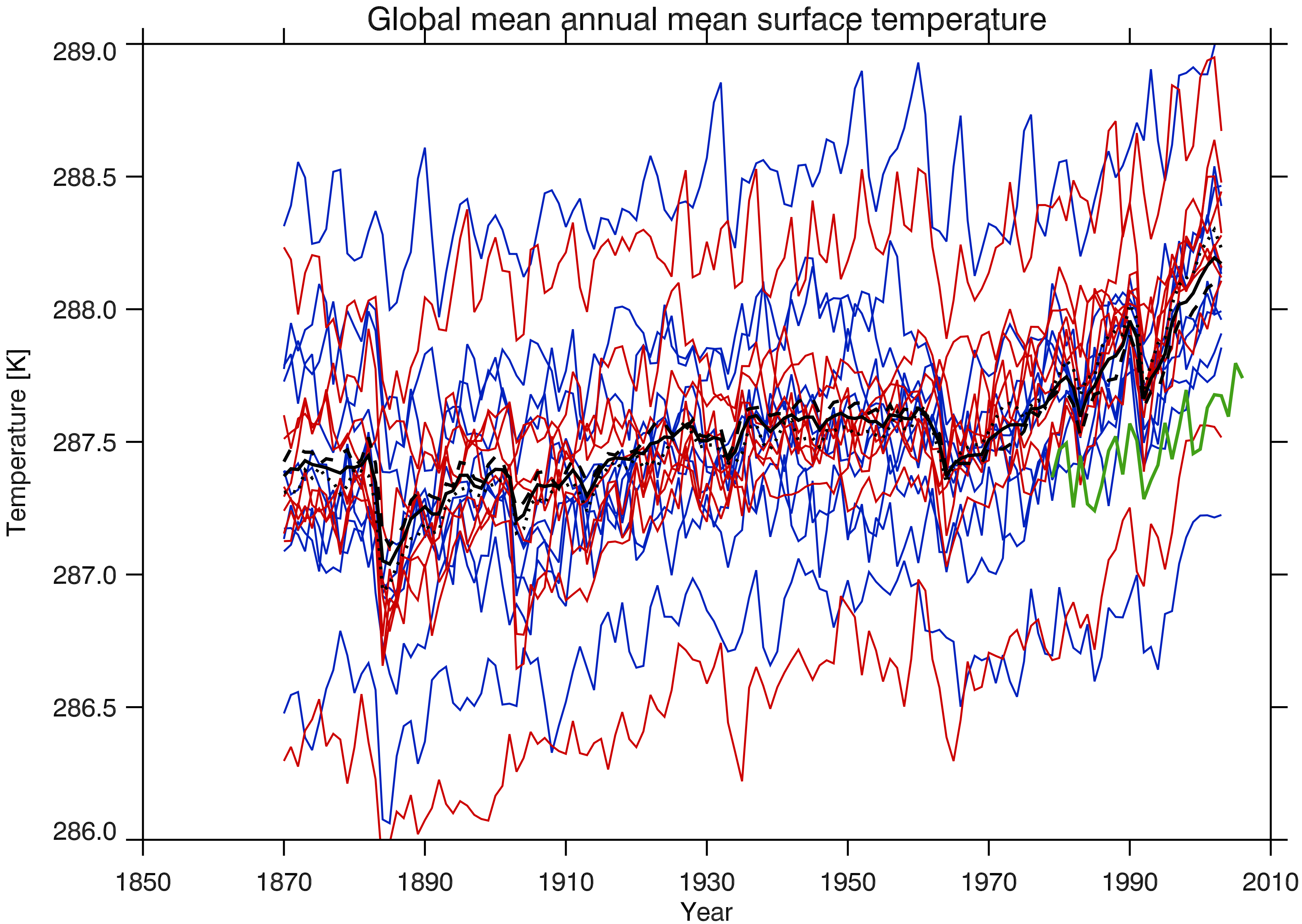
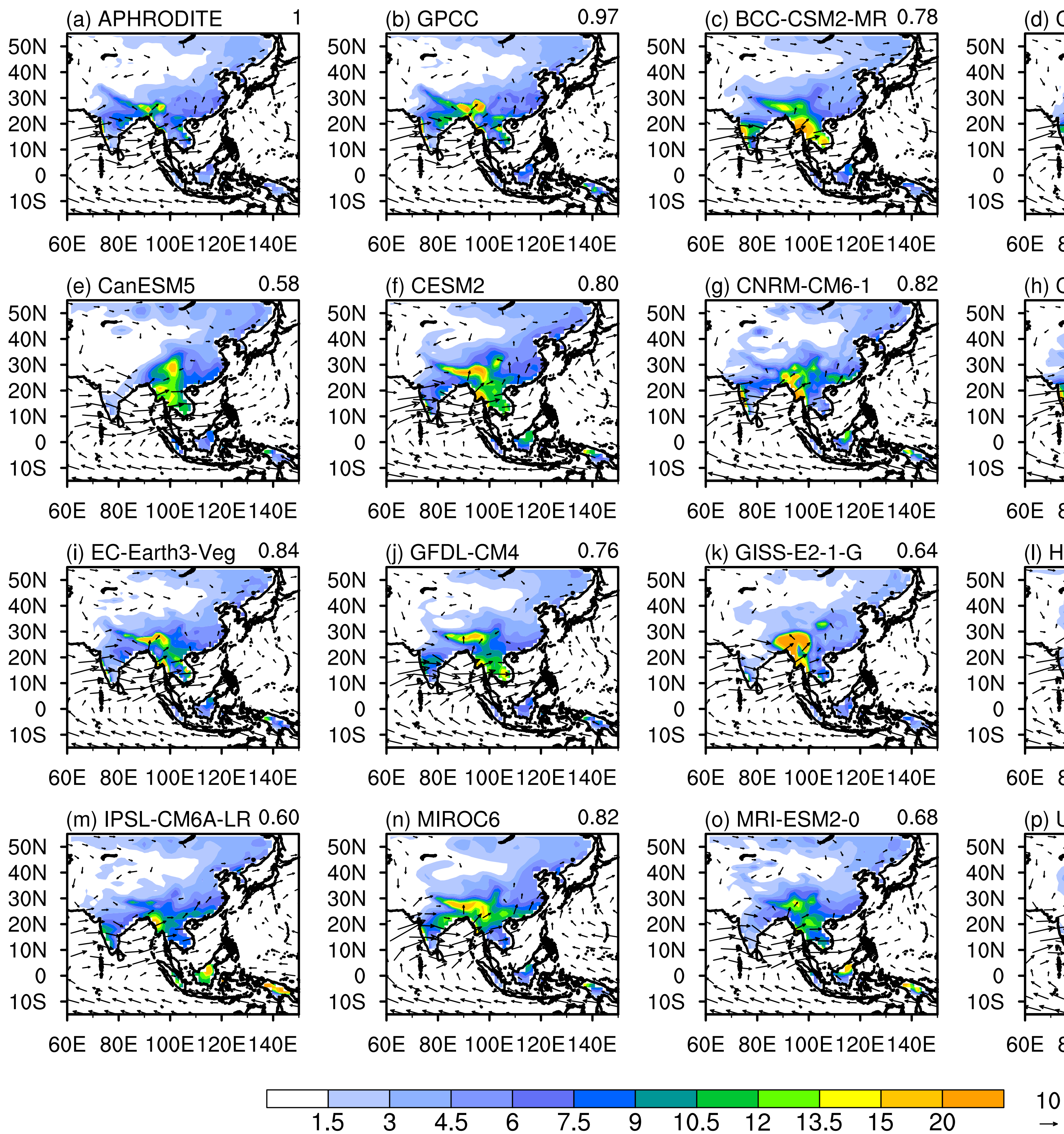
Model diversity: friend or foe?



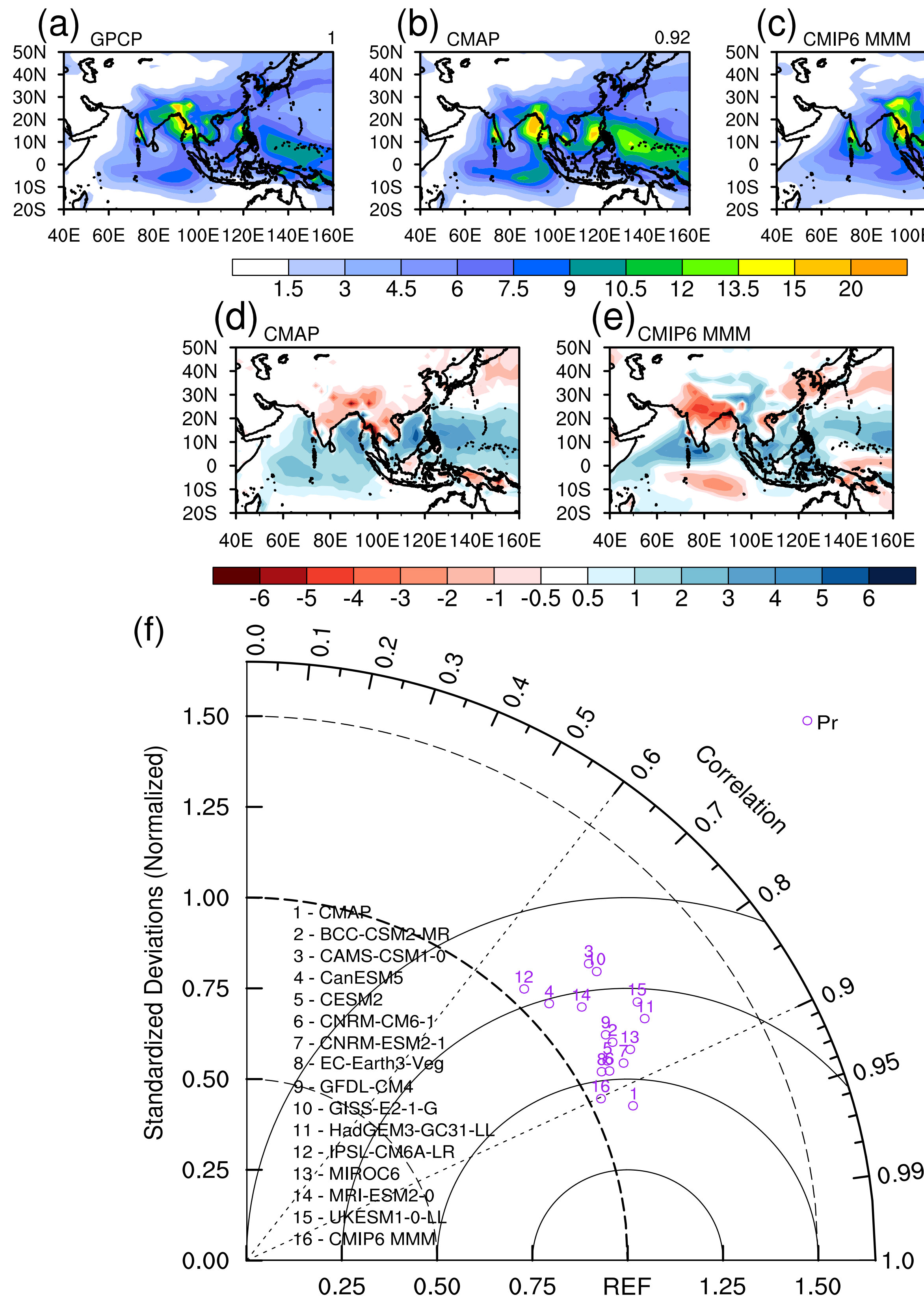
Wilcox et al. (2013)

Model diversity: friend or foe?



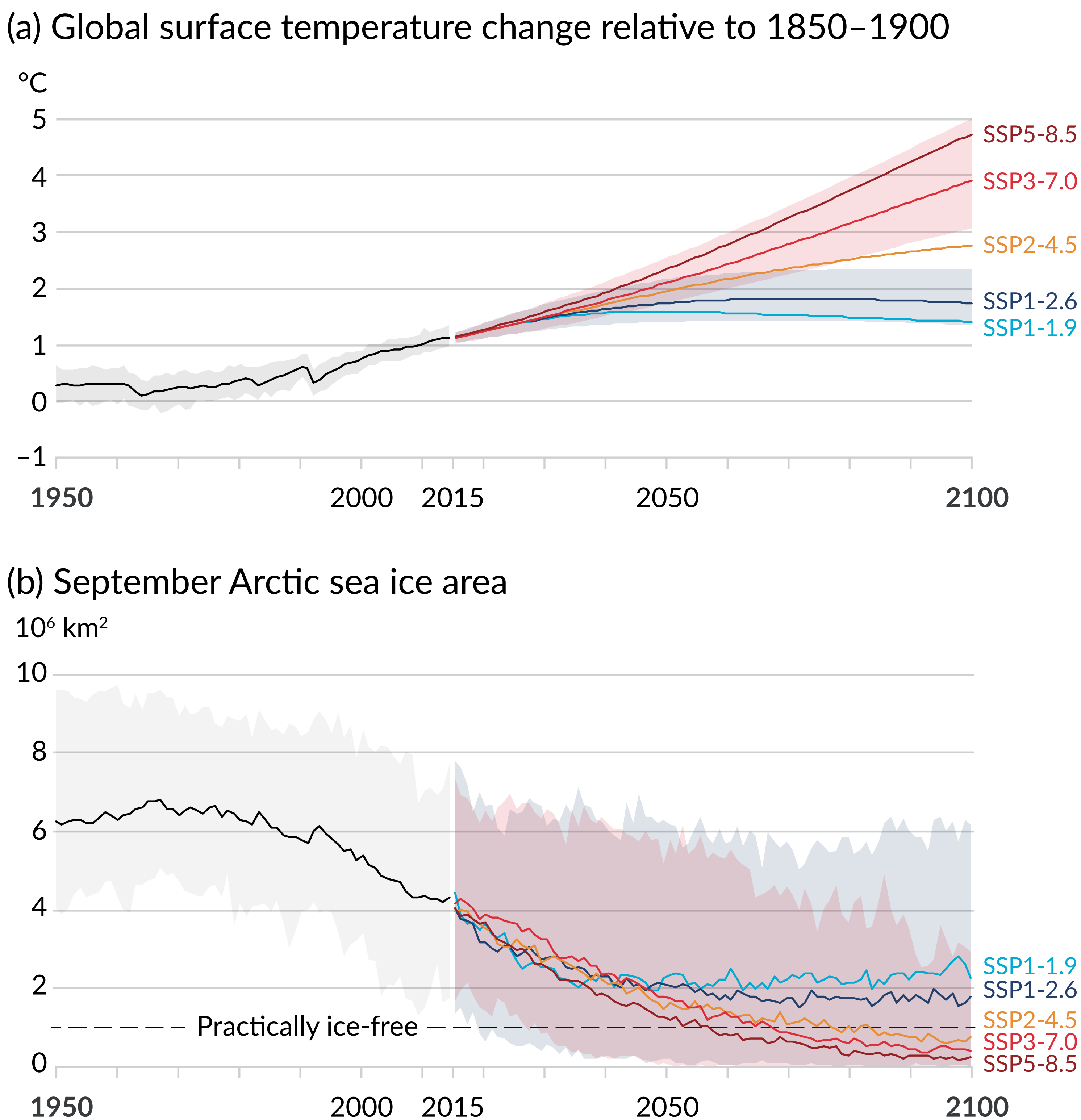
Wilcox et al. (2020)

Model diversity: friend or foe?



Wilcox et al. (2020)

Model diversity: friend or foe?

