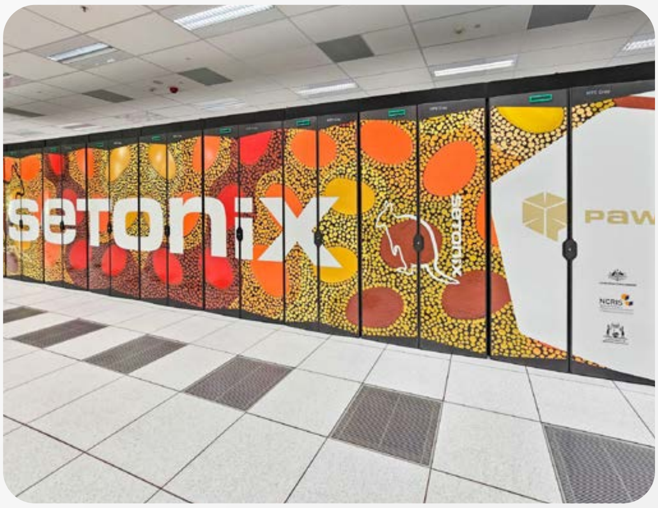
Government of **Western Australia**
Department of **Water and Environmental Regulation**

Climate Science Initiative WA

Everything you need to know about the latest in climate modelling

After reading this fact sheet, you will have an understanding of:

- How climate models work and what they tell us
- How climate models might evolve in the future
- What downscaling is and what its benefits are
- What's new about CMIP6 and the switch from RCPs to SSPs.
- The transition from RCP8.5 to SSP3-7.0 as a representative high range scenario
- Climate change projections for Western Australia



Global climate models

Global climate models (GCMs) are computer simulations of the Earth's climate system that replicate key processes in the atmosphere, oceans, land and ice. These models provide a way to understand the changes in the climate which are summarised in the assessment reports produced by the Intergovernmental Panel on Climate Change (IPCC).

GCMs simulate the global processes through time, including how they are influenced by factors like Greenhouse Gas (GHG) concentrations and how they interact, to recreate the past climate, and construct projections of what the future climate might look like under different assumptions. The outputs from these models are multidimensional datasets with gridded values for a range of climate variables (e.g. temperature, humidity etc.) at multiple time steps (e.g. hourly, daily).

When used and interpreted correctly, the outputs from GCMs provide a high degree of confidence in the likely range of future climates that can be used to assess risks, anticipate likely impacts, and inform climate policy and appropriate adaptation decisions. The variation in simulated climates among different models is occasionally portrayed as a weakness in climate science because of the ongoing uncertainty about the exact amount and rate of climate change we can expect. However, the collective modelling effort across different groups provides a detailed picture of possible future climates under different conditions.

Climate models have advanced significantly, allowing for a broader range of atmospheric processes to be simulated. These improvements are a result of the inclusion of more observation data to calibrate the models, a better understanding of atmospheric processes and interactions, more sophisticated analytical techniques, and accelerating computer capabilities. The following section provides an overview of the changes and improvements in the latest generation of climate models.

At the global scale, climate models typically use a grid cell size of 100–200 km. This means their outputs will project the same climate for any place within a given grid cell up to 200 km across, and will not reflect variation from changes in local conditions related to altitudinal differences, topography, distance from the coast etc. To provide more useful representations of regional or local climate conditions, a process called downscaling is used to generate projections data on smaller grid cells.

Dynamical downscaling refers to a process where a high-resolution climate model for a defined region is run using the output from a global-scale climate model as input at the regional boundary. This process is typically used to generate projections down to 4–20 km grids.

Climate models at both the global and regional scales have advanced significantly, allowing for a broader range of atmospheric processes to be simulated. These improvements are a result of the inclusion of more observation data to calibrate the models, a better understanding of atmospheric processes and interactions, more sophisticated analytical techniques, and accelerating computer capabilities. The following section provides an overview of the changes and improvements in the latest generation of climate models.

Coupled Model Intercomparison Project

Multiple research organisations around the world build, maintain and run a range of climate models called Global Climate Models (GCMs). These efforts are coordinated through the Coupled Model Intercomparison Project (CMIP) under the World Climate Research Programme. This collaborative effort is currently in its sixth phase, referred to as CMIP6. The results from CMIP6 models feature in the latest Sixth Assessment Report (AR6) from the Intergovernmental Panel on Climate Change (IPCC).

CMIP6 introduced some important changes in how emissions scenarios are described in the models in comparison to the previous phase, CMIP5.

CMIP5

CMIP5 models informed the IPCC's Fifth Assessment Report (AR5) released in sections between 2013 and 2014. CMIP5 models considered several different trajectories for future changes in the concentration of atmospheric GHGs described using Representative Concentration Pathways (RCPs).

