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Challenges and opportunities for climate modelling from a CMIP perspective

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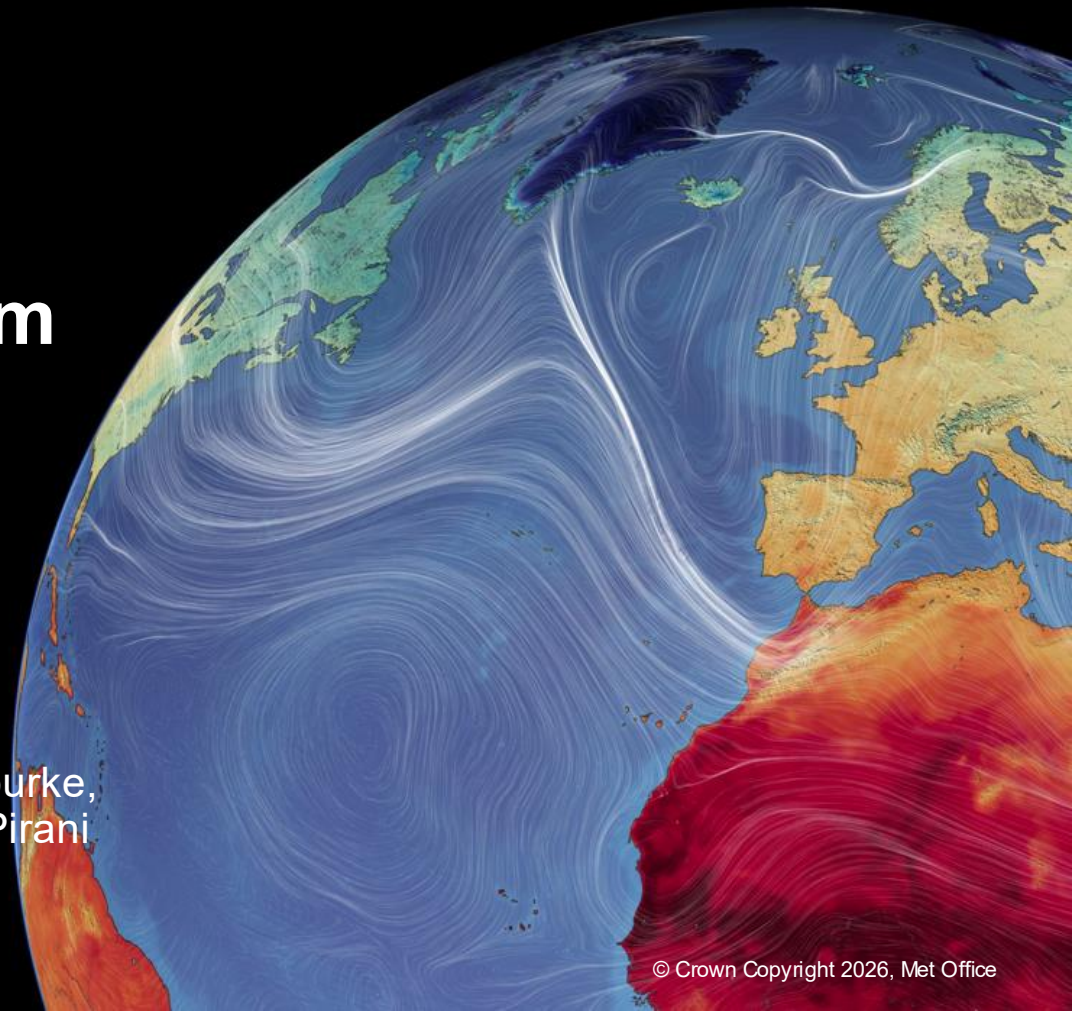
(Met Office Science Fellow,
CMIP Co-chair)

With thanks to John Dunne, Eleanor O'Rourke, Malcolm Roberts, Ben Sanderson, Anna Pirani



