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Emulating climate impacts within the OSCAR simple Earth system model

Thomas Gasser, Biqing Zhu, Danni Zhang, Xinrui Liu, and colleagues

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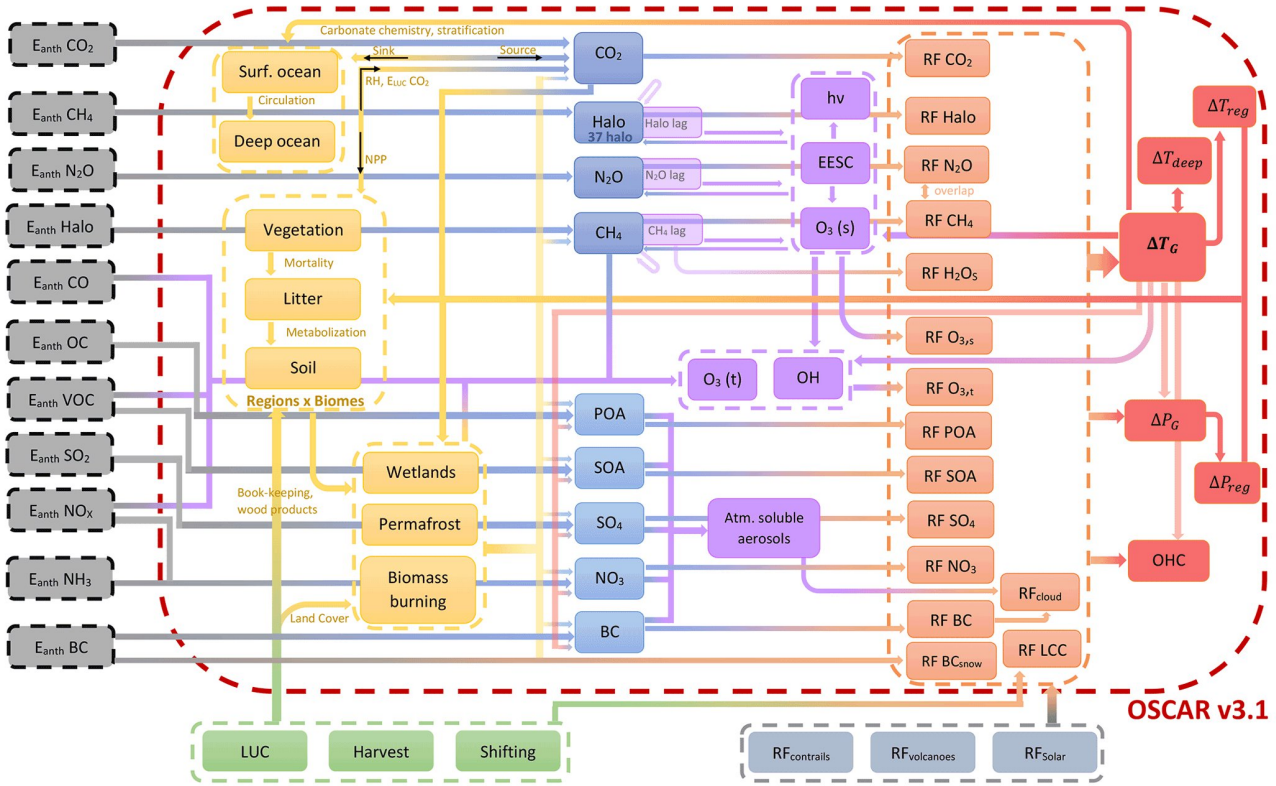
RESCUE

What is OSCAR?

- A simple (or reduced-complexity) Earth system model whose modules are calibrated to emulate the behavior of complex models
- Fairly simple: 155 equations, 23 state variables, 198 parameters (although many are defined along extra dimensions)
- Running time: 20-60 min for ~1000 realizations of a historical simulation on a desktop computer
- Basic inputs: emissions of anthropogenic GHGs and other active species, land-use change data
- Basic outputs: global temperature change (no IAV), any intermediate variable (most of them global)
- Code (in python) open-source: https://github.com/tgasser/OSCAR

