Quantifying progress of climate models across different CMIP phases

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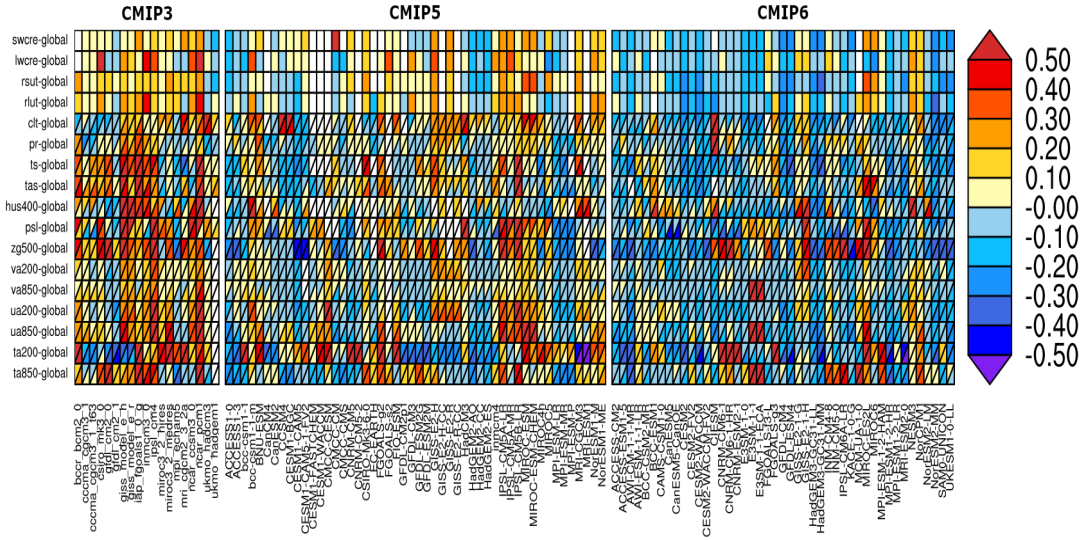

CRESCENDO GENERAL ASSEMBLY

15-17 March 2021

CMIP
The World Climate Research Programme's Coupled Model Intercomparison Project

ESMValTool
Earth System Model eValuation Tool

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Coupled Model Intercomparison Project Phase 6 (CMIP6)

A handful of common experiments

i. AMIP simulation (~1979-2014)

ii. Pre-industrial control simulation

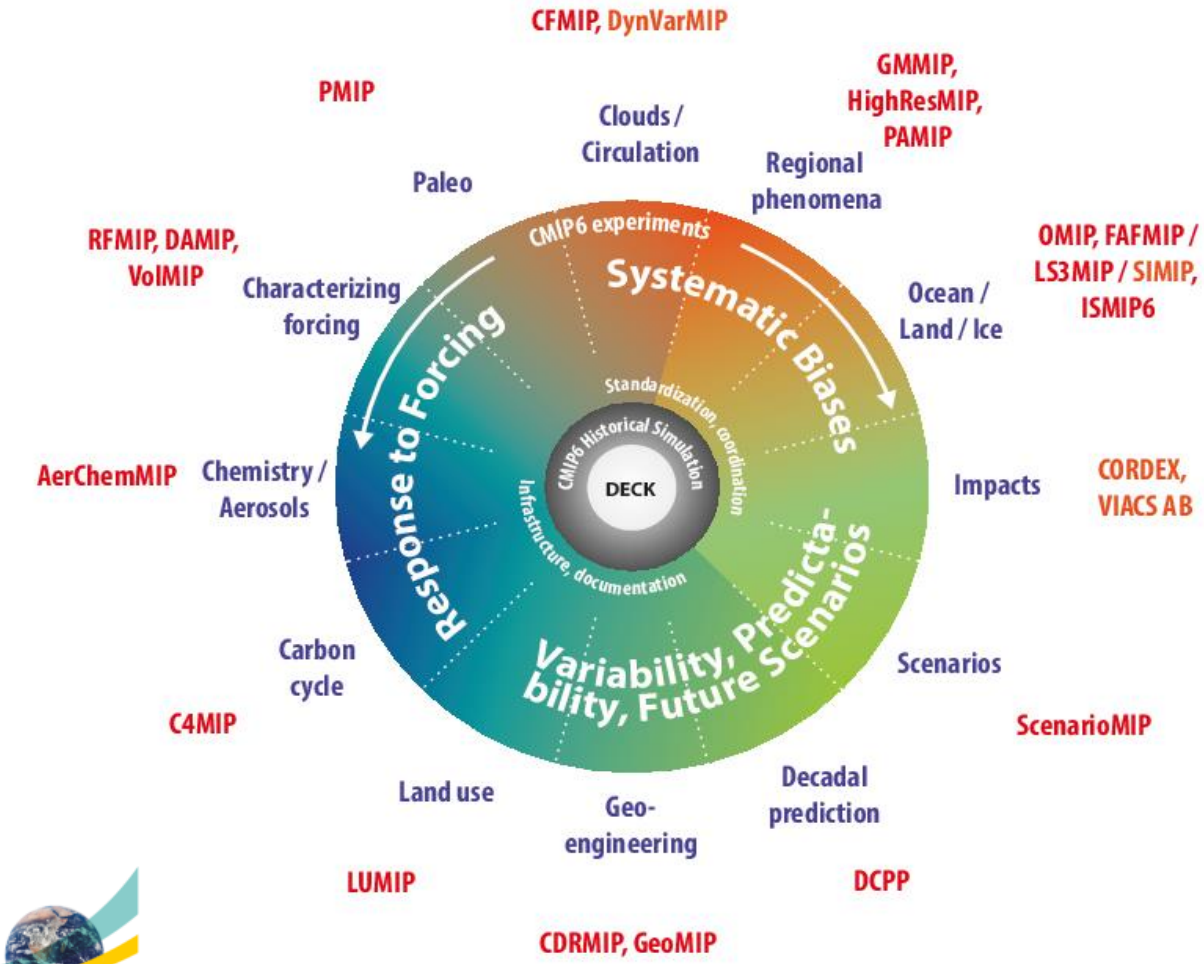
iii. 1%/year CO_2 increase

iv. Abrupt 4xCO_2 run

} **DECK** (entry card for CMIP)

