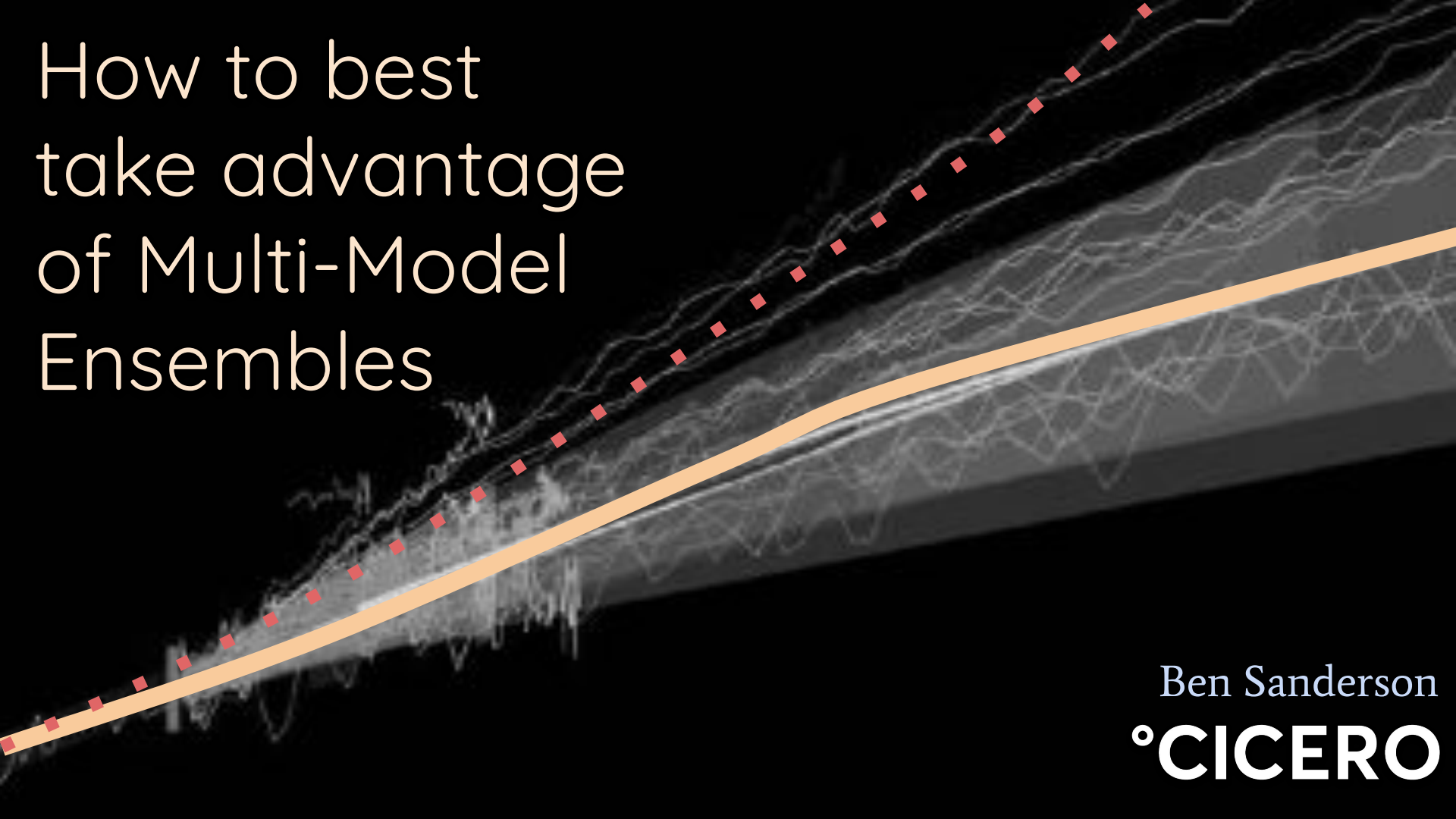
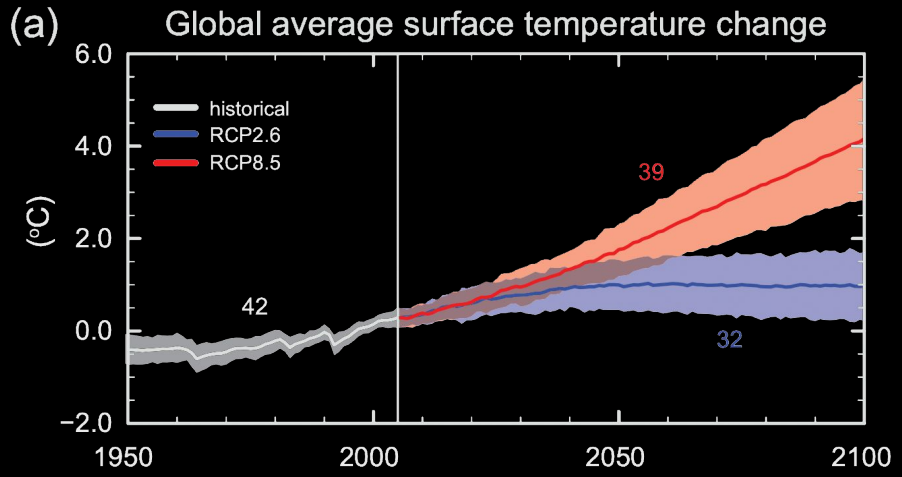
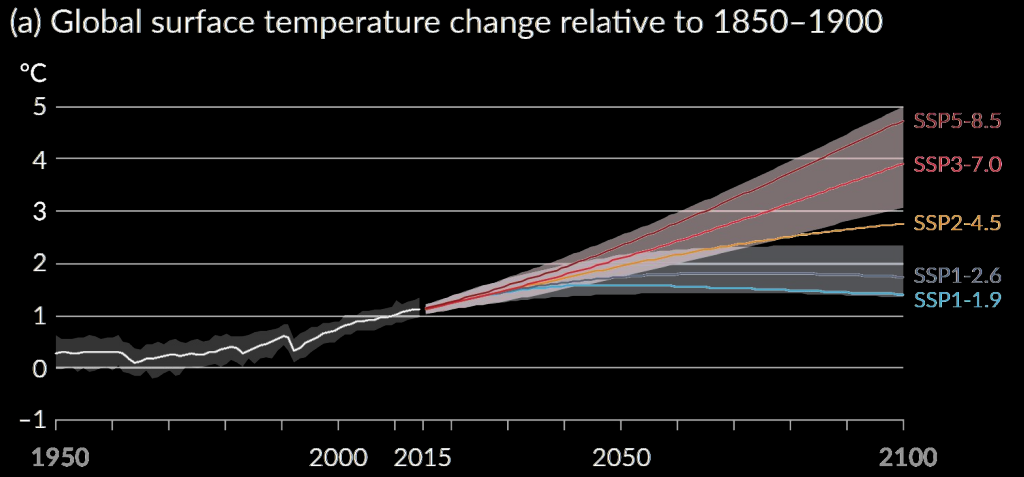
How to best take advantage of Multi-Model Ensembles



Ben Sanderson
°CICERO

Has CMIP become a secondary line of evidence?





IPCC AR5 SPM → IPCC AR6 SPM

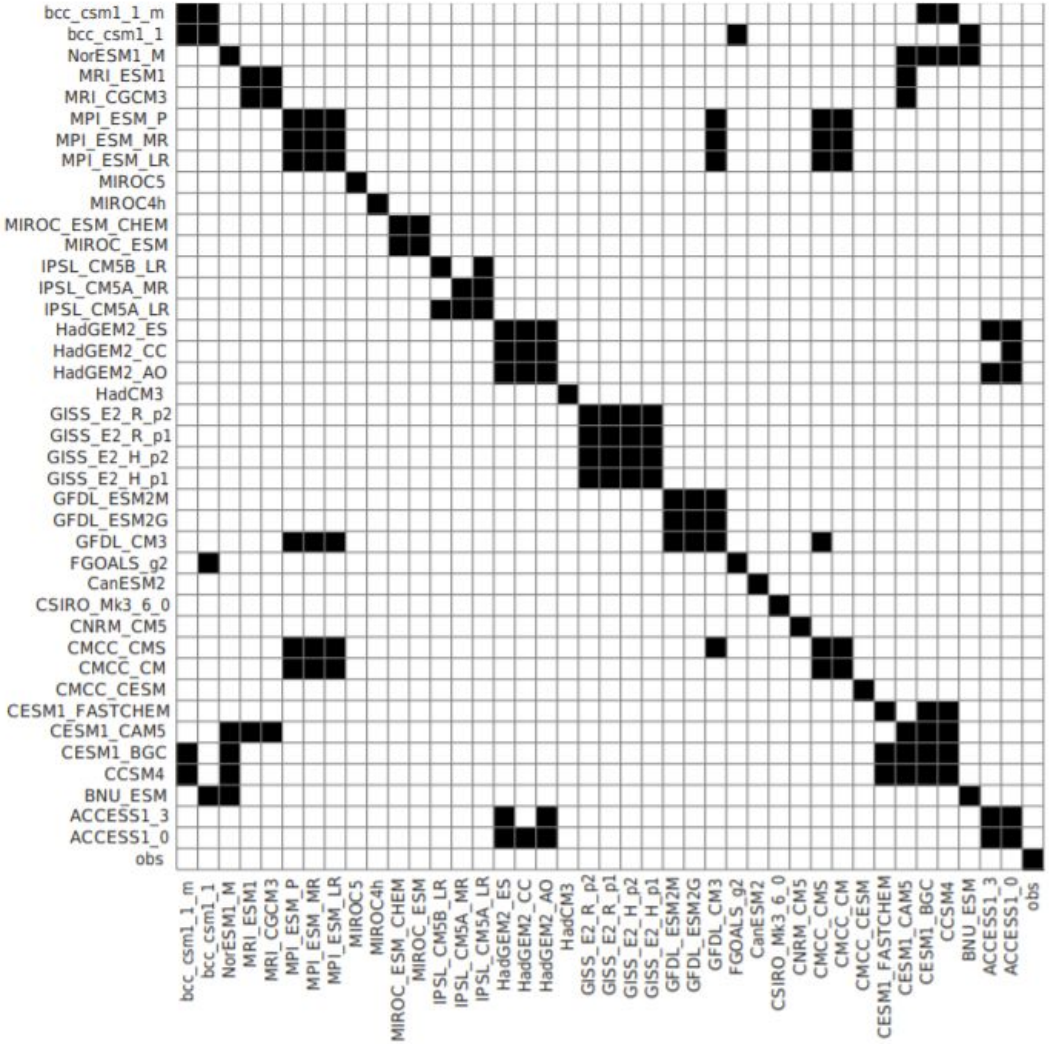
I. What changed?
II. Where next?