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Outline

- Coupled Model Intercomparison Project (CMIP)
- Science questions for CMIP7 and opportunities to address them
- Looking to operational climate projections

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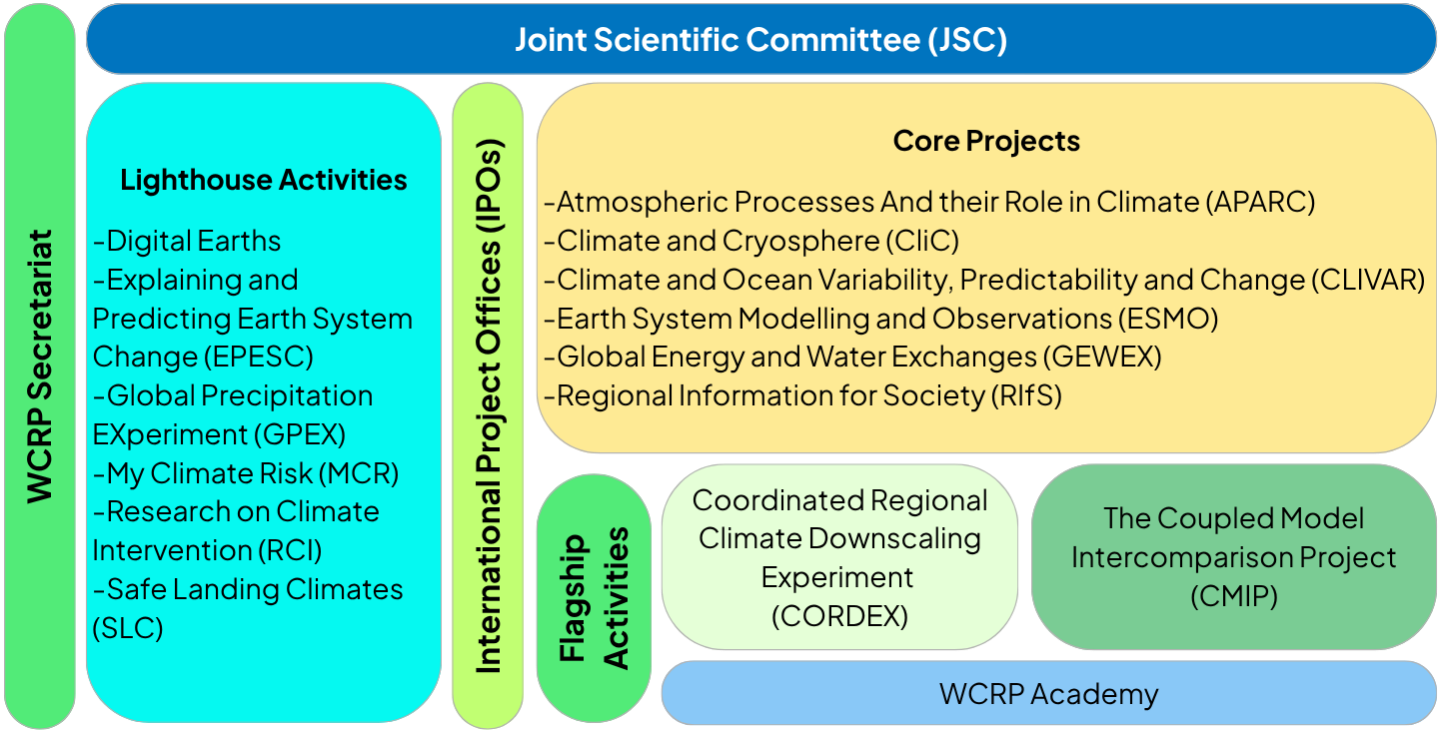
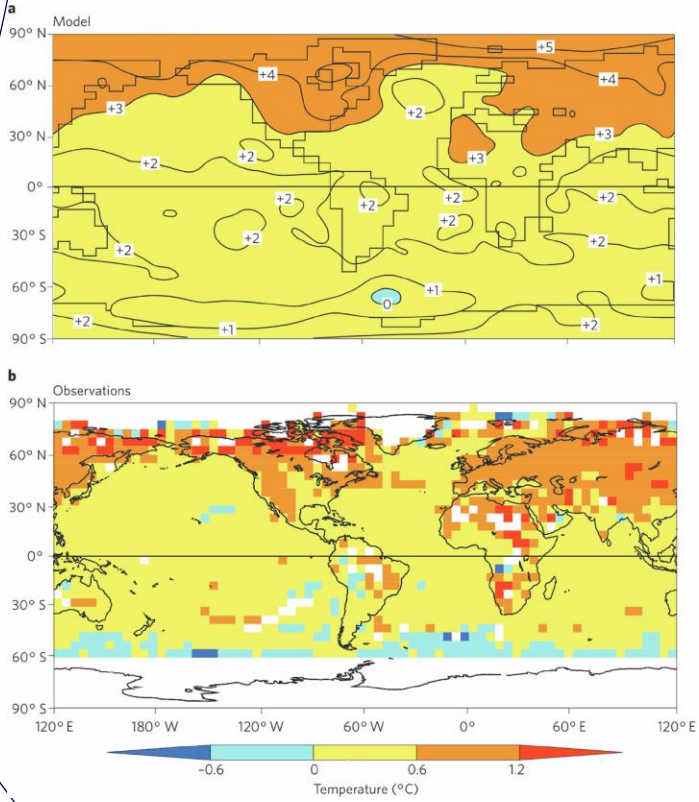
Coupled Model Intercomparison Project