v. Historical simulation using CMIP6 forcings (1850-2014)

} entry card for CMIP6



CMIP
The World Climate Research Programme's Coupled Model Intercomparison Project

Eyring et al., Geosci. Model Dev., 2016

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CMIP6: Participating model groups

CMIP
The World Climate Research Programme's Coupled Model Intercomparison Project

	Institute	Country		Institute	Country		Institute	Country		Institute	Country
1	**AER**	USA	13	**CSIRO**	Australia	25	**KIOST**	Korea	37	**NIWA**	New Zealand
2	**AS-RCEC**	Taiwan	14	**CSIRO-ARCCSS-BoM**	Australia	26	**MESSy-Consortium**	Germany	38	**NOAA-GFDL**	USA
3	**AWI**	Germany	15	**DKRZ**	Germany	27	**MIROC**	Japan	39	**NUIST**	China
4	**BCC**	China	16	**DWD**	Germany	28	**MOHC**	UK	40	**RTE-RRTMGP**	USA
5	**BNU**	China	17	**E3SM-Project**	USA	29	**MPI-M**	Germany	41	**RUBISCO**	USA
6	**CAMS**	China	18	**EC-Earth-Consortium**	Sweden	30	**MRI**	Japan	42	**SNU**	Korea
7	**CAS**	China						USA	43	**THU**	China
8	**CCCm**							USA	44	**UA**	USA
9	**CCCF**							SA	45	**UCI**	USA
10	**CMCC**							rway	46	**UHH**	Germany
11	**CNRM CERFA**								47	**UofT**	Canada
12	**CSIR-C**						**RMA**	Korea	48	**UTAS**	Australia

- 48 institutions/consortia have registered (CMIP5: 31)
- 126 models are registered (CMIP5: 59)
- 299 experiments defined (CMIP5: 33)
- 10 – 50 PB of model output expected (CMIP5: ~2 PB)

→Challenges for the entire community

https://wcrp-cmip.github.io/CMIP6_CVs/docs/CMIP6_institution_id.html

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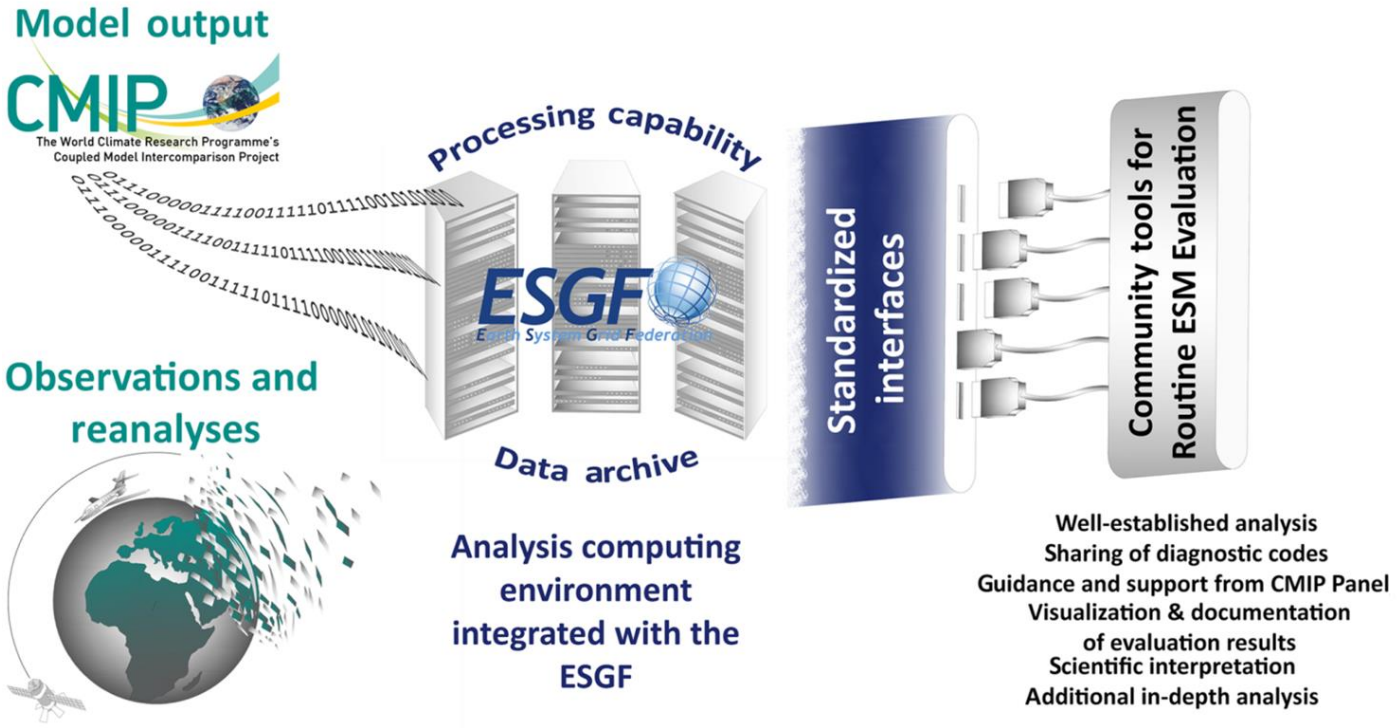
Major Goal CMIP6: Enhanced Routine Model Evaluation