An RCP describes a trajectory for future GHG concentrations based on assumptions about how different natural processes and human activities may change the rate of emissions (and sequestration) of GHGs. These assumptions do not just relate to emissions policy and activities, but also other factors including social, economic and natural forces.

There are four standard RCPs applied in climate modelling. The number included in the name for each RCP refers to the increase in climate forcing in the year 2100, resulting from the level of atmospheric GHGs (in watts per square metre) – a bigger number indicates more climate warming associated with higher concentrations of GHGs.

- RCP2.6 – describes a pathway to a low GHG concentration where it peaks somewhere in the middle of the century and then declines to 420 parts per million (ppm) as GHG emissions are substantially reduced over time with ambitious mitigation efforts. It is aligned with ambitious mitigation efforts aiming to limit the increase of global mean temperature to 2°C.
- RCP4.5 – describes a pathway where GHG concentrations stabilise at 540 ppm by 2100, where there is strong global action to reduce emissions by the end of the century.
- RCP6.0 – describes a pathway where GHG concentrations stabilise shortly after 2100 at 660 ppm by 2100 due to the application of some mitigation strategies and technologies.
- RCP8.5 – represents a future with little reduction in GHG emissions where GHG concentrations reach 940 ppm by 2100. In this RCP, there is little global action to reduce greenhouse gas emissions.

In 2022, the global average GHG concentration (measured in carbon dioxide equivalent) reached 418 ppm, almost twice the pre-industrial level of 278 ppm.

In their design, no RCP is inherently more or less likely than the others and they are not forecasts. However, an RCP may appear to be more or less likely depending on how policy and other parameters evolve in comparison to their assumptions or how actual GHG concentrations track against the modelled trajectories over time. RCP8.5 is often described as a 'worst case' or the 'business-as-usual' scenario, but this is not the case; it is simply a possible high-end scenario based on assumptions that included no effective climate policy response.

Many existing data sources on future climate change include projections based on at least two RCPs (usually RCP4.5 and RCP8.5) to compare the different outcomes of the pathways. These represent a low and high emissions scenario pathway and will correspond to the next generation of emissions scenarios that are further described in the table below, derived from the IPCC AR6 chapter 1.

SSPX-Y scenario	Description from an emissions/concentrations and temperature perspective	Closest RCP scenarios
SSP1-1.9	Holds warming to approximately 1.5°C above 1850–1900 in 2100 after slight overshoot (median) and implied net zero CO2 emissions around the middle of the century.	Not available. No equivalently low RCP scenario exists.
SSP1-2.6	Stays below 2.0°C warming relative to 1850-1900 (median) with implied net zero CO2 emissions in the second half of the century.	RCP2.6, although RCP2.6 might be cooler for the same model settings.
SSP2-4.5	Scenario approximately in line with the upper end of aggregate NDC emissions levels by 2030 (Sections 1.2.2 and 4.3; SR1.5, (IPCC, 2018), Box 1). CO2 emissions remaining around current levels until the middle of the century. The SR1.5 assessed temperature projections for NDCs to be between 2.7°C and 3.4°C by 2100 (Section 1.2.2; SR1.5 (IPCC, 2018); Cross-Chapter Box 11.1), corresponding to the upper half of projected warming under SSP2-4.5 (Chapter 4). New or updated NDCs by the end of 2020 did not significantly change the emissions projections up to 2030, although more countries adopted 2050 net zero targets in line with SSP1-1.9 or SSP1-2.6. The SSP2-4.5 scenario deviates mildly from a 'no-additional-climate-policy' reference scenario, resulting in a best- estimate warming around 2.7°C by the end of the 21st century relative to 1850-1900 (Chapter 4). An intermediate-to-high reference scenario resulting from no additional climate policy under the SSP3 socioeconomic development narrative. CO2 emissions roughly double from current levels by 2100. SSP3-7.0 has particularly high non-CO2 emissions, including high aerosols emissions.	RCP4.5 and, until 2050, also RCP6.0. Forcing in the latter was even lower than RCP4.5 in the early decades of the 21st century.
SSP3-7.0	An intermediate-to-high reference scenario resulting from no additional climate policy under the SSP3 socioeconomic development narrative. CO2 emissions roughly double from current levels by 2100. SSP3-7.0 has particularly high non-CO2 emissions, including high aerosols emissions.	Between RCP6.0 and RCP8.5, although SSP3-7.0 non-CO2 emissions and aerosols are higher than in any of the RCPS.
SSP5-8.5	A high-reference scenario with no additional climate policy. CO2 emissions roughly double from current levels by 2050. Emissions levels as high as SSP5-8.5 are not obtained by integrated assessment models (IAMS) under any of the SSPS other than the fossil-fuelled SSPS socioeconomic development pathway.	RCP8.5, although CO2 emissions under SSP5-8.5 are higher towards the end of the century (Cross-Chapter Box 1.4, Figure 2). CH. emissions under SSP5-8.5 are lower than under RCP 8.5. When used with the same model settings, SSP5-8.5 may result in slightly higher temperatures than RCP8.5 (Section 4.6.2).

