Advances in climate modelling, scenario development and use

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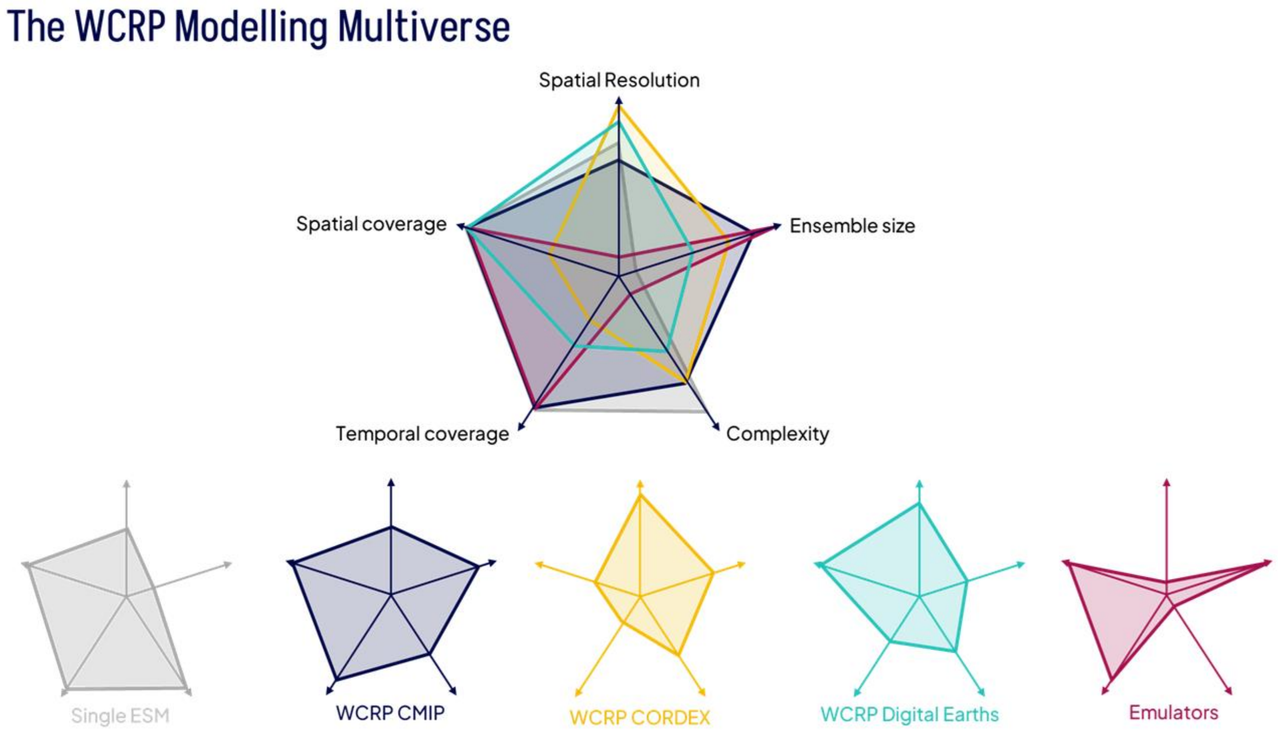
on behalf of
CMIP Panel, CMIP7 Task Teams, Fresh Eyes on CMIP and WCRP ESMO Infrastructure Panel

Key advances across the modelling multiverse



Dingley et al. (2023)

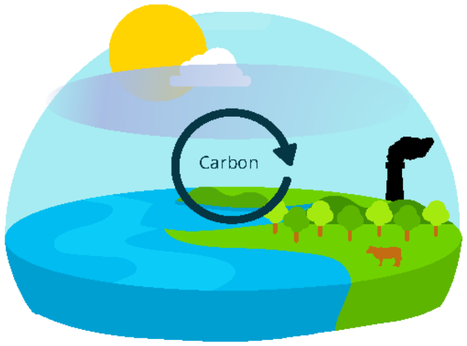
- **Increased comprehensiveness** offers understanding on how processes interact.
- **Increased resolution** (km scale), and **regional downscaling** offer better granularity on patterns and extremes.
- **Multi-model ensembles** support statistical attribution of extreme events.
- **Integration of AI** offers rapid analysis of vast data volumes.
- **Addressing key sources of uncertainty** e.g., cloud processes and carbon cycle feedback.
- Developing **pathways to operational delivery** of climate projections.