To ensure rapid and comprehensive evaluation of the models with observations, DLR is developing the **Earth System Model Evaluation Tool (ESMValTool)** in cooperation with > 60 international institutions.

ESMValTool
Earth System Model eValuation Tool

- **Open source community development**
- **Rapid development** since the first release in 2016 with the support of **FP7 / H2020 projects**
- Now a **well-tested tool** providing **end-to-end provenance** to ensure **reproducibility**
- Used in several **IPCC WGI AR6 chapters**

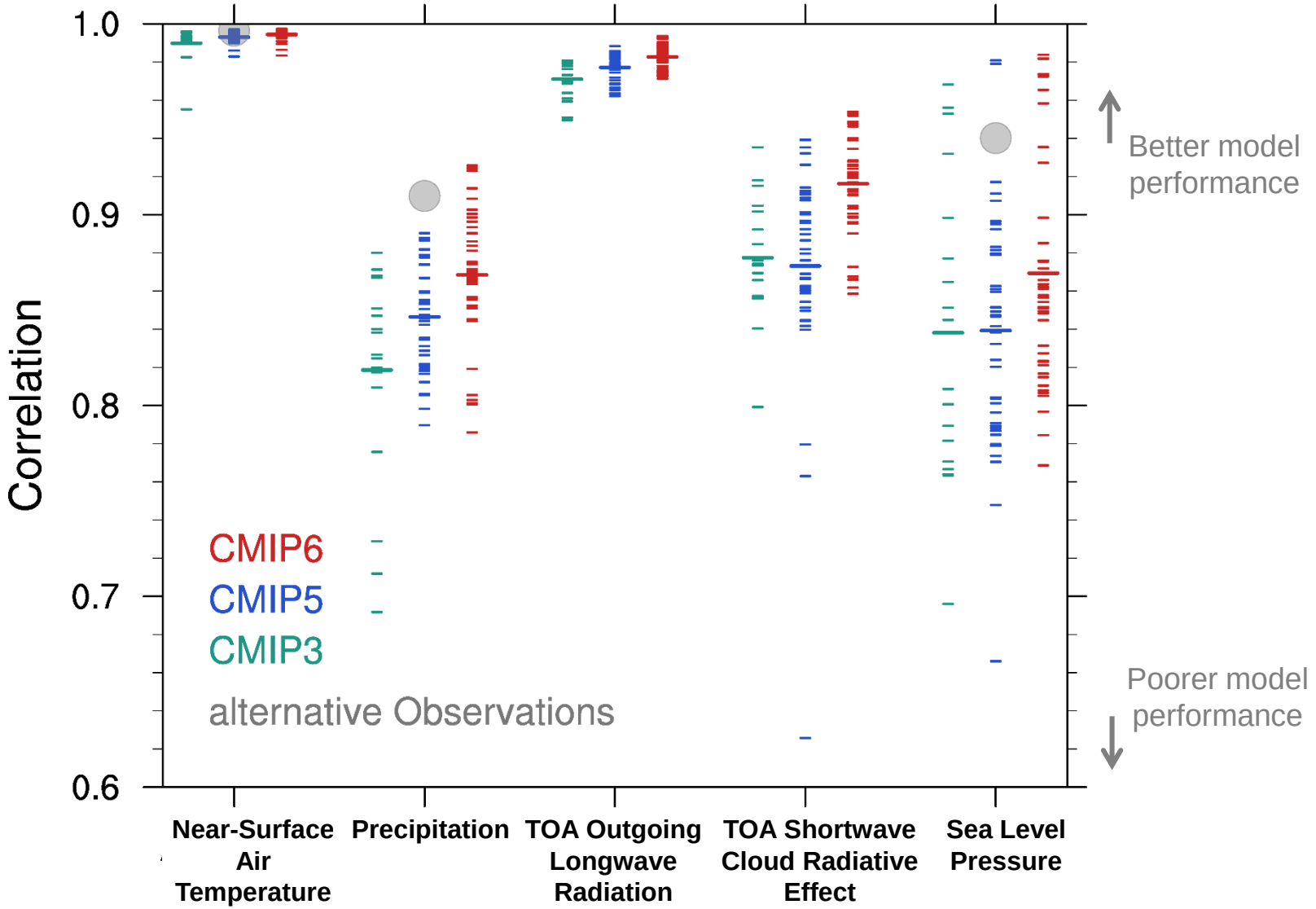
Righi et al. *GMD, 2020;* ***Eyring et al***., *GMD, 2020;* ***Lauer et al***., *GMD., 2020;* ***Weigel et al***., *GMD, in rev.*