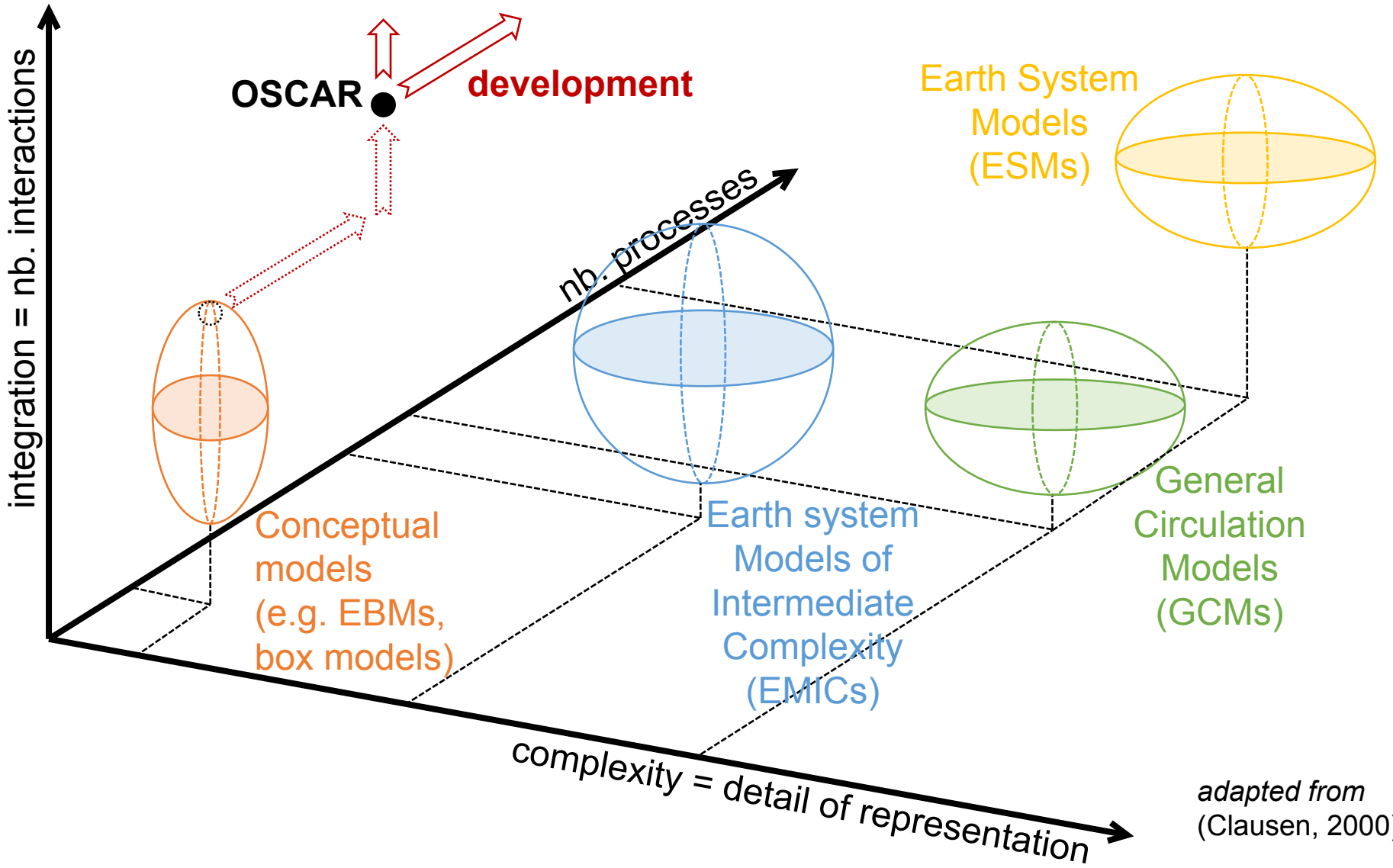


Overview of OSCAR's structure (Quilcaille et al., 2023)

OSCAR in the hierarchy of models

Underpinning philosophy of development:

- high number of processes
- coupled together
- but each with simple formulation



adapted from (Clausen, 2000)