WCRP Organizational Structure

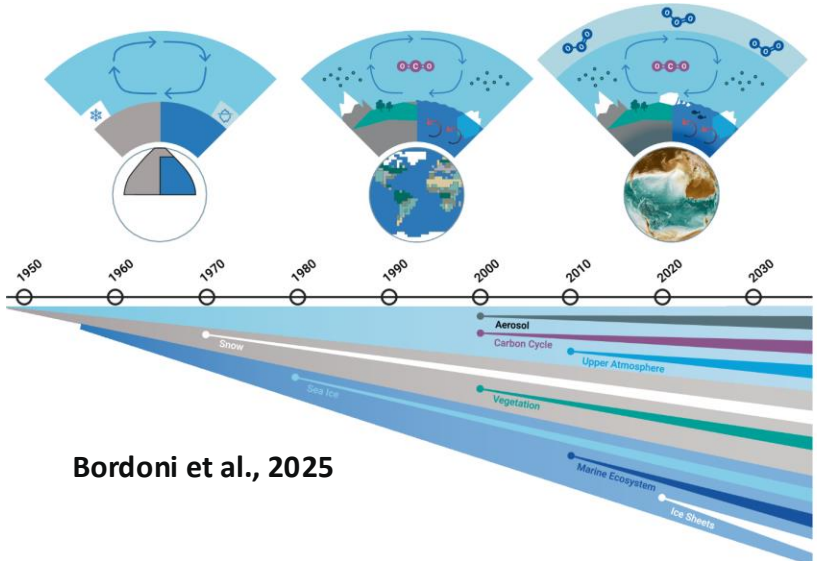


CMIP | WCRP

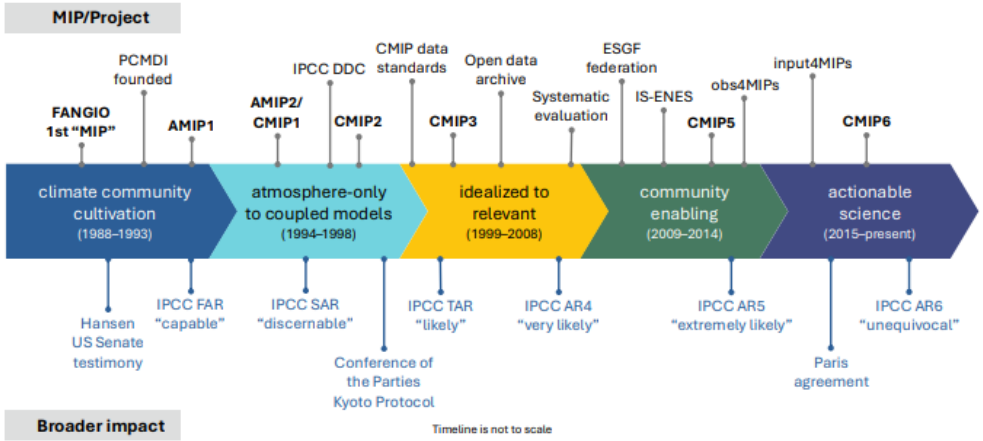
History of CMIP



Stouffer and Manabe, 2017



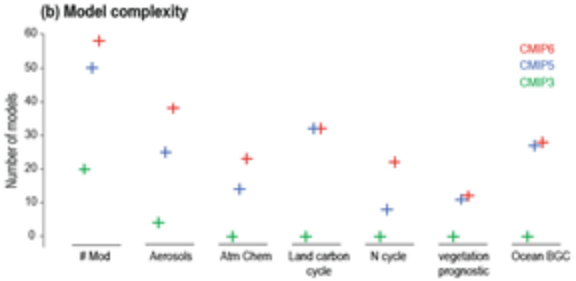
Bordoni et al., 2025

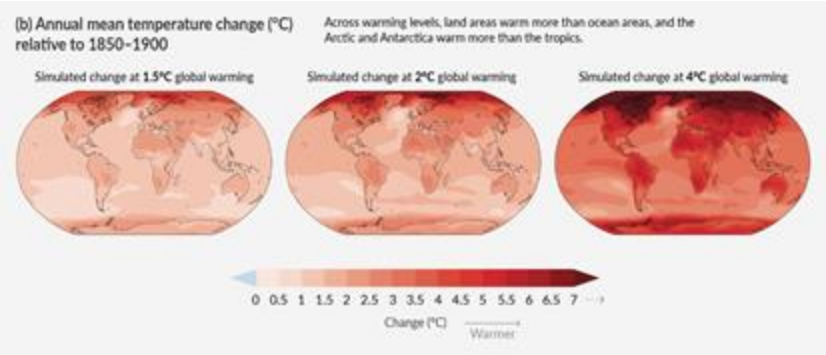


Durack et al., 2025

CMIP | WCRP

CMIP: driving science, informing policy





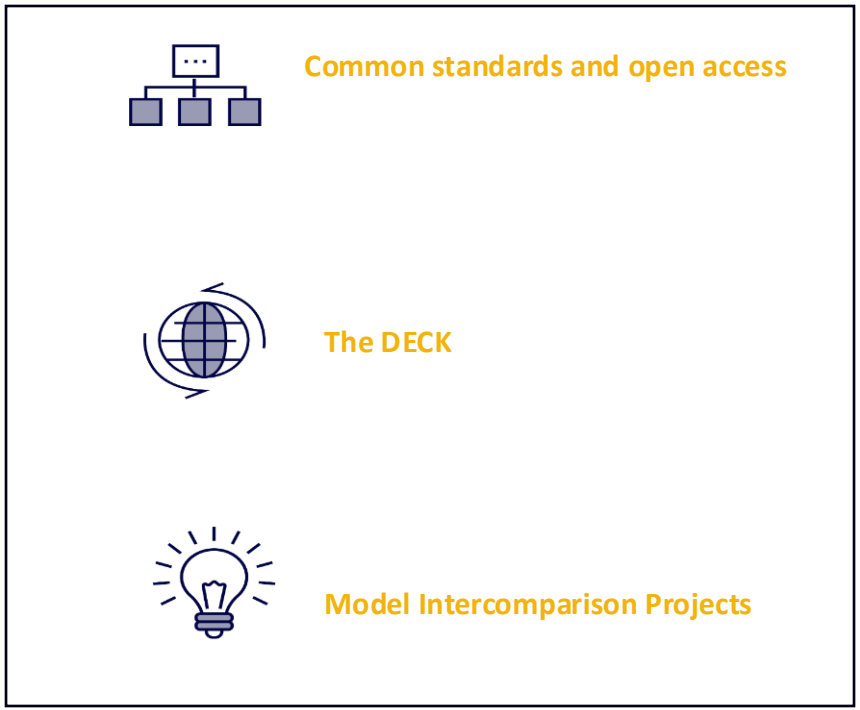
CMIP6: biggest yet!

- 24 endorsed MIPs
- 25 countries
- 43 institutions
- 131 models
- 322 experiments
- 8450 citations of CMIP6 and MIP design papers
- Nearly 25 PB of CMIP6 data
- 30+ ESGF data nodes

CMIP has influenced how we do climate modelling

These are key parts of CMIP that have enabled:

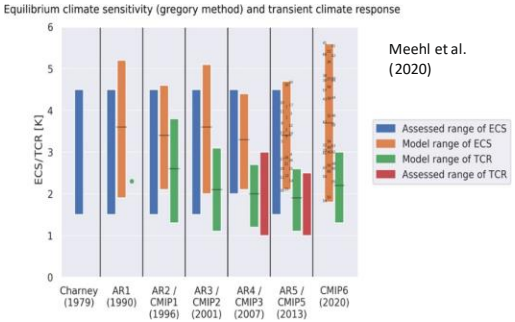
- the infrastructure for model data sharing
- benchmarking of models
- broad scientific understanding



CMIP | WCRP

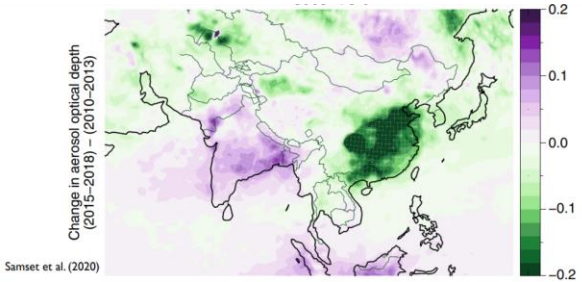
CMIP contributes to high level WCRP science objectives

1 Fundamental understanding of the climate system

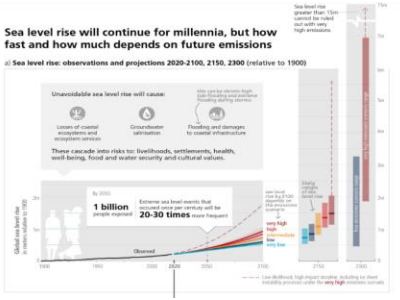


Meehl et al. (2020)