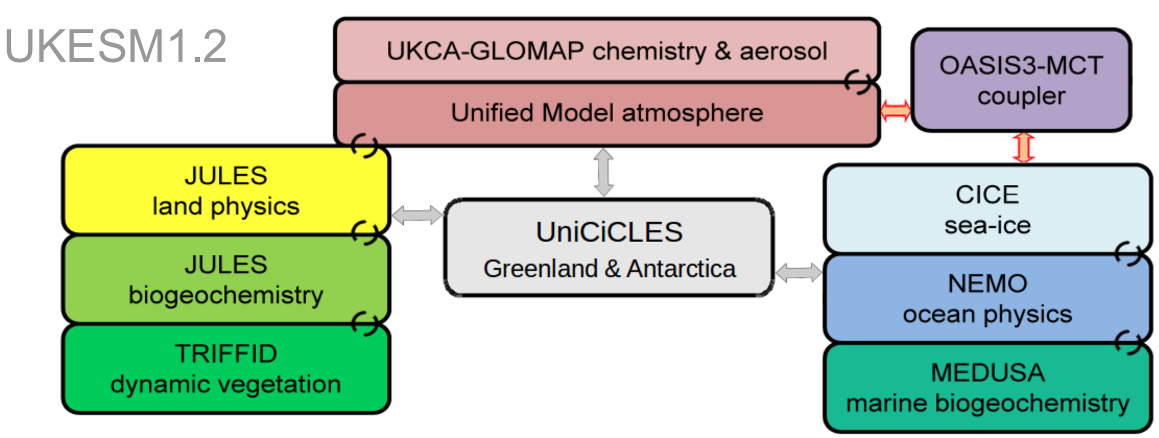


AR6 WG1 SPM

About me

RAMIP

Regional Aerosol
Model Intercomparison Project



Associate Professor at the National Centre for Atmospheric Science, University of Reading

Chair of the Regional Aerosol Model Intercomparison Project (RAMIP)

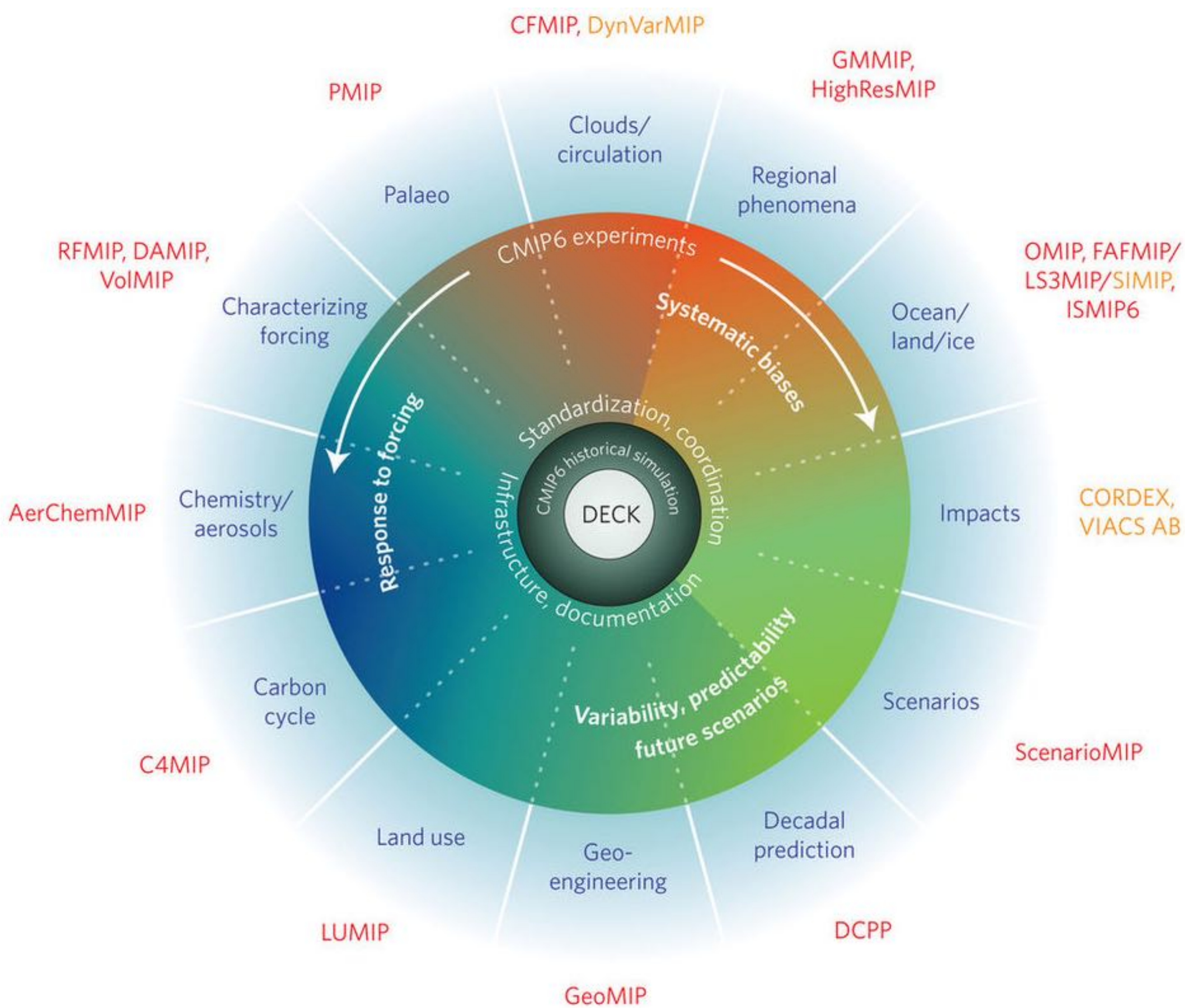
IPCC AR6 WG1 Chapter 8 author (water cycle change)

Member of the Atmosphere author team for the CMIP7 data request

Some (limited!) involvement in the development and testing of the UK Earth System Model (UKESM)

A long-term user of CMIP

The Coupled Model Intercomparison Project



Eyring et al. (2016)

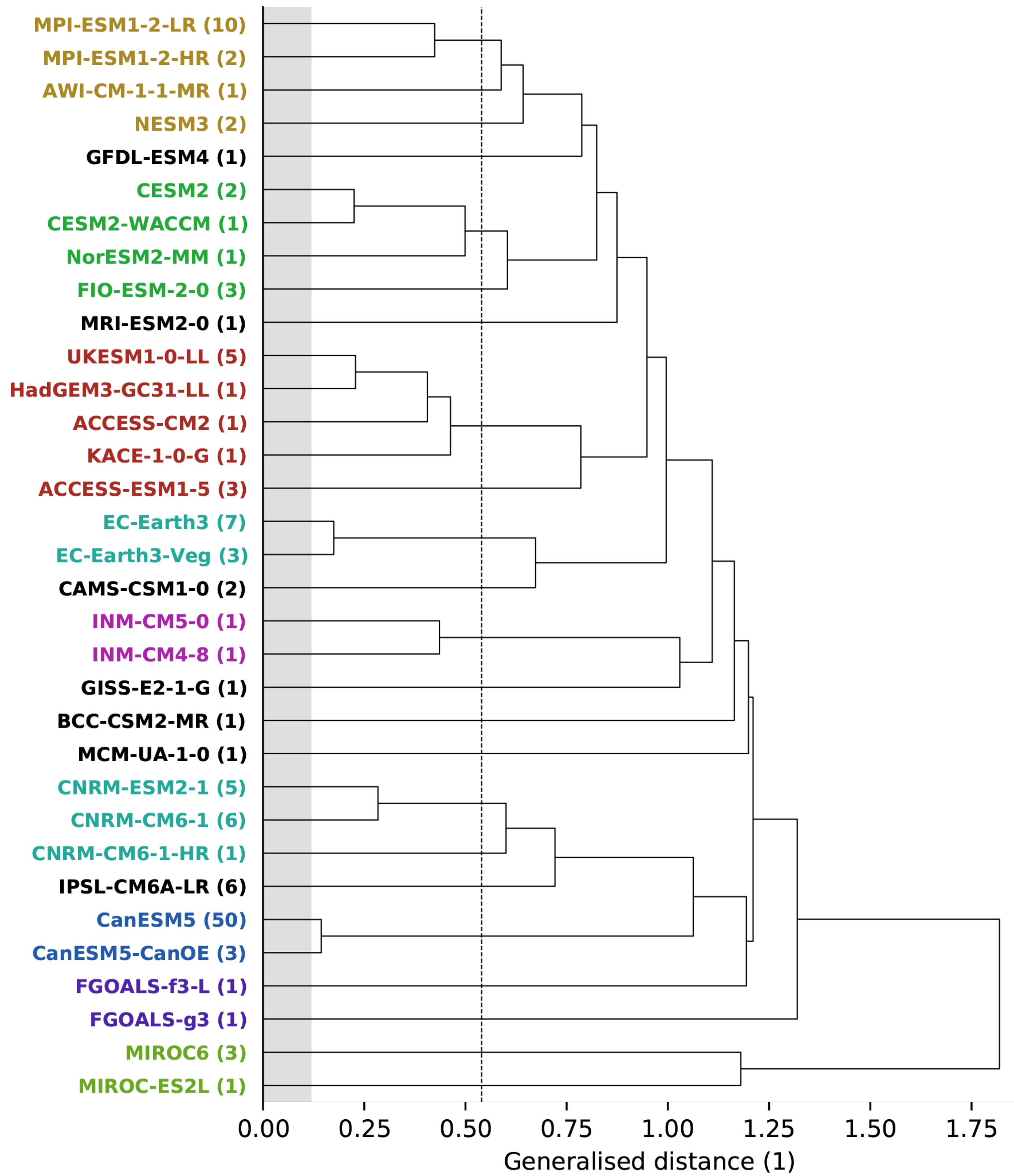
Core DECK (piControl, ….) and historical simulations, with endorsed MIPs exploring key science questions

A MIP explores the same question, in the same (ish) way, in multiple models, allowing us to explore the effects of model **structural uncertainty**

CMIP experiments allow us to explore the effects of emission uncertainty (e.g. ScenarioMIP), or quantify the role of individual climate forcers in the role of climate change (e.g. DAMIP, AerChemMIP), etc.

Considering these experiments as part of a MIP allows us to better quantify uncertainty, and to learn which processes might be important for climate responses to forcing

The CMIP6 models



78 models from 32 centres participated in CMIP6

Example family tree for 33 CMIP6 models.

Models branching further to the left are more dependent

Labels with the same colour indicate models with obvious dependencies, such as shared components or the same origin

Models with no clear dependencies are labeled in black.

An estimation of internal variability is given using grey shading

Brunner et al. (2020)

The CMIP6 models

OSF HOME

Search Support Donate Sign Up Sign In

Opinion: The Role of AerChemMIP in Advancing Climate an...

CMIP6_AerChemMIP_model_details.csv

Sheet 1

Show rows with cells including:

		Emergent ...			Model com...					
Model	Centre	ECS (Schlu...	ERF_AA	ASR_HD	Atmosphere	Aerosol	Chemistry	Ocean	Sea Ice	Land
ACCESS-CM2	CSIRO-AR...	4.72	-1.09	2.19	MetUM-Had...	UKCA-GLO...		ACCESS-O...	CICE5.1.2	CABL
ACCESS-E...	CSIRO	3.87	-1.15	1.90	HadGAM2	CLASSIC (v...		ACCESS-O...	CICE4.1	CABL
AWI-ESM-1...	AWI	3.16			ECHAM6.3....	MACv2-SP		FESOM 1.4	FESOM 1.4	JSBA
BCC-CSM2-...	BCC	3.04		0.60	BCC_AGC...	MACv2-SP		MOM4	SIS2	BCC_
BCC-ESM1	BCC	3.26		2.04	BCC_AGC...		BCC-AGCM...	MOM4	SIS2	BCC_
CAMS-CSM...	CAMS	2.29		-0.01	ECHAM5_C...			MOM4	SIS 1.0	CoLM
CanESM5	CCCma	5.62	-0.85	1.61	CanAM5	Interactive	Specified ox...	NEMO3.4.1	LIM2	CLAS
CAS-ESM2-0	CAS	3.51		2.51	IAP AGCM 5.0	IAP AACM	IAP AACM	LICOM2.0	CICE4	CoLM
CESM2-FV2	NCAR	5.14		2.95	CAM6	MAM4	MAM4	POP2	CICE5.1	CLM5
CESM2	NCAR	5.16	-1.37	2.55	CAM6	MAM4	MAM4	POP2	CICE5.1	CLM5
CESM2-WA...	NCAR	4.79		2.82	WACCM6	MAM4	MAM4	POP2	CICE5.1	CLM5
CESM2-WA...	NCAR	4.75		2.74	WACCM6	MAM4	MAM4	POP2	CICE5.1	CLM5
CIESM (EC...	THU	5.67		0.45	CIESM-AM	MAM4	trop_mam4	CIESM-OM	CICE4	CIESM

Metadata

OSF

File Metadata

Resource type
Dataset
Resource language
English

Project Metadata

Title
Opinion: The Role of AerChemMIP in Advancing Climate and Air Quality Research
Description
Opinion/Review paper for CMIP6-endorsed sub-project AerChemMIP. Review paper for CMIP6 DeCK CMIP and ScenarioMIP tropospheric ozone. https://doi.org/10.5194/acp-21-4187-2021
License
CC-By Attribution 4.0 International
Date created
April 10, 2025

Help

https://doi.org/10.17605/OSF.IO/8FWJ3

Wilcox (2025)

User beware....

Different models aren't always so different….

- CESM2 and CESM-FV2 just have different resolutions
- CESM2 and CESM2-WACCM have atmospheric chemistry

The same model is sometimes different….