Eyring et al., ESD, 2016

http://www.esmvaltool.org/

Earth System Models are Improving: Mean Climate



Geographical Pattern Correlation

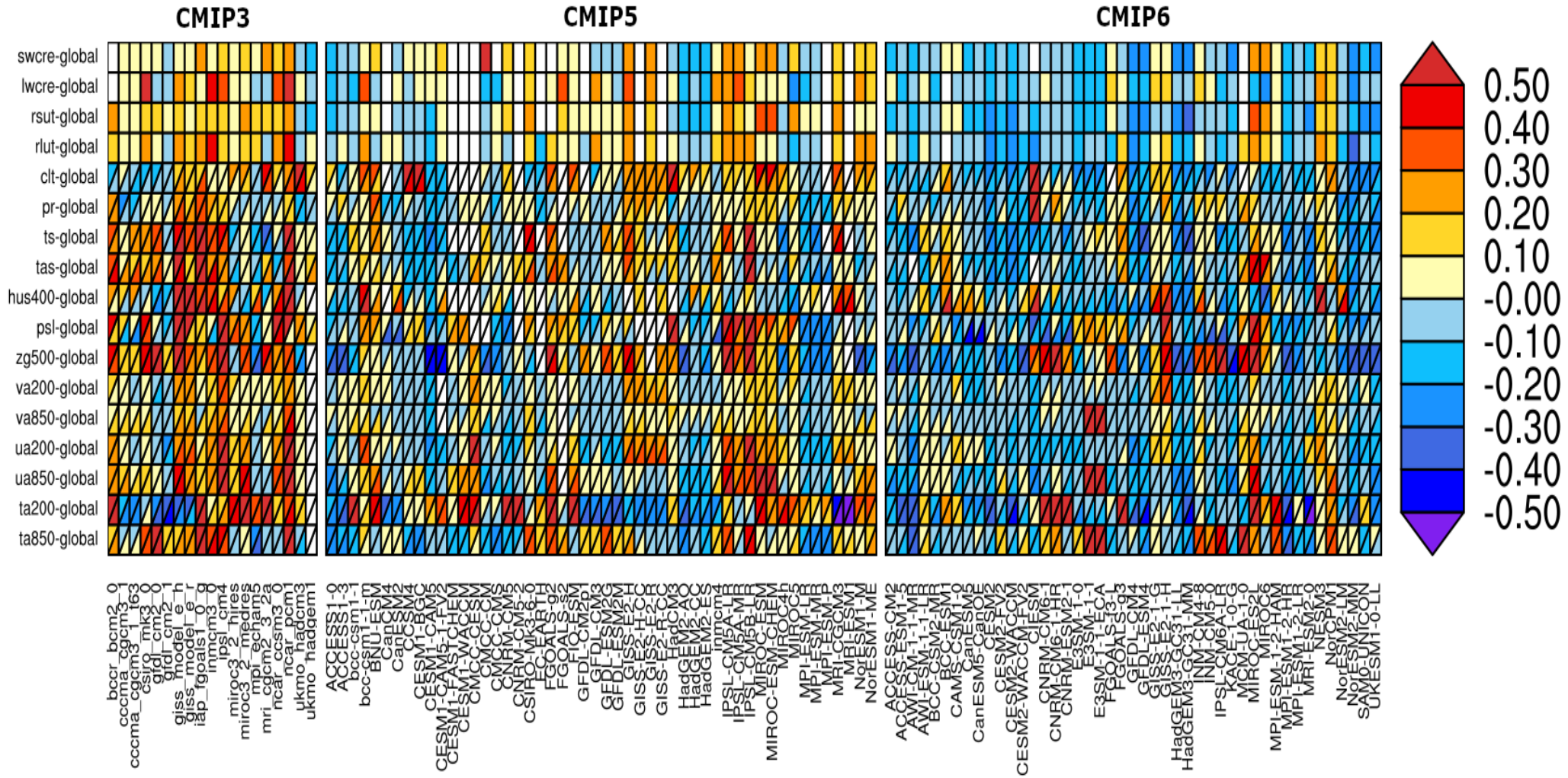
Annual climatological mean (1980-1999)

Are climate models improving?

- Significant improvements in mean climate from CMIP3 to CMIP6 in **model performance**
- CMIP6 ensemble shows **mostly better model agreement**

