Taihoro Nukurangi

User Guidance of CMIP6 Downscaled Data for Aotearoa New Zealand

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Executive summary

This report provides summary information and guidance for users of the Coupled Model Intercomparison Project Phase Six (CMIP6) downscaled data for Aotearoa New Zealand produced by NIWA. An accompanying NIWA report ('Bias Correction of Downscaled CMIP6 output') focuses on the bias correction methodology in greater detail, while this report focuses on the dynamical downscaling approach, model evaluation, as well as data access and guidance on usage.

The Conformal Cubic Atmospheric Model (CCAM) was the primary dynamical model used for downscaling in the CMIP6 projections. While the focus of downscaling is on New Zealand, CCAM is a global physics-based model with a stretched grid configuration. This enables enhanced horizontal spatial resolution over both New Zealand and the wider South Pacific region. The enhanced and seamless grid resolution over an extended domain can assist in the representation of storms before they reach New Zealand and provide additional insight into projected changes. Six global climate models from CMIP6 were downscaled using CCAM across both the historical period (years 1960-2014) and various Shared Socioeconomic Pathways (years 2015-2099). The final bias corrected product is provided on a 5-km grid over New Zealand.

Model evaluation of the downscaled output was comprehensively assessed through the 'added value' framework. Through this, biases in the downscaled output are compared against biases from the global climate model output to investigate where improvements are made through downscaling. This is assessed across mean climatological statistics as well as for extreme event indices. Added value from downscaling is clear, especially for temperature and orographic precipitation. Several temperature and precipitation-based extreme indices also show large improvements. The representation of tropical cyclones reaching at least category-2 intensity is also improved relative to global climate models that consistently underrepresent these events. Remaining biases from the downscaled output were then targeted through bias-correction.

Guidance on how to use different formats of the data is provided. Users (e.g. stakeholders, researchers) often have different requirements, so different formats of the data have been produced. Details on these datasets, the file format and conventions, and data access is documented here. We recommend that stakeholders using these data for climate change risk assessment and adaptation purposes consider and stress-test plans and strategies across a range of the scenarios and downscaled models provided.

1 Downscaling Methodology

In regions characterised by complex and coastal terrain, such as New Zealand, the raw output from relatively coarse resolution global climate models (GCMs) can contain large biases. This generally means that GCMs should not be used directly in downstream climate impact studies, especially for local and regional applications. Well-known issues include that GCMs struggle to capture orographic precipitation and extremes over New Zealand, the intensity of extreme events such as tropical cyclones, as well as the impact of elevation and coastal processes on temperature variability (Gibson et al., 2024a)

Due to these issues, dynamical downscaling is a valuable tool for better capturing smaller scale processes that impact climate while enhancing the spatial resolution of projections (see Figure 1). CCAM is used here as the primary model for downscaling selected CMIP6 GCMs over New Zealand. CCAM has been extensively used for downscaling over Australia in CMIP3 (Perkins et al., 2014), CMIP5 (Evans et al., 2021), and CMIP6 (Chapman et al., 2023; Grose et al., 2023) generations of climate projections.

1.1 CMIP6 Downscaling Methodology

The CCAM model, grid configuration, physics settings, and experiment design have been extensively documented in Gibson et al. (2023, 2024a), which the reader is referred to for technical details. A summary table of the main components of the downscaling methodology and model output is provided in Table 1.

The first important step of dynamical downscaling involves choosing which GCMs to downscale from the larger CMIP6 ensemble. Developing climate projections from a range of GCMs is important for capturing model uncertainty in the downscaling. From a computational resource perspective, it is not practical to downscale all GCMs (the CMIP6 ensemble contains over 60 GCMs). From a scientific perspective, this would also not be ideal, since certain GCMs have relatively poor performance for key indicators over the region (Gibson 2016, Gibson et al., 2024b, Ministry for the Environment, 2018) and since the ensemble includes several highly inter-dependent models (e.g. different models that share much of the same model components and source code). Based on available computational resources, it was determined that dynamical downscaling of six GCMs would be feasible. The choice of which GCMs to downscale was based on a balanced consideration of data availability, historical model evaluation, model independence, and future warming rate. As detailed in Table 1, the six final GCMs selected for downscaling were: ACCESS-CM2, EC-Earth3, NorESM2-MM, GFDL-ESM4, AWI-CM-1-1-MR, CNRM-CM6-1.