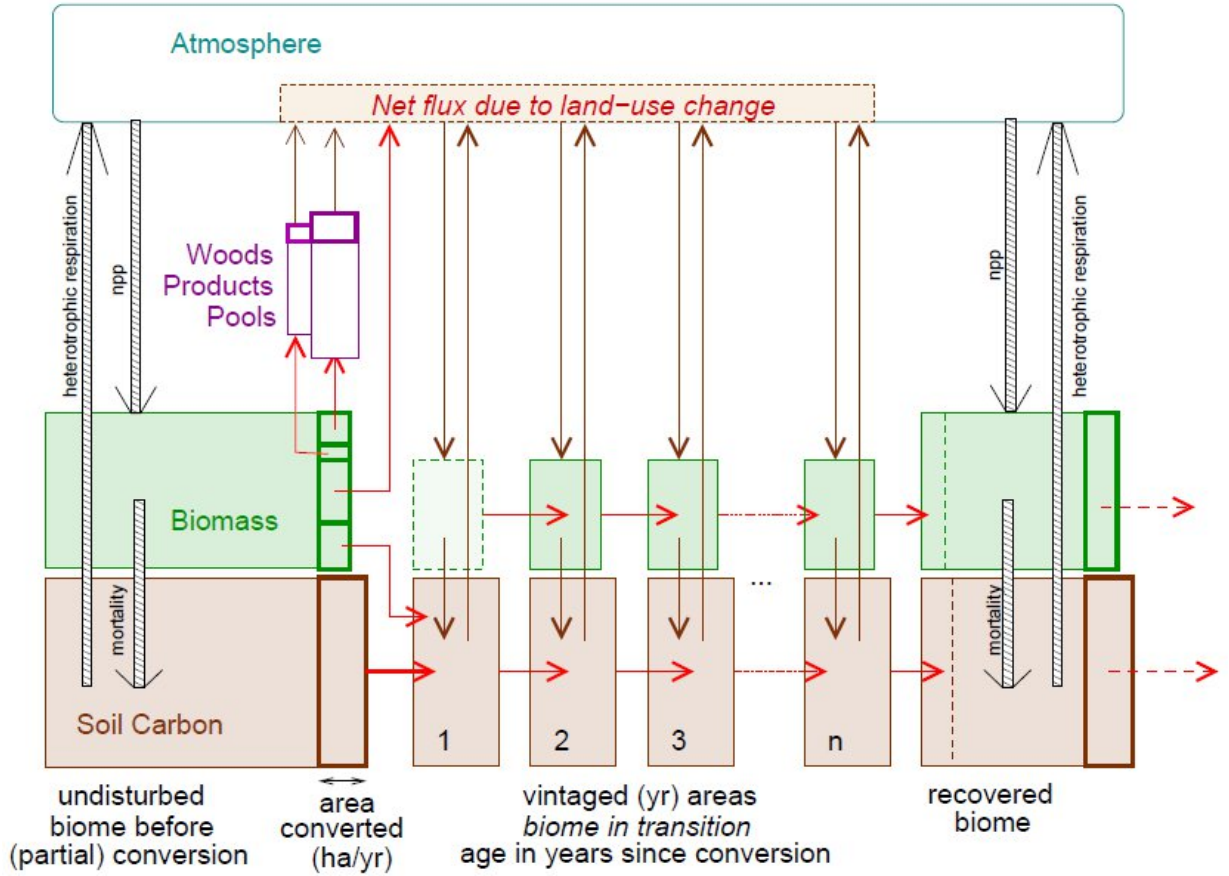
Model niche and concept

Core concept:

- OSCAR is a combination of emulators
- Pro: easier to add processes and feedbacks
- Con: harder to exactly emulate a given model

Model focus:

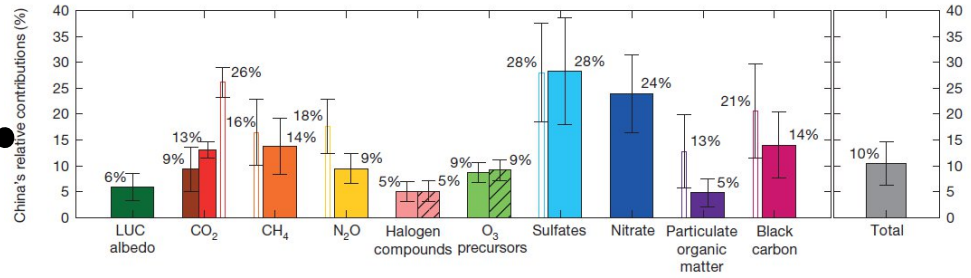
- Land carbon cycle: regionalized (up to ~300 regions in the upcoming v4)
- Biogeochemical feedbacks are endogenous:
  - land-use CO2 emissions (Ⓟ) reported annually in the *Global Carbon Budget* (GCB)
  - land cover albedo radiative forcing reported annually in the *Indicators of Global Climate Change* (IGCC)
  - wetlands CH4 emissions (based on WETCHIMP)
  - permafrost carbon thaw and release