2 Prediction of the near-term evolution of the climate system

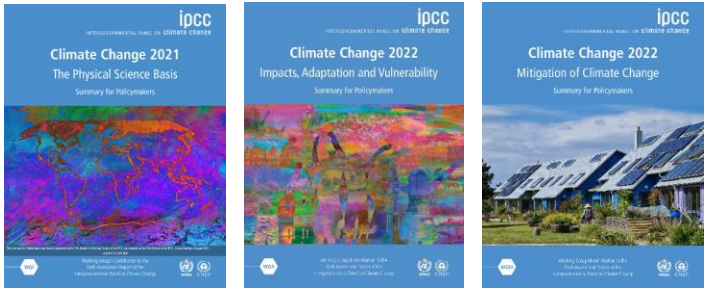


3 Long term response of the climate system



4 Bridging climate science and society

CORDEX
Coordinated Regional Climate Downscaling Experiment



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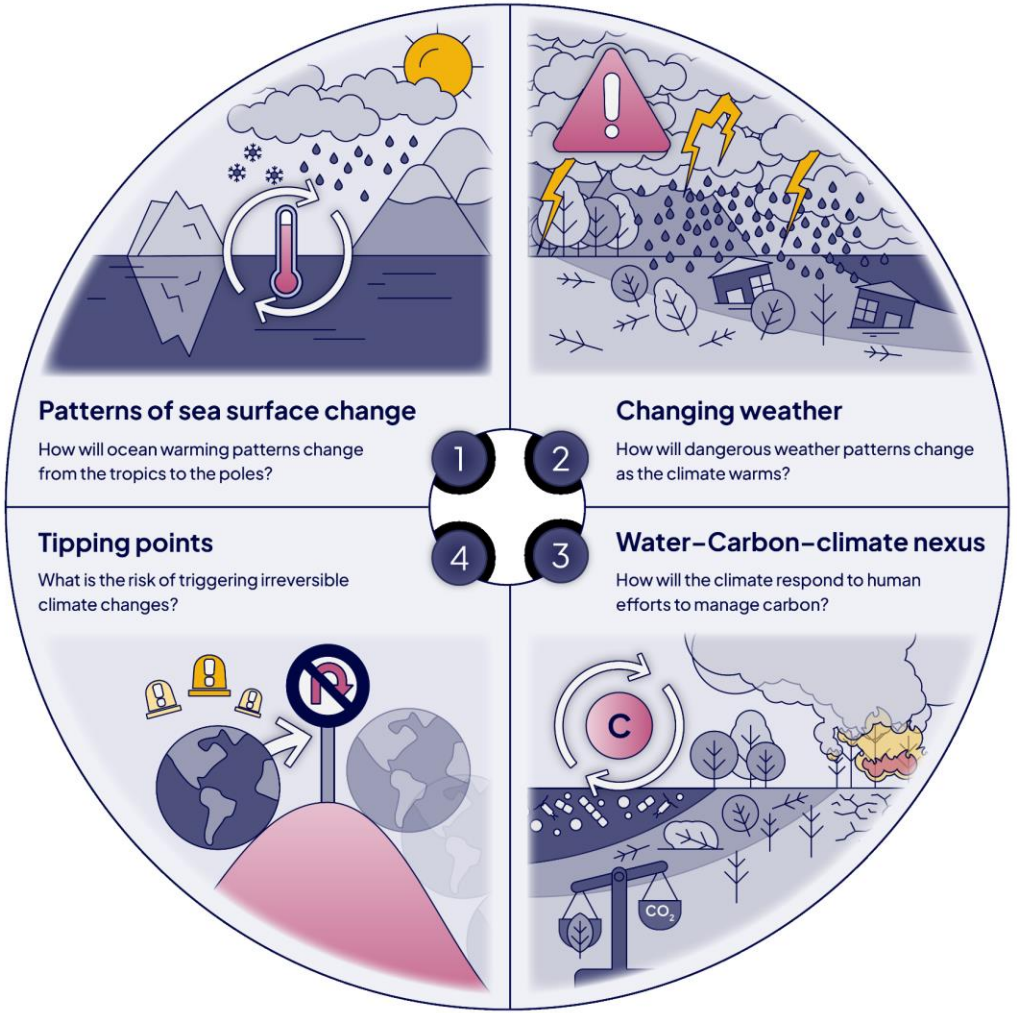
Science Questions for CMIP7

CMIP | WCRP

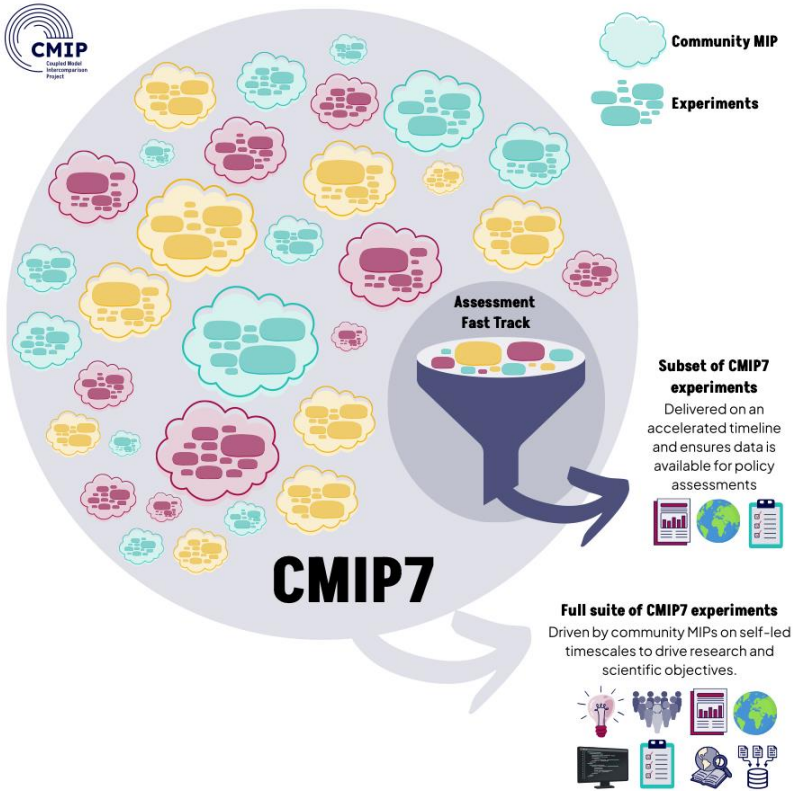
Science Questions for CMIP7

The CMIP panel put forward these four questions for CMIP7 to work towards addressing

Experiments in the Assessment Fast Track are aligned to these



What will CMIP7 look like?



The CMIP7 Assessment Fast Track is:

- A small subset of CMIP7 experiments identified as being critical for scientific and policy assessments e.g., IPCC AR7.
- Includes the historical and scenario experiments.
- Will be used as an input by other groups that create climate information, including organisations involved in regional downscaling (CORDEX) and modelling climate impacts (ISIMIP) and ice-sheet changes (ISMIP7).

New for CMIP7: updated historical forcing datasets

These are the standardised input datasets for models which describe the natural and anthropogenic external drivers (“forcings”) for CMIP historical simulations.