Table 1 Interlinkages between the CMIP5 and CMIP 6 emission scenarios. Source: IPCC AR 6 Ch1

CMIP6: A new generation of climate models

CMIP6 models represent a new generation of climate models and are highlighted in the most recent AR6 report from the IPCC (released between 2021 and 2023).

In comparison to CMIP5, CMIP6 includes more models based on the latest understanding of ocean and atmospheric processes (such as improved descriptions of cloud processes and biogeochemical cycles). CMIP6 also features finer resolution and a wider range of climate sensitivities (the average change in global mean temperature in response to a change in climate forcing).

CMIP5 models use a baseline period of 1986 to 2005 while CMIP6 models use a baseline of 1995–2014. CMIP6 models also employ a new way to describe future GHG trajectories using **Shared Socioeconomic Pathways (SSPs)**.

The SSP socioeconomic narratives describe the broad trends that could shape society in the future. These include population growth, economic growth, technological development, education and urbanisation. SSPs are intended to span the range of plausible futures; however, other combinations of factors are possible. While there are similarities with the RCPs, the SSPs are more highly developed, more coherent and able to be used in a broader range of applications in addition to climate modelling. The five SSP narratives are:

- SSP1 – A more sustainable, equitable and inclusive world with more focus on human wellbeing and environmental boundaries.
- SSP2 – A 'middle of the road' world where social, economic and technological trends do not shift markedly from historical patterns.
- SSP3 – A fragmented world of nationalism and regional rivalry where priority is increasingly placed on national and regional interests, including energy and food security over sustainability goals.
- SSP4 – A world of ever-increasing inequality leading to disparities in economic opportunity and political power.
- SSP5 – A world of rapid and unconstrained economic growth and energy use with increasing faith in competitive markets and innovation to deliver sustainable development goals.

The SSP 'name' consists of two parts:

- The 'SSP Family' code based on one of five global socioeconomic narratives (described above)
- The extra energy (in W/m2) reaching the earth by 2100. This was used for the previous 'RCP' scenarios.

Climate modelling initiatives focus on a set of five combined scenarios:

- SSP1-1.9 – This is the most optimistic of the scenarios where global GHG emissions are cut aggressively to net zero by about 2050. This scenario aligns most closely with the goal of keeping warming below 1.5°C at 2100 (although there may be a bit of 'overshoot' where temperatures rise beyond the 1.5°C goal temporarily before dropping below the goal by the end of the century).
- SSP1-2.6 – Under this scenario, global emissions are reduced but don't reach net zero until after 2050 and warming stabilises at about 1.8°C by 2100.

SSP scenario	SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
Socioeconomic narrative	Sustainability	Sustainability	Middle of the road	Regional rivalry	Fossil-fueled
Emissions	Very low	low	Moderate	High	Very high
Energy mix					
CO_2 concentration	390ppm	440ppm	600ppm	870ppm	1130ppm
Global mean temperature increase	1.0 – 1.8°C	1.3 – 2.4°C	2.1 – 3.5°C	2.8 – 4.6°C	3.3 – 5.7°C
Mean sea level rise @2100	28 – 55cm	32 – 62cm	44 – 76cm	55 – 90cm	63 – 101cm

Figure 1 An overview of the five Shared Socioeconomic Pathways (SSPs) used in modelling the global climate. Sources: IPCC AR6 WG1 and CarbonBrief.

- SSP2-4.5 – This scenario has emissions steady at roughly the same as current levels before starting to fall in the middle of the century and net zero is not reached by 2100, with temperatures rising by about 2.7°C by the end of the century.
- SSP3-7.0 – Under this scenario, both emissions and temperatures continue to rise, the latter by about 3.6°C by 2100.
- SSP5-8.5 – This high-growth, energy-intensive scenario has emissions roughly doubling by 2050 and global average temperatures rising by about 4.4°C by the end of the century.

While these SSPs feature the same climate forcing values at 2100 as the RCPs in CMIP5, the starting positions, drivers and pathways to get there can be quite different. Therefore, not all combinations of the SSPs and RCPs are compatible because of conflicting policy assumptions. In addition to the four RCPs described for CMIP5, the SSPs have added RCP1.9, RCP3.4 and RCP7.0. Figure 1 below illustrates the projected global mean surface temperature change to 2100 under these five scenarios (relative to the period from 1850 to 1900).