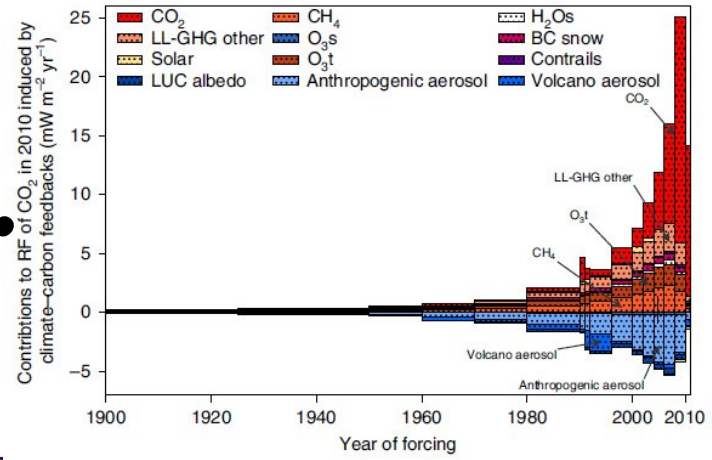
OSCAR's original book-keeping module (Gitz, 2004)

Some illustrative past works

- Attributed China's historical contribution to global radiative forcing (Li et al. 2016)
- Integrated permafrost C into the system, and demonstrated its path-dependent impact on the remaining C budget (Gasser et al., 2018)
- Isolated the climate-carbon feedback to correct AR5 estimates of GWPs & GTPs (Gasser et al., 2017)
- Demonstrated that short-lived species have a long-term climate effect through the climate-carbon feedback (Fu et al., 2020)
- Coupled a crop yield emulator and investigated the feedback loop between climate – crop yield – negative emissions availability (Xu et al., 2022)
- Re-estimated land-use change emissions in the AR6 scenario database consistently with national inventories (Gidden et al., 2023)



	GWP			GTP		
Time horizon (in years)	20	50	100	20	50	100
	CH_4[a]					
AR5 (default)[b]	84	48	28	67	14	4
AR5 + Collins[b]	*85*	52	34	70	20	11
AR5 + OSCAR	86	52	31	70	18	5
AR5 + OSCAR + climate IRF update	86	51	31	60	14	7
AR5 + OSCAR + IRF and REs updates	96	57	34	67	16	7
All OSCAR	96	57	34	66	18	9
All OSCAR (no CC-fdbk)	96	57	34	65	16	8



Why extend OSCAR with sectoral impacts?

- For impact assessment, large ensemble projections:
  - Uncertainty analysis through Monte Carlo
  - Multi-scenario analysis
  - Typically, 2000 realizations × 10–1000 scenarios

- For climate assessment, additional feedbacks in the Earth system (permafrost, peatland, fire, …)
  - OSCAR can integrate more process than state-of-the-art ESMs
  - Be ready for CMIP7/AR7 scenarios

- For scenario assessment, more climate change and climate impact indicators available:
  - Great for scenario classification
  - Target use case: AR7 WG3

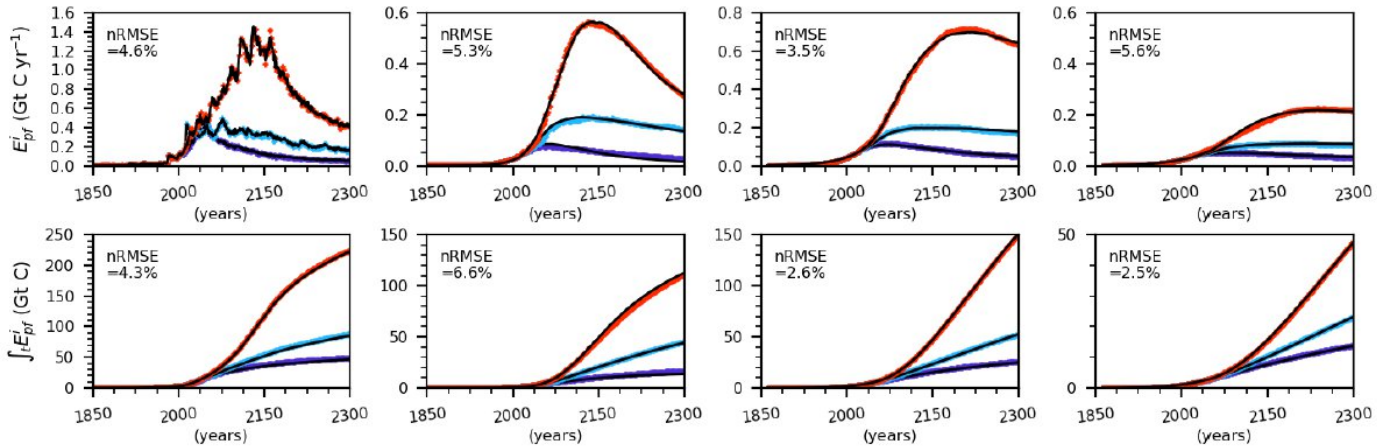
- Ultimate goal, implementation within IAM / scenario modeling:
  - Integration of impacts on socio-economic system (WG2-WG3 linkage)
  - Backward-inference inference of pathways compatible with limiting impacts (WG2-WG1 linkage)