Bock et al., JGR: Atmospheres, 2020

Earth System Models are Improving: Mean Climate



ESMValTool
Earth System Model eValuation Tool

Bock et al., JGR: Atmospheres, 2020

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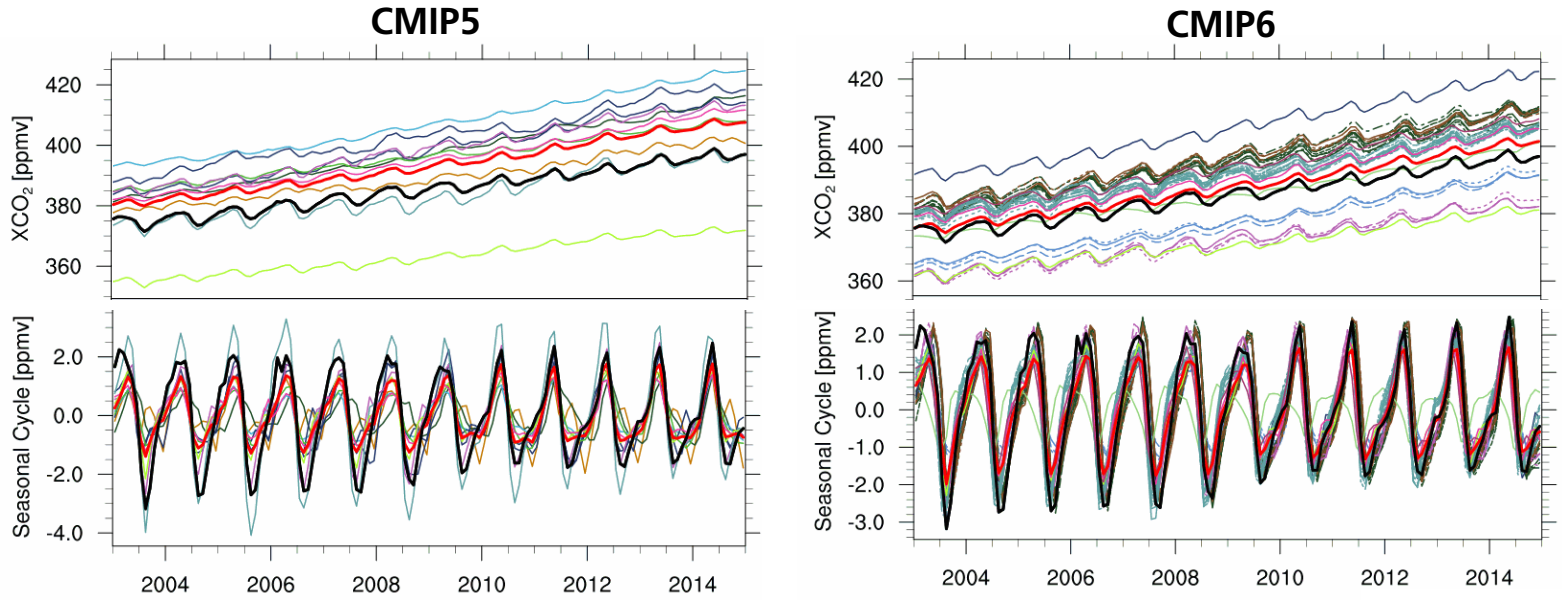
Earth System Models are Improving: Carbon Cycle



Timeseries for column-averaged CO_2

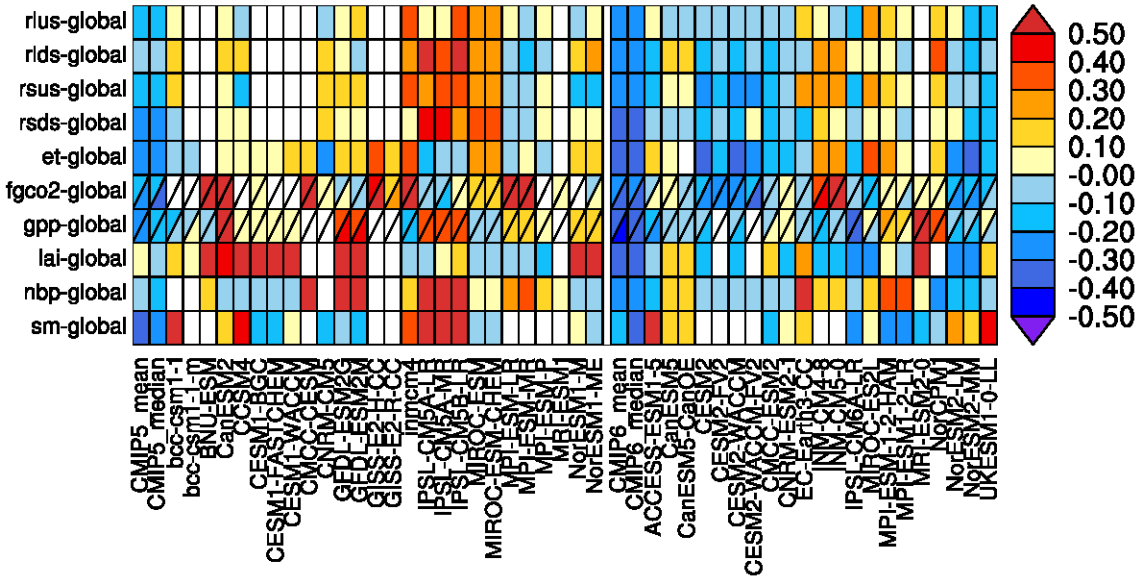
Gier et al., Biogeosciences, 2020;

Gier et al., in prep., 2021

CMIP6 vs. CMIP5

- CMIP6 similar spread than in CMIP5
- BUT: **smaller bias** in multi-model mean, better growth rate reproduction, more closely resembles seasonal cycle amplitude
- **Improvements** in all carbon cycle variables

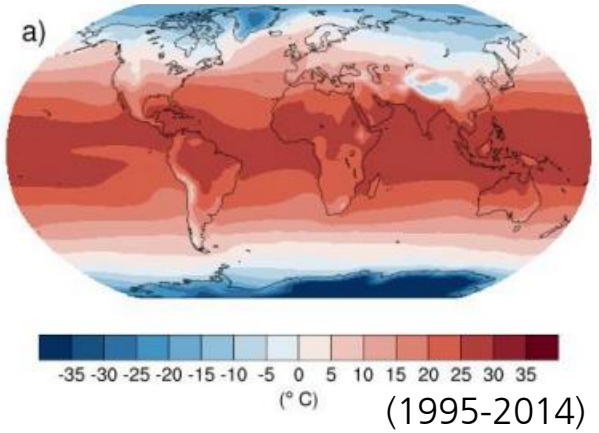
Performance Metrics



Systematic Biases: Near-surface Temperature

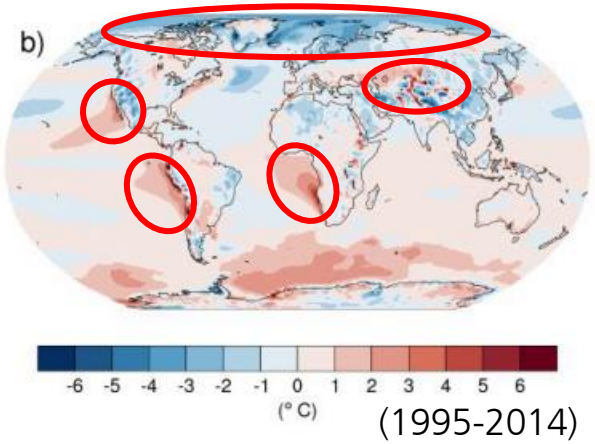
Annual climatological multi-model mean (MMM)