Land use

Aerosol optical properties

Anthropogenic SLCF and CO_2 emissions

Open biomass burning emissions

Stratospheric volcanic SO_2 emissions and aerosol optical properties

AMIP sea surface and sea ice boundary forcing

Population density

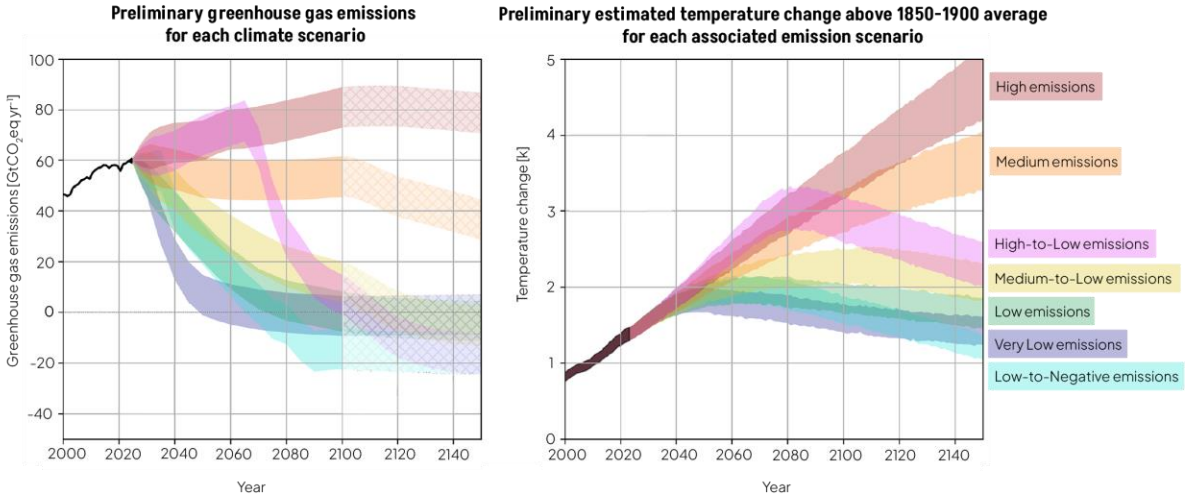
GHG historical concentrations

Ozone concentrations

Nitrogen deposition

Solar

New for CMIP7: Scenarios



van Vuuren et al. (2026)

Scenarios for CMIP7: key points

High scenario results in lower emissions

Falls in the cost of renewable energy and emissions, following the middle of road scenario since CMIP6, means the High scenario results in lower emissions than RCP 8.5 (CMIP5) and SSP5-8.5 (CMIP6).

Warming estimate for 2100 is around 3.5ºC

Despite lower emissions, the preliminary estimate of warming in 2100 for the High scenario is around 3.5ºC above pre-industrial levels and continue to rise after 2100.

Lowest scenario overshoots 1.5ºC

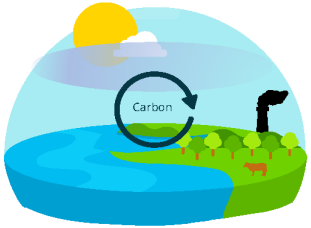
Even the lowest scenario is expected to overshoot the 1.5°C goal by at least 0.2 to 0.3°C before returning to 1.5°C by the end of this century and requires large scale application of Carbon Dioxide Removal (technology and nature based).

Temperature overshoot scenarios

To investigate impacts of reversing warming trends by removing carbon from the atmosphere and better understand impacts on society and ecosystems.

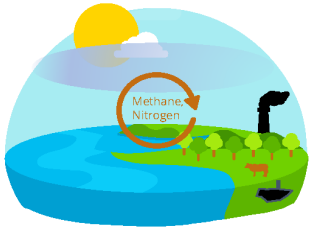
New for CMIP7: emissions driven scenarios and simulations

Carbon emission driven Model (CMIP7 proposal)



Closed carbon cycle. CO_2 concentrations and aerosols calculated as a function of human emissions and land use

Carbon emission driven Model (beyond CMIP7)



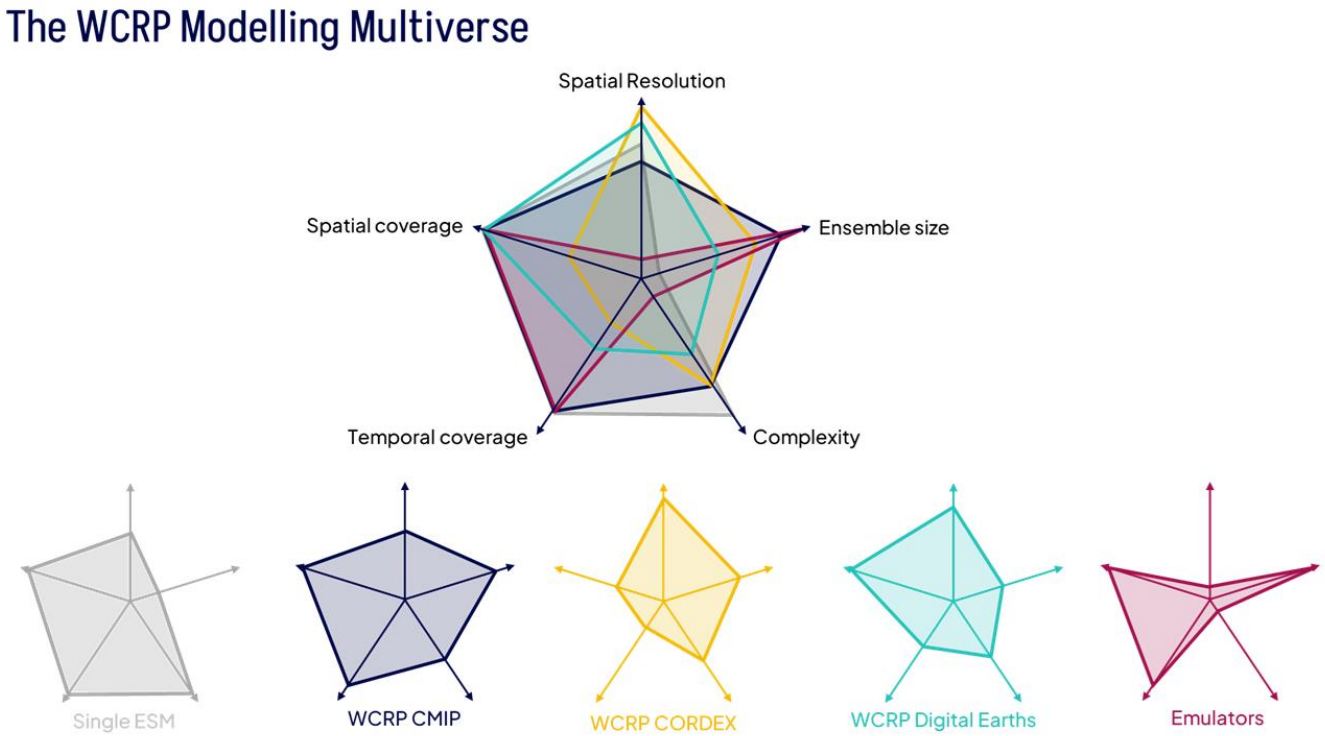
Closed nitrogen and methane cycles. Process-based CDR and SRM strategies.

- Many CMIP7 models will run in "emissions-driven mode" - the model itself simulates the carbon cycle and resulting levels of CO_2 in the atmosphere.
- Enables a more realistic representation of the carbon cycle and a better understanding of how it might change under different levels of warming.
- Climate policies are typically defined in terms of emissions rather than atmospheric concentrations.