Past work: permafrost

ARTICLES
https://doi.org/10.1038/s41561-018-0227-0
nature geoscience
Corrected: Author Correction

Path-dependent reductions in CO_2 emission budgets caused by permafrost carbon release

T. Gasser[1*], M. Kechiar[1,2], P. Ciais[3], E. J. Burke[4], T. Kleinen[5], D. Zhu[3], Y. Huang[3], A. Ekici[6,7] and M. Obersteiner[1]



(Gasser et al., 2018)

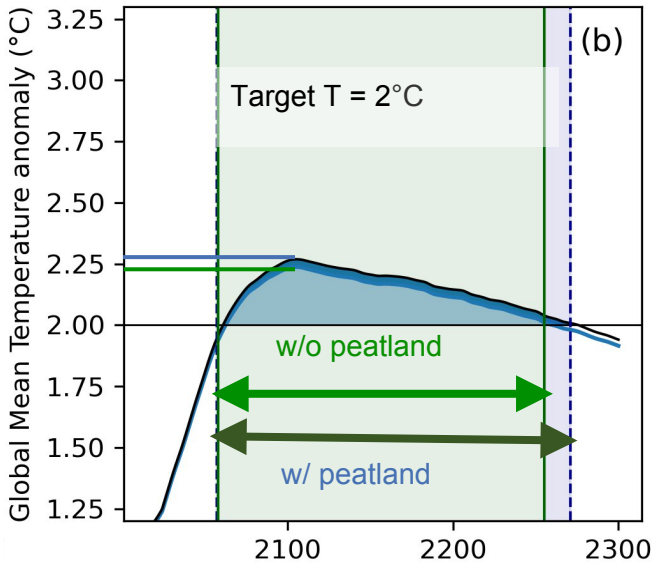
- Study: effect of permafrost C release on remaining carbon budgets across ~3000 scenarios
- Conclusion: non-linearity and importance of overshoot
- Lessons learned: simulations up to 2300 are important!
  - For OSCAR: helps constrain parameters for long timescales
  - For ISIMIP: required to fully assess slow processes' response
- Next: update on ISIMIP3b models (but requires **cSoilLayer** variable)

Recent work: peatland

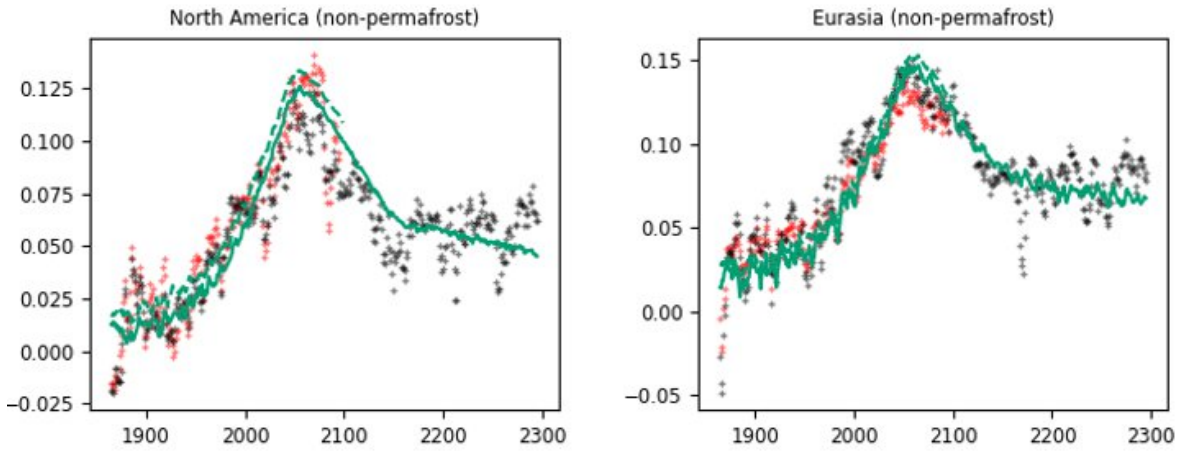
Warming of Northern Peatlands Increases the Global Temperature Overshoot Challenge