New for CMIP7: Emissions driven simulations

- 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.
- Land use scenarios represent CO_2 removal through:
  - Bioenergy with Carbon Capture and Storage (BECCS)
  - Direct Air Capture with Carbon Storage (DACCS)
  - Afforestation and reforestation

  and report underlying information on food versus bioenergy production.

Carbon emission driven Model (CMIP7 proposal)



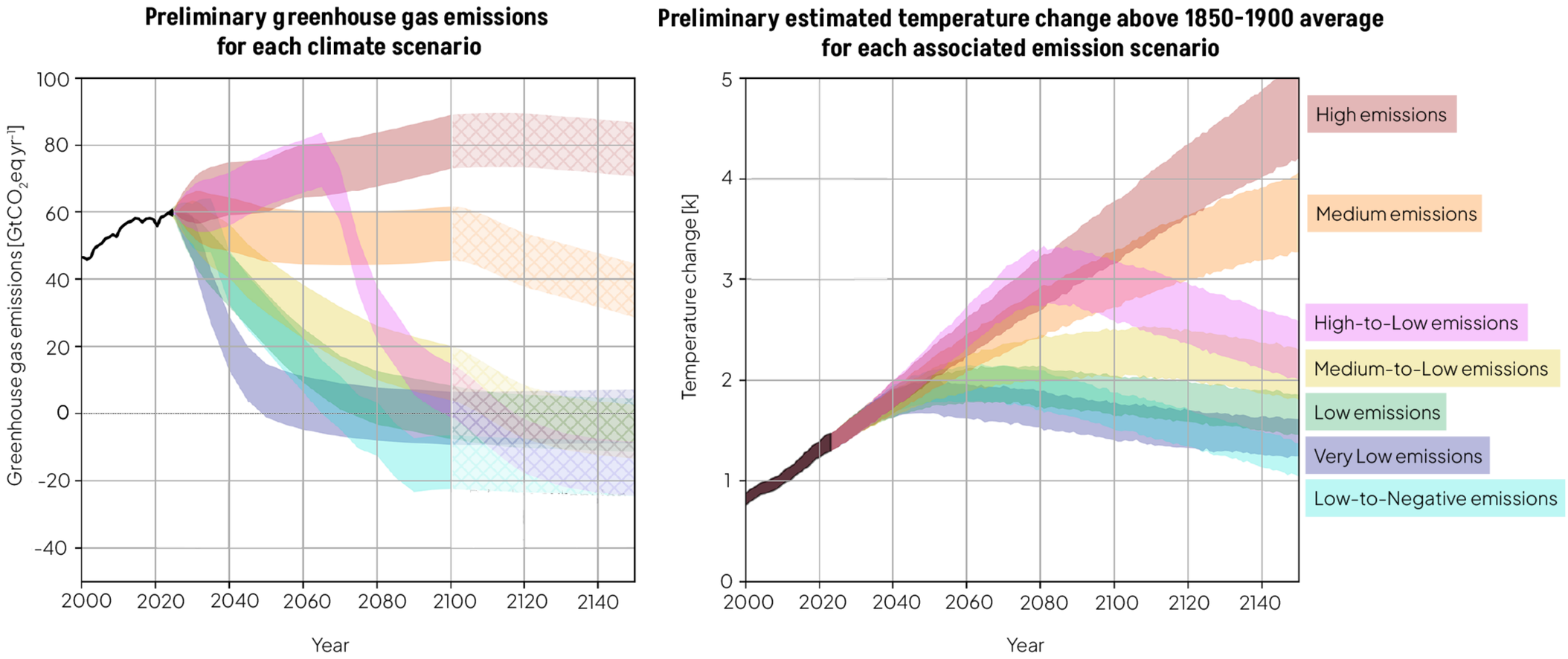
Closed carbon cycle. CO_2 concentrations and aerosols calculated as a function of human emissions and land use