I. What changed?

1. The end of model democracy
2. Mitigation focused science
3. The rise of emulators

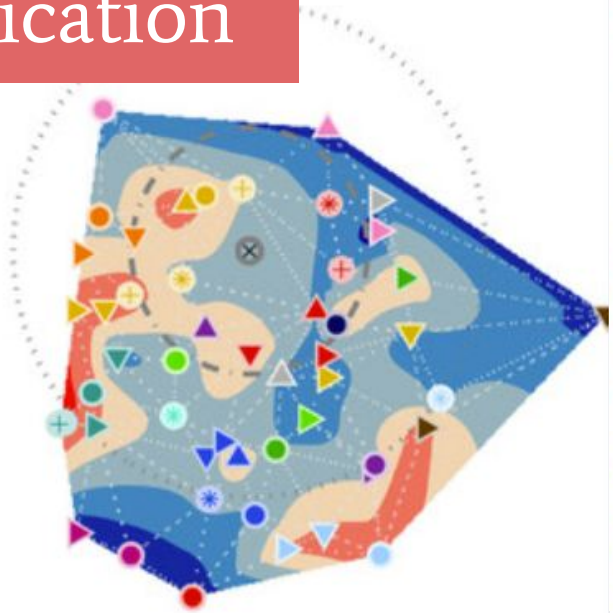

1. Democracy
is dead

Models are not (and have never been) independent



Sanderson, B. M., Wehner, M., and Knutti, R.: Skill and independence weighting for multi-model assessments, Geosci. Model Dev., 10, 2379–2395, https://doi.org/10.5194/gmd-10-2379-2017, 2017.

But we have developed reliable approaches to address replication



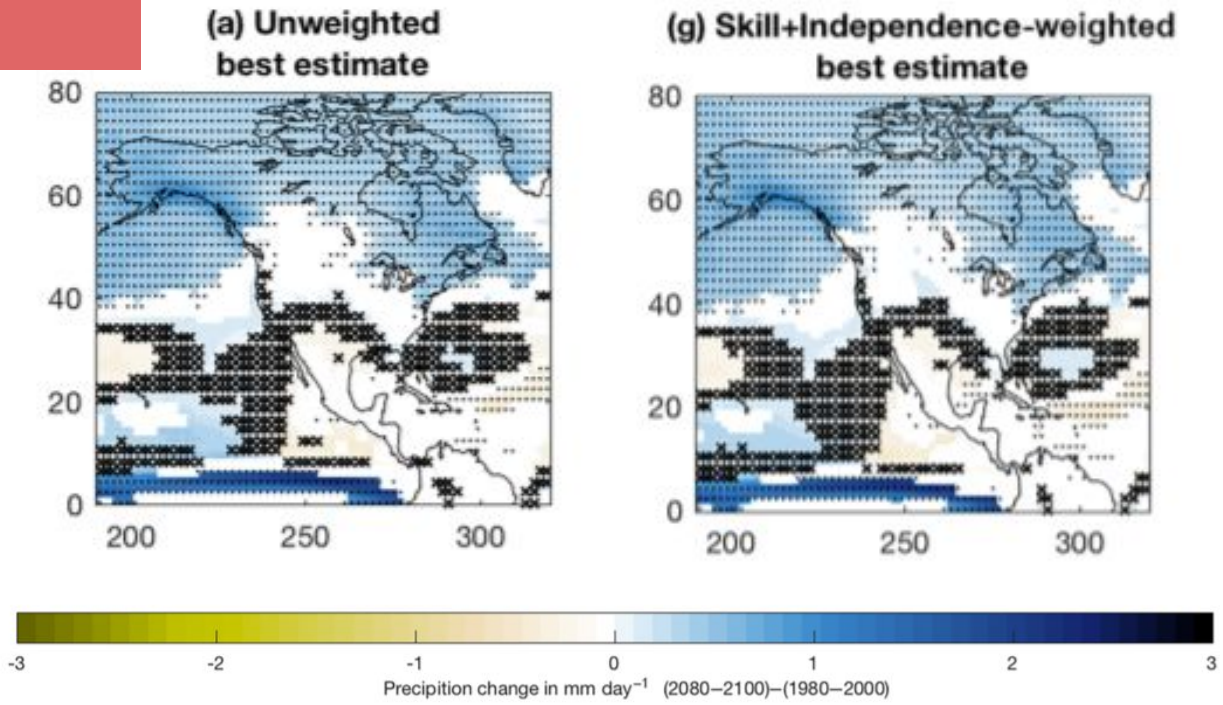
NorESM1-ME(5)
NorESM1-M(5)
NCAR-PCM1(3)
MRI-CGCM3(5)
MRI-CGCM2.3.2A(3)
MPI-ESM-MR(5)
MPI-ESM-LR(5)
MPI-ECHAM5(3)
MIROC5(5)
MIROC3.2-MEDRES(
MIROC3.2-HIRES(3)
MIROC-ESM-CHEM(
MIROC-ESM(5)
IPSL-CM5B-LR(5)
IPSL-CM5A-MR(5)
IPSL-CM5A-LR(5)
IPSL-CM4(3)
INMCM4(5)
INMCM3(3)
IAP-FGOALS1.0-G(3
IAP-FGOALS-g2(5)
HadGEM2-ES(5)
HadGEM2-CC(5)
HadGEM2-AO(5)
HadGEM1(3)
HadCM3(3)

GISS-E2-R(5)
GISS-E2-H(5)
GISS-E-H(3)
GFDL-ESM2M(5)
GFDL-ESM2G(5)
GFDL-CM3(5)
GFDL-CM2.1(3)
GFDL-CM2(3)
CanESM2(5)
CSIRO-Mk3-6-0(5)
CSIRO-MK3.0(3)
CNRM-CM5(5)
CESM1-WACCM(5)
CESM1-CAM5(5)
CESM1-BGC(5)
CCSM4(5)
CCSM3(3)
CCCMA-CGCM3.1-T63(3)
CCCMA-CGCM3.1(3)
BNU-ESM(5)
BCC-CSM1-1-M(5)
BCC-CSM1-1(5)
ACCESS1-3(5)
ACCESS1-0(5)
Narrow Std.Dev,
Gaussian Std.Dev
I/C Variability
Observations

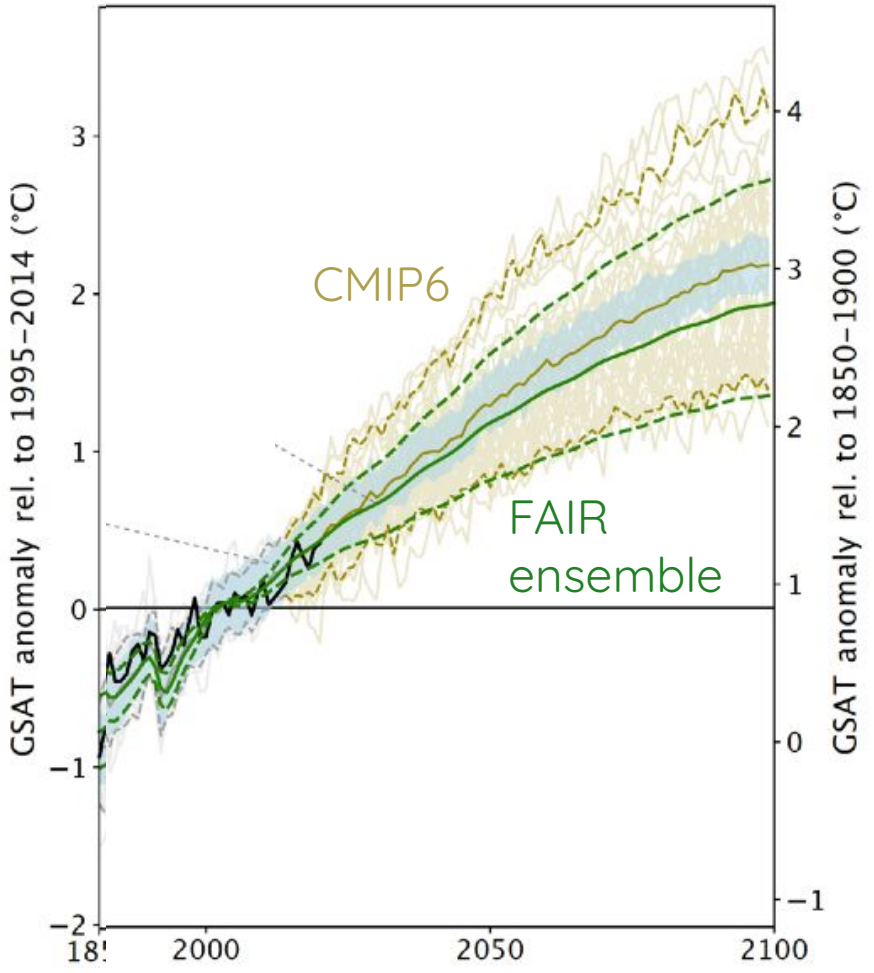
Sanderson, Benjamin M., Reto Knutti, and Peter Caldwell. "Addressing interdependency in a multimodel ensemble by interpolation of model properties." *Journal of Climate* 28.13 (2015): 5150-5170.