In terms of historical model performance of CMIP6 GCMs, this was assessed with a comprehensive evaluation of all available models in the CMIP6 ensemble (Gibson et al., 2024a). The evaluation compared and ranked GCMs for the following climatological indices relative to reanalysis (years 1979-2014) over both the New Zealand and a wider South Pacific domain for:

1. The annual mean, seasonal cycle and the interannual standard deviation for mean sea level pressure, surface air temperature and precipitation.
2. The correlation between the Southern Oscillation Index (SOI) and mean sea level pressure, surface air temperature and precipitation.

3. Annual cycle in climatological mean sea level pressure differences used to diagnose regional circulation indices Z1, Z2, M1 (Trenberth 1976), and the SOI.

4. The position and the intensity of the winter and summer Southern Hemisphere zonal wind maxima and high-pressure belt maxima.

In terms of warming rate, the spread of the models selected for downscaling is shown to be a good representation of the spread from the wider CMIP6 ensemble (Figure 2 and Figure 3). This is important to avoid excessively oversampling from the unusually 'hot' or 'cold' models in the ensemble (Hausfather et al., 2022). This can be seen through the perspective of equilibrium climate sensitivity (ECS, Figure 2) which describes the eventual temperature rise associated with doubling CO_2. This can also be seen through a regional perspective, focusing on the rate of temperature increase over the New Zealand region (Figure 3).