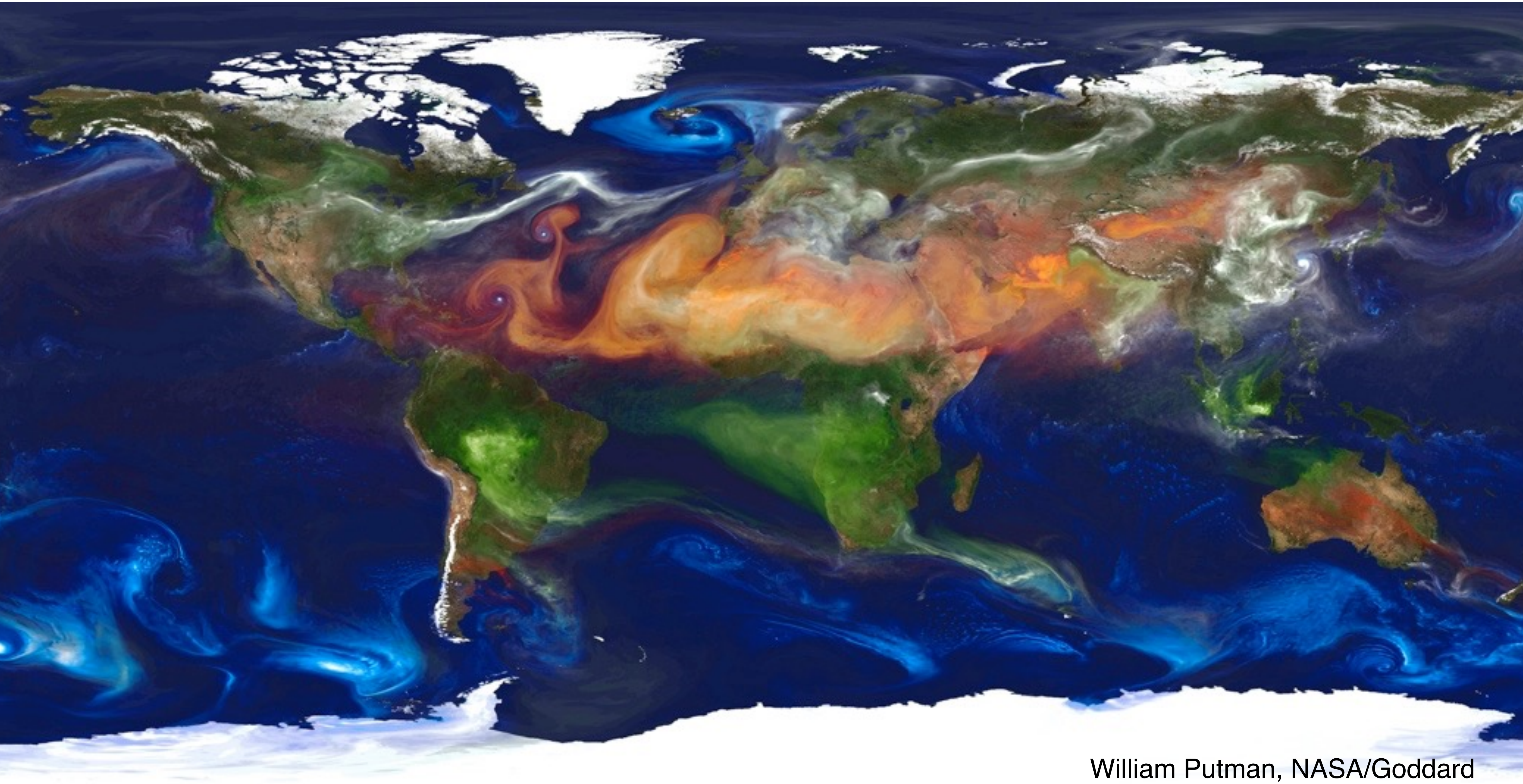
- GISS use ensemble physics codes to distinguish between model versions.
- rXiXpXfX
- GISS-E2-1-G r1i1p1f1, r1i1p3f1, and r1i1p5f1 all have different chemistry schemes - very different models, which are often lumped together due to this labelling

While sometimes, the same model really is just the same…

- CanESM5 p1 and p2 refer to a micro perturbation. As long as you're not looking at variables closely related to the perturbed variable, you can just lump all of these together to create a larger ensemble

Wilcox (2025)

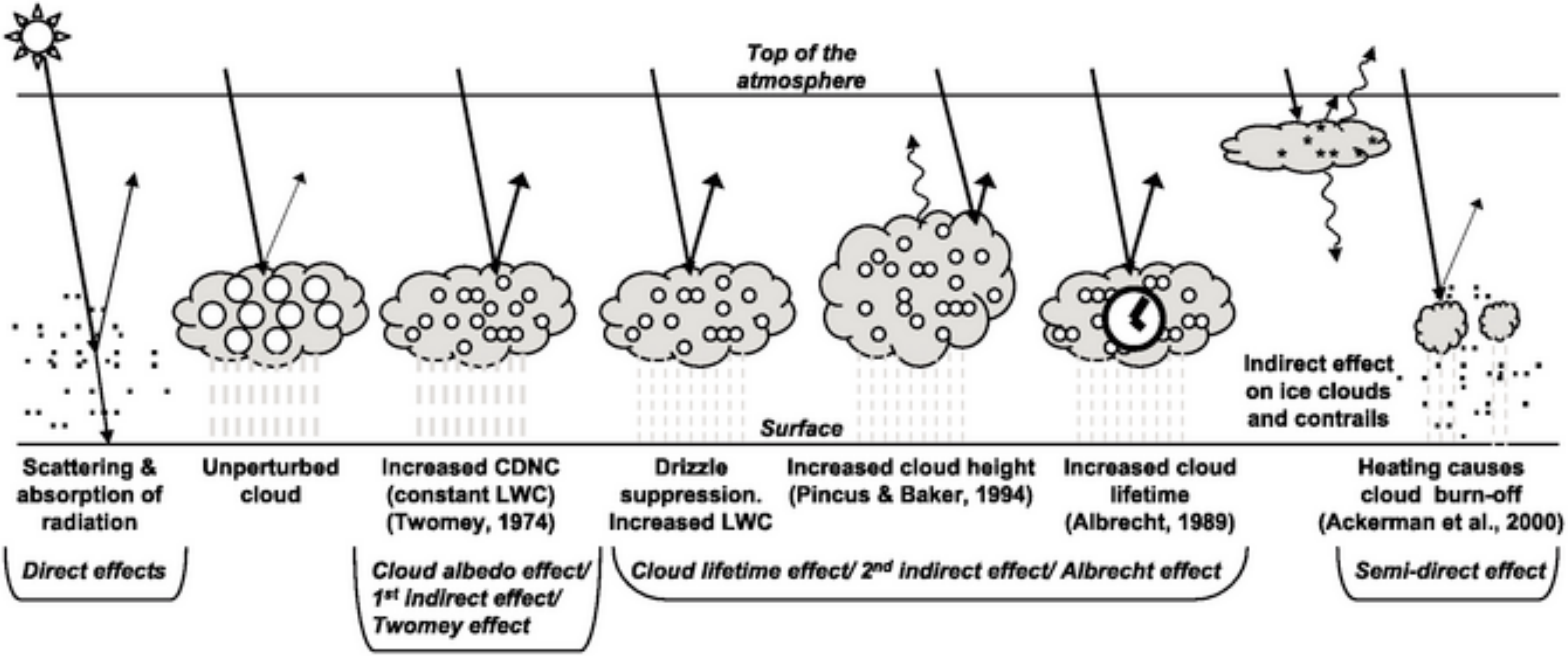
Global aerosol



William Putman, NASA/Goddard

GEOS-5, 10km resolution
Red: Dust   Blue: Sea salt   Green: Smoke   White: Sulphate

Aerosol effects on climate



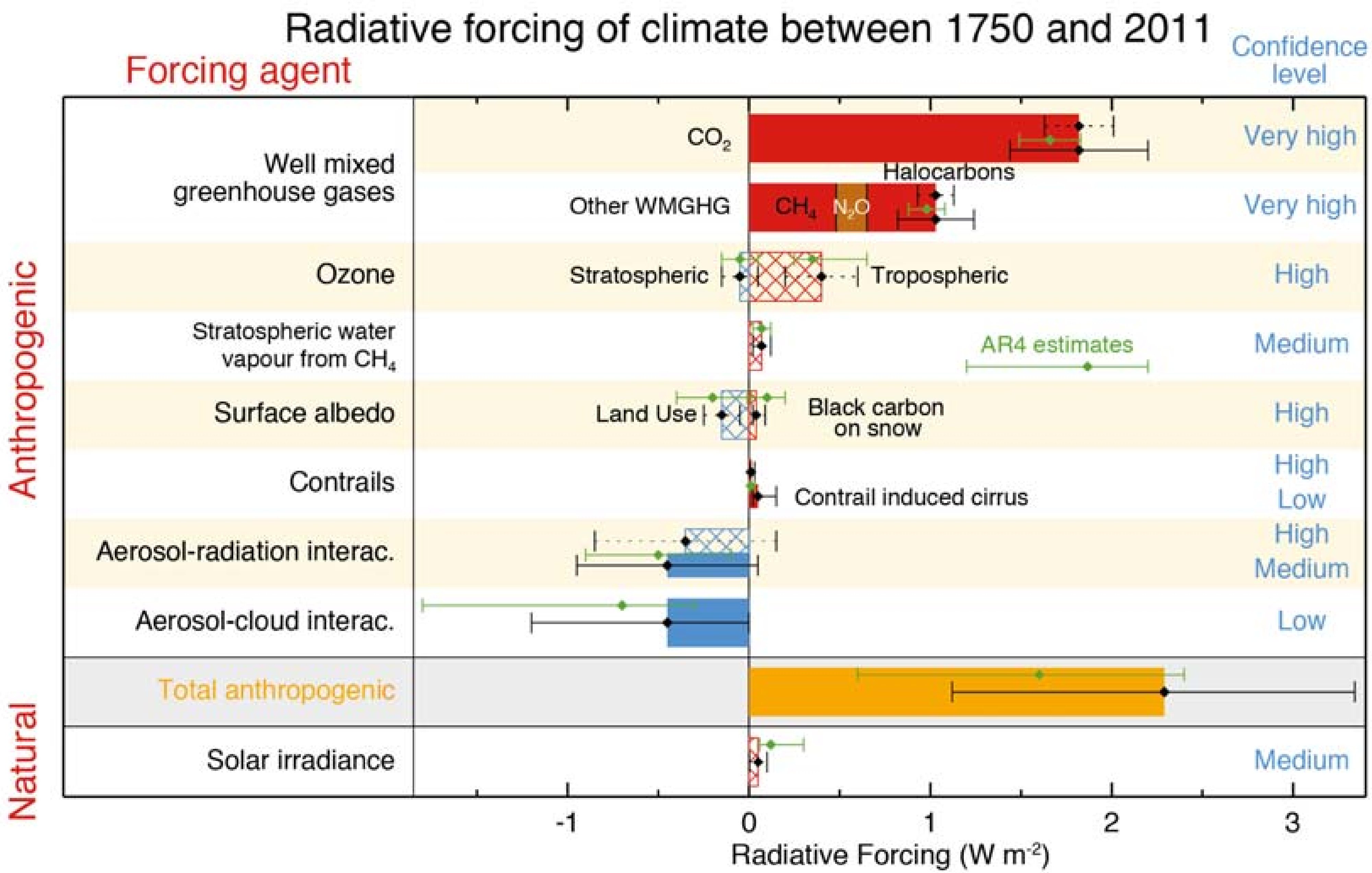
Many ways for aerosols to interact with climate

Some models don't simulate these interactions

Different models have different approaches to representing these interactions

IPCC (2007)

Aerosol effects on climate

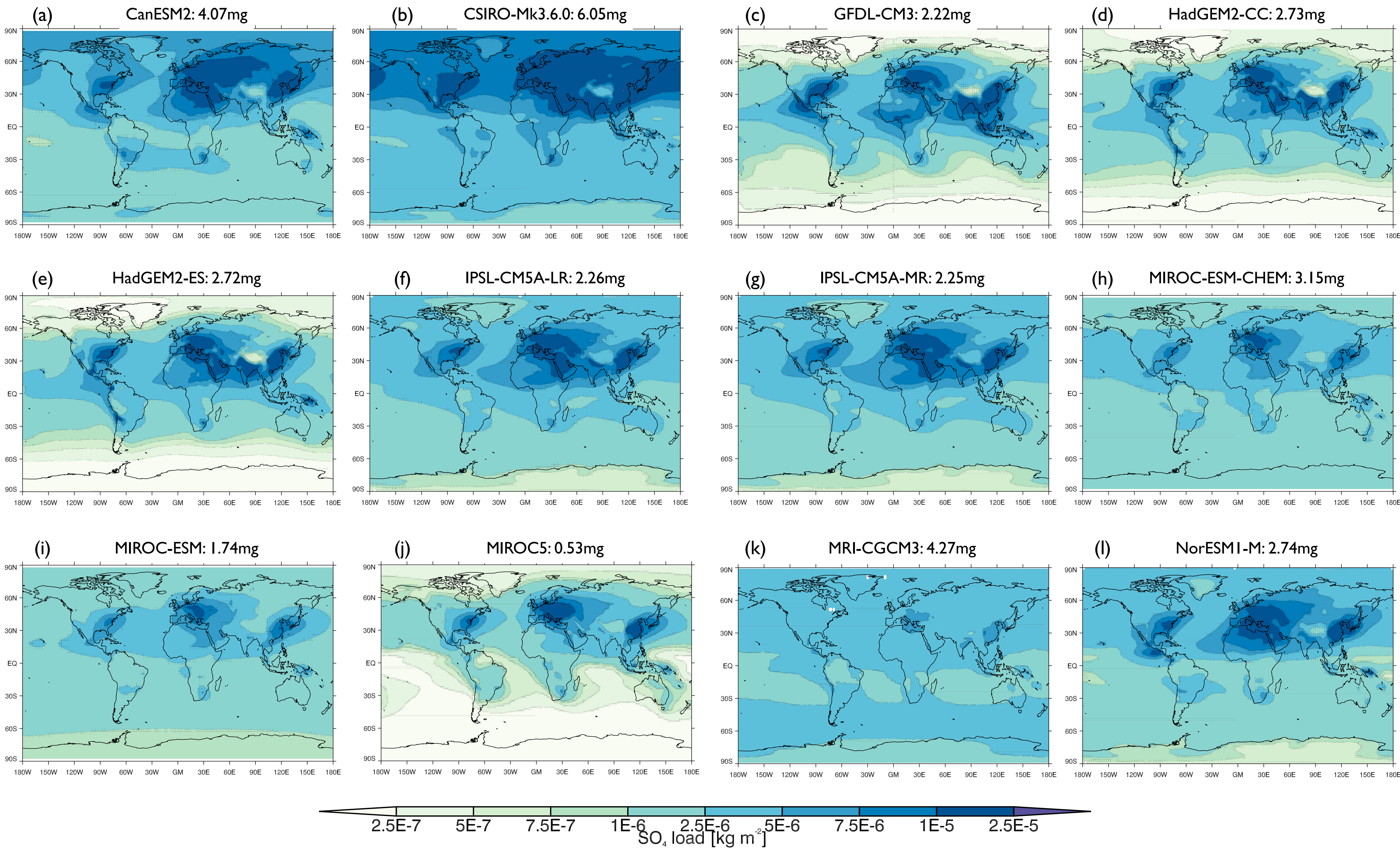


Aerosol forcing is the most uncertain anthropogenic climate forcing, reflecting challenges with both observations and modelling

IPCC (2013)

Models are driven with the same emissions

1986 - 2005 mean sulphate load

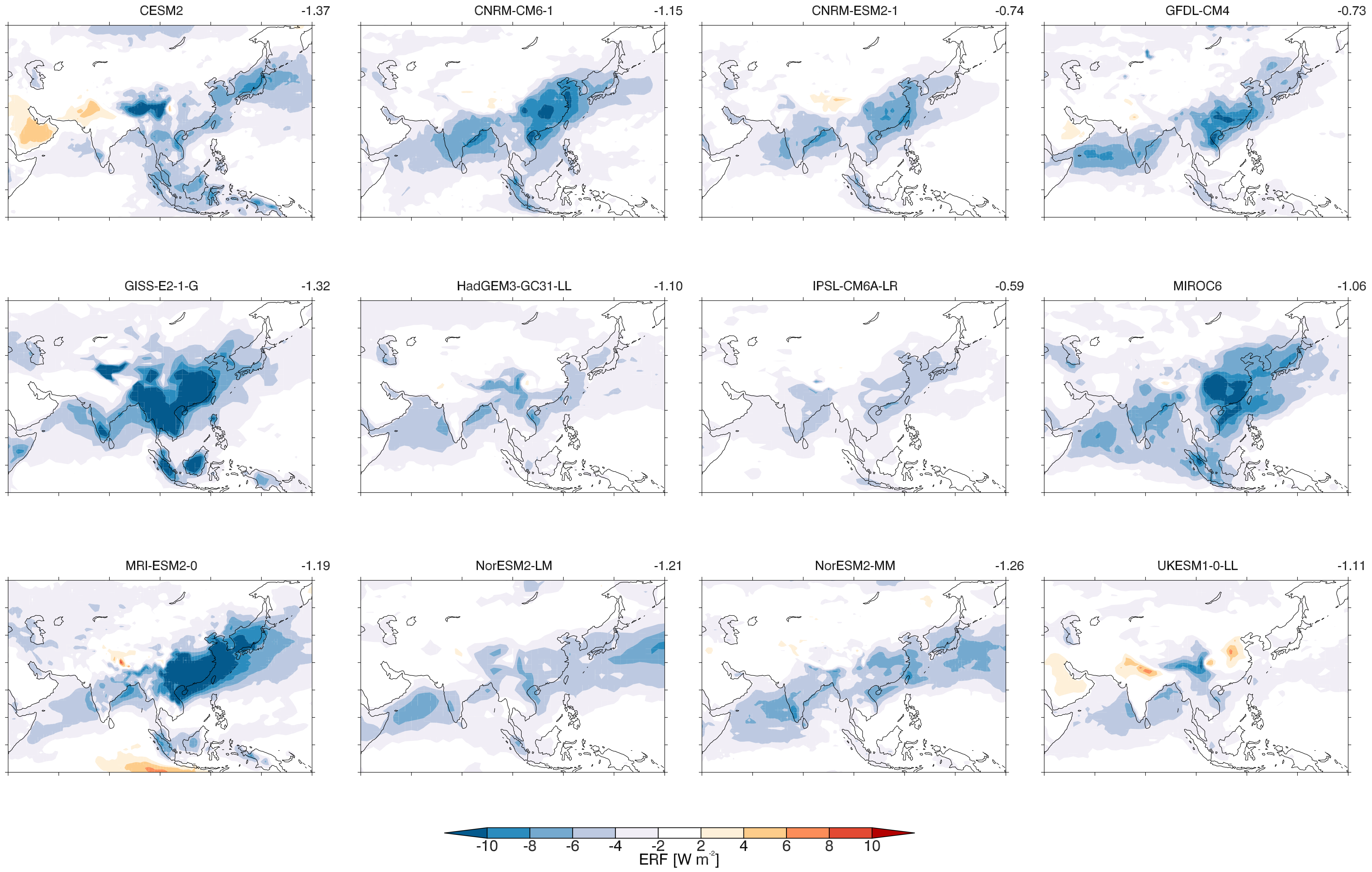


- Substantial inter-model diversity in aerosol load, even in the preindustrial period
  - Diversity in absolute mass and distribution
  - Factor of four spread in the global mean