And, up to CMIP5, it didn't make much difference

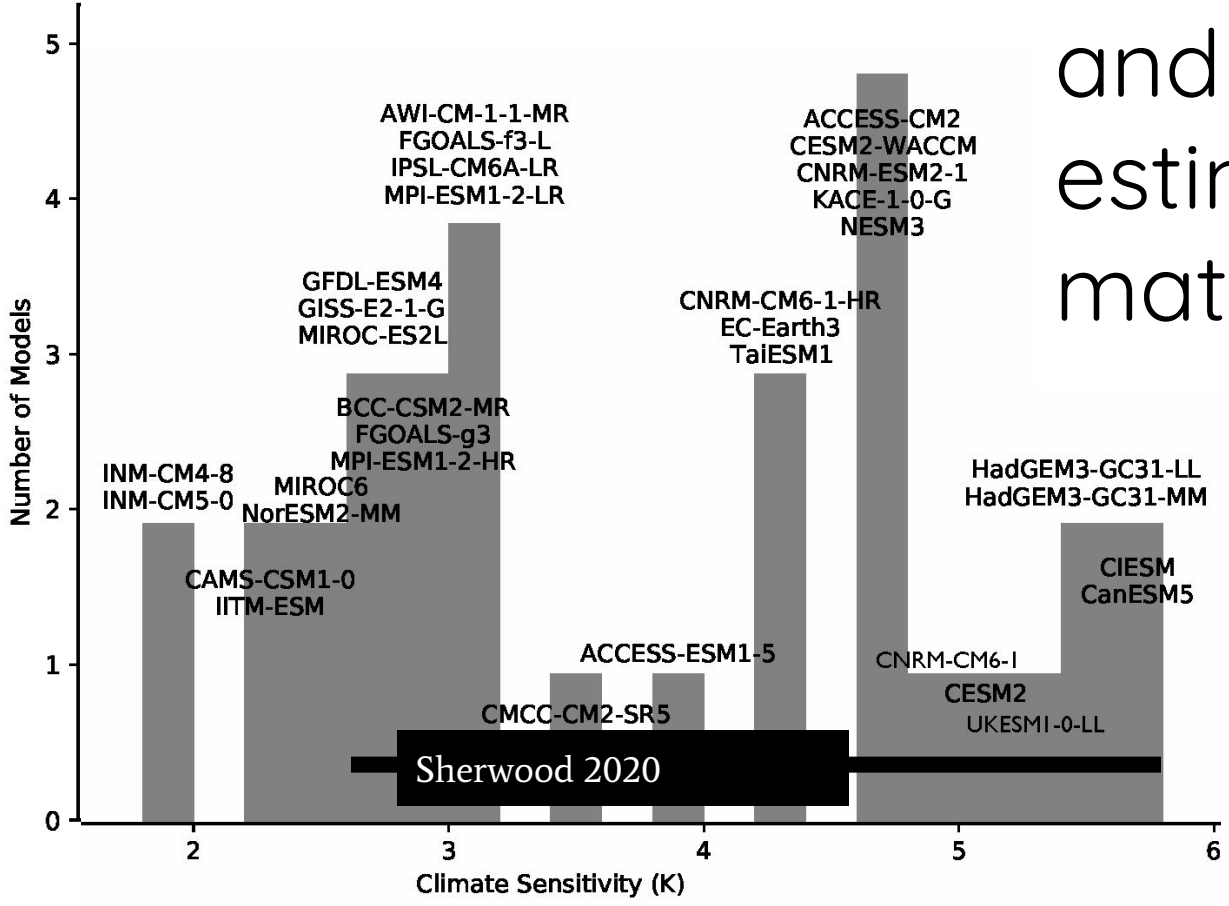
Sanderson, B. M., Wehner, M., and Knutti, R.: Skill and independence weighting for multi-model assessments, Geosci. Model Dev., 10, 2379–2395, https://doi.org/10.5194/gmd-10-2379-2017, 2017.



But CMIP6 is different: Inconsistencies with observed warming rates challenge model democracy assumptions



Issue 1: Bottom-up and top-down ECS estimates don't match



2. Paris changed everything

Pre-Paris

What is the Earth System response to continued emissions?

Pre-Paris

What is the Earth System response to continued emissions?

Post-Paris

What does a net-zero world look like?

Pre-Paris

What is the Earth System response to continued emissions?

- Fundamental ES parameters (ECS, TCR, TCRE)
- Modest mitigation and BAU scenarios
- Physical process understanding

Post-Paris

What does a net-zero world look like?

Pre-Paris

What is the Earth System response to continued emissions?

- Fundamental ES parameters (ECS, TCR, TCRE)
- Modest mitigation and BAU scenarios
- Physical process understanding

+

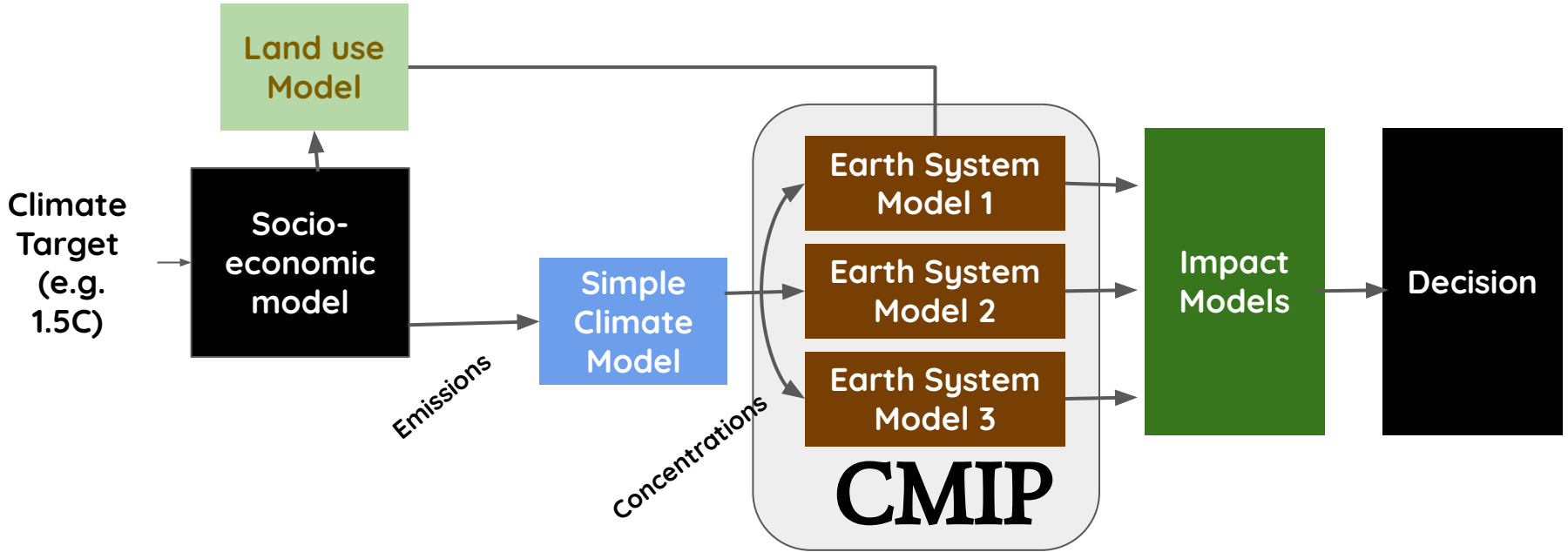
Post-Paris

What does a net-zero world look like?

- Emissions driven, mitigation-centric parameters (ZEC)
- Radical mitigation scenarios
- Coupled human-physical process understanding


Mitigation projection uncertainty is dominated by Human-climate interactions, which have not been a focus of CMIP

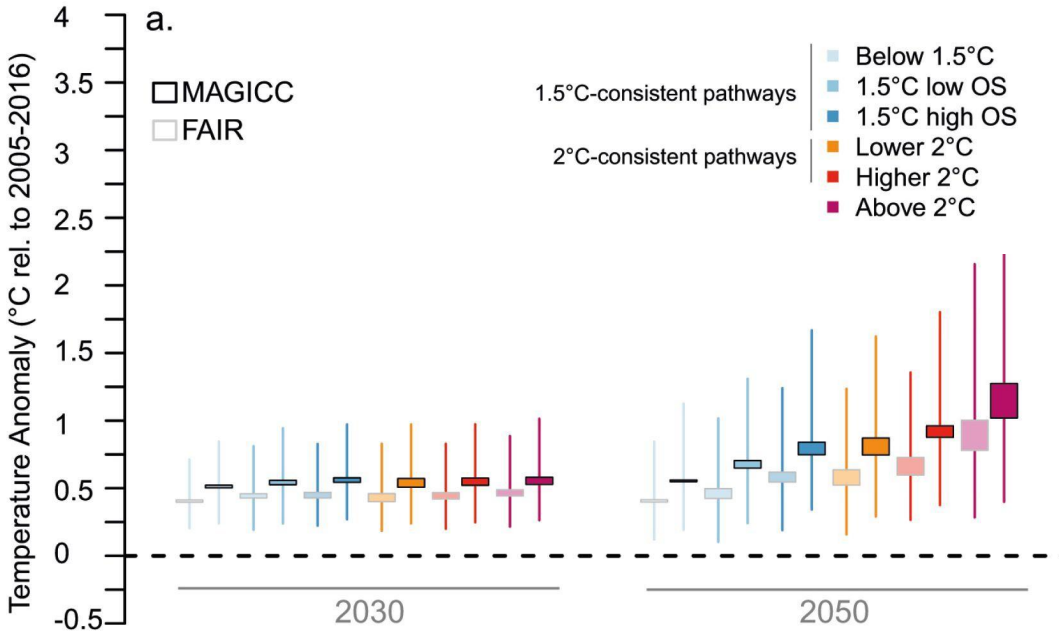
Issue 2: ESMs are our most comprehensive models of CDR, but output cannot flow ‘upstream’ to scenarios or policy.



3. Renaissance of the toy model

3. Renaissance of the toy model

Rapid turnaround and flexible codebases have made SCMs the default approach for policy framing