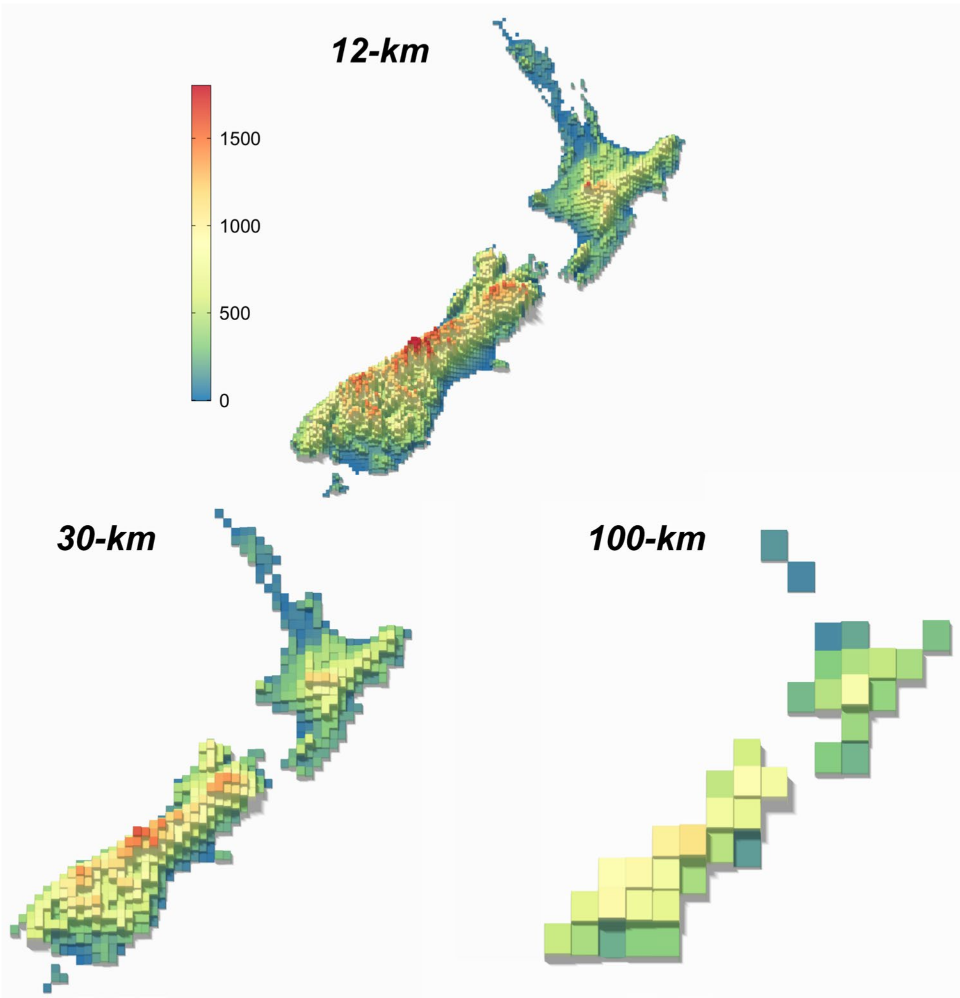

Figure 1: Elevation maps showing the representation of New Zealand at different model resolutions. Shaded colours show elevation in meters above mean sea level. The 12km model resolution (top) is compared to 30km model resolution (similar to that used in CMIP5 downscaling) and to 100km model resolution (typical of a CMIP6 global climate model).

Table 1: Summary of main details of the CMIP6 downscaled methodology. Additional details describing the model output are provided in Table 2 and Table 3. For each GCM, the specific ensemble member downscaled is given in brackets. While not included here, an additional project at NIWA is underway to downscale SSP5-8.5 following the same approach.

Time period (historical)	Years 1960-2014, inclusive
Time period (future period)	Years 2015-2099, inclusive
Scenarios and SSPs downscaled	Historical, SSP1-2.6, SSP2-4.5, SSP3-7.0
Reanalysis and GCMs downscaled	ERA5 (reanalysis) ACCESS-CM2 (r4i1p1f1) NorESM2-MM (r1i1p1f1) EC-Earth3 (r1i1p1f1) GFDL-ESM4 (r1i1p1f1) AWI-CM-1-1-MR (r1i1p1f1) CNRM-CM6-1 (r1i1p1f2)
Model (CCAM) horizontal resolution	Bias corrected resolution over New Zealand: ~5km CCAM model resolution over New Zealand: ~12km CCAM model resolution over South Pacific: ~12-35km
Model (CCAM) vertical resolution	35 vertical levels

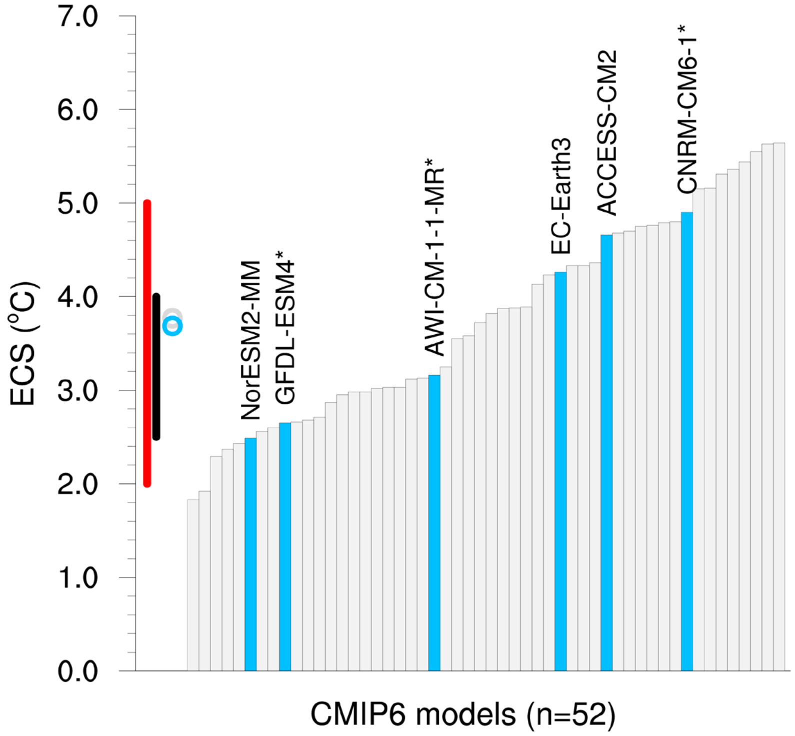

Figure 2: Spread of equilibrium climate sensitivity (ECS) across CMIP6 models (grey bars) alongside those selected for downscaling with CCAM (blue bars). Larger values indicate more warming. The grey circle is the ECS mean of all available CMIP6 models (n=52), the blue circle is the ECS mean of the downscaled CMIP6 models (n=6). The black line represents the IPCC Sixth Assessment Report 'likely range' (ECS between 2.5 and 4°C) and the red line represents the 'very likely range' (ECS between 2 and 5°C). Figure adapted from Gibson et al. (2024a).