Wilcox et al. (2015), GRL

Models are driven with the same emissions

2014 vs. 1850
aerosol ERF

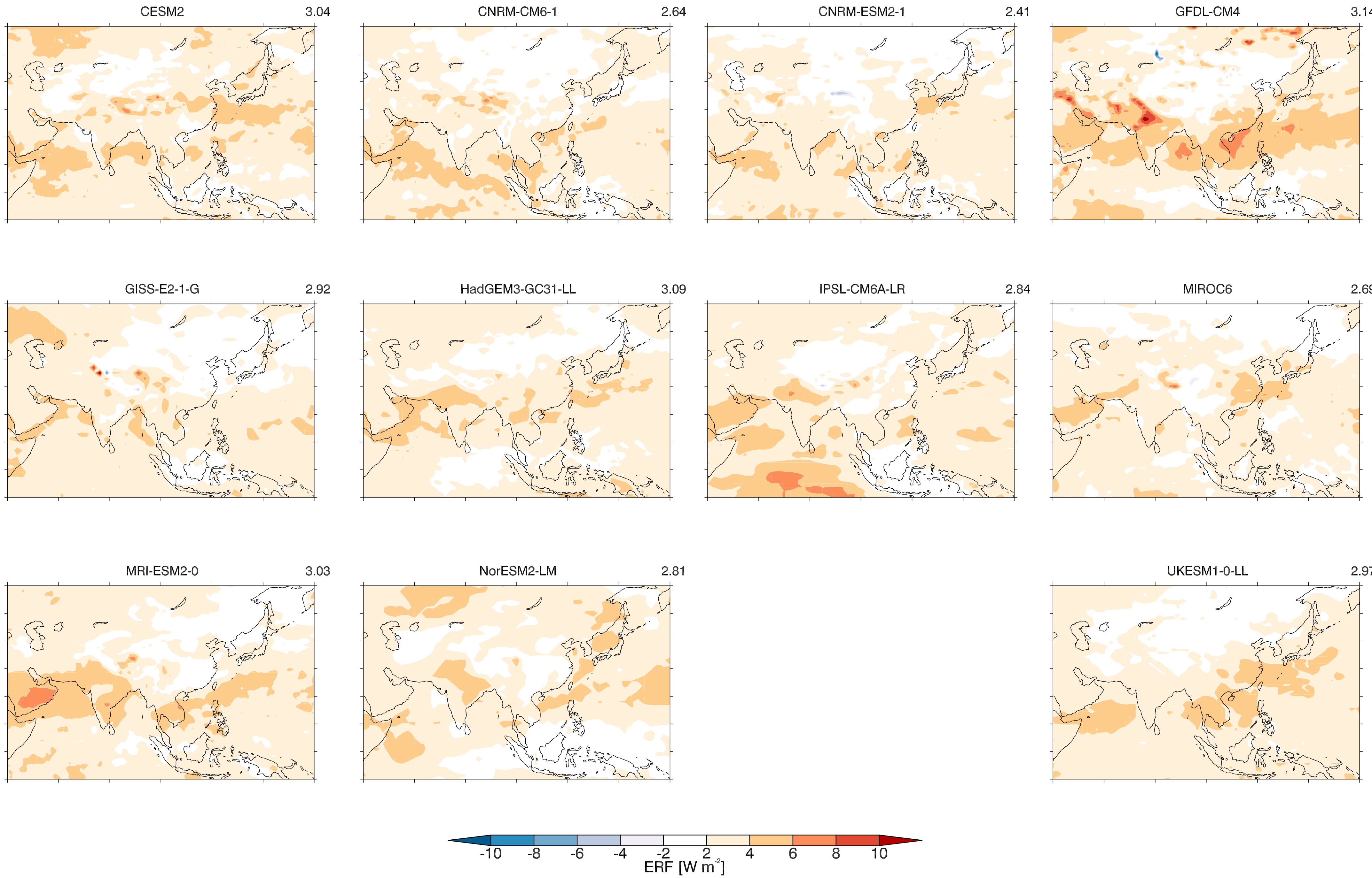


- Different aerosol process representation means this diversity propagates through to ERF

Wilcox et al. (2020), ACP

Models are driven with the same emissions

2014 vs. 1850 GHG ERF

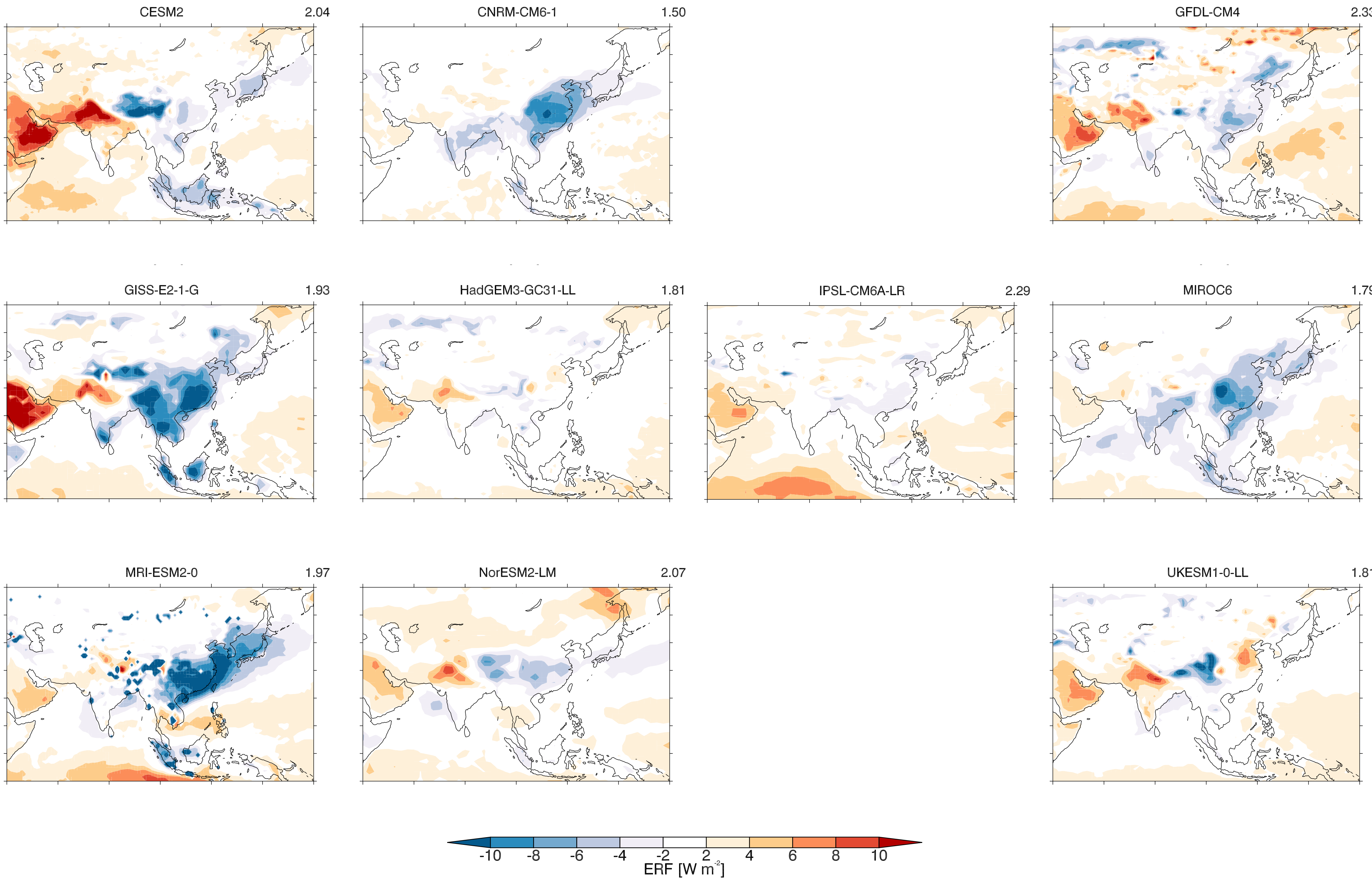


- Different aerosol process representation means this diversity propagates through to ERF

Wilcox et al. (2020), ACP

Models are driven with the same emissions

2014 vs. 1850
anthropogenic ERF



- Different aerosol process representation means this diversity propagates through to ERF

Wilcox et al. (2020), ACP

Model diversity can:

1. show us which processes are important for model performance
2. help us to understand the causes of biases in our own model
3. help us to understand the physical drivers of uncertainties in the simulated response to forcing
4. be used to constrain model estimates

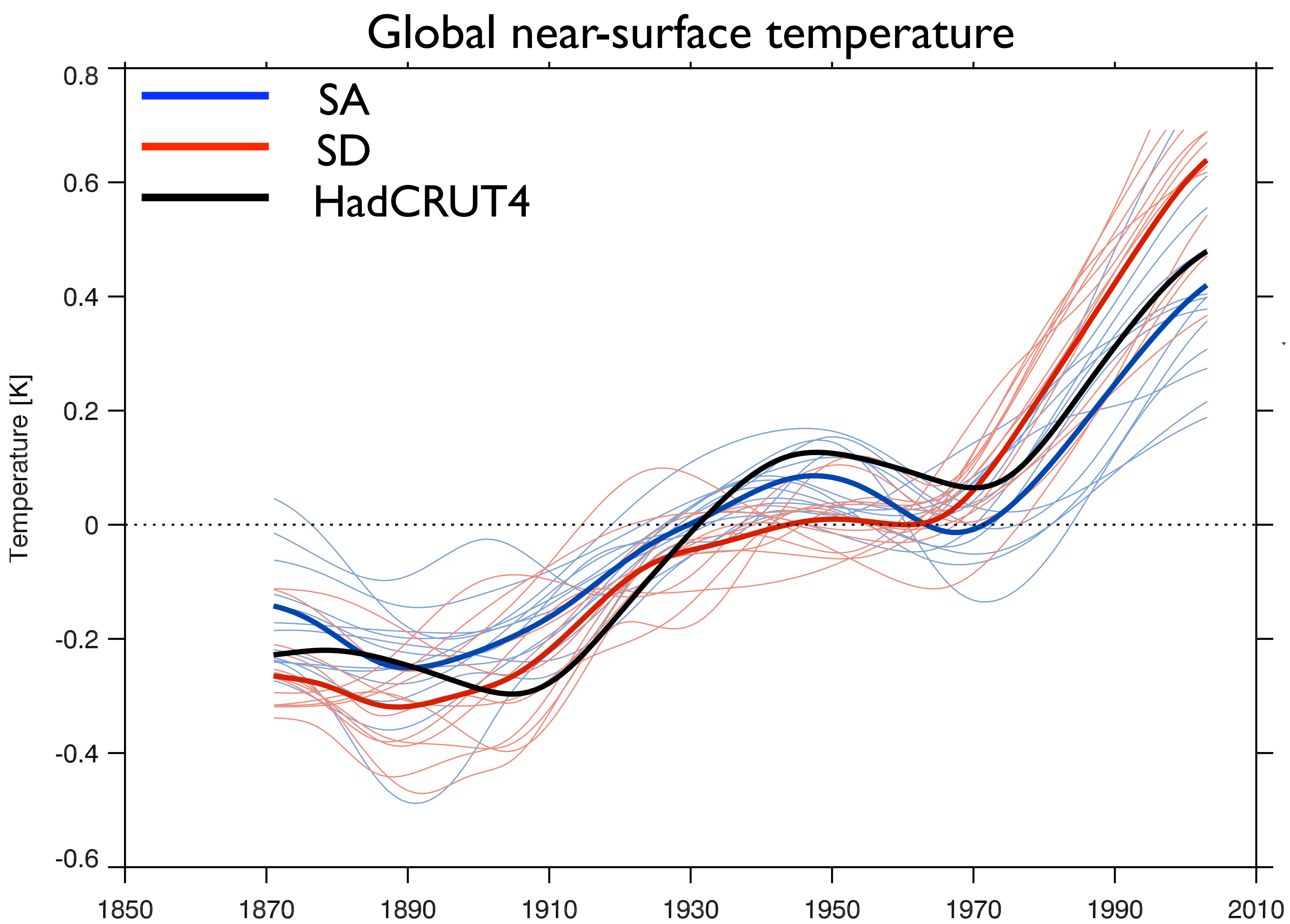
But, it can be difficult to use an ‘ensemble of opportunity’ to isolate the role of the thing you’re interested in

Model diversity can:

1. show us which processes are important for model performance
2. help us to understand the causes of biases in our own model
3. help us to understand the physical drivers of uncertainties in the simulated response to forcing
4. be used to constrain model estimates

But, it can be difficult to use an 'ensemble of opportunity' to isolate the role of the thing you're interested in

Model diversity can show us which processes are important



Wilcox et al. (2013), ERL

CMIP5 contained an unprecedented number of models with a representation of the indirect effect