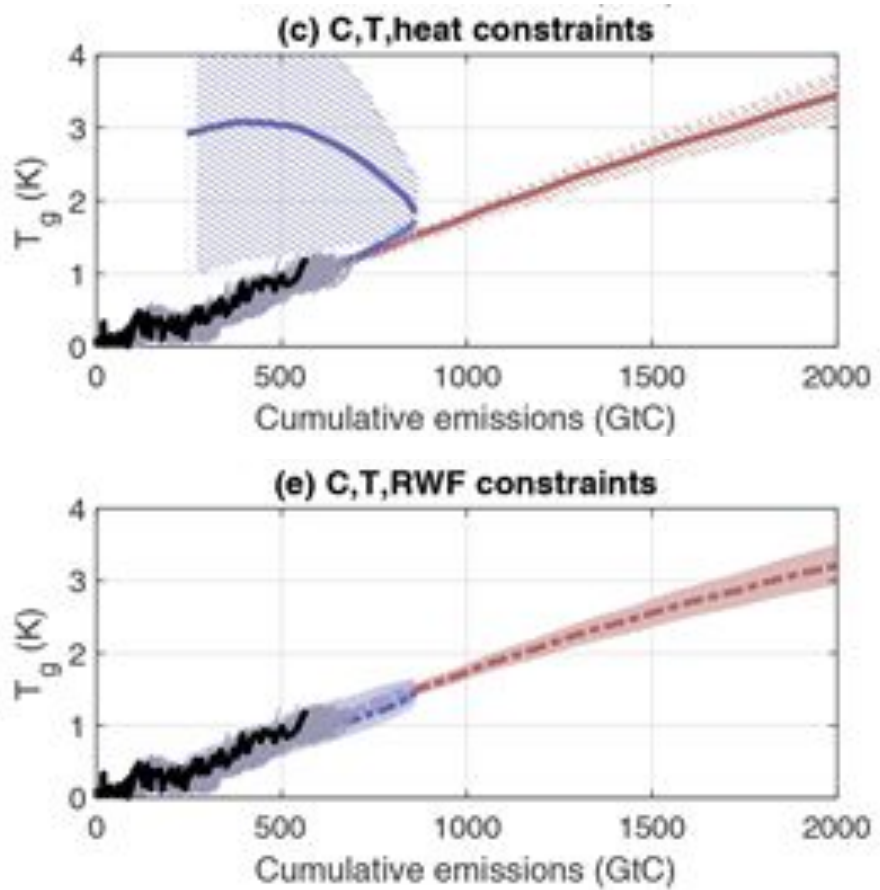


RCMIP

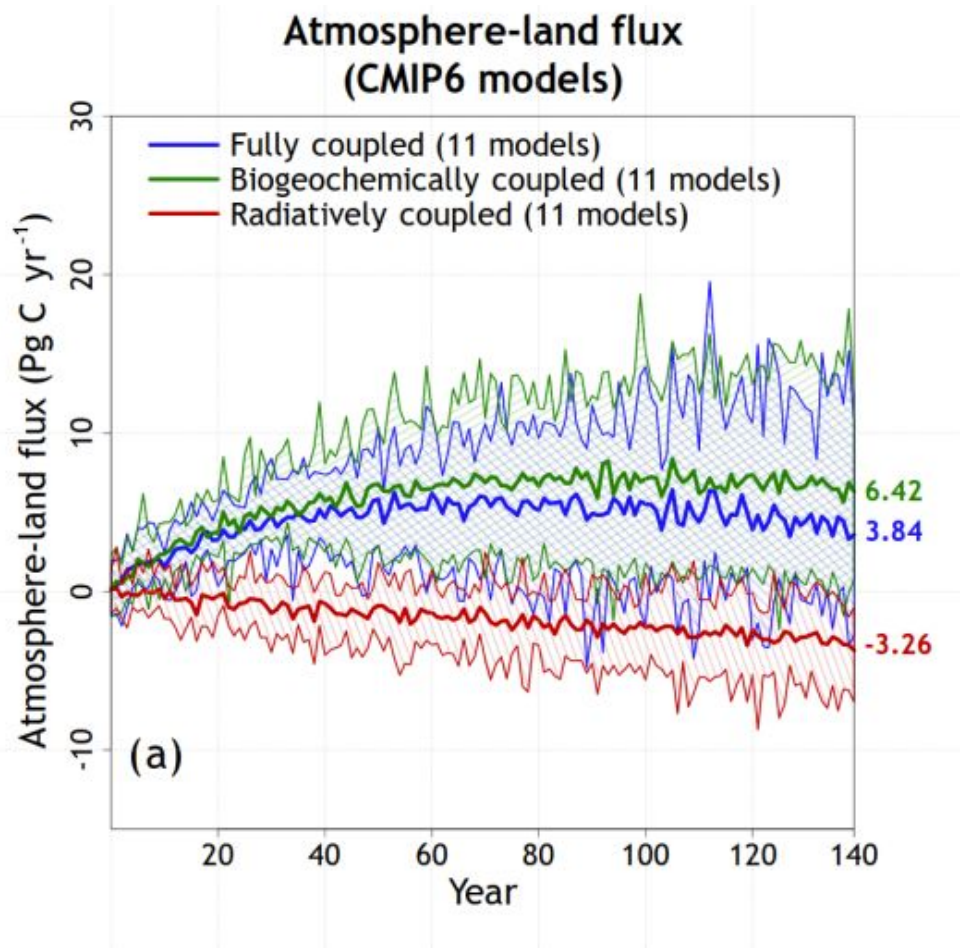
Reduced Complexity Model Intercomparison Project

The role of the ESM is increasingly as a target for robust emulation

Low mitigation emulation targets allow large uncertainties in parameters relating to equilibration and ZEC

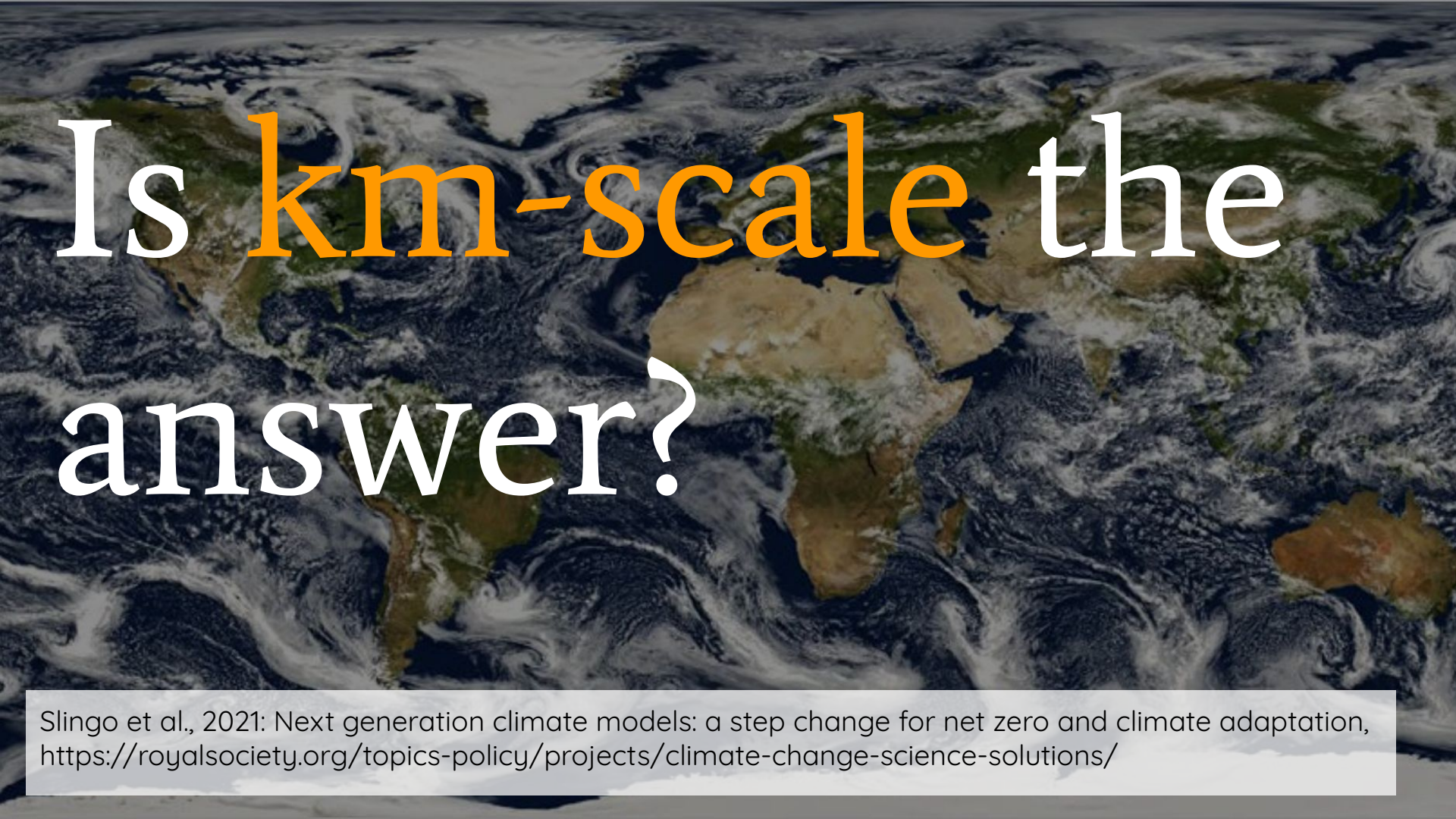


Sanderson, B.: The role of prior assumptions in carbon budget calculations, Earth Syst. Dynam., 11, 563–577, https://doi.org/10.5194/esd-11-563-2020, 2020.