Model independence across CMIP6 models was assessed qualitatively based on existing literature and prior knowledge of each model. Models that lack independence include those with obvious institutional dependencies (e.g. different variants of the EC-Earth3 model) as well as sharing of major components between models, such as the same underlying atmospheric model (e.g. ACCESS-CM2 and UKESM1-0-LL). Here, the 6 GCMs chosen for downscaling were all produced by different institutions and have notably different atmospheric models. For the ocean model components, there are some dependencies. Namely, ACCESS-CM2 and GFDL-ESM4 implement different versions of the Modular Ocean Model (MOM) while CNRM-CM6-1 and EC-Earth3 both implement version 3.6 of the Nucleus for European Modelling of the Ocean (NEMO). Importantly, overall, the six chosen models span a wide range of the larger CMIP6 ensemble in terms of temperature, and circulation fields, as quantified in Brunner et al (2020). The selected models also span different 'storylines' for how precipitation is projected to change over New Zealand in different seasons across the wider CMIP6 ensemble (Gibson et al., 2024b).

Another important technical aspect of the downscaling methodology concerns how the input data from the GCM is used to drive CCAM. Given that CCAM is a global model, there is flexibility to drive CCAM from only sea surface temperature (SST) and sea ice concentration (SIC) fields from the GCM (e.g. Gibson et al. 2023, Chapman et al., 2023) or from full atmospheric spectral nudging to the GCM fields (Thatcher and McGregor, 2009). In related climate projections work for CORDEX Australasia, both approaches have been implemented with CCAM and then combined to form a larger downscaled ensemble (Grose et al., 2023). Each approach has advantages and disadvantages, as discussed in more detail in Gibson et al. (2024a). The SST/SIC driven CCAM simulations have a warming rate that is mostly governed by the warming rate over the oceans from the GCM. The 'nudged' simulations follow the GCMs more closely, since the weather patterns (6-hrly input fields) are directly related to those from the GCM. Here, the decision to implement downscaling through three 'SST-driven' GCMs (GFDL-ESM4, AWI-CM-1-1-MR, CNRM-CM6-1) and three 'nudged' GCMs (ACCESS-CM2, EC-Earth3, NorESM2-MM) was in part based on data availability from the CMIP6 ensemble and GCM model performance. In particular, the data requirements for the nudged simulations are much greater and include 6-hrly fields at multiple vertical levels in the atmosphere. This is prohibitive as several GCMs in the CMIP6 ensemble do not provide these fields in the model output. As such, we chose three of the top performing (evaluation criteria described above) GCMs from those that had these full fields available for downscaling with nudging. The performance assessment of the remaining three SST-driven GCMs was based on a reduced set of criteria that targeted different aspects of near-surface air temperature climatology. The reader is referred to Gibson et al. (2024a) for further details.