CMIP6 MMM



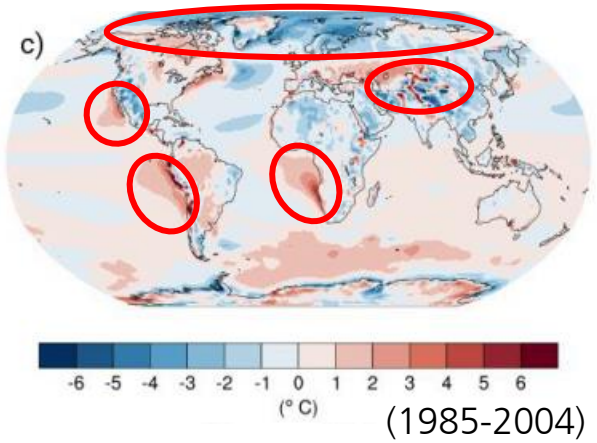
(1995-2014)

CMIP6 MMM Bias



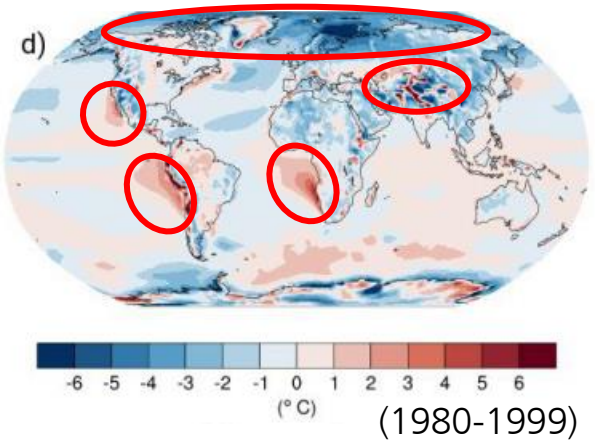
(1995-2014)

CMIP5 MMM Bias



(1985-2004)

CMIP3 MMM Bias



(1980-1999)

Reference data set: ERA5

Distribution overall well reproduced, but systematic biases remain in CMIP6

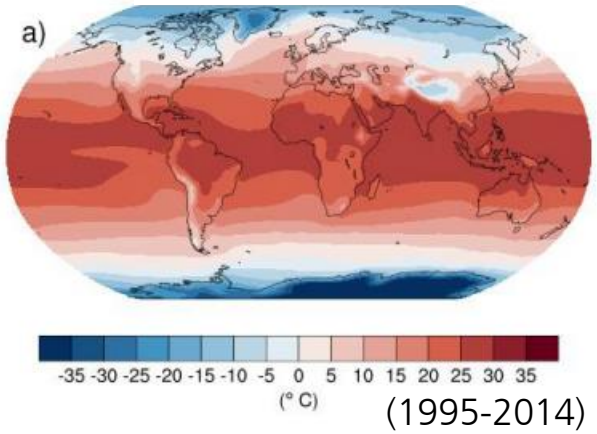
- In **high elevation** regions
- Near **ice edge** in the North Atlantic
- Over **ocean upwelling regions**
- Many reasons: errors in simulated **cloud properties**, errors in **oceanic circulation**, etc.

Bock et al., JGR: Atmospheres , 2020

Systematic Biases: Near-surface Temperature

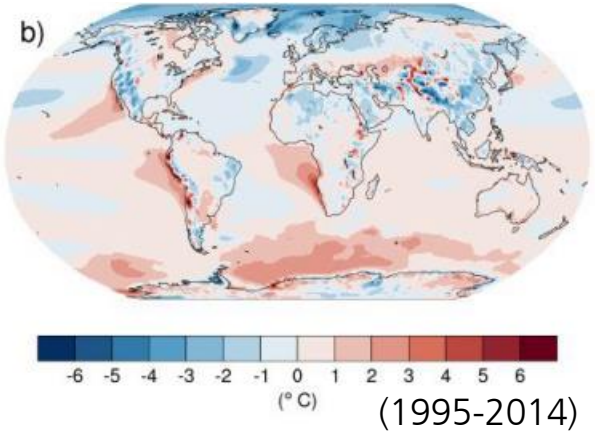
Annual climatological multi-model mean (MMM)

CMIP6 MMM



(1995-2014)