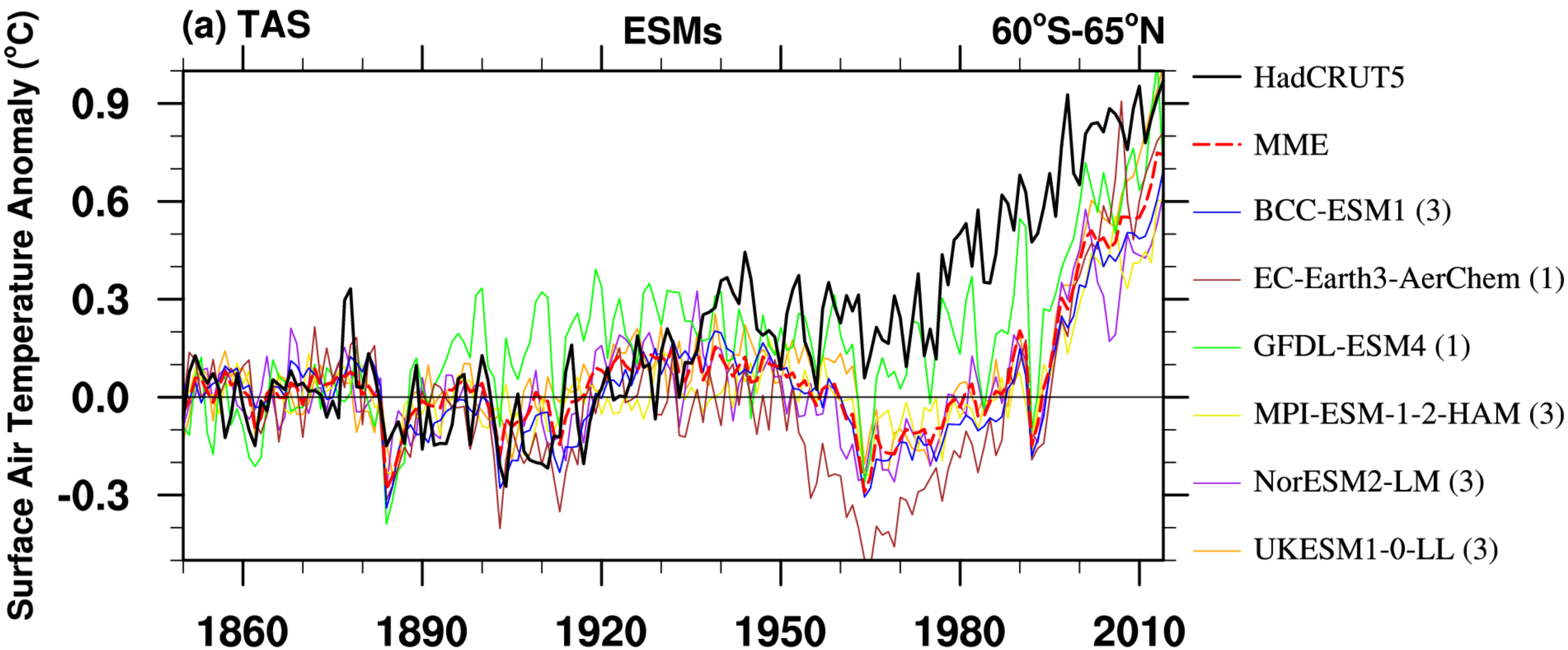
These models give a better reproduction of historical trends due to greater aerosol cooling

Model diversity can:

1. show us which processes are important for model performance
2. help us to understand the causes of biases in our own model
3. help us to understand the physical drivers of uncertainties in the simulated response to forcing
4. be used to constrain model estimates

But, it can be difficult to use an 'ensemble of opportunity' to isolate the role of the thing you're interested in

Model diversity can help us to understand biases in our own model



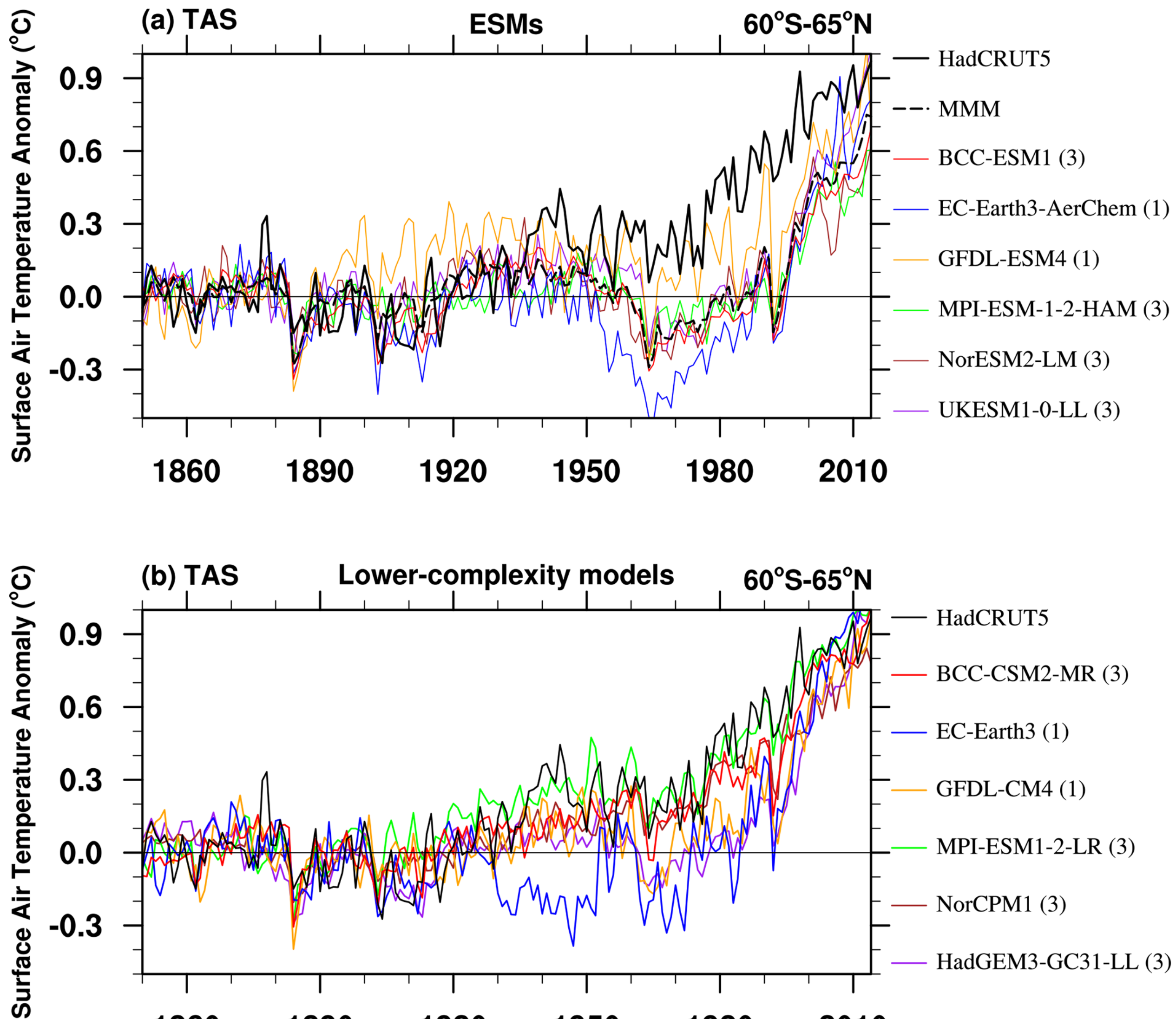
Earth system models cool too much in the mid-twentieth century

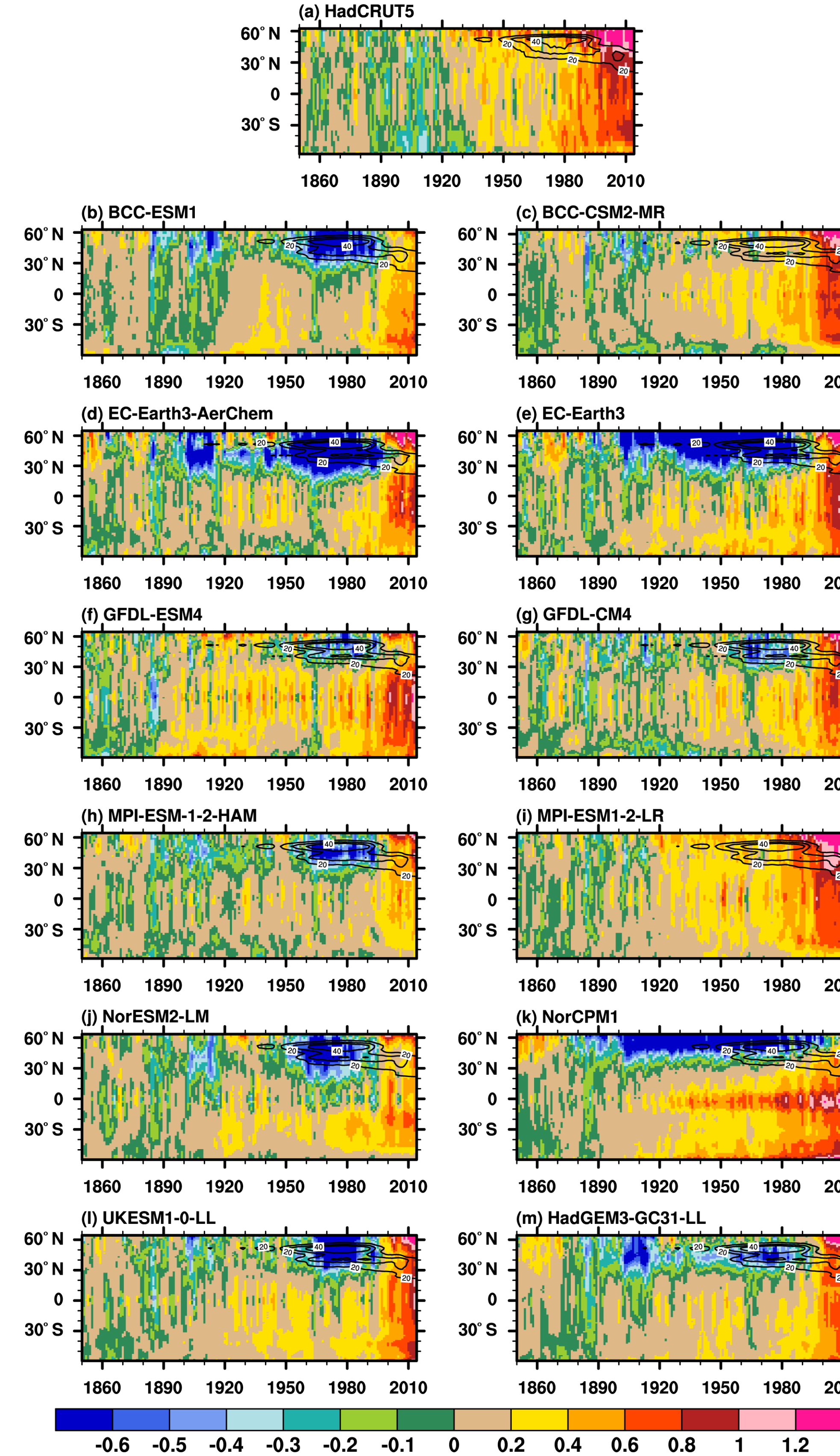
Linked to large sensitivity to aerosol changes in these models

This example is a case of more sophisticated models having poorer performance….

Zhang et al. (2021)

Better is not always better…





Zhang et al. (2021)

Pothole bias not present in physical models

Comparison of ESMs and physical models within the same family shows that the bias relates to excessive high latitude cooling

Model diversity can:

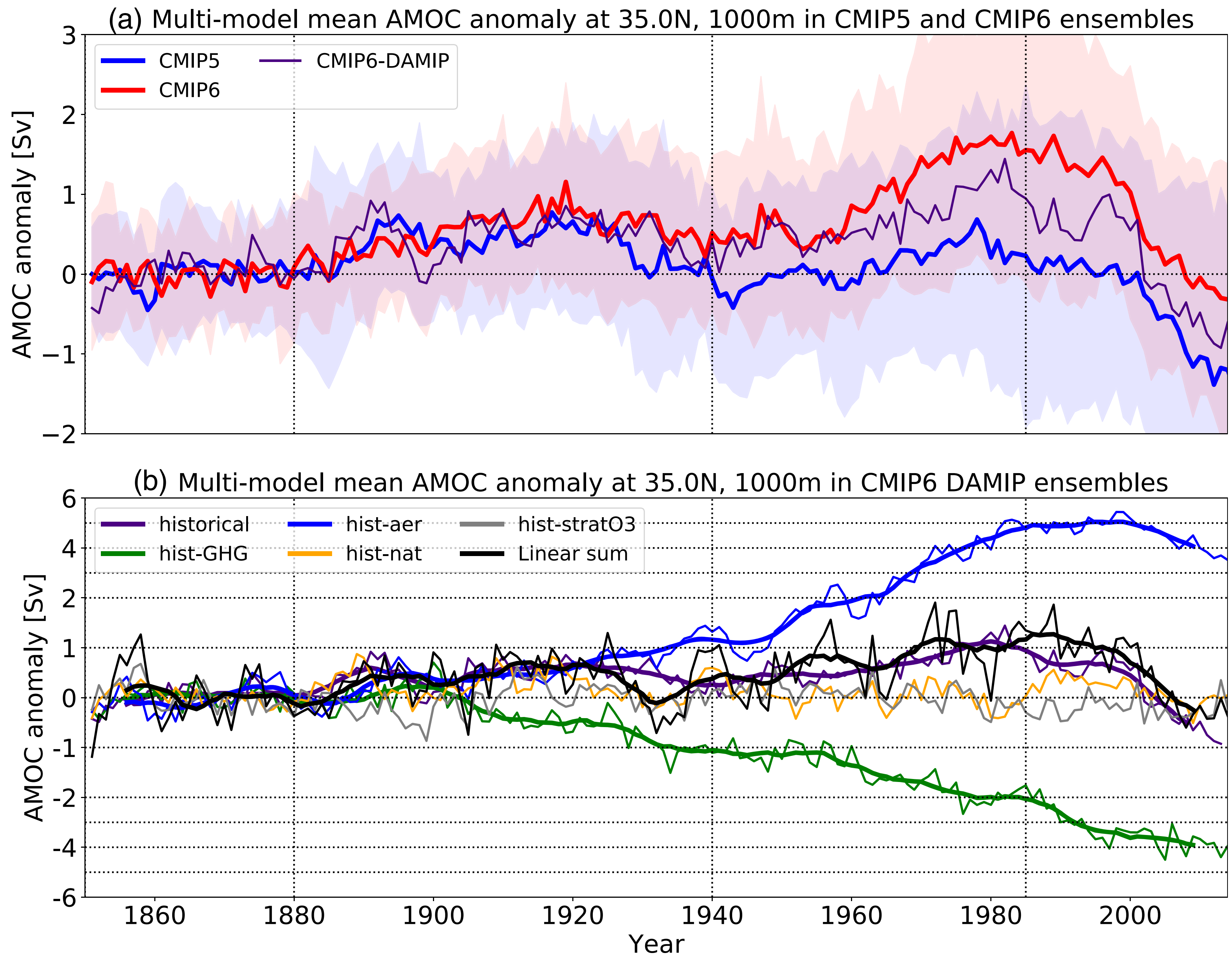
1. show us which processes are important for model performance
2. help us to understand the causes of biases in our own model
3. help us to understand the physical drivers of uncertainties in the simulated response to forcing
4. be used to constrain model estimates

But, it can be difficult to use an ‘ensemble of opportunity’ to isolate the role of the thing you’re interested in

AMOC response to aerosol changes

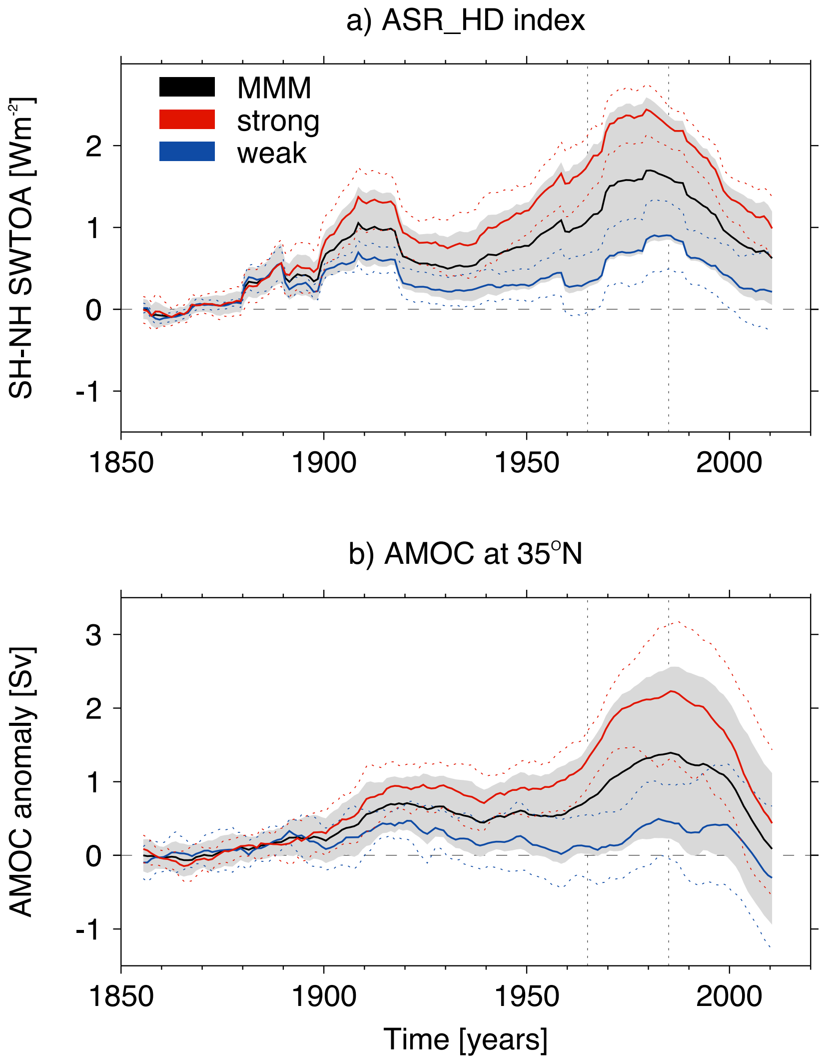
Decadal variability in the Atlantic Meridional Overturning Circulation (AMOC) is influenced by changes in anthropogenic aerosol, but the **extent and mechanism of influence is uncertain.**

Differences between CMIP5 and CMIP6 attributed to differences in the strength of the aerosol forcing.