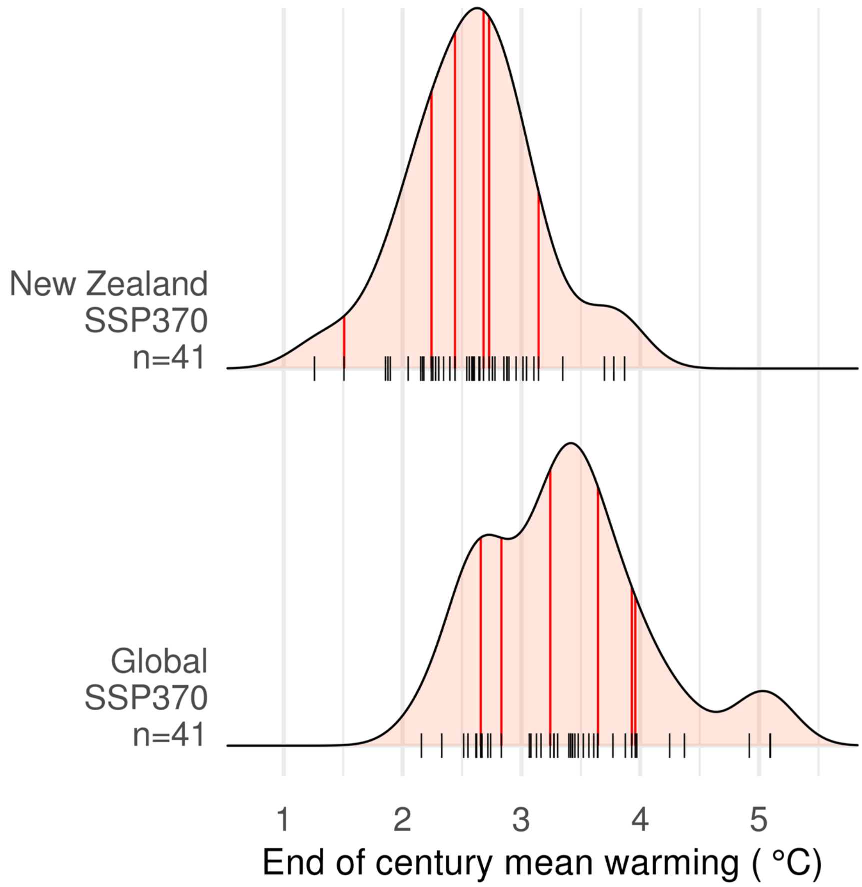

Figure 3: Distribution of CMIP6 models' end-of-century near-surface air temperature warming (years 2070-2100 minus 1970-2000) averaged over the New Zealand region (top) and global domain (bottom) under SSP3-7.0 over both land and ocean grid cells. The small black vertical lines along the x-axis indicate warming from individual CMIP6 models (n=41, based on data availability), thick red vertical lines indicate warming from the CMIP6 models selected for downscaling (n=6).

The final step of the downscaling involved bias correcting and empirical downscaling select variables to a 5-km New Zealand-wide grid. The bias correction was performed using NIWA's Virtual Climate Station Network (VCSN, Tait et al., 2012; Tait and Macara, 2014) as the reference data. The underlying motivation for the bias correction was to reduce CCAM biases over the historical period (including seasonal variability) while closely preserving the climate change signal from CCAM. Only select variables were bias corrected at the daily temporal frequency. These daily variables were: daily maximum and minimum temperature, the daily temperature range, daily accumulated precipitation, potential evapotranspiration (PET), and potential evapotranspiration deficit (PED). A decision was made not to bias correct certain other variables, including near-surface wind speeds, relative humidity and incoming shortwave radiation. This decision was based on the relatively large observational uncertainty for these variables for nationwide daily fields. For consistency the output is still provided on the regridded 5-km resolution for these additional variables. Future work could consider additional approaches to bias correcting these fields for individual sites or regions where confidence can be placed in the observational data used for bias correction.

1.2 Additional Downscaled Models

As described above, CCAM was the primary dynamical model used for downscaling. Other candidate regional models were also investigated, both in terms of historical performance and spread in future projections when downscaling select GCMs. The additional regional models evaluated were the Weather Research and Forecasting Model (WRF, Advanced Research version 4.3) and the Unified Model (UM, version 10.3). While the data from these other regional models are not part of the 'core' CMIP6 downscaled set of simulations (e.g. from which the multi-model mean is computed), they are briefly discussed here.

In a first of its kind for New Zealand, Campbell et al. (2024a) compared multi-decade historical simulations from three regional models (CCAM, WRF, UM) at 12-km resolution over New Zealand. Each regional model was driven by reanalysis, in an 'observational setting'. This setup enables comparisons against observations for evaluation purposes and enables isolation of biases that stem from the regional models themselves (separate from GCM biases). Consistent with studies in other regions, Campbell et al. (2024a) show that there is no overall best performing regional model for New Zealand, with each having various strengths and weaknesses. For example, the tuned WRF configuration showed very good results for precipitation, including extreme events and variability; CCAM on the other hand showed very good results for temperature-related fields and extreme events. When selecting CCAM as the primary regional model for downscaling, these evaluation results alongside other practical considerations were factored in. These included computational performance of CCAM at this resolution, and the established partnership with CSIRO which aided in technical aspects of the downscaling workflow. For New Zealand, another unique aspect of CCAM includes the global stretched grid configuration enabling a more seamless representation of circulation features and storms as they enter the New Zealand region (Gibson et al., 2023).