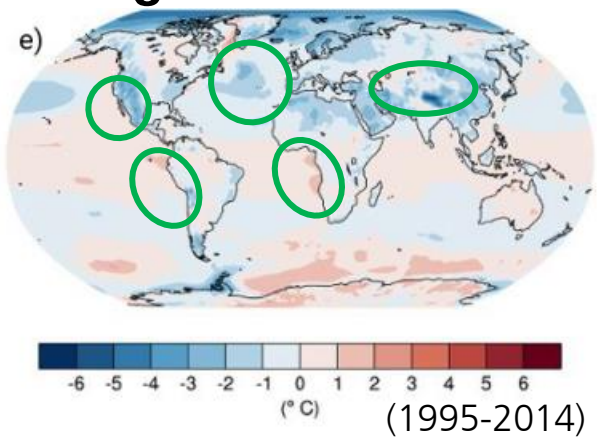
CMIP6 MMM Bias



(1995-2014)

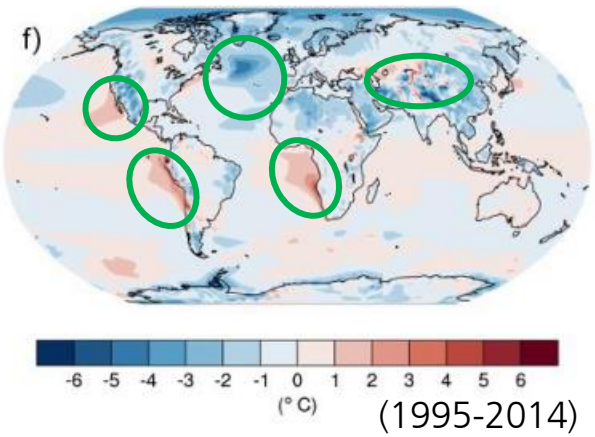
HighResMIP

High res MMM Bias



(1995-2014)

Low res MMM Bias



(1995-2014)

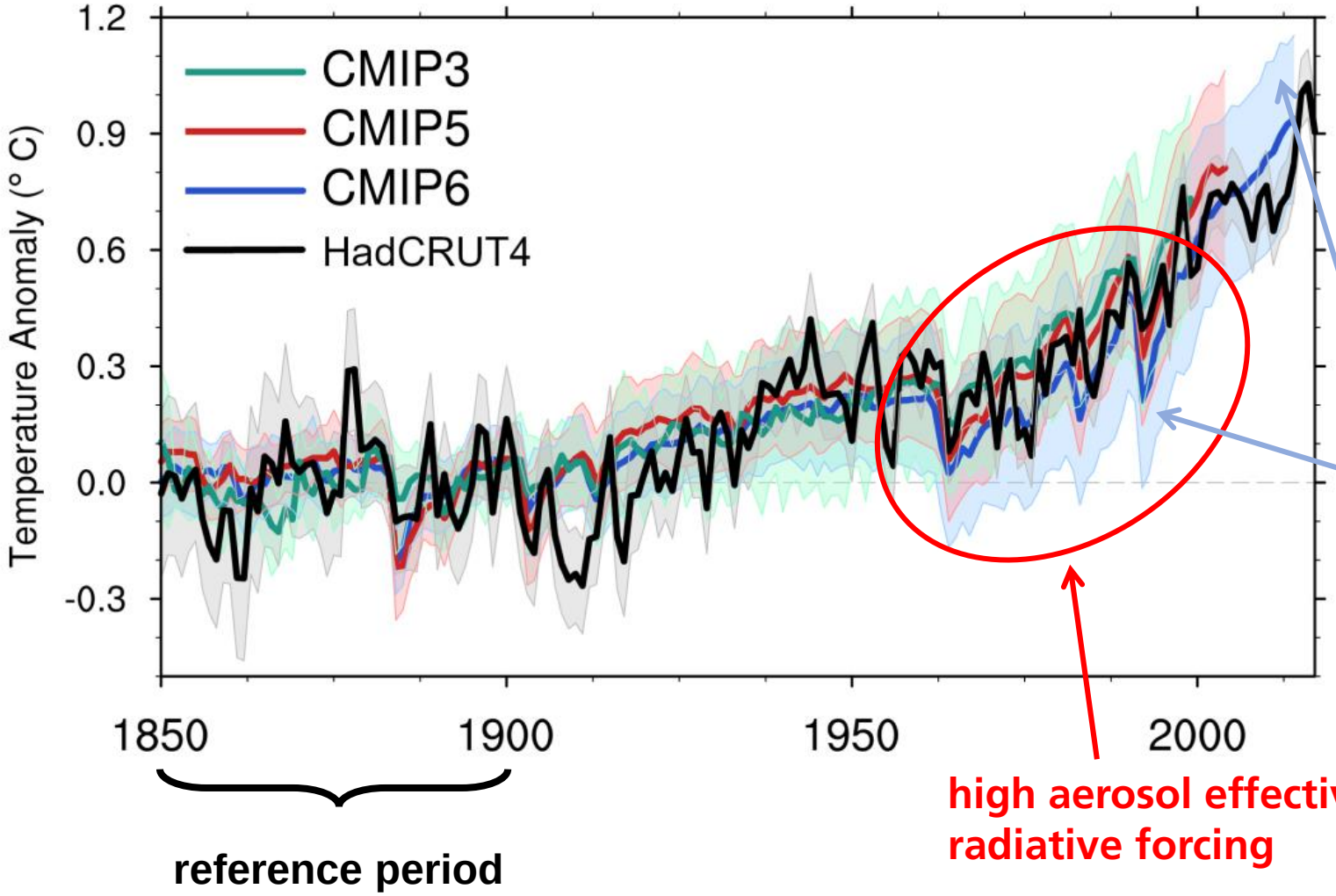
Reference data set: ERA5

Related to horizontal resolution?