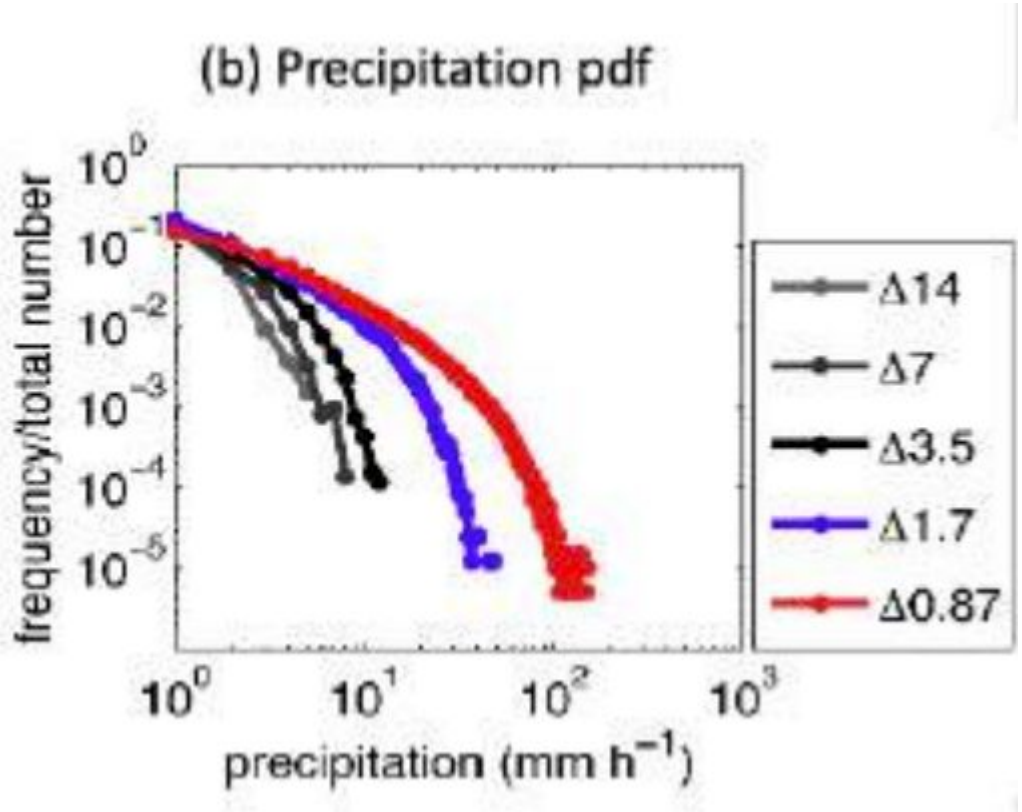


Issue 3. Current CMIP ensemble design is not optimized for emulator calibration

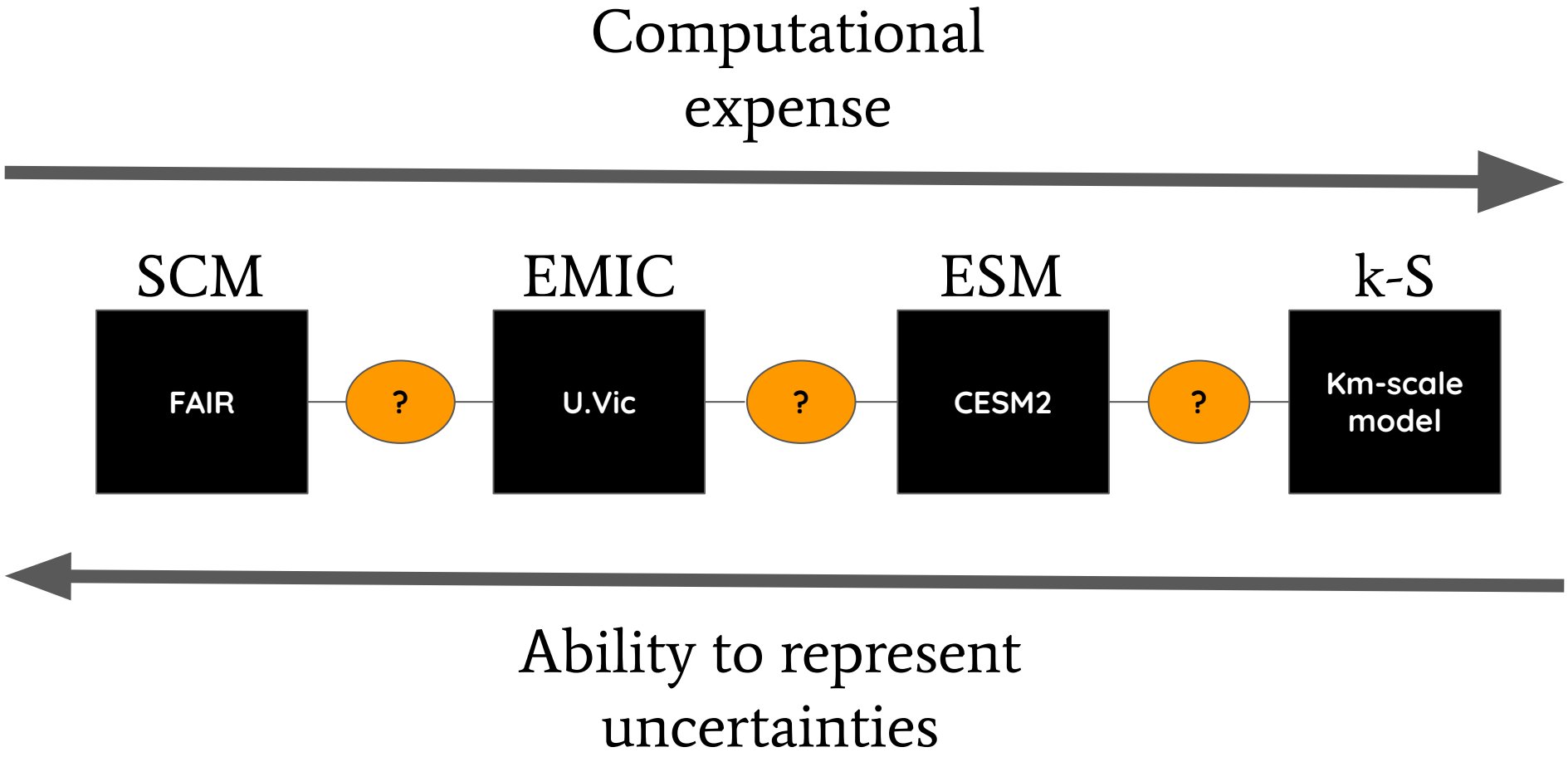
I. What changed?
II. Where next?



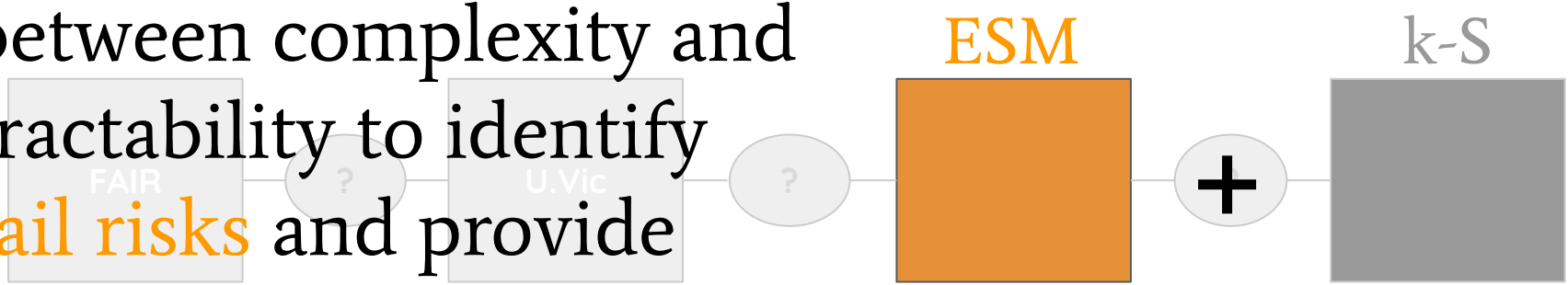
Slingo et al., 2021: Next generation climate models: a step change for net zero and climate adaptation, https://royalsociety.org/topics-policy/projects/climate-change-science-solutions/



K-scale models provide insight into a subset of impacts as experienced at the regional scale


Computational expense
SCM
EMIC
ESM
k-S
FAIR
?
U.Vic
?
CESM2
?
Km-scale model
Ability to represent uncertainties

CMIP-class models must occupy the ‘sweet spot’ between complexity and tractability to identify tail risks and provide ground truth for out-of-sample projections



What is needed from CMIP to understand the pathway to a net zero world?

Longer simulations

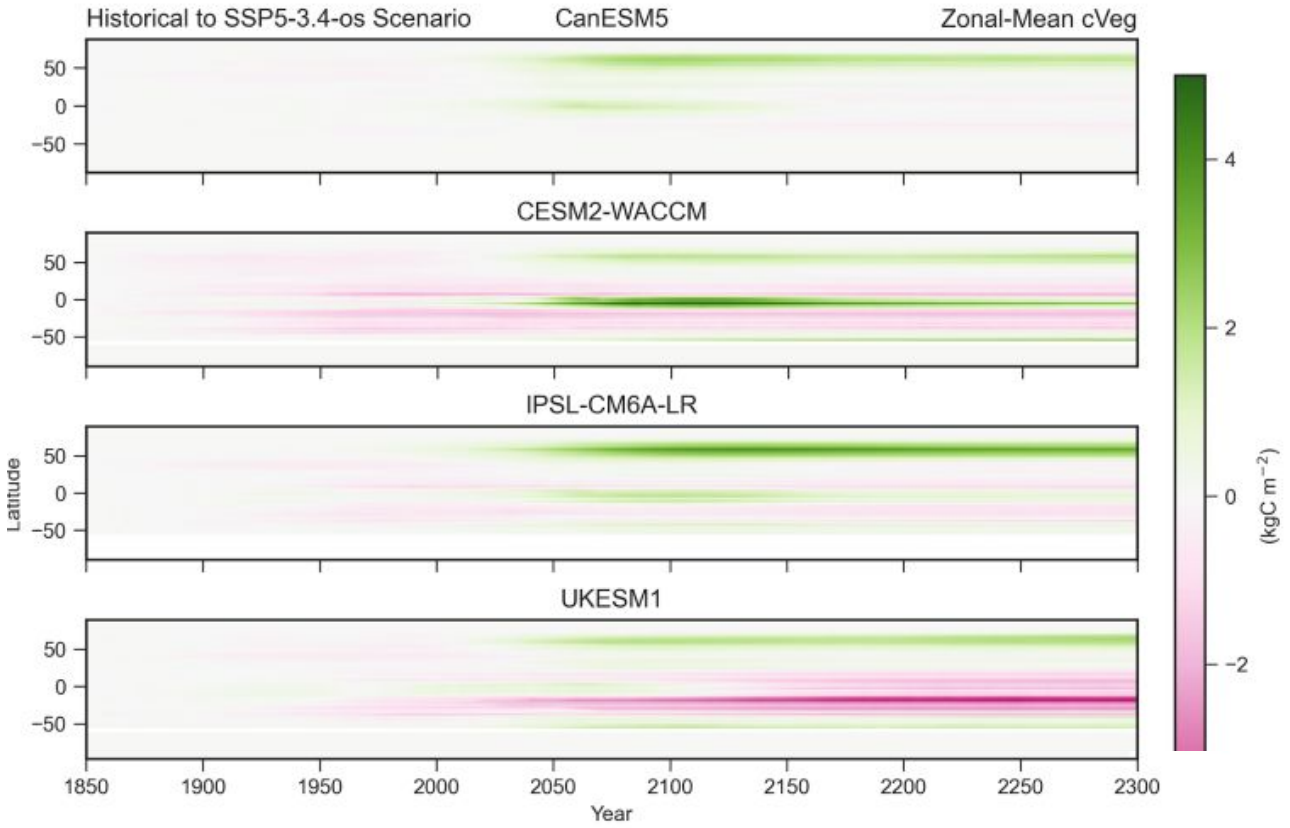
More Diversity

Modular Complexity

Human systems

Longer Simulations

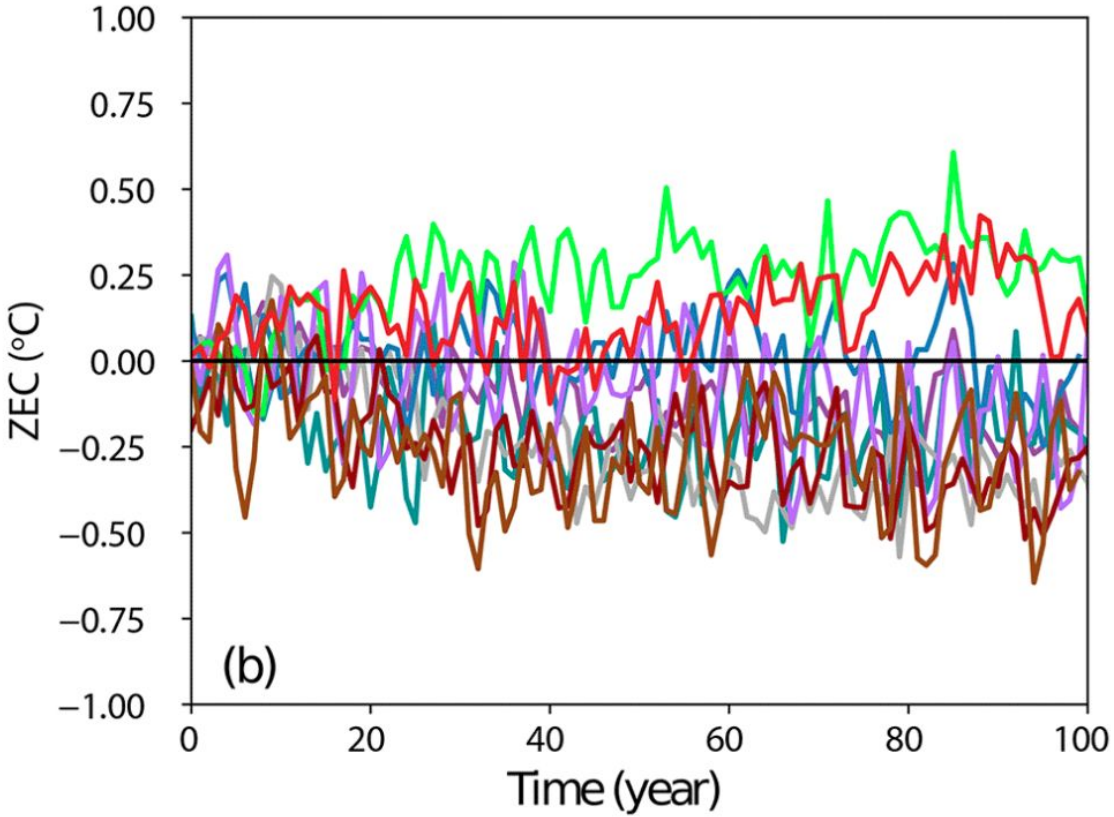
21st century simulations are insufficient to constrain emissions requirements for long term emissions targets (2100 is only 78 years away)



Koven, C., Arora, V. K., Cadule, P., Fisher, R. A., Jones, C. D., Lawrence, D. M., Lewis, J., Lindsey, K., Mathesius, S., Meinshausen, M., Mills, M., Nicholls, Z., Sanderson, B. M., Swart, N. C., Wieder, W. R., and Zickfeld, K.: 23rd Century surprises: Long-term dynamics of the climate and carbon cycle under both high and net negative emissions scenarios, Earth Syst. Dynam. Discuss. [preprint], https://doi.org/10.5194/esd-2021-23, in review, 2021.