Adapted from Sanderson et al. (2024)

CMIP | WCRP

Diversity in modelling approaches: the modelling multiverse



CMIP7 HighResMIP

https://highresmip.org/

Co-leads:
Malcolm J. Roberts (Met Office, UK),
Qing Bao (IAP, China),
Kevin A. Reed (Stony Brook University, USA)

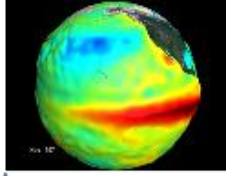
Updated experimental design compared to CMIP6

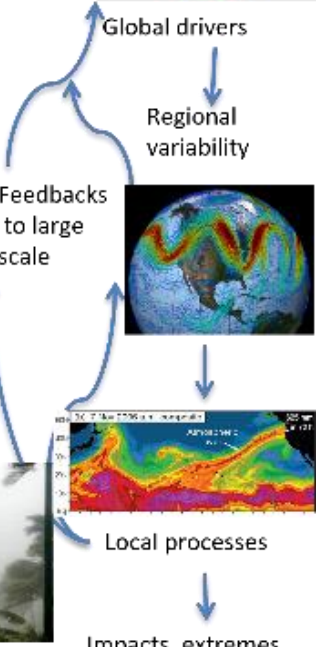
- **less compromises** (e.g. aerosol), to 2100, no required low res counterpart
- aiming for more coupled models with **eddy-rich ocean and/or 10km atmos**
- **more idealised runs for characterisation and links to CMIP7,** e.g. abrupt4xCO2-1950
- build **links with km-scale efforts**, e.g. 1 year simulation

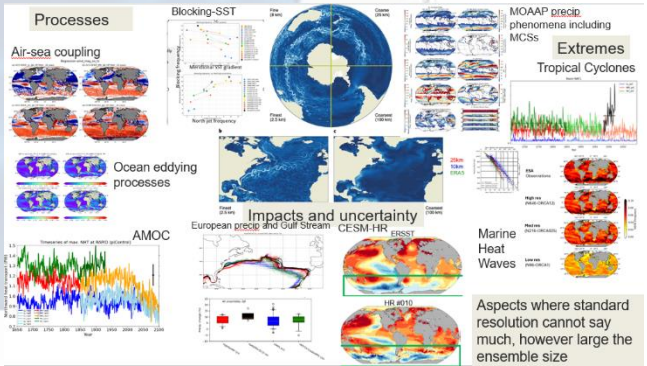
11 modelling groups so far expressed interest in joining

- Mostly aiming at late 2026-2027 for simulations
- Some simulations with CMIP6 forcing complete e.g. EU EERIE models, 10km-5/10km coupled

Aiming to contribute to CMIP7 questions: **dangerous future weather, and evolution of large-scale patterns**

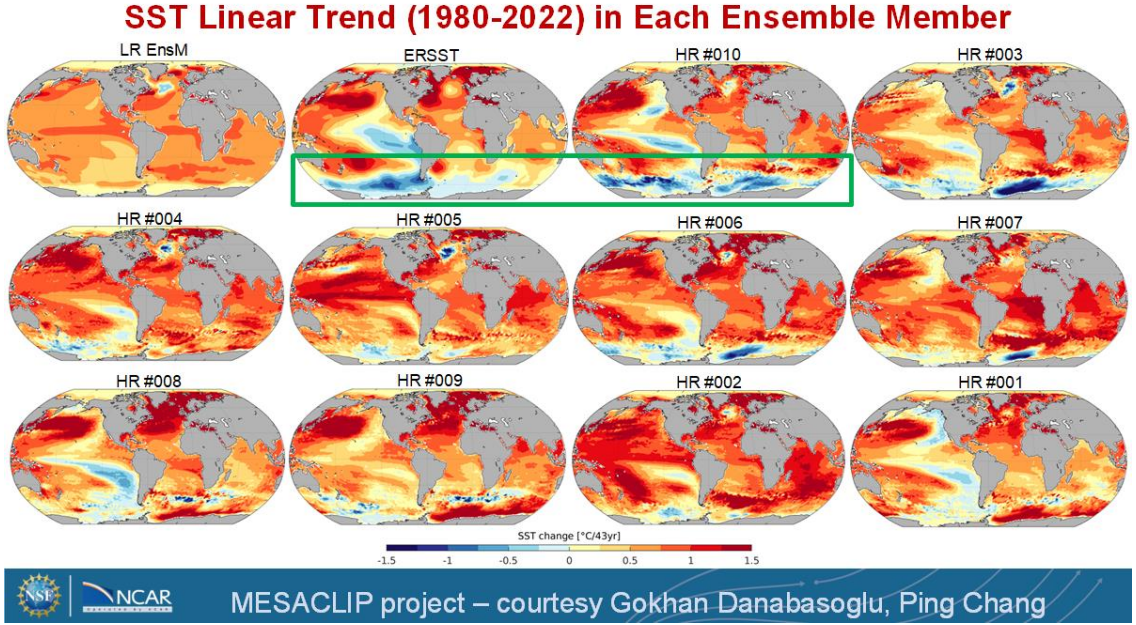






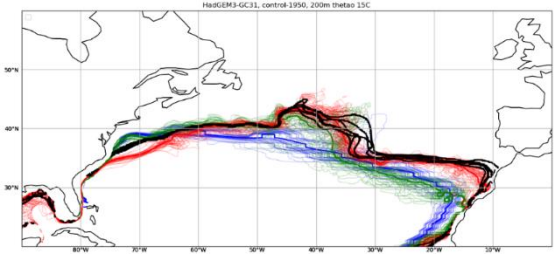
Model name	Modelling group	Mid-lat atmosphere resolution (km)	Mid-lat ocean resolution (km)	HighResMIP simulation type (Atmos-only AMIP, coupled)	Planned start date	Data available on ESGF by (hopefully)	Other information Using this model for CMIP7 FastTrack before any HighResMIP runs
UKCM2a-HH	UK Met Office	20	8	AMIP, coupled	Late 2026/early 2027	mid-2027	
CAS-ESM2	Chinese Academy of Sciences (CAS)	25	10	AMIP, coupled	2027	2028	
FGOALS-f4	Chinese Academy of Sciences (CAS)	12.5	10	AMIP, coupled	2027	2028	
BCC-CSM3-HR	Chinese Meteorological Agency (CMA) Earth System Modeling and Prediction Center	30	25	AMIP, coupled	2027	2028	
MRI-ESM3	Meteorological Research Institute (MRI)	20	10	AMIP, coupled	2027	2028	
NICAM, NICOCO	Japan Agency for Marine-Earth Science and Technology	14	10 or 25	AMIP, coupled	2027	2028	Our plan depends on the actual performance of the 5th generation Earth Simulator to be installed in 2027 spring.
GFDL-CM4C1M4	Geophysical Fluid Dynamics Laboratory/NOAA	25	25 (maybe 10)				
CMCC-CM3-LT	Euro-mediterranean center on climate change (CMCC)	25	25	AMIP, Coupled	Early/mid 2026	mid/late 2027	
ACCESS-CM3	ACCESS-NRI & CSIRO	25	8	AMIP, Coupled	2027	2028	This is an aspirational goal. We are yet to source Australian funding and compute resources for HighResMIP.
TaESM1	RCEC, Academia Sinica (AS-RCEC)	25	10	AMIP, Coupled	mid-2026	2028	
CESM	NCAR	25		AMIP, maybe Coupled	2027	2028	Plans are still evolving