- Most biases **decrease** for HighResMIP model simulations (ocean upwelling regions, high elevations, etc.)
- Direct comparison to CMIP6 ensemble **not possible** due to different experiment setups

Bock et al., JGR: Atmospheres , 2020

Global Annual Mean Surface Temperature Trends



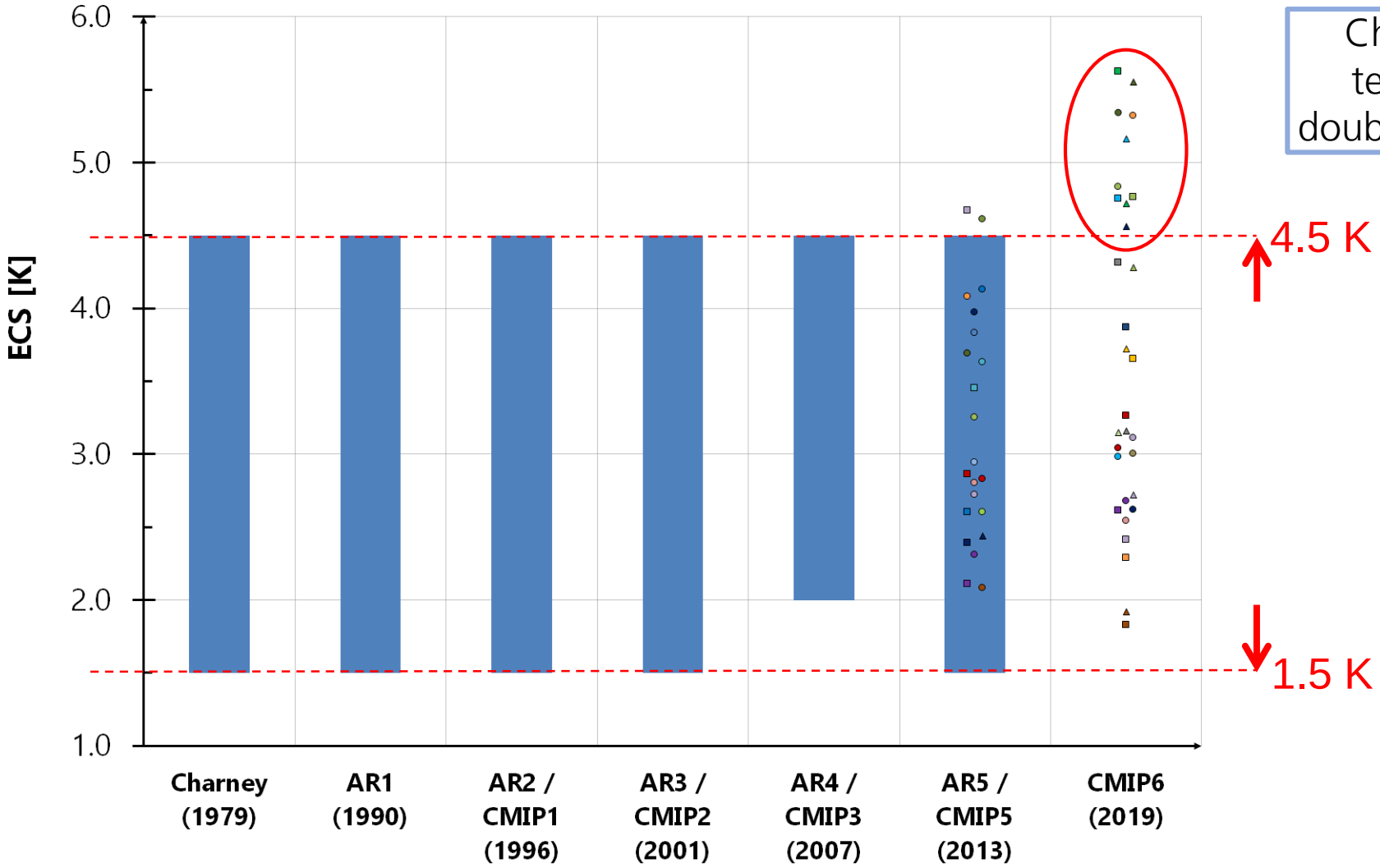
CMIP6 vs. CMIP5

- Overall warming trend **similar**
- Stronger reduction in warming over the period 1950-1990 in CMIP6
- Some CMIP6 models have larger warming in recent decades than observed

Bock et al., JGR: Atmospheres, 2020

Effective Climate Sensitivity (ECS)

Change in global mean 2m surface air temperature at equilibrium caused by doubling of atmospheric CO_2 concentration



ECS in CMIP6

- Assessed range has not decreased since 1979
- Several **high-sensitivity** models in CMIP6
- Increases the uncertainty in temperature projections
- Mainly related to uncertainty in clouds

Meehl et al. (incl. Eyring, Schlund), Science Advances, 2020

Summary

- More than 40 climate modelling centers worldwide participate in CMIP6

- ESMValTool enables a comprehensive, rapid, and reproducible performance assessment

Righi et al., *Geosci. Model Dev., 2020;* ***Eyring et al.***, *Geosci. Model Dev., 2020;*
Lauer et al., *Geosci. Model Dev., 2020;* ***Weigel et al.***, *Geosci. Model Dev., in review.*

- Quantifying progress of climate models across different CMIP phases:

  - Significant improvements from CMIP3 to CMIP6 in **model performance**
  - High resolution models reduce **long-standing biases** in ESMs
  - **Increased ECS** in more complex ESMs (related to cloud feedbacks)

Bock et al., *JGR: Atmospheres, 2020*