Longer Simulations

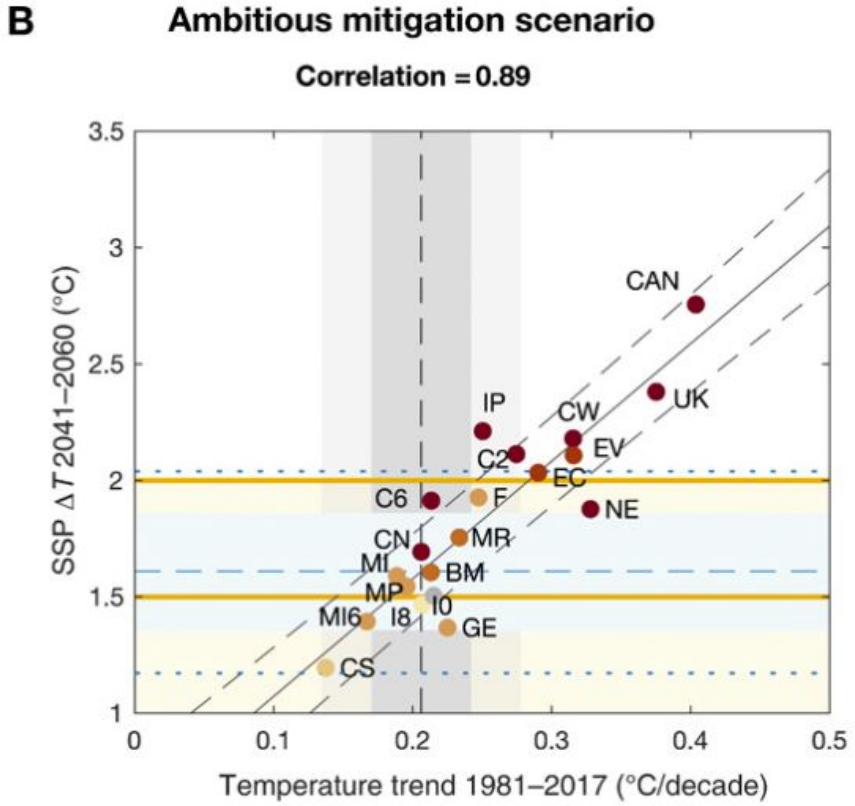
ESMs must provide unambiguous emissions-driven targets for emulator calibration.



MacDougall, A. H., Frölicher, T. L., Jones, C. D., Rogelj, J., Matthews, H. D., Zickfeld, K., ... & Ziehn, T. (2020). Is there warming in the pipeline? A multi-model analysis of the Zero Emissions Commitment from CO 2. *Biogeosciences*, *17*(11), 2987-3016.

More Diversity

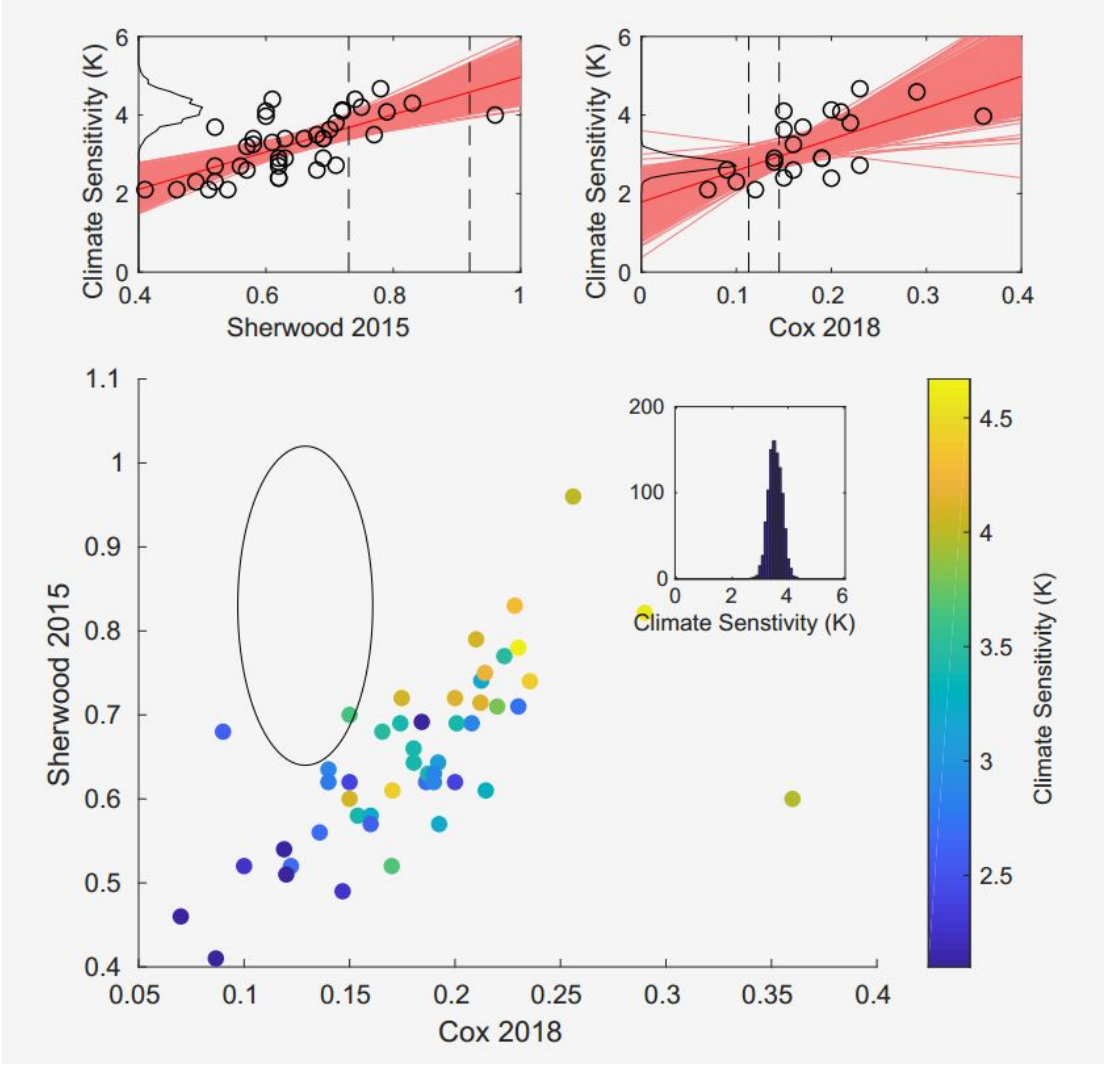
Biases in the CMIP6 warming distribution appear to rule out higher climate sensitivities



Tokarska, K. B., Hegerl, G. C., Schurer, A. P., Forster, P. M., & Marvel, K. (2020). Observational constraints on the effective climate sensitivity from the historical period. *Environmental Research Letters*, *15*(3), 034043.

More Diversity

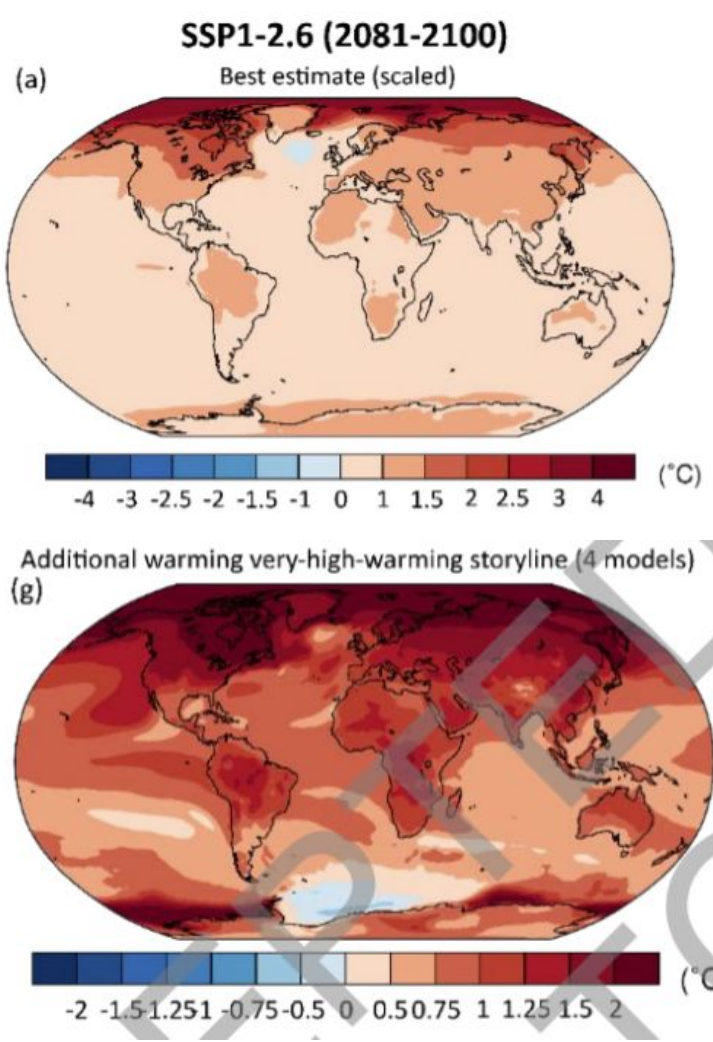
But we should be wary of weighting models on a single line of evidence



Sanderson, B. M., Pendergrass, A. G., Koven, C. D., Brient, F., Booth, B. B., Fisher, R. A., & Knutti, R. (2021). The potential for structural errors in emergent constraints. *Earth System Dynamics*, *12*(3), 899-918.

