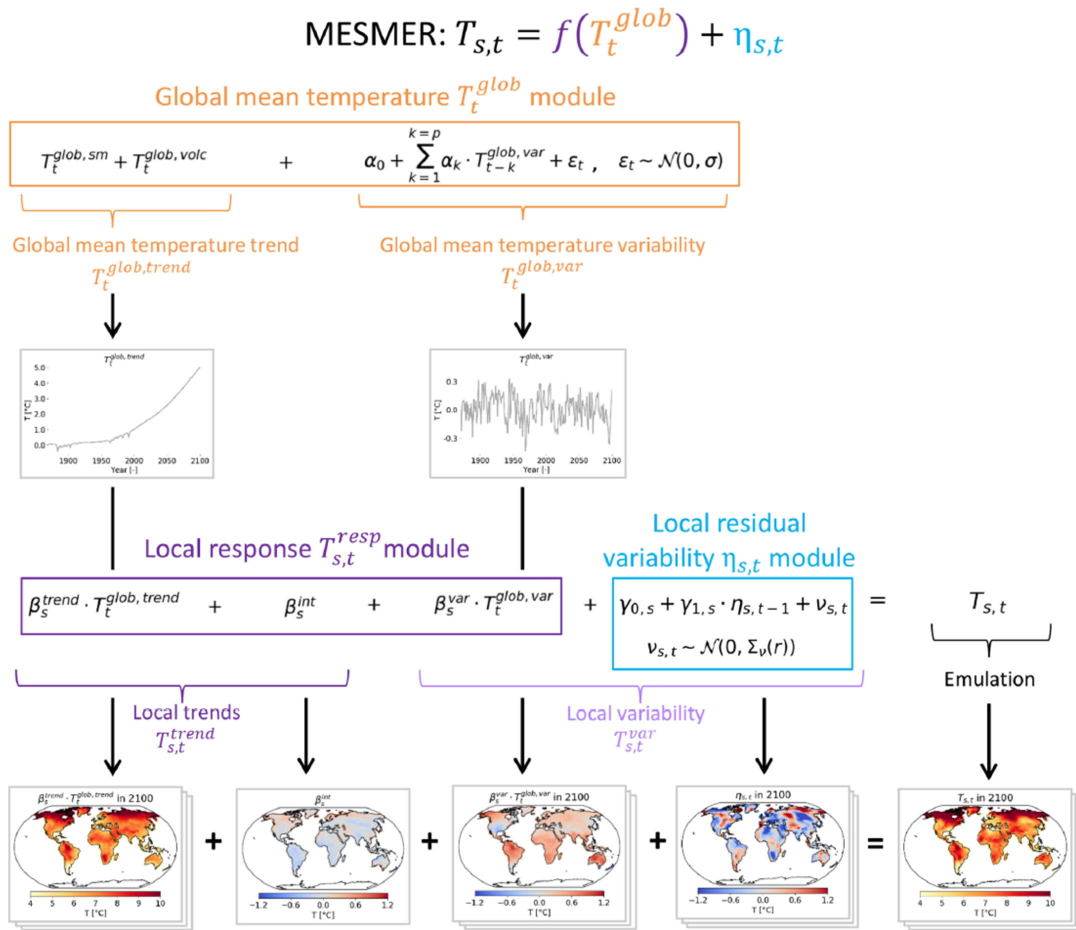
Earth Syst. Dynam., 11, 139–159, 2020
https://doi.org/10.5194/esd-11-139-2020

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
Correspondence: Lea Beusch (lea.beusch@env.ethz.ch)