Menary et al. (2020)

AMOC response to ‘strong’ and ‘weak’ aerosol forcing

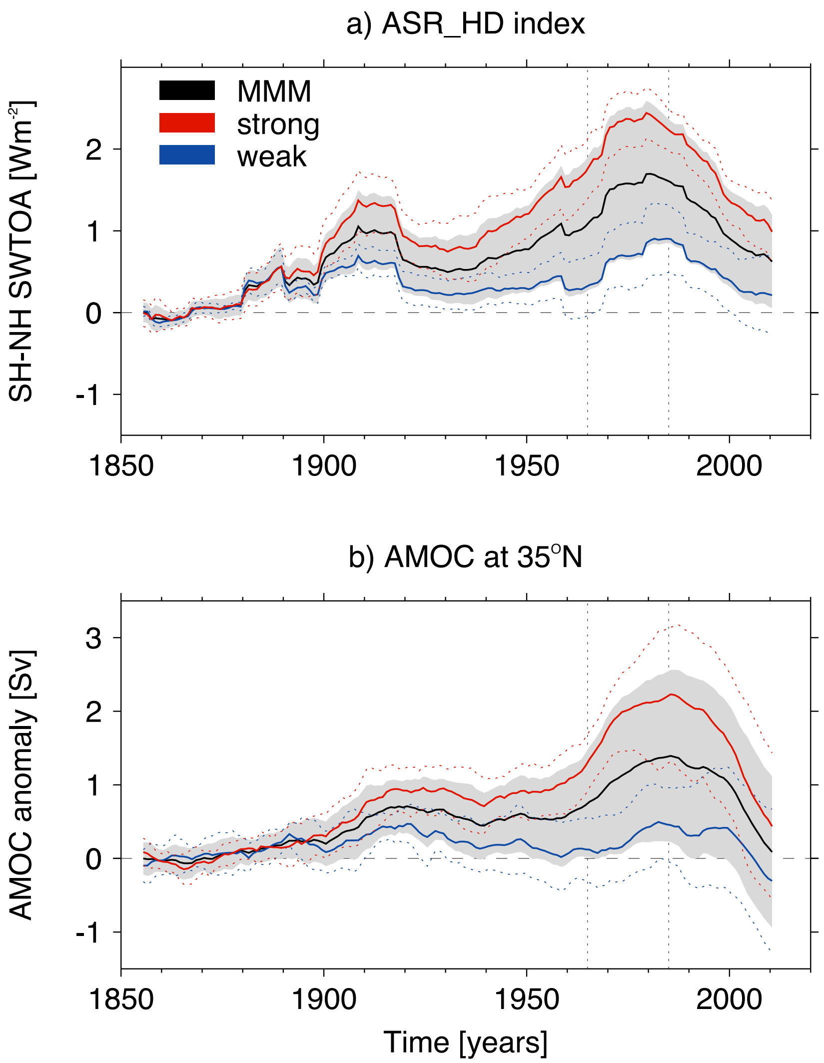


Not possible to calculate aerosol forcing for all CMIP6 models (needs a dedicated RFMIP experiment) so design a metric that can be calculated from the historical experiment…

ASR_HD: SH - NH net solar radiation at the top of the atmosphere
-> positive values indicate less radiation absorbed by NH

Robson et al. (2022)

AMOC response to ‘strong’ and ‘weak’ aerosol forcing



ASR_HD: SH - NH net solar radiation at the top of the atmosphere
-> positive values indicate less radiation absorbed by NH

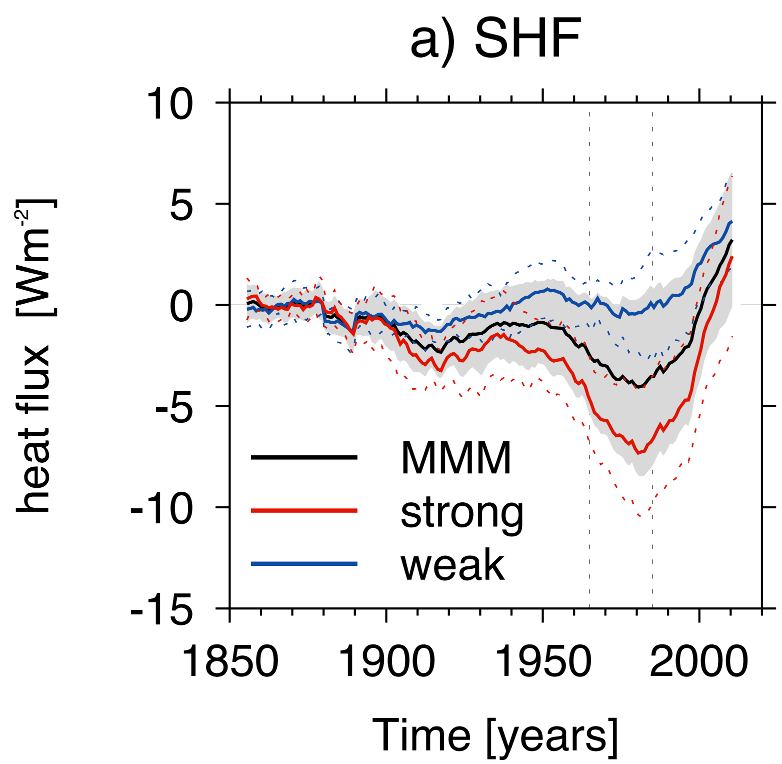
Strong models have a linear change in ASR_HD between 1850 and 1985 **greater than 1.5 Wm^{-2}**
-> 9 strong models and 8 weak models

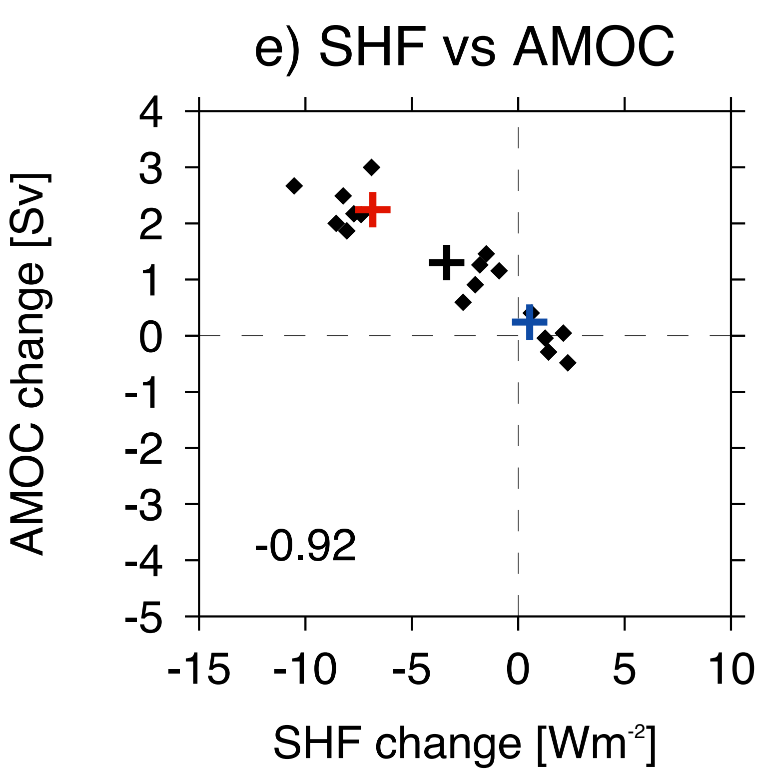
Increase in both ASR_HD and the AMOC from 1850–1985 with the fastest increase over ~1940–1985

Strong models have **4x larger anomaly in ASR_HD**, and **8x larger anomaly in AMOC**, vs. weak models for 1965-1985 relative to 1850-1879.

Robson et al. (2022)

AMOC response to ‘strong’ and ‘weak’ aerosol forcing





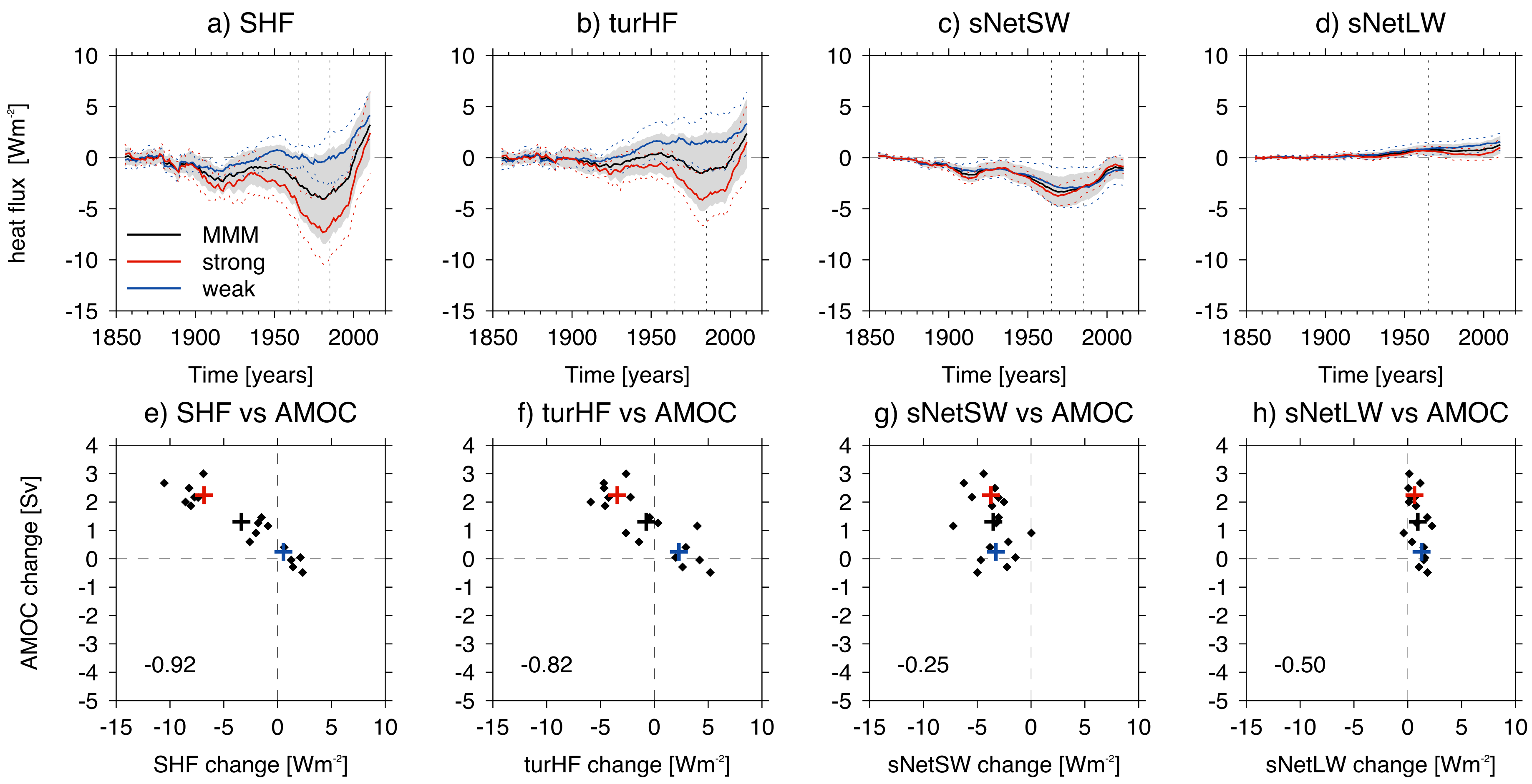
SHF: surface heat flux
turHF: turbulent heat flux
sNetSW: surface net shortwave
sNetLW: surface net longwave

SHF anomalies **dominated by strong models**

SHF dominates the overall surface density flux anomalies

AMOC anomalies in CMIP6 are consistent with the evolution of **surface heat fluxes, and their impact on surface density fluxes, driving the AMOC** in the ‘strong’ models

AMOC response to ‘strong’ and ‘weak’ aerosol forcing



SHF: surface heat flux
turHF: turbulent heat flux
sNetSW: surface net shortwave
sNetLW: surface net longwave

MMM SHF dominated by sNetSW

Differences in SHF anomalies between *strong* and *weak* models are **dominated by differences in turHF**