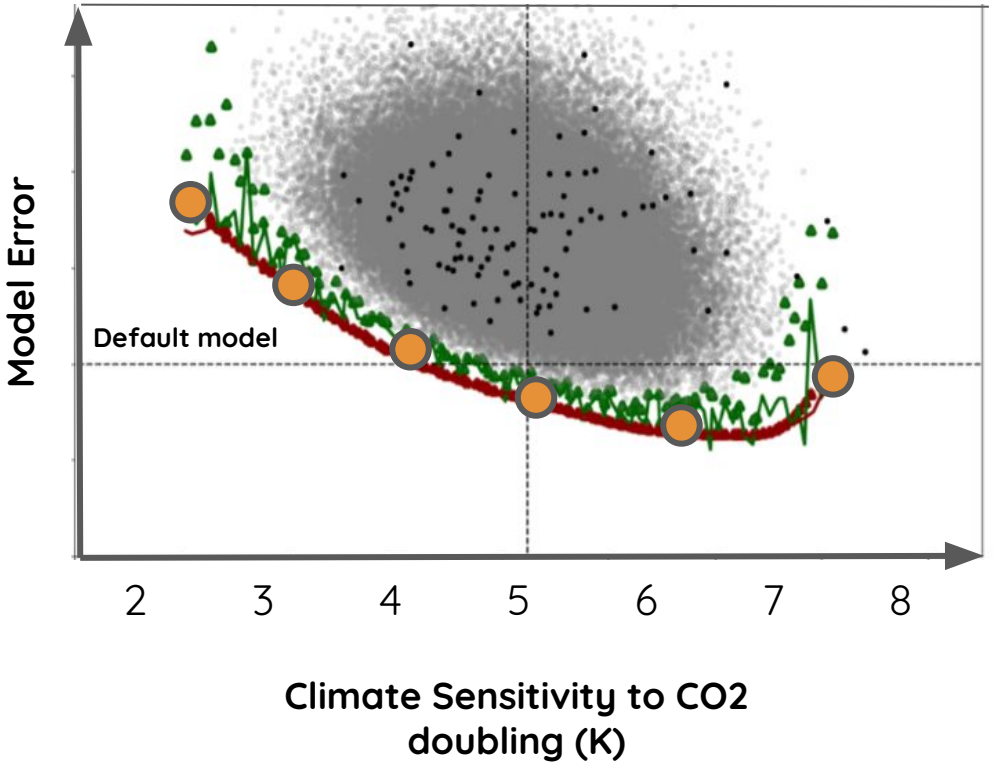
More Diversity

The ‘storyline’ framework allows to represent results outside of emulated expectations



More Diversity

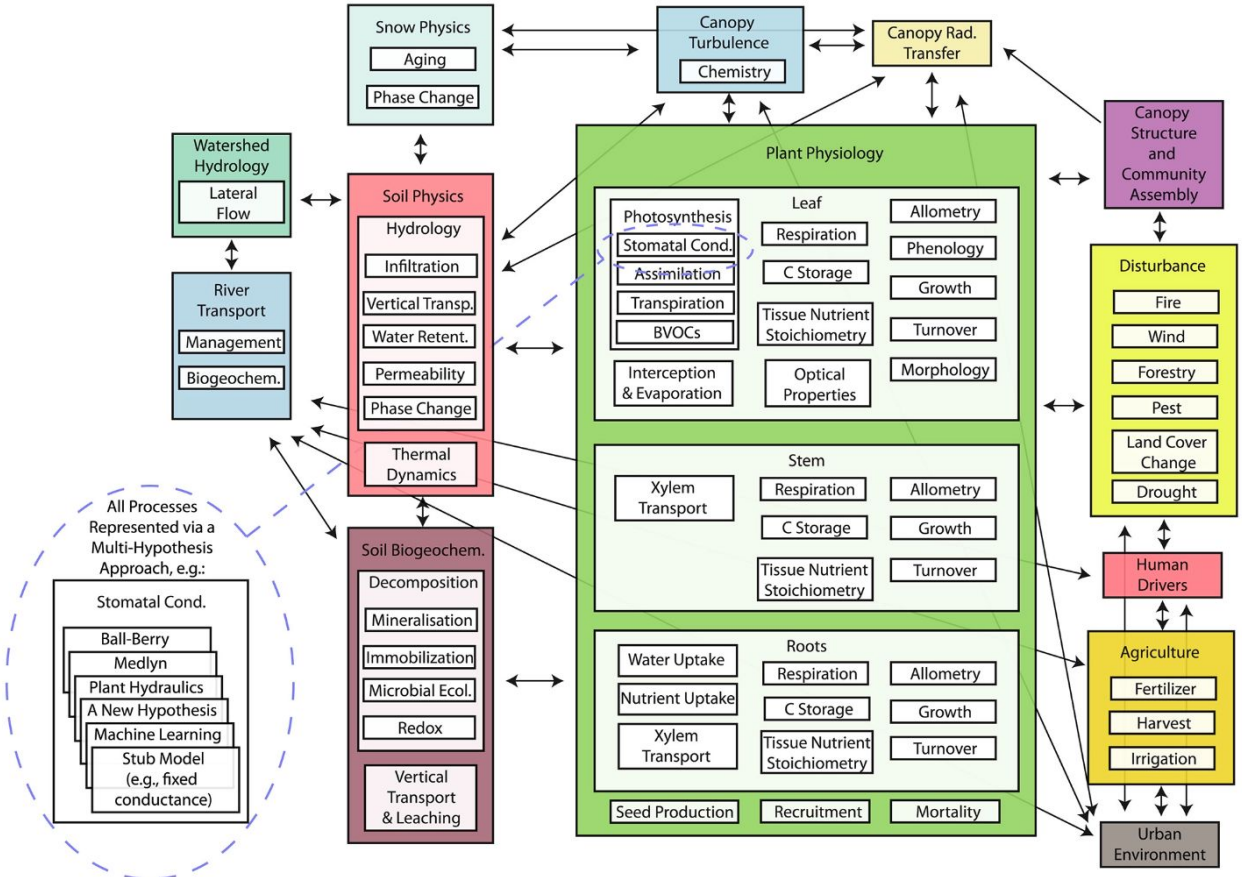
Operational exploration of parametric uncertainty in fundamental climate parameters could improve assessment of high-risk futures



Peatier *et al,* Evaluating parametric sensitivity of climate feedbacks in the atmospheric component of CNRM-CM6-1, Geophysical Research Letters (in Review)

Modular Complexity

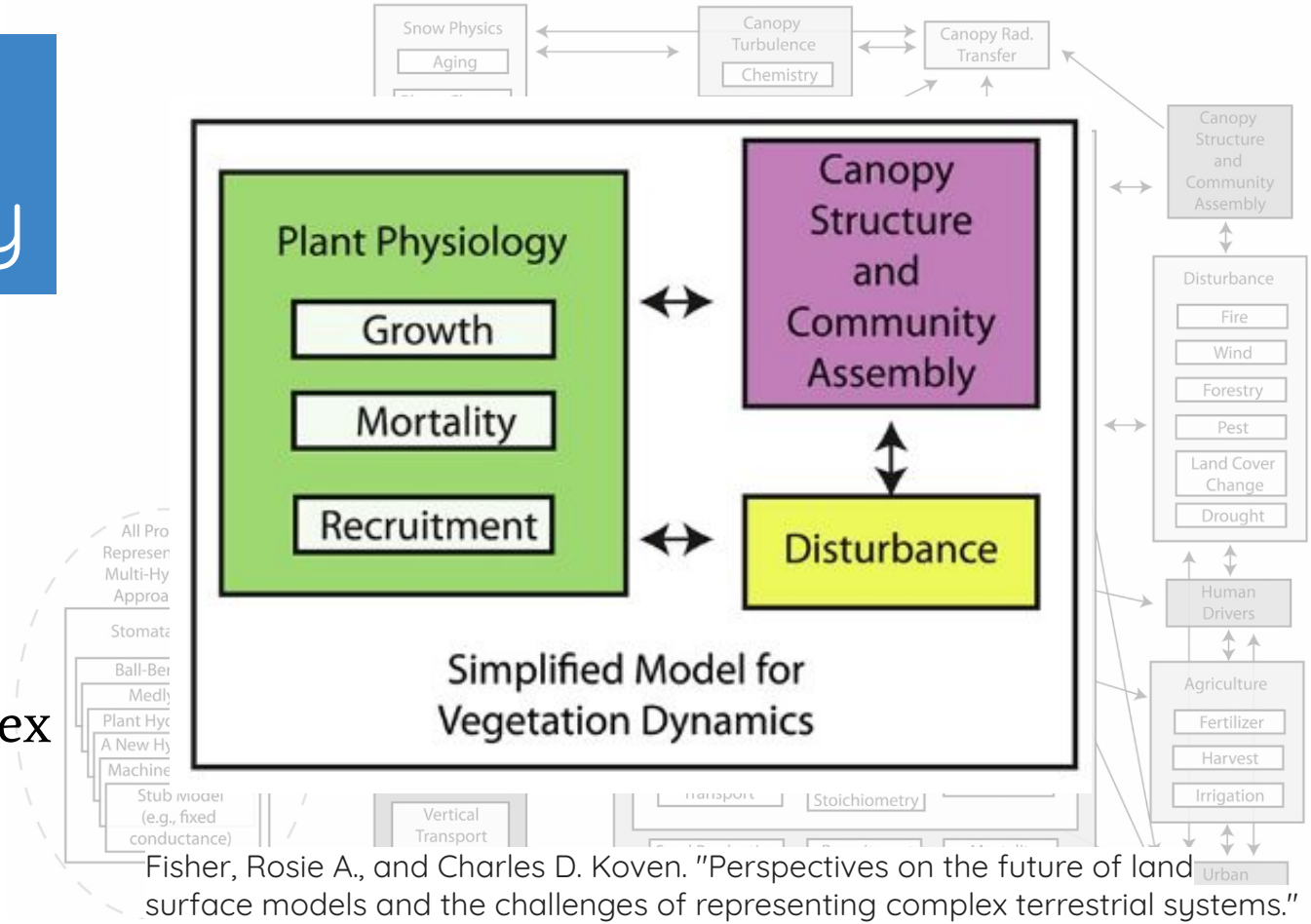
Earth System models have added value due to process-level representation, but complexity makes them increasingly hard to tune and understand



Fisher, Rosie A., and Charles D. Koven. "Perspectives on the future of land surface models and the challenges of representing complex terrestrial systems." *Journal of Advances in Modeling Earth Systems* 12.4 (2020): e2018MS001453.