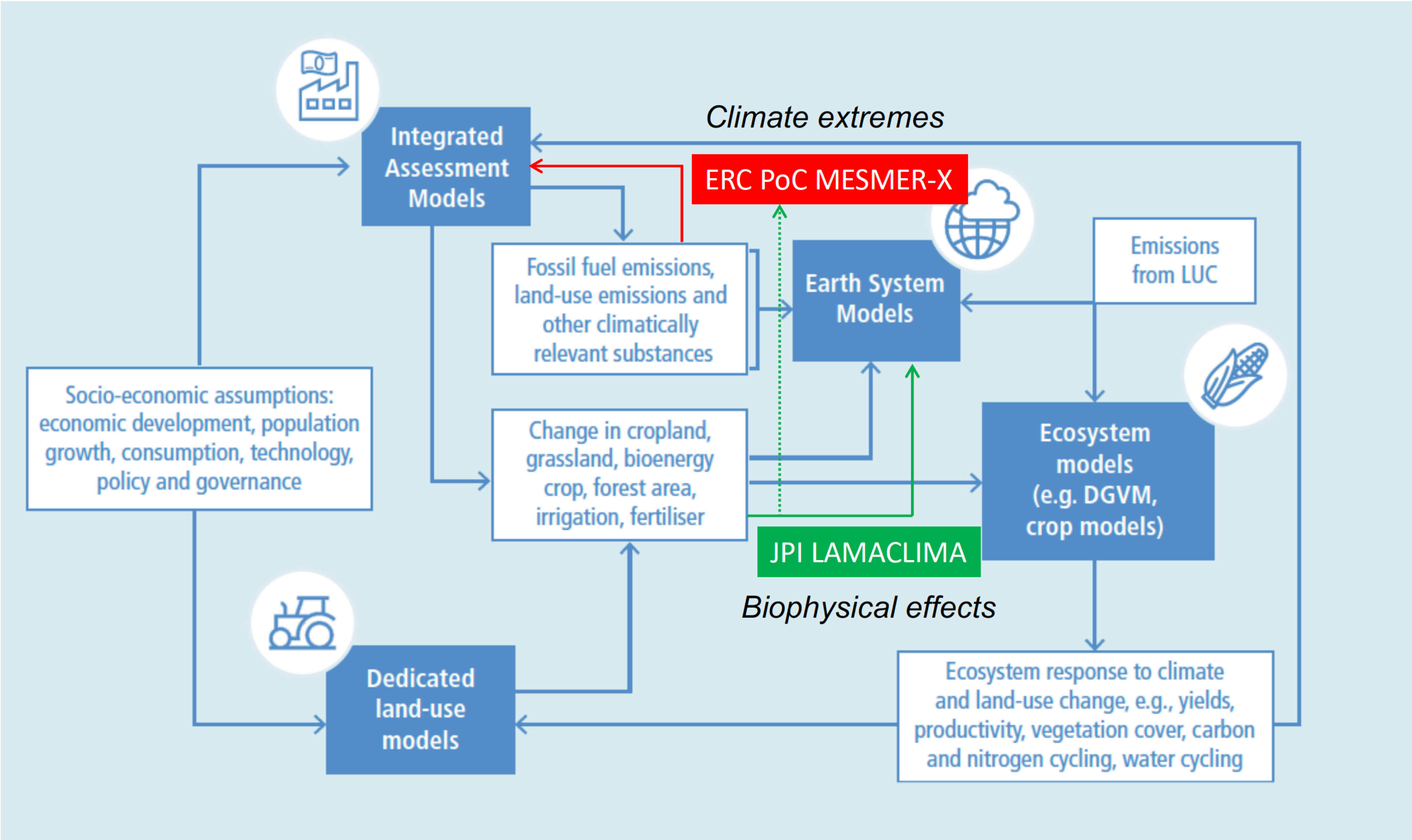
Received: 27 June 2019 – Discussion started: 2 July 2019
Revised: 8 November 2019 – Accepted: 6 January 2020 – Published: 17 February 2020



Expanding phase space with grid-cell MESMER-X ESM emulator → inform emissions scenario development (bread-basket regions, afforestation)
(ERC Proof-of-concept, 2021-2022)

(Beusch et al. 2020, ESD)

ERC PoC MESMER-X & JPI LAMACLIMA



Conclusions and outlook

- Biophysical effects of land use changes (e.g. albedo, irrigation, land cover type) are of strong relevance for temperature extremes, in particular in low-emissions scenarios (e.g. 1.5ºC, 2ºC)

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- Resilience of land cover changes to extremes need to be carefully quantified! Develop IAM-ESM emulator interface.