While not formally part of CMIP6, the New Zealand Earth System Model (NZESM) (Williams et al. 2016) was also downscaled as an additional 7th GCM. The NZESM was developed through the Deep South National Science Challenge, and as part of that project was further downscaled with the UM10.3 (GA7 configuration, Walters et al. 2019) to 12km resolution over New Zealand. This downscaled data is provided in the same format (i.e. with bias correction and regridding, described further below in Section 3) as the downscaled CCAM simulations to facilitate usage and comparisons. Further details of the NZESM downscaled simulations, and comparisons with CCAM will be provided in Gibson et al. (2024).

1.3 Comparisons to CMIP5 Downscaling

Here we provide a brief overview comparing the methodology from NIWA's previous CMIP5 downscaling (utilised in Ministry for the Environment, 2018) with the current CMIP6 downscaling. The CMIP6 downscaling has been driven by updated CMIP6 GCMs and scenarios, different regional models run at higher resolution, and a modified bias correction methodology has been applied. These details are summarised below in Table 2.

Table 2: Summary of how the current CMIP6 downscaling methodology compares to the previous CMIP5 downscaling carried out by NIWA. While not included here an additional project at NIWA is underway to downscale SSP5-8.5 following the same approach.

	CMIP5 downscaling	CMIP6 downscaling
GCMs	6 different CMIP5 GCMs	6 different CMIP6 GCMs, additional comparisons with NZESM
Reanalysis (evaluation run)	ERA-40	ERA5
Scenarios	RCP2.6, RCP4.5, RCP6.0, RCP8.5	SSP1-2.6, SSP2-4.5, SSP3-7.0
Regional model(s)	UM4.5 (HadAM3P/HadRM3P)	CCAM, additional comparisons with UM10.3 and WRF4.3
Downscaling procedure	6 GCMs with initial SST bias correction. HadAM3P run globally. HadRM3P run regionally.	3 GCMs downscaled directly with spectral nudging. 3 GCMs with initial SST/SIC bias correction.
Regional model horizontal resolution	2-step procedure: ~150-km global run then ~30km regional run over NZ domain.	~12km over New Zealand. 1-step procedure with global stretched grid to permit enhanced resolution over wider South Pacific (~12-35km).
Bias correction resolution	Final output bias corrected on 5km grid spanning NZ.	Final output bias corrected on 5km grid spanning NZ.
Bias correction methodology	Semi-empirical approach. Performed on reanalysis-driven evaluation run then applied to different GCMs. Not designed to preserve trends explicitly.	Based on quantile mapping to the VCSN. Different variations of quantile mapping for different variables Performed on a 'per-GCM' basis. Designed to preserve trends.
Computational resources (estimate)	~0.5 million core hours	>12 million core hours

2 Evaluation of downscaled output

Before producing future climate change projections, CCAM was comprehensively evaluated in a historical setting (Gibson et al., 2023; Gibson et al., 2024a; Campbell et al., 2024a, b), which is summarized in this section. The added value of downscaling with CCAM is quantified in Gibson et al. (2024). Added value refers to the reduction in model biases after downscaling. Added value is found for several important variables across most regions and seasons. For climatological mean fields, large improvements were found for the representation of precipitation in high-elevation regions, and for daily maximum and minimum temperatures across wide regions of the country. Added value for extreme event indices, such as annual daily precipitation maximum, annual temperature maximum and minimum, and frost day frequency, also show large and robust improvements. While tropical and ex-tropical cyclones remain challenging to simulate even in state-of-the-art high-resolution models, there is also considerable improvements in how these are captured in CCAM after downscaling, compared to in the GCM output.

Consistent with other studies, regional models do not improve on biases for all variables everywhere. Some important remaining biases in the raw CCAM output were identified and targeted through bias correction. These included a wet bias in the lee of the Southern Alps, a warm bias in maximum temperatures in certain regions, and biases in the seasonal cycle of precipitation in some regions and models. These biases were targeted and substantially reduced through the subsequent bias correction procedure. The reader is referred to the accompanying bias correction report (Campbell et al., 2024b) for further details and guidance on usage and model uncertainty in the bias corrected model output.