Relationship between AMOC and SHF is **due primarily to turHF**

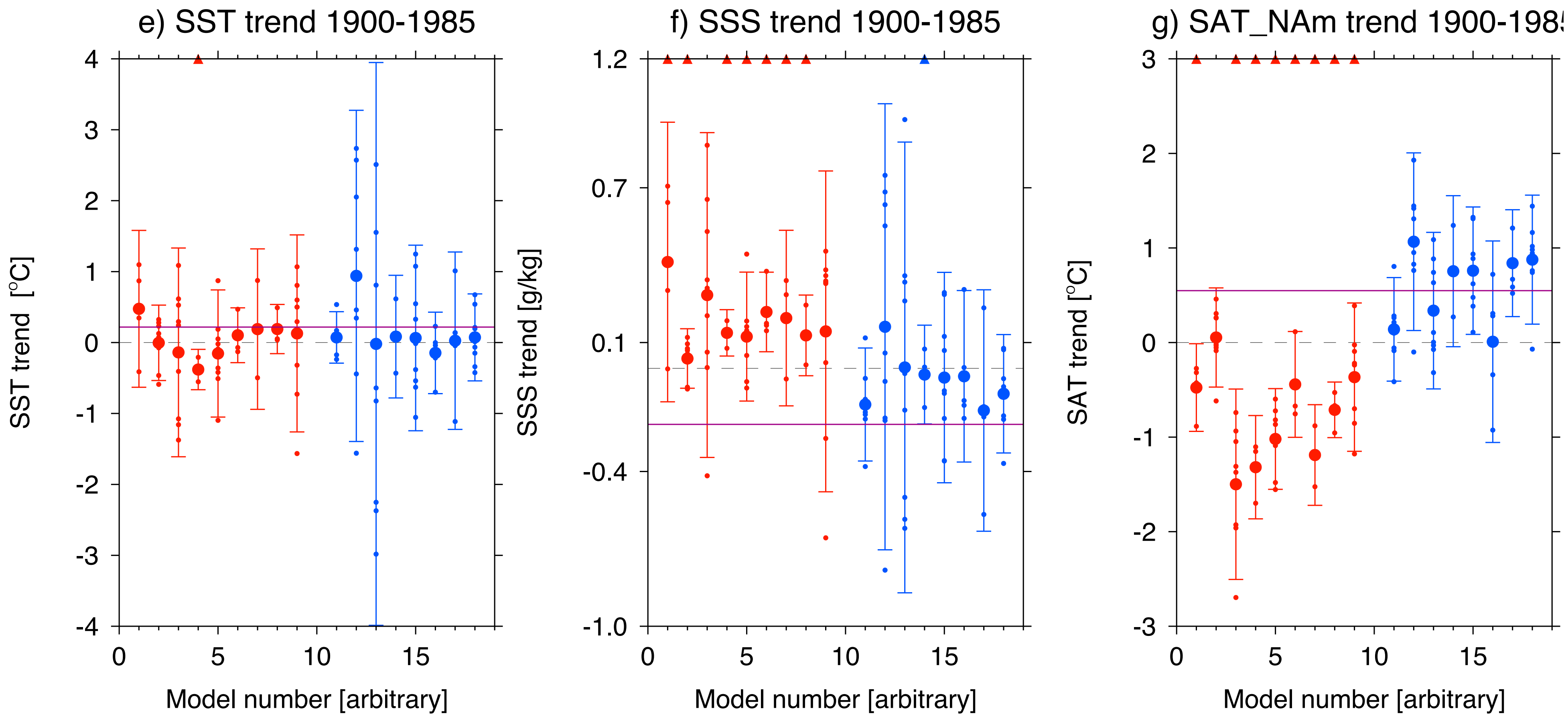
Robson et al. (2022)

Model diversity can:

1. show us which processes are important for model performance
2. help us to understand the causes of biases in our own model
3. help us to understand the physical drivers of uncertainties in the simulated response to forcing
4. be used to constrain model estimates

But, it can be difficult to use an ‘ensemble of opportunity’ to isolate the role of the thing you’re interested in

Constraining simulated AMOC changes



SST is a weak constraint

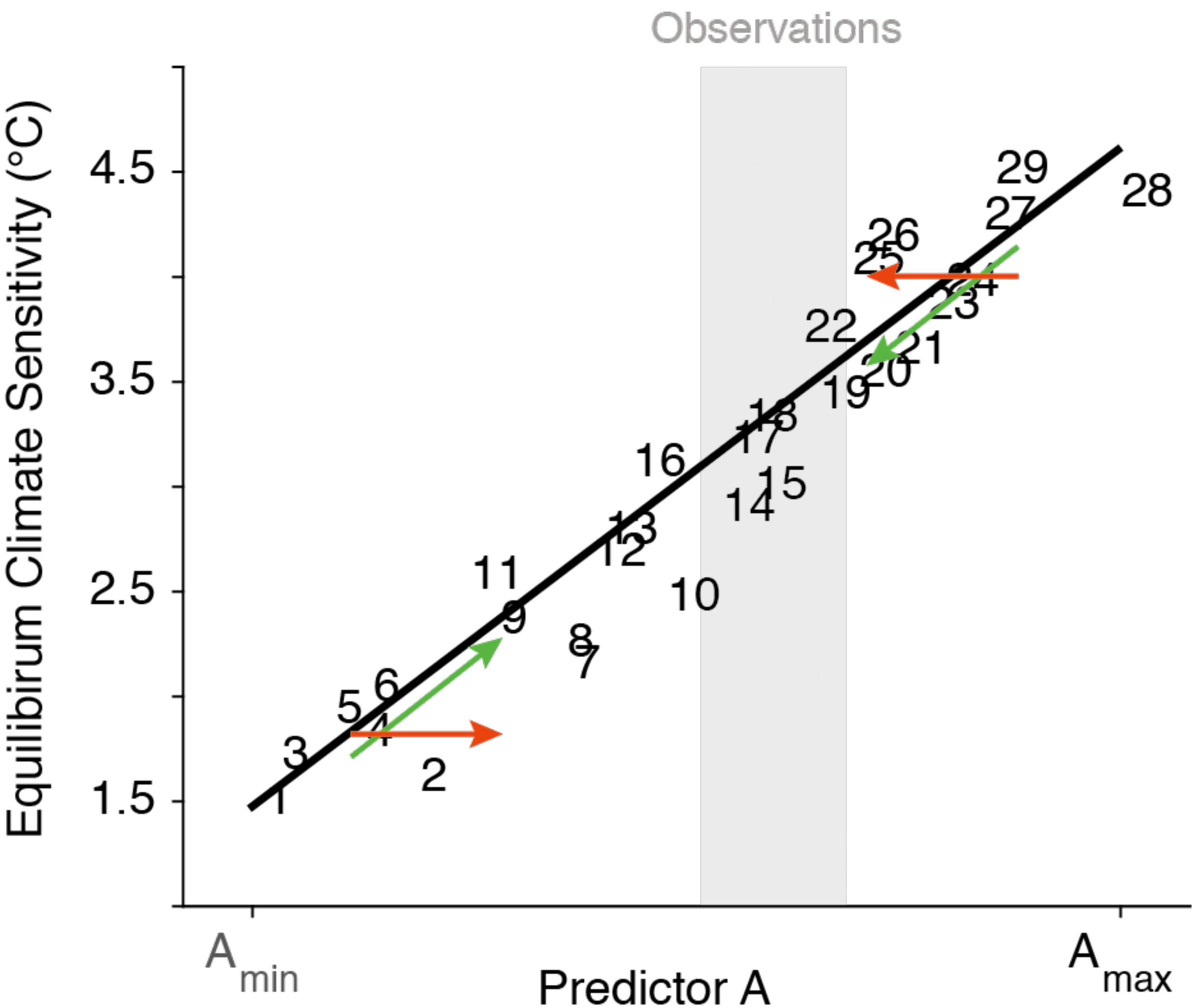
Increased salinity in strong models **inconsistent with observations**

North American cooling, and weak trends in Northern Hemisphere temperature are **inconsistent with observations**

Forced AMOC strengthening in strong models not consistent with observations
-> **aerosol forcing, or the response to it, is too large in strong models**

Robson et al. (2022)

Emergent constraints

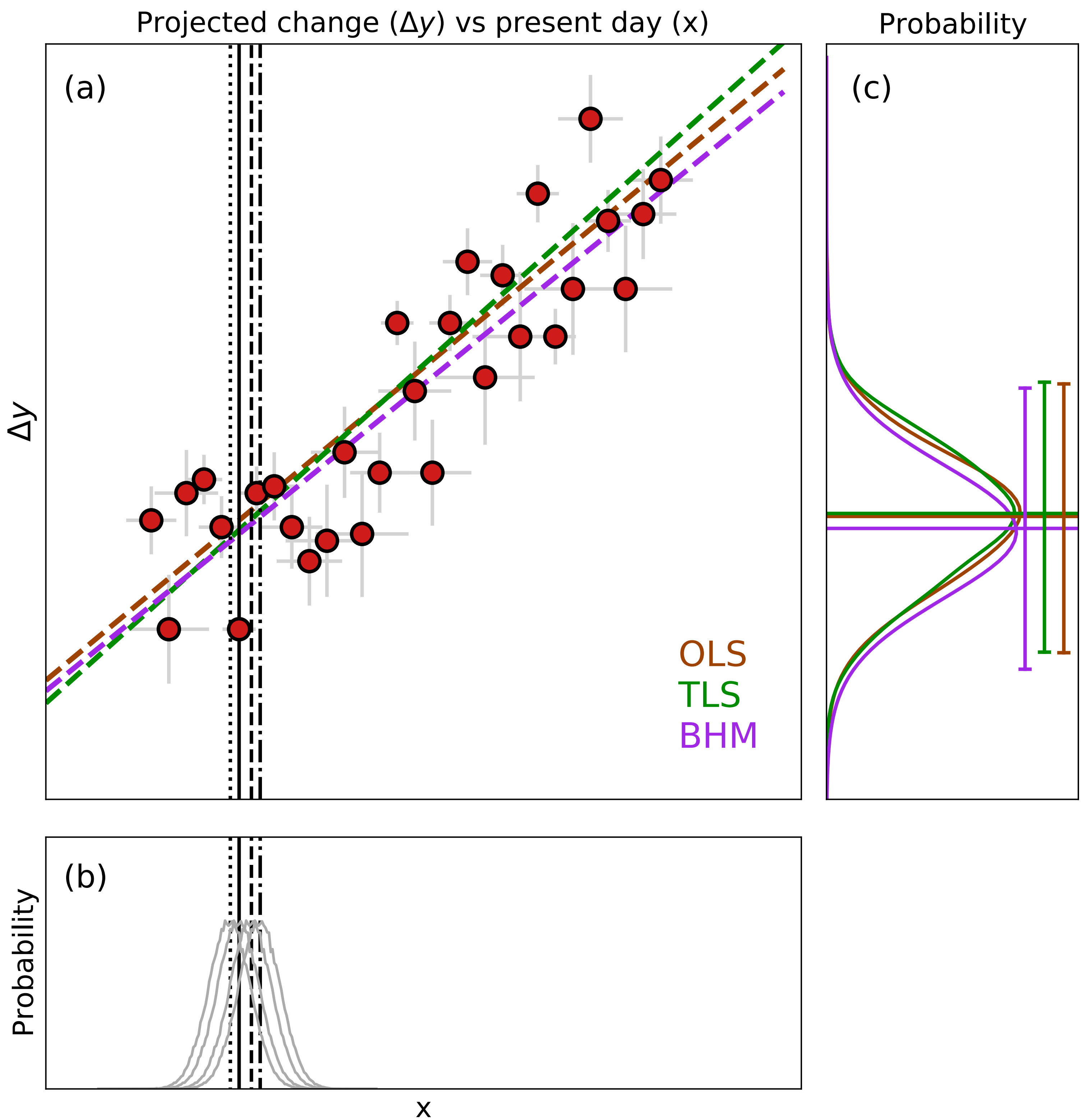


Identify an empirical relationship between an observable variable and response to forcing, with credible physical mechanisms

Observed range of predictor can then be used to constrain simulated response by e.g. weighting or rejecting models outside observed range

Florent Brient, 2016

Emergent constraints

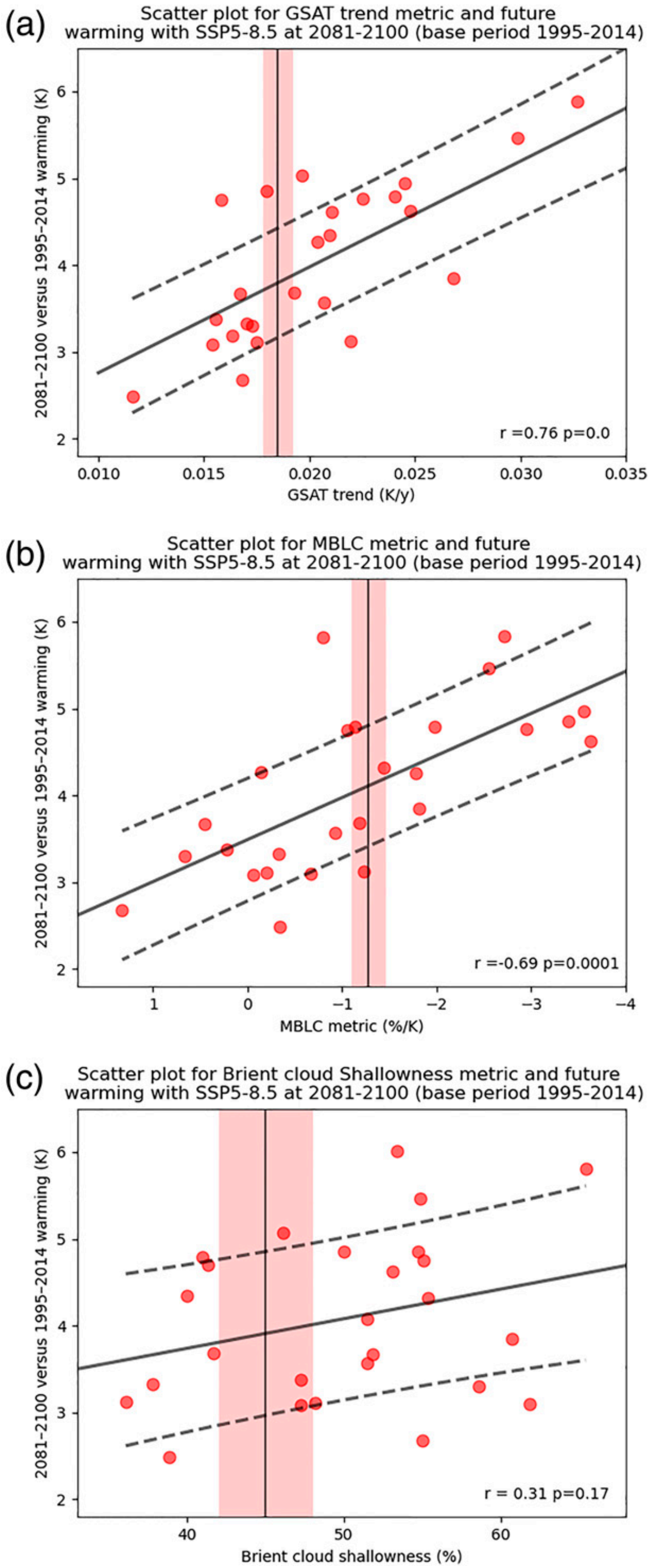


Identify an empirical relationship between an observable variable and response to forcing, with credible physical mechanisms