Carbon emission driven Model (beyond CMIP7)

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

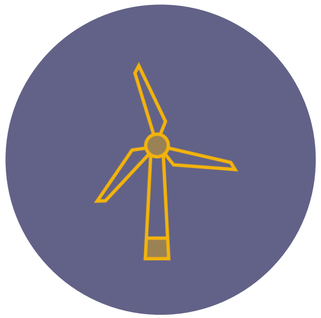
Adapted from Sanderson et al. (2024)

Scenarios for CMIP7



Adapted from 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 3.5°C 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

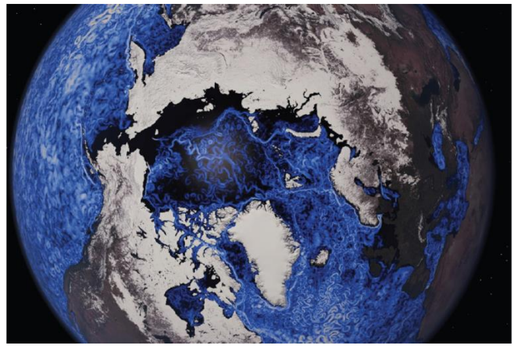
To investigate impacts of reversing warming trends by removing carbon from the atmosphere and better understand impacts on society and ecosystems.

Van Vuuren et al. (2026), Explainer: Scenarios for CMIP7

Scenarios for CMIP7: consideration of equity and justice

- The CMIP7 models are sensitive to outcomes such as global emission levels and land use but do not explicitly address equity and justice.
- The scenarios do include a regional differentiation of mitigation effort in the first few decades.
- To address equity and justice issues in the scenarios, further research is needed by the wider science community.
- Other available scenarios:
  - Network for Greening the Financial System (NGFS)
  - Policy-Aligned Model Intercomparison Project(PolMIP)

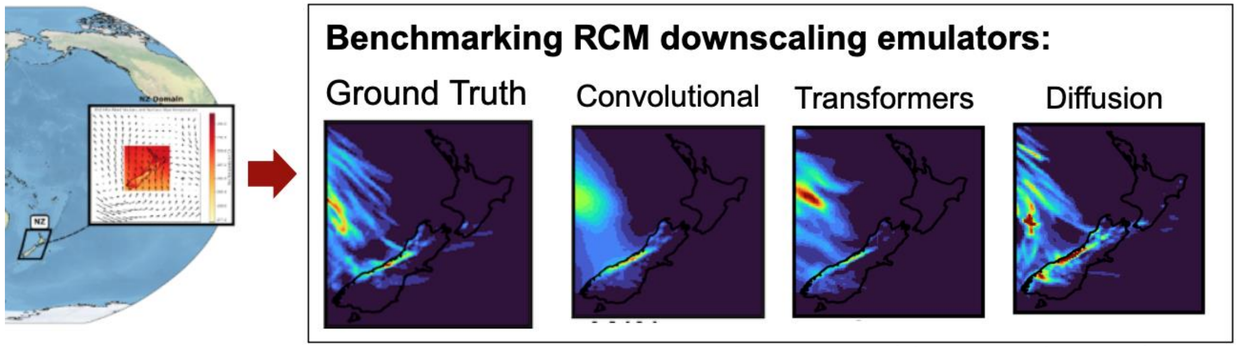
Supporting regional climate information provision



MPI-M, DKRZ, NVIDIA

- Evolution towards a Regional Earth System Model framework and approaching km-scale resolution at continental scale, linking with the global km-scale community offering advances such as improved extreme events and convective processes representation.