3 Guidance on usage, data format, and access

NIWA recommend that stakeholders using these data for climate change risk assessment and adaptation purposes consider and stress-test plans and strategies across a range of SSP scenarios and downscaled models. While this will vary according to application, this includes comparing across the 'low' (e.g. SSP1.2-6), 'medium' (e.g. SSP2-4.5), and 'high' (e.g. SSP3-7.0) emissions scenarios provided. Furthermore, for a given scenario, the range of warming across models can provide practical and useful information around uncertainty (Figure 2 and 3). For example, for a given SSP, the ACCESS-CM2 and CMRM-CM6-1 CCAM downscaled output have larger warming signals than the other downscaled models. Users required to disclose their climate-related financial risks can also utilise these data to represent short, medium and long-term future climate changes for the purpose of scenario analysis, as described in the Aotearoa New Zealand Climate Standard NZCS1.

To accommodate different users, three main downscaled climate projections datasets have been produced and made publicly available. First, the 'core' set comprises GIS-based output displayed through the main web-based portal tool hosted by MfE. Second, daily bias-corrected fields will be provided on a 5-km national grid for key variables, hosted through the MfE Data Store. Third, a larger suite of files for various downscaled variables, from hourly to monthly temporal resolution, spanning both New Zealand and wider South Pacific region, hosted on NIWA's High Performance Computing (HPC) facility. Each of these is described below in more detail.

3.1 'Core' GIS-based data from MfE web portal

The core dataset includes more than 20 climate indicators computed from the downscaled output and produced on a final nationwide 5-km grid (see Table 3). This set of indicators was developed based on discussions with various stakeholders over the last few years about their CMIP5 data needs.

As described above, with the exception of solar radiation, relative humidity, and wind speed-based indicators, these indicators have been computed from bias corrected model output. A detailed description of the bias correction methodology is presented in Campbell et al. (2024b).

Table 3: Summary details of the various climate indicators provided through the web portal hosted by MfE. A cross indicates whether the indicator is provided in annual and seasonal formats.

Climate Indicator	Annual	Seasonal	Units historical	Units change	Additional Details
T	x	x	°C	°C	Daily mean 2m air temperature
TX	x	x	°C	°C	Daily maximum 2m air temperature
TN	x	x	°C	°C	Daily minimum 2m air temperature
DTR	x	x	°C	°C	Daily temperature range
TX25	x	x	days	days	Number of hot days (>25°C)
TX30	x	x	days	days	Number of very hot days (>30°C)
FD	x	x	days	days	Number of frost days (<0°C)
TXx	x		°C	°C	Temperature on hottest day of the year
TNn	x		°C	°C	Temperature on coldest day of the year
GDD5	x		GDD	GDD	Growing degree days (base 5°C) [1] - accumulated number of degrees above 5°C
GDD10	x		GDD	GDD	Growing degree days (base 10°C) [1]
CD18	x		CDD	CDD	Cooling degree days (base 18°C) [2] - accumulated number of degrees above 18°C
HD18	x		HDD	HDD	Heating degree days (base 18°C) [3] - accumulated number of degrees below 18°C
PR	x	x	mm	%	Total rainfall
DD1mm	x	x	days	days	Number of dry days (<1mm)
RR1mm	x	x	days	days	Number of wet days (≥1mm)
RR25mm	x	x	days	days	Number of heavy rainfall days (>25mm)
R99pVAL	x	x	mm	%	Heavy rainfall value (99th percentile)
PEDsrad	x		mm	mm	Potential evapotranspiration deficit Calculated using a water balance model with precipitation and potential evapotranspiration (PET).
sfcWind	x	x	m s^{-1}	%	Average daily 10m wind speed
Wd10	x	x	days	days	Number of days with average wind speed above 10 m s^{-1}
Wd99pVAL	x	x	m s^{-1}	%	Strong winds value (99th percentile)
hurs	x	x	%	%	Average relative humidity
rsds	x	x	W m^{-2}	W m^{-2}	Incoming solar radiation

[1] https://www.stats.govt.nz/indicators/growing-degree-days

[2], [3]. https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Annex_VI.pdf

For each of the climate indicators detailed in Table 3, static change maps and data are provided with the following:

- The average (i.e. multi-model mean) of the six downscaled GCMs.
- Three SSPs (SSP1-2.6, SSP2-4.5 and SSP3-7.0)
- Three future periods (2021-2040, 2041-2060 and 2081-2100)
- Four global warming levels (1.5°C, 2°C, 3°C and 4°C)
- Two historical baselines (1986-2005 and 1995-2014).