Biqing Zhu[1,2,*], Chunjing Qiu[3,4,2*], Thomas Gasser[1], Philippe Ciais[2], Robin D. Lamboll[5], Ashley Ballantyne[2,6], Jinfeng Chang[7], Nitin Chaudhary[8,9], Angela V. Gallego-Sala[10], Bertrand Guenet[11], Joseph Holden[12], Fortunat Joos[13,14], Thomas Kleinen[15], Min Jung Kwon[2,16], Irina Melnikova[2,17], Jurek Müller[13,14], Susan Page[18], Elodie Salmon[2], Carl-Friedrich Schleussner[19,20,1], Guy Schurgers[21], Gaurav P. Shrivastav[1], Narasinha J. Shurpali[22], Katsumasa Tanaka[2,17], David Wårlind[8], Sebastian Westermann[23], Yi Xi[2], Wenxin Zhang[8,21], Yuan Zhang[2,24], Dan Zhu[25]

(Zhu et al., 2025; accepted in One Earth)

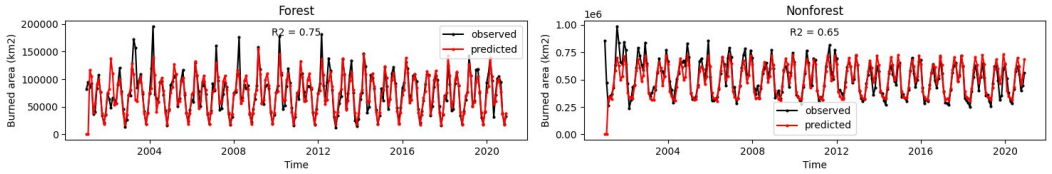


- Study: effect of peatland in overshoot scenarios
- Conclusion: can strengthen and lengthen the overshoot
- Lessons learned: overshoot scenarios are important / CO2-sensitivity simulations as well
  - For OSCAR: validation purposes / avoid too many covariations
  - For ISIMIP: policy relevance / process