Modular Complexity

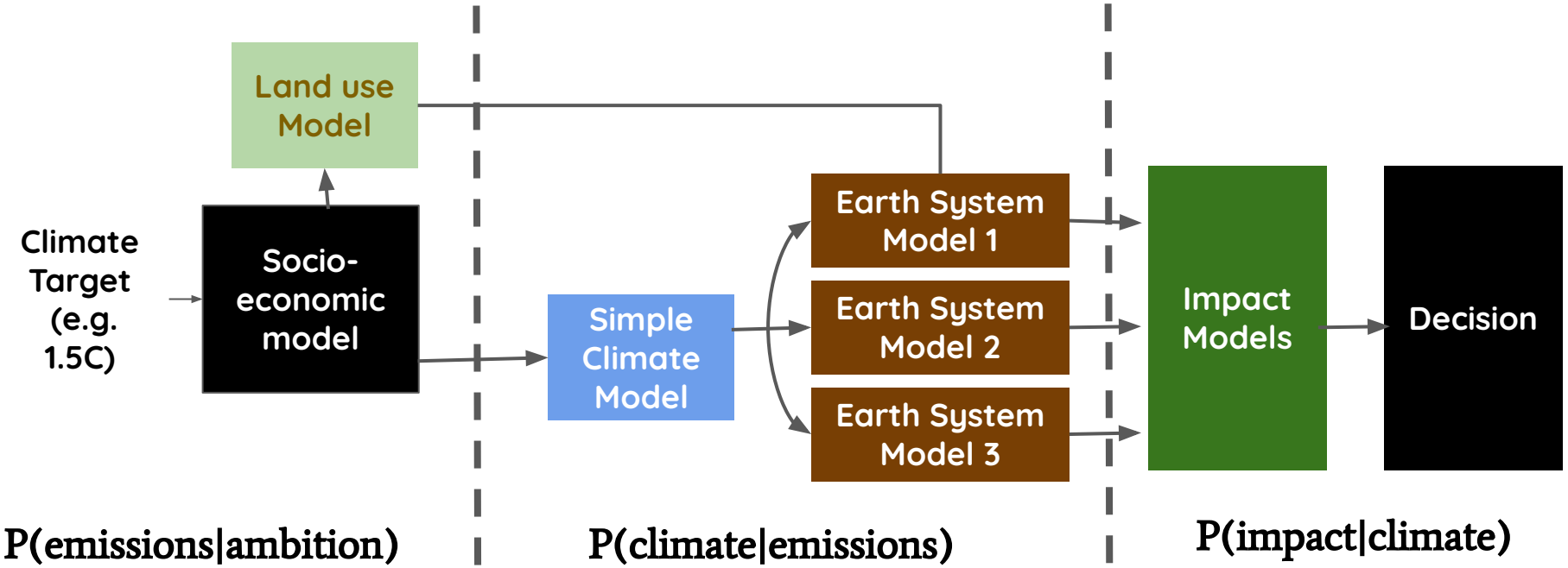
Modular design enables objective calibration and process understanding in increasingly complex architectures



Fisher, Rosie A., and Charles D. Koven. "Perspectives on the future of land surface models and the challenges of representing complex terrestrial systems." *Journal of Advances in Modeling Earth Systems* 12.4 (2020): e2018MS001453.

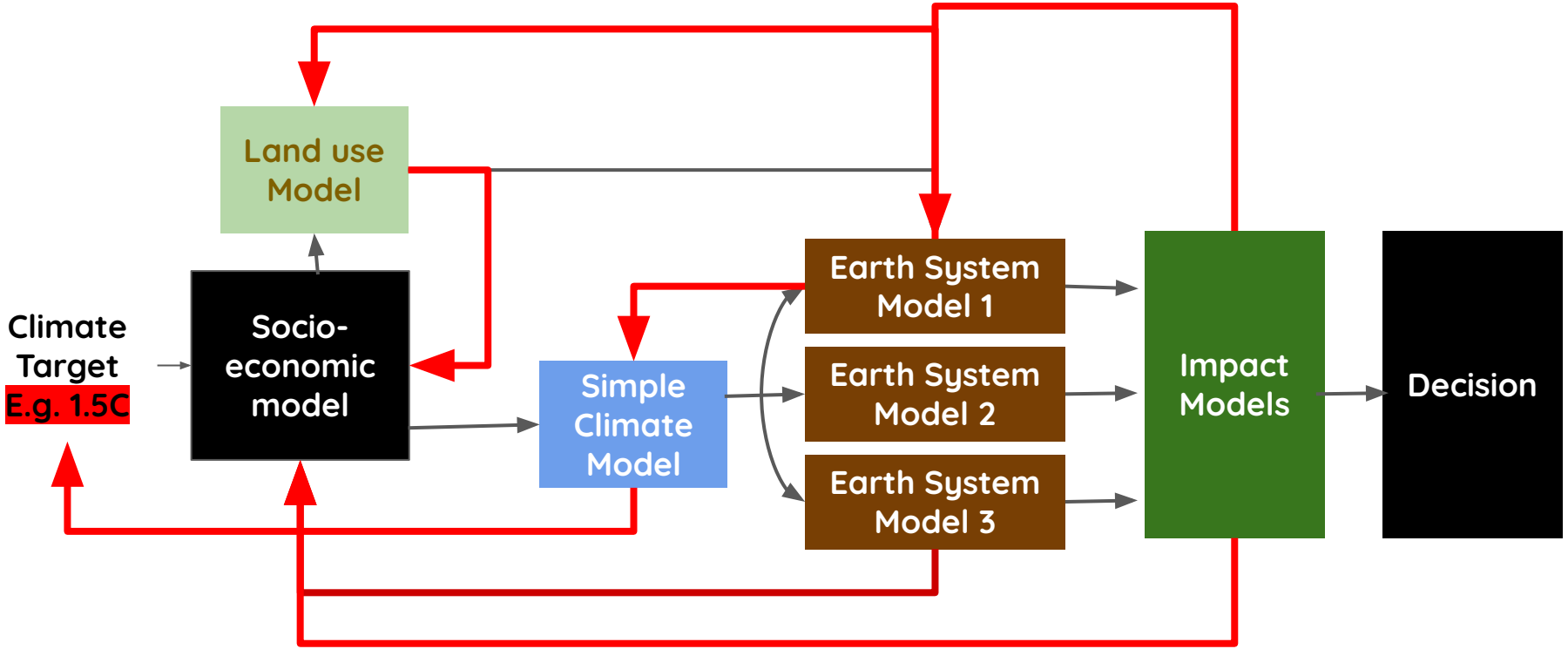
Human systems

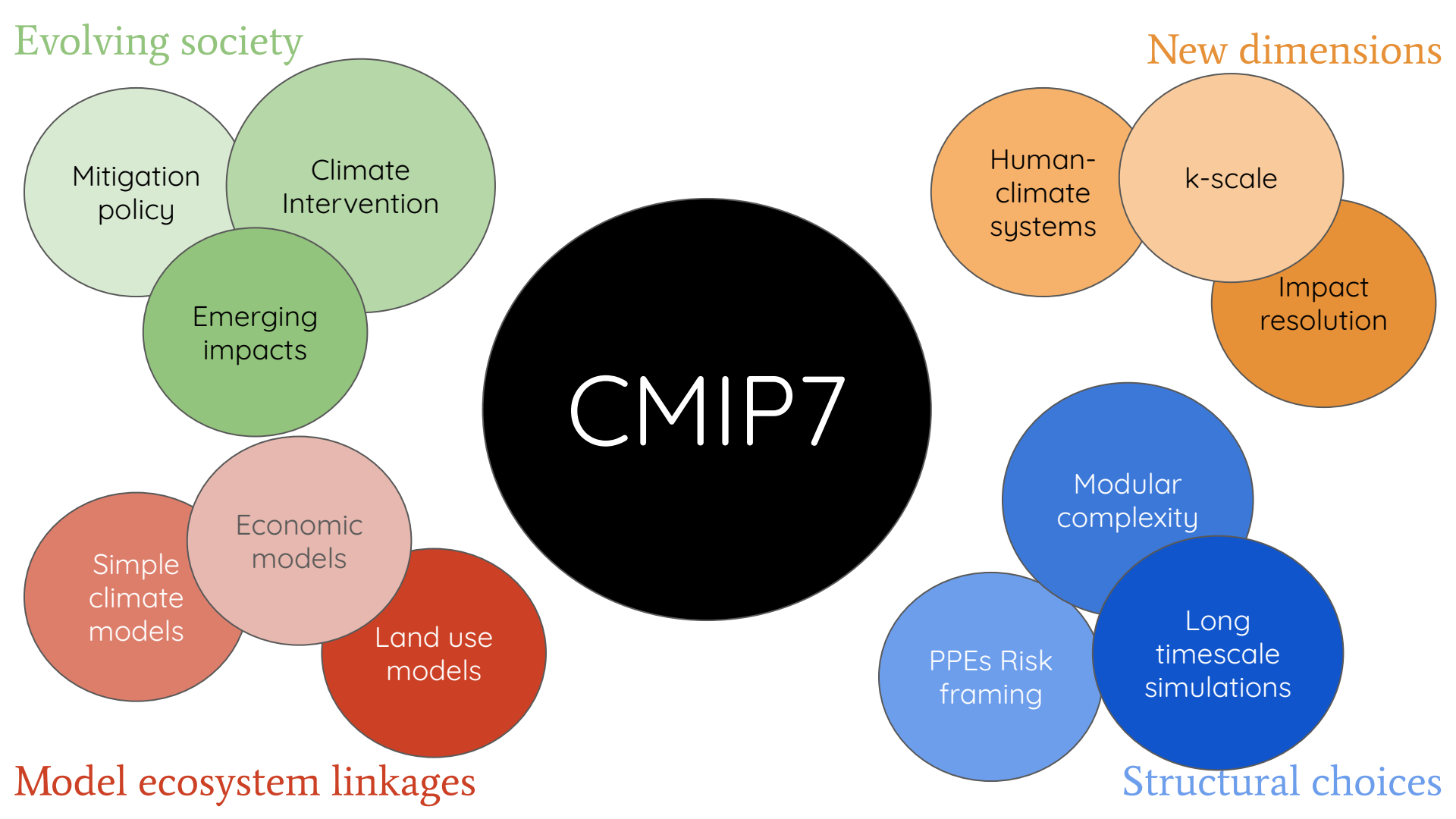
Traditional partitioning of uncertainties between disciplines cannot represent key mitigation processes (e.g. BECCS)



Human systems

"Upstream" effects and coupled human-climate systems are needed to understand tractability of pathways to Paris temperature targets




Evolving society
Mitigation policy
Climate Intervention
Emerging impacts
New dimensions
Human-climate systems
k-scale
Impact resolution
CMIP7
Simple climate models
Economic models
Land use models
Modular complexity
PPEs Risk framing
Long timescale simulations
Model ecosystem linkages
Structural choices