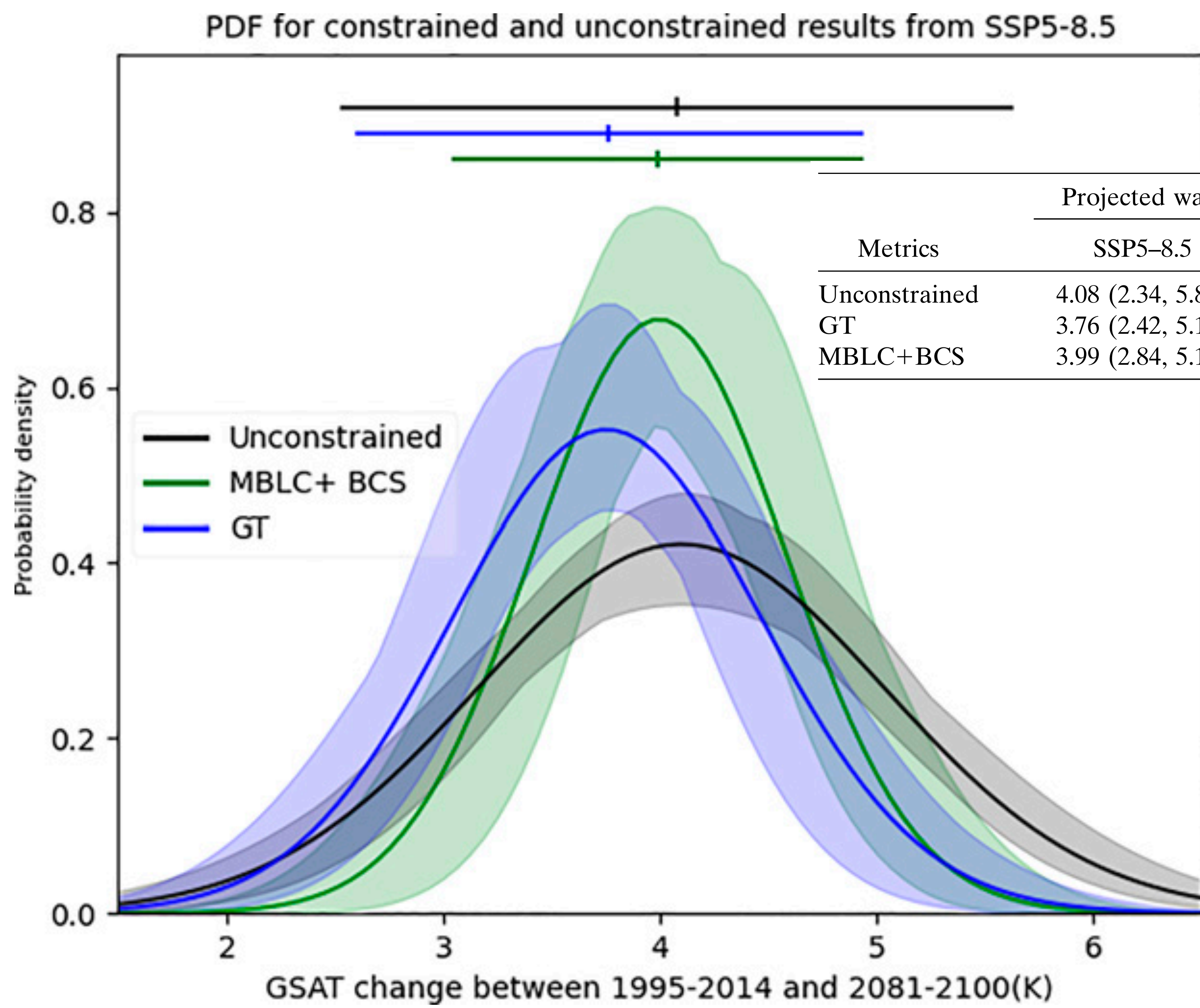
Observed range of predictor can then be used to constrain simulated response by e.g. weighting or rejecting models outside observed range

Simpson et al. (2021)

Emergent constraints



Past temperature trend with future temperature trend, and tropical cloud properties with future temperature trend



	Projected warming (5%–95%; units: K)	
Metrics	SSP5–8.5	SSP1–2.6
Unconstrained	4.08 (2.34, 5.81)	1.30 (0.38, 2.04)
GT	3.76 (2.42, 5.11)	1.09 (0.33, 1.85)
MBLC+BCS	3.99 (2.84, 5.12)	1.15 (0.60, 1.70)

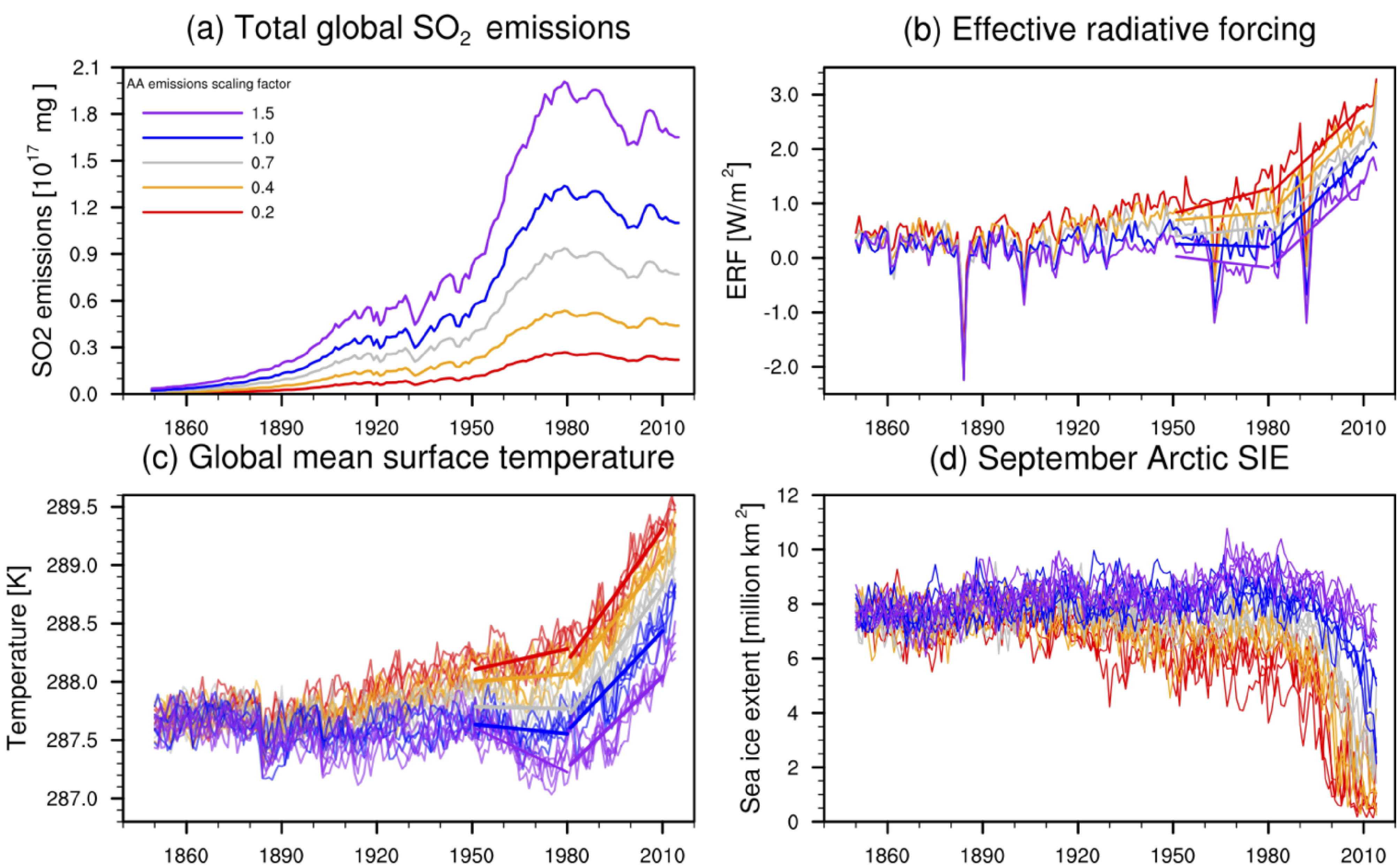
Liang et al. (2022)

Model diversity can:

1. show us which processes are important for model performance
2. help us to understand the causes of biases in our own model
3. help us to understand the physical drivers of uncertainties in the simulated response to forcing
4. be used to constrain model estimates

But, it can be difficult to use an 'ensemble of opportunity' to isolate the role of the thing you're interested in

HadGEM3-GC3.1 ensemble with scaled aerosol emissions

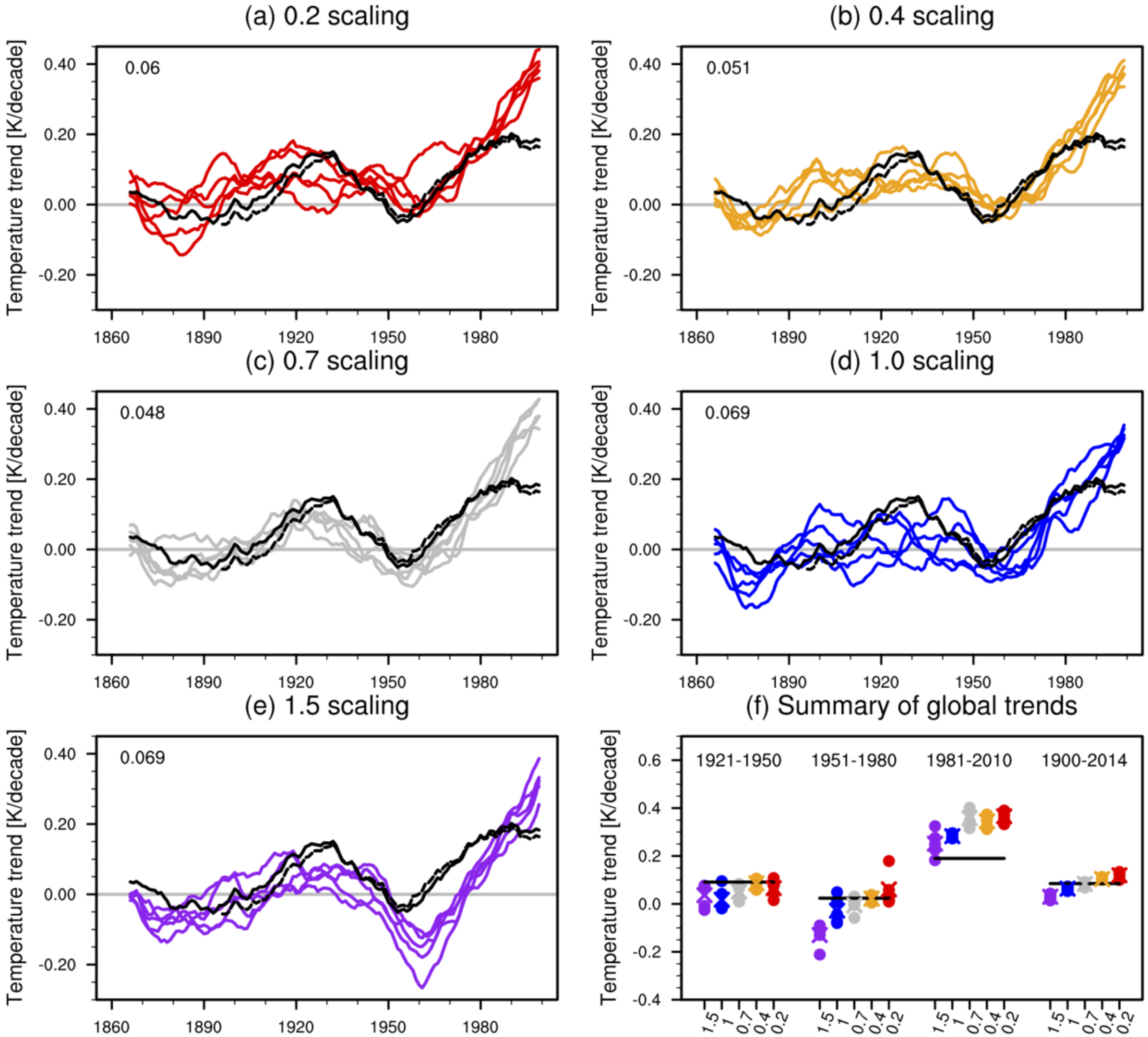


Scaling	ERF (W/m2)
0.2	-0.3
0.4	-0.6
0.7	-1.0
1.0	-1.3
1.5	-1.6

- Span a large portion of the IPCC range for aerosol ERF

Dittus et al., 2020

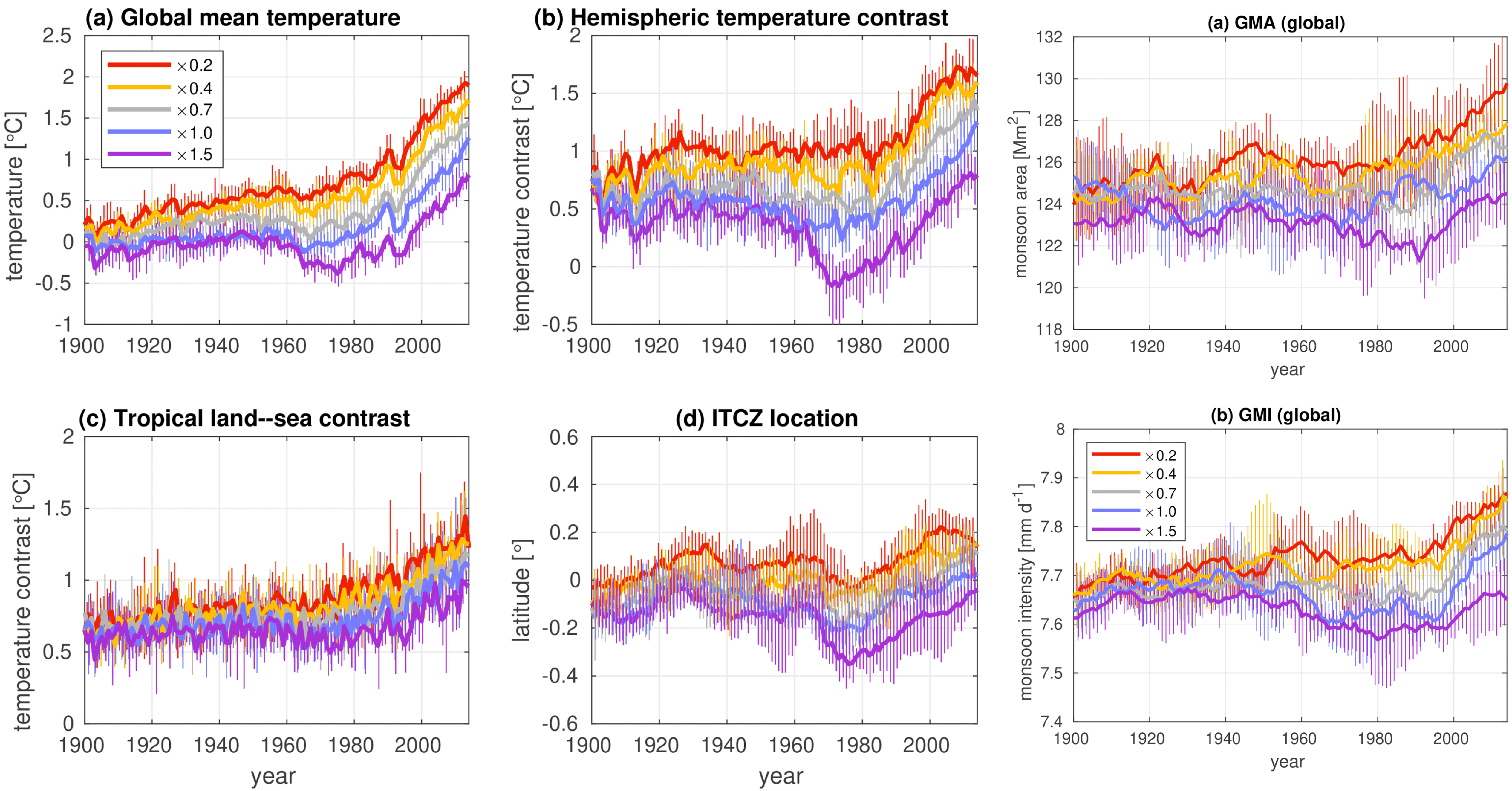
HadGEM3-GC3.1 ensemble with scaled aerosol emissions



- All scalings warm too quickly since 1981 - GC3.1 has a high climate sensitivity and large aerosol forcing

Dittus et al., 2020

HadGEM3-GC3.1 ensemble with scaled aerosol emissions



The effect of the uncertainty in aerosol radiative forcing on GMA and GMI is a reduction of 2.99 % and 1.93 % respectively, when increasing the scaling across its range

Magnitude of this impact is equivalent to that from a degree of global warming

Shonk et al., 2020

Model diversity can:

1. show us which processes are important for model performance
2. help us to understand the causes of biases in our own model
3. help us to understand the physical drivers of uncertainties in the simulated response to forcing
4. be used to constrain model estimates

But, it can be difficult to use an ‘ensemble of opportunity’ to isolate the role of the thing you’re interested in