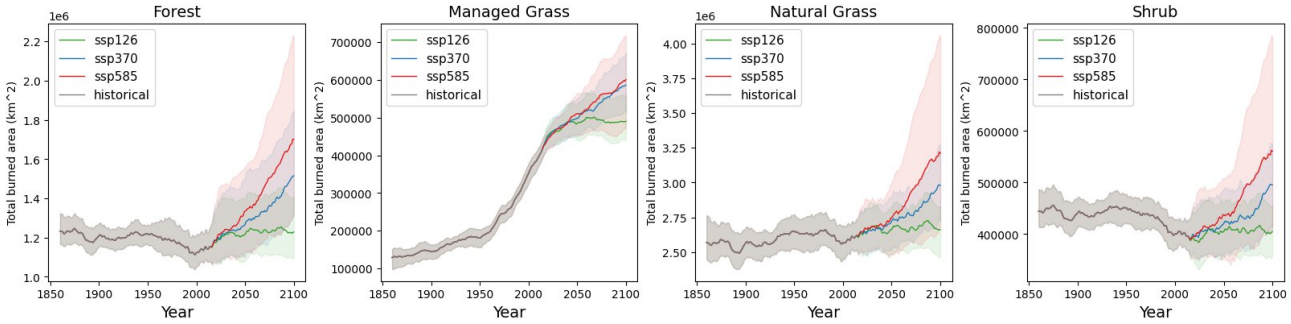


Ongoing work: fire

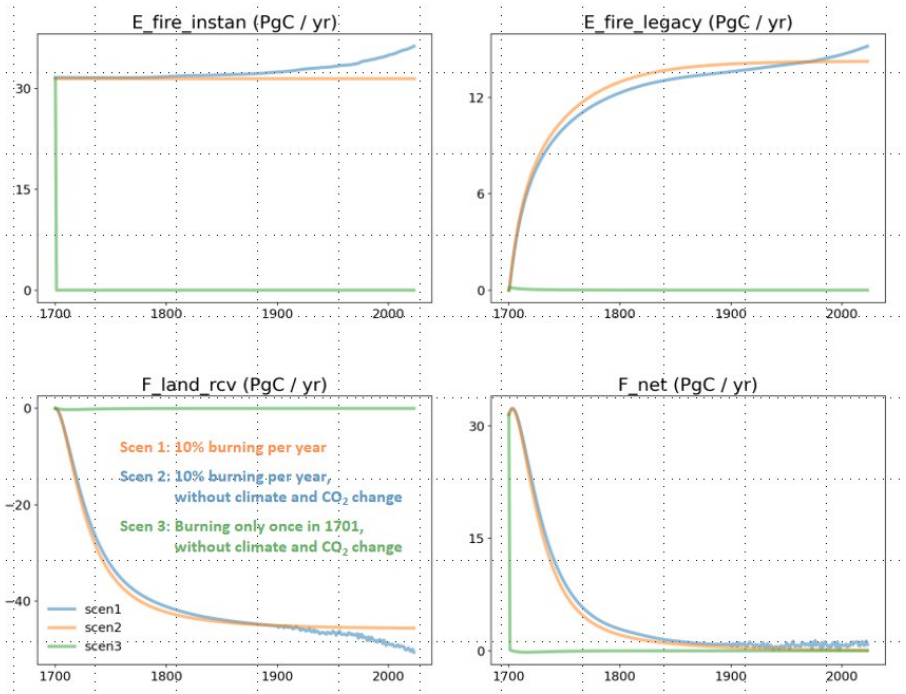
- 1st attempt: direct emulation of GFED5 burnt area
  - Works well of intra-annual cycle
  - Leads to decrease in future burnt area



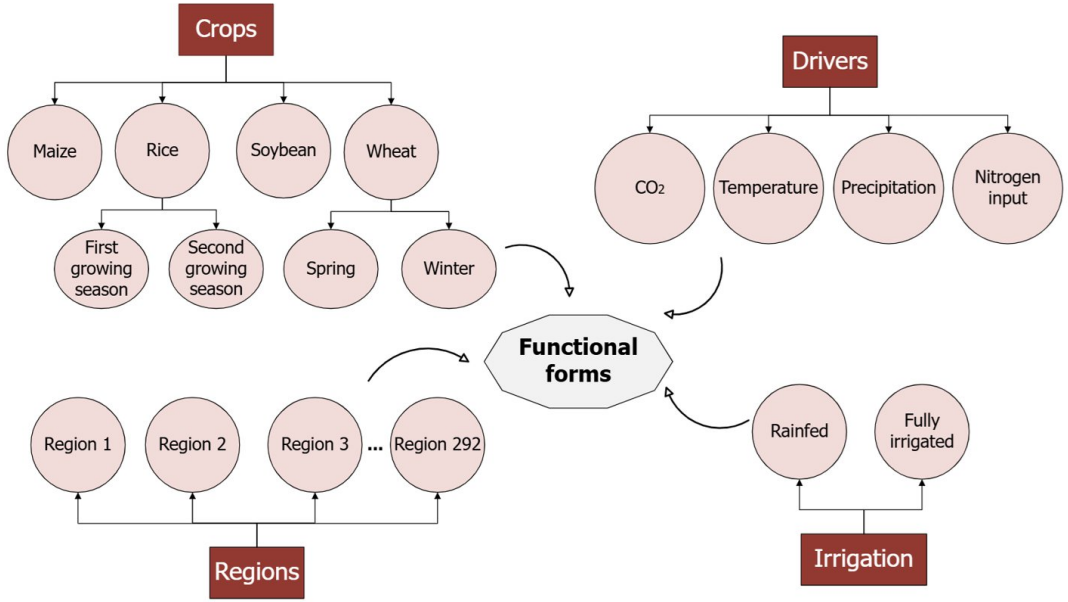
- 2nd attempt: emulation of an ML model used over the historical period for the GCB
  - Doubts about emulation of emulation…