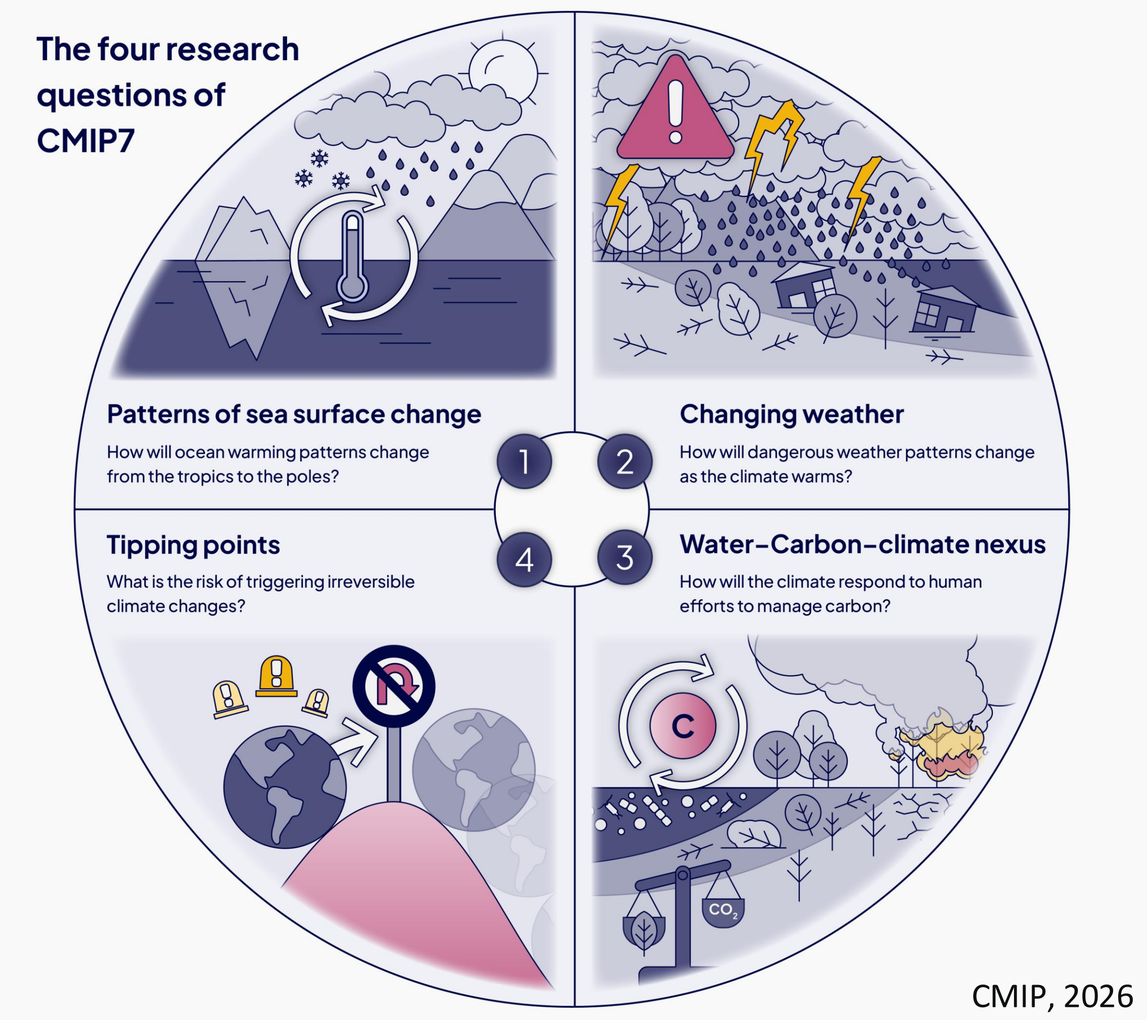
- Use of Machine Learning (ML) emulators to allow for AR7 assessment of CORDEX-CMIP7 downscaling to be available and enable alignment across WGI and WGII.



CORDEX Machine Learning Task Force

- Seeking to address the increasing challenge of advances in modelling raising the barrier further for under-represented regions, potentially impacting the delivery of regionally relevant climate information.

Research needs and knowledge gaps



CMIP, 2026

Looking beyond CMIP7 there is a need to:

- Improve understanding of early (pre-1850) historical forcing, natural variability, spin-up, and aerosol–cloud interactions to better represent historical heat and carbon uptake for comparison with observations.
- Continue to progress towards km-scale modelling to strengthen regional climate information and process representation.
- Investigate use of AI to expand scenario exploration, enlarge ensembles, and investigate tipping points and high-end outcomes.
- Explore pathways to sustained, quasi-operational climate information for attribution and projections.

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Thank You


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