Large-scale trends with high resolution simulations

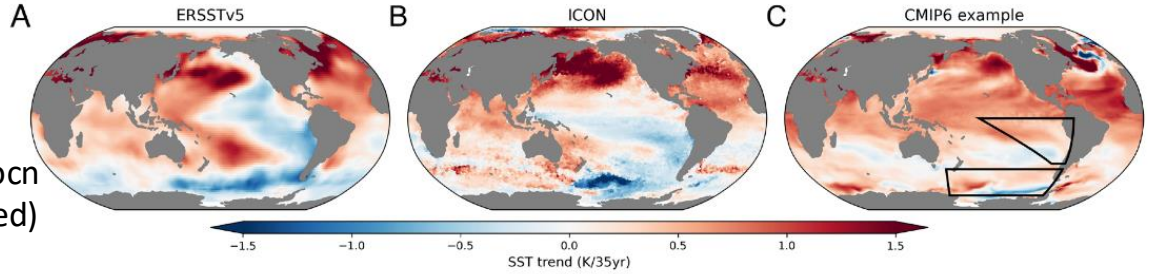


MESACLIP Texas A&M + NCAR
10 member ensemble
25km-10km atm-ocn
CMIP5 forcing

Gulf Stream position + future change
=> implications for European rainfall



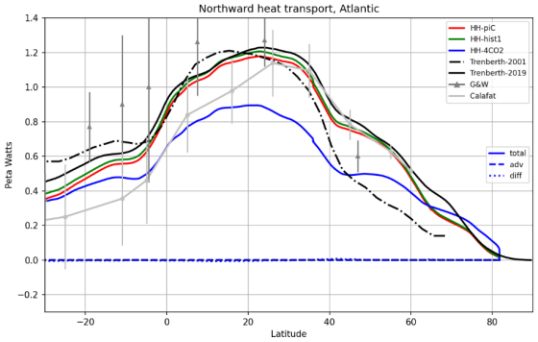
Kang et al., 2026, ICON 10km -5km atm-ocn coupled model (note ENSO is not well simulated)



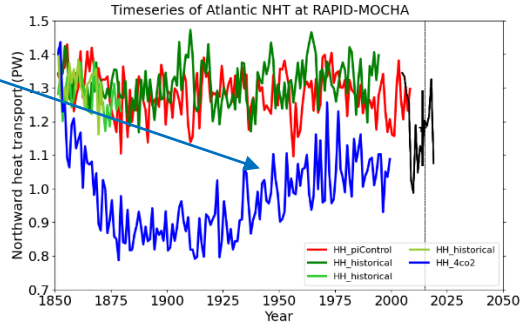
Met Office UKCM2a-HH for CMIP7 AFT

- UKCM2a-0-HH (as used in EU EERIE project)
  - ~20km-8km global physical coupled model
  - running subset of AFT simulations
  - aim to deliver first completed scenario simulations to 2100 by ~Oct 2026
  - plan to regrid some data to make access easier

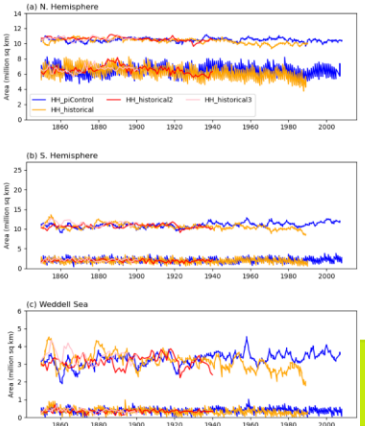
Atlantic northward heat transport looks great

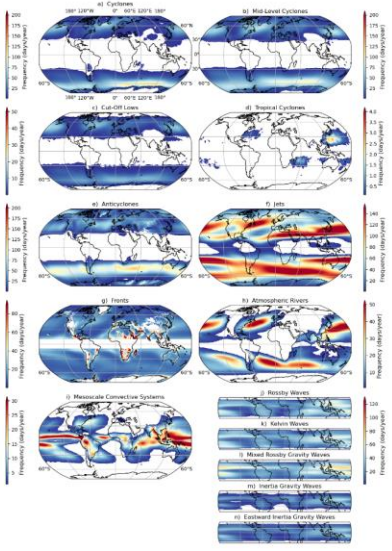


abrupt4xCO2 recovers quite strongly



sea-ice remains poor (too little) in both hemispheres





MOAAP (Prein et al 2023)
MCS and other weather extremes included (to at least some extent)

Model resolution	AMIP 1979-2022	+4K 1979-2022	highresSST-present 1980-2022	piClim-control 30 years	piClim-aer 30 years
UKCM2a-0-HH	1 member	1 member	1 member	1 member	1 member

Coupled

Complete Ongoing To do

Model resolution Atmos/Ocean	piControl 500 years	historical 1850-2022	future scenarios 2023-2100	4xCO2 150 years	1% CO2 150 years
UKCM2a-0-HH 20km-8km	1 member	3 members	3 members x (at least) 2 scenarios	1 member	1 member