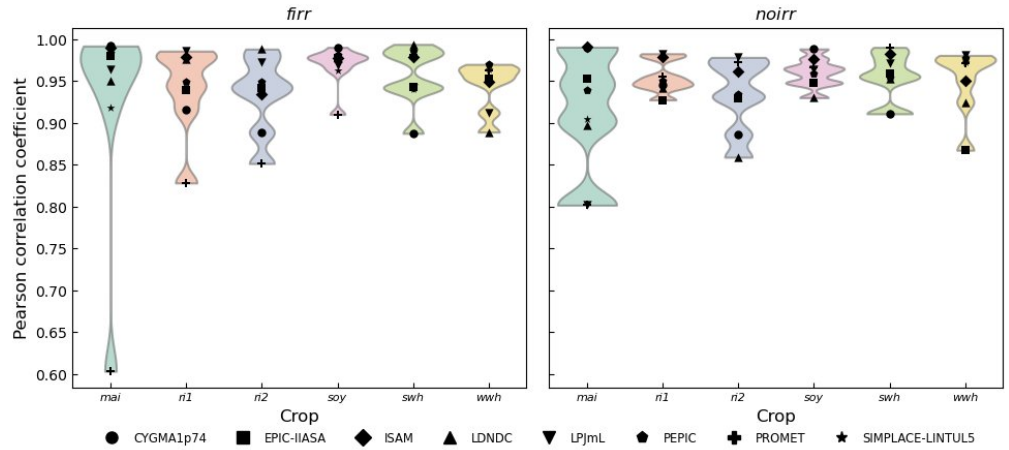


- Next: calibration on ISIMIP3b models (but requires PFT-based burnt area)
- Goal: net C budget of fires included regrowth through bookkeeping

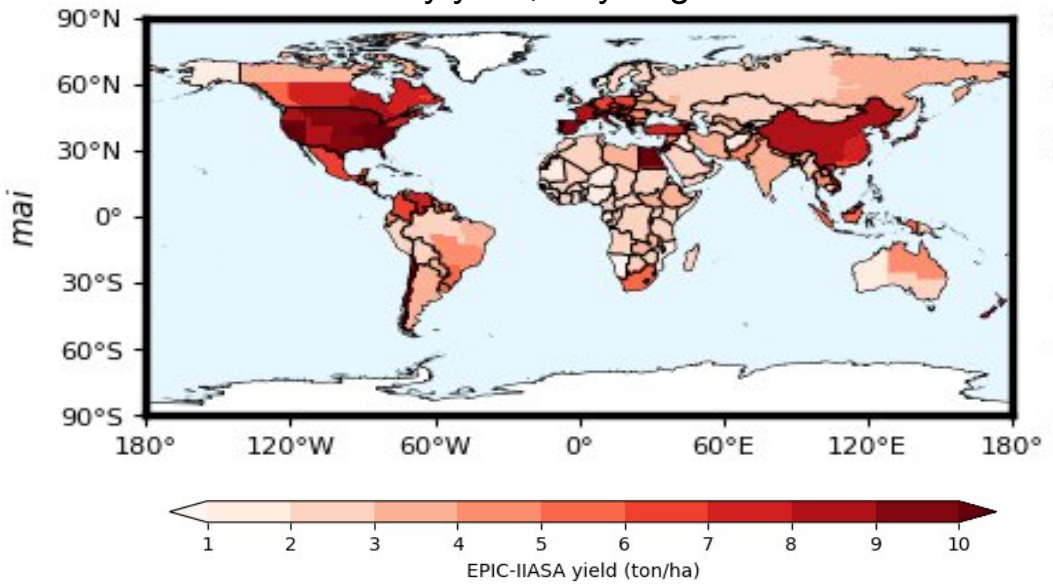


Ongoing work: crop yields





Present-day yield, fully-irrigated condition



- Next: add bio-energy crops (using ORCHIDEE, **other models very welcome!)**
- Goal: estimate negative emissions potential in AR6 and AR7 scenarios

Concluding remarks

- This is a call for collaboration!
  - If you have data pending upload, we're looking forward to it
  - Sometimes additional simulations are extremely valuable…
  - … if we contact you, please consider it carefully
  - We're very happy to invite modelling teams on our papers!

- The emulation of sectoral impacts is a topic of growing importance with a lot of potential down the road regarding linking IPCC WGs
  - OSCAR is a great tool to do this integration!
  - Opportunity to extend to other sectors, especially land-related (biomes, biodiversity, …)

- WE NEED YOU! (check out Biqing Zhu's poster tomorrow)

Thank you.

Thomas Gasser

Senior Research Scholar
Coordinator of the Earth system modeling theme
Advancing Systems Analysis program (ASA)
& Energy, Climate, and Environment program (ECE)

International Institute for Applied Systems Analysis (IIASA)
Laxenburg, Austria

gasser@iiasa.ac.at