Socioeconomic narratives describe the broad socioeconomic trends that could shape future society that will influence future emissions and adaptive capacity (e.g. population growth or patterns of consumption). Emissions provide a high-level description of the resulting emissions trajectory to 2100. Energy mix describes the assumed composition of energy generation technologies including renewables and fossil-fuels. CO2 concentration is the resulting atmospheric concentration of greenhouse gases in 2100. Global mean temperature increase provides the modelled likely range of the increase in global mean temperature by 2100. Mean sea level rise provides the modelled likely range of sea level rise under each scenario by 2100.

Which CMIP5 and CMIP6 scenarios to consider

Within the climate science community, RCP8.5 was considered to be a good representation of a high range emissions scenario for the CMIP5 suite of models that could be used to inform the upper bounds of possible climate change for policy development and risk assessments. However, changes in baselines, the passing of time, more recent data and an improved understanding of how the main drivers of future emissions are likely to change over time (particularly the proportion of fossil fuels used in energy generation as the relative costs change rapidly to favour renewables) mean that SSP3-7.0 is now considered to be good representation of a high-end emissions scenario within the CMIP6 suite of models (i.e. because emissions higher than described in SSP3-7.0 are now considered very unlikely).

For policy and climate risk assessments, it's useful to consider at least two emissions scenarios to provide a picture of a range of possible future climates. A climate risk methodology can guide the selection of the most appropriate scenarios to use for a particular purpose, or an organisation may have a policy position that specifies which scenarios to use. For most purposes, this would include one scenario representing the lower margin of likely range of future emissions (e.g. SSP1-2.6) and one representing a high-range emissions trajectory (e.g. SSP3-7.0).

CMIP6 projections for Western Australia

Across Australia, government agencies and research organisations are using the new CMIP6 models to produce downscaled, fine resolution regional climate projection information. This work is coordinated through the National Partnership for Climate Projections to ensure consistency in the models and scenarios that are used by multiple teams. The Climate Projections Roadmap for Australia describes the approach to deliver comparable, robust, fit-for-purpose future climate information to assess climate risks and inform adaptation planning. Typically, CMIP6 projections are being produced for three possible global future emissions scenarios: SSP1-2.6 (low emissions), SSP2-4.5 (moderate emissions) and SSP3-7.0 (high emissions).

The Climate Science Initiative (CSI) is producing the most comprehensive climate change projections for WA. The project is being led by the Department of Water and Environmental Regulation (the department) in partnership with the NSW Government and Murdoch University through the NSW and Australian Regional Climate Modelling Project (NARCliM 2.0), and the Pawsey Supercomputing Research Centre.

Projections are being produced at the 20-km and 4-km resolution up to the year 2100. Statewide climate change projections at a 20 km grid resolution will be available to technical users by the end of 2024. Projections at a finer 4 km resolution are anticipated to be available for the South West in mid-2025 and for the North West, covering the Pilbara and Kimberly regions, in 2026.

Producing climate projections at this scale is complex and time-consuming process. It involves solving hundreds of equations simultaneously on high-performance supercomputers. The CSI is using Pawsey's Setonix supercomputer, one of the world's most powerful, to produce the projections for WA. On average, it takes the CSI scientists and Setonix one week to simulate two to three years. CSI's projections span 150 years from 1950 to 2100. Extensive data processing and validation is also underway to ensure the accuracy and reliability of the climate projections produced. This involves analysing model outputs, comparing them with historical data and observations, and assessing model performance across different scenarios and timeframes.

The CSI is following the international best-practice experiment protocol for dynamical downscaling, the Coordinated Regional Climate Downscaling Experiment (CORDEX), to produce comparable climate parameters with other countries.

Selecting projections data for climate risk assessments

CMIP6 models can provide advantages through the description of possible future climates, particularly for more sophisticated analyses where the outputs of GCMs are used as inputs for further modelling. Examples include regional downscaling simulations or analyses that focus on implications for climate hazards or systems (such as extreme events or implications for ice sheets etc.) that are dependent on information on ocean and atmospheric processes at fine spatial and temporal resolutions.

However, for the purposes of climate risk assessments and adaptation planning, CMIP6 models are unlikely to provide any substantial differences to CMIP5 models in relevant climate parameters that would have a material effect on risk classification or decisions on adaptation options. CMIP5 projections can continue to be applied in climate risk assessments with confidence pending the development of projections from CMIP6 models.

More information

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Climate Science Initiative WA

Climate Systems

National Environmental Science Program

This fact sheet was developed in collaboration with the National Environmental Science Program Climate Systems Hub with contributions from Dave Putland of the Queensland Future Climate Science Program.

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