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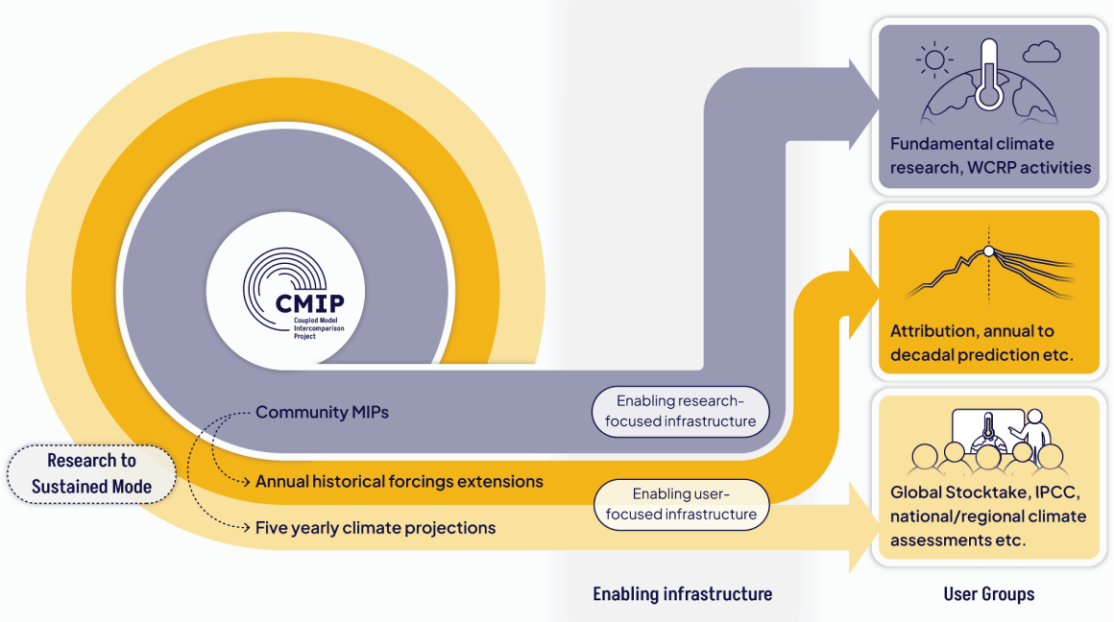
Looking to operational climate projections

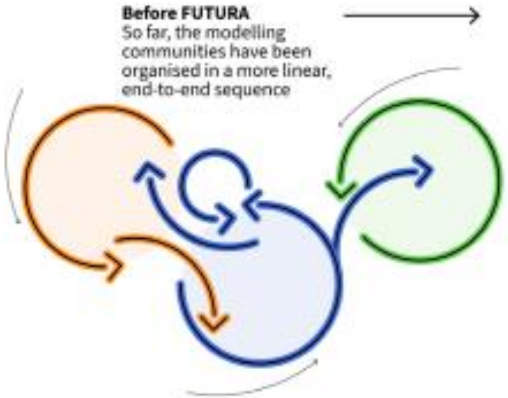
CMIP vision for projections (and recent past)

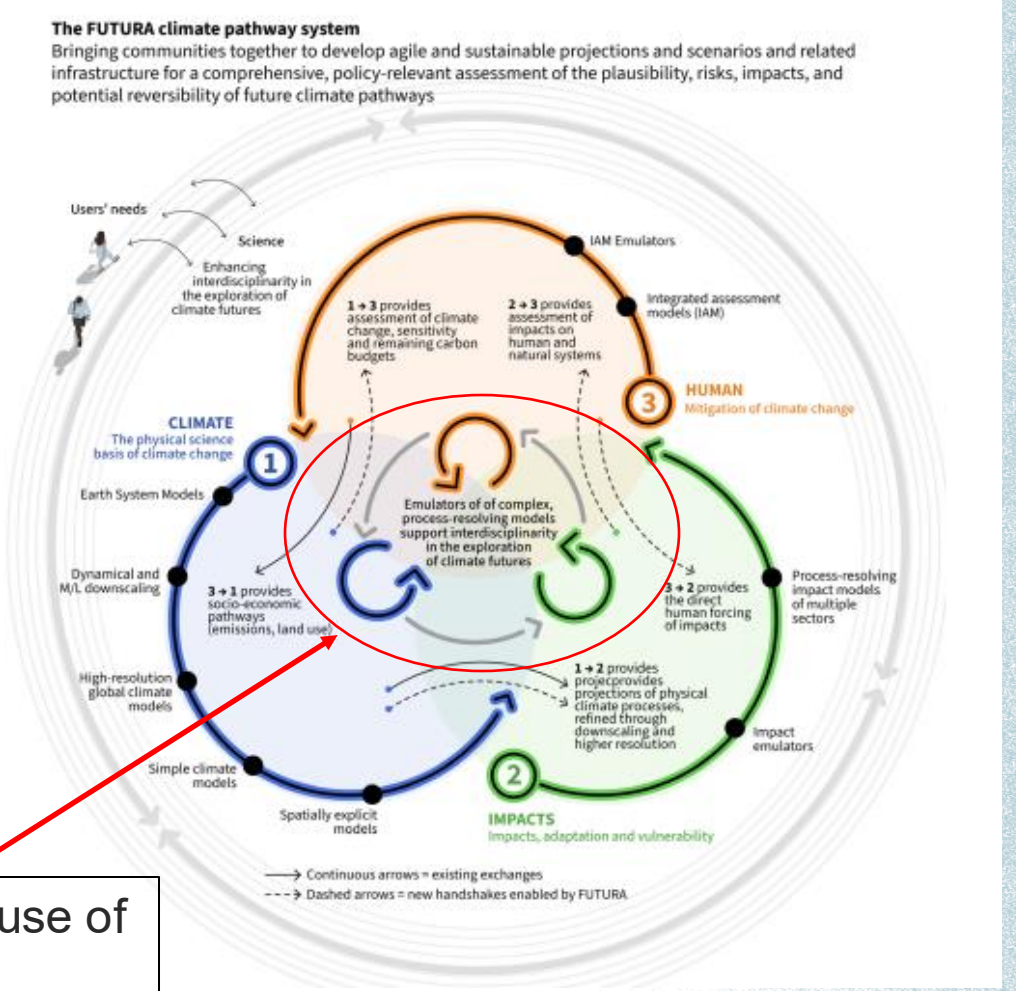
- Sustained rather than operational
- Implies regular (timely) updating as well as sustained funding for key external dependencies
- Forcing extensions wider benefits beyond projections



Hewitt et al., 2025

Climate pathways system





Increased use of emulators

Funded by the European Union

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Summary

- CMIP has been key to climate modelling over the last 30 years but continues to evolve to be more streamlined, inclusive and strategic. CMIP continues to be a foci for standards in sharing model data
- Climate forcing for historical and future period are key inputs to climate modelling for understanding past and future climate
- With pressing science questions to address, there is an opportunity to build on the diversity of approaches within WCRP – spanning Model Intercomparison Projects in CMIP, exploring the frontiers of complexity in CMIP and resolution with Digital Earth and CORDEX as well as looking to see where AI can supplement our modelling capabilities
- As demands for climate information increase, CMIP is looking at how to provide more regular information aligned with new scenarios. There is an opportunity here but also a big challenge in trying to link a number of communities together

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Challenges for the future

- Infrastructure remains one of the big challenges – coordinating everything that needs to happen to share climate model data with scientists, policymakers and private sector – and getting it funded!
- Planning is starting for CMIP sustained mode and notably we have routes to annual updates on forcings
- Beyond CMIP7, we will plan to take advantage of opportunities to bring in higher resolution, AI approaches and work with Integrated Assessment Modellers and Impacts community to bring the information chain together


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