The time slices, warming levels and baselines are consistent with those used in the IPCC Working Group 1 Atlas (Regional Information). Additionally, these same change maps and data are also provided on a per-model basis through the MfE Data Store.

As a technical note, it is important to understand what the warming level change maps represent here. Since the downscaled (i.e. CCAM) simulations begin in 1960, it was not possible to compute warming level change maps relative to a pre-industrial base-period from CCAM. As such, the warming level change maps instead display the climate change signal relative to a modern base-period (i.e. optionally 1986-2005 or 1995-2014). However, the future period associated with these change maps is based on when a global warming level is reached utilising data from the host GCM, defined as the 20-year window when the rolling mean reaches the corresponding global warming level relative to the pre-industrial mean (1850-1900), following the IPCC Atlas. For certain scenarios, a particular warming level may not be reached in all models. The multi-model mean for the corresponding warming level is therefore only included if at least four of the six models reach the warming level.

3.2 Daily bias-corrected data from MfE Data Store

For users wanting access to individual (i.e. per-model) bias-corrected 5-km national projections, these daily-resolution data will be hosted through the MfE Data Store. The main details of these data are provided in Table 4 below. These datasets are provided in NetCDF CF compliant file format, with separate files according to scenario, variable, and host model. Potential users of these data could include researchers wanting to compute or investigate additional climate indices from the daily model output, or to input daily climate data into biophysical models such as for assessing the impact of climate change on crop productivity.

3.3 Raw downscaled model output from NIWA

For users wanting access to the raw downscaled model output (i.e. non-bias corrected), these data are accessible through NIWA's HPC. This dataset includes the raw CCAM downscaled model output for several variables on both a national (~12-km) and wider South Pacific (~35-km) domain. The main details are provided in Table 4 below. Potential users of these data could include those wanting to develop bespoke bias correction for a particular application, or researchers wanting to compute or investigate additional climate indices from the model output, among others.

For consistency, files follow the following naming convention:

[variable]_[scenario]_[GCM]_[RCM]_[temporal resolution]_[domain]_[bias correction].nc e.g. tasmax_ssp370_ACCESS-CM2_CCAM_daily_NZ12km_raw.nc

This example file contains daily maximum temperature fields, for scenario SSP3-7.0 (years 2015-2099, daily temporal resolution) for CCAM downscaling the ACCESS-CM2 GCM over the New Zealand domain. The suffix 'raw' indicates that the CCAM model output is provided here without bias correction. Variables closely follow CORDEX CMIP6 naming conventions.

Table 4: Summary details of different datasets provided, additional to the 'core' GIS-based data. All data is provided on a 'per-model' basis spanning both the historical period (years 1960-2014) and various scenarios/SSPs (years 2015-2099).

Dataset and region	Details	Access
NZ domain (daily 5-km, bias corrected output)	National ~5-km grid consistent with VCSN (land-only) at daily temporal resolution, for the following bias-corrected variables: Daily maximum 2m air temperature (tasmax) Daily minimum 2m air temperature (tasmin) Daily accumulated precipitation (pr) Daily Potential Evaportranspiration (PET) Daily Potential Evapotranspiration Deficit (PED) Additionally, spatially regridded ~5-km daily variables (not bias-corrected): Daily mean 10m wind speed (sfcWind) Daily max 10m wind speed (sfcWindmax) Daily mean 2m relative humidity (hurs) Daily mean incoming solar radiation (rsds)	MfE Data Store
NZ domain (raw CCAM output)	National ~12-km grid extended domain (land and ocean), Latitude range (degrees): [52.21°S, 32.86°S] Longitude range (degrees): [164.86°E, 183.96°E] Over 20 CORDEX-defined variables. The CORDEX-CMIP6 CORE[1] variable list is prioritized. Includes 1-hourly, daily, 1-monthly depending on variable.	NIWA HPC
Wider South Pacific domain (raw CCAM output)	Wider South Pacific domain ~35km grid (land and ocean), Latitude range (degrees): [90°S, 5°S] Longitude range (degrees): [110°E, 240°E] The CORDEX-CMIP6 CORE[1] variable list is prioritized. Output is 6-hourly for select variables.	NIWA HPC

1. https://cordex.org/experiment-guidelines/cordex-cmip6/data-request-cordex-cmip6-rcms/

Access to the raw downscaled model output is granted through contacting the NIWA authors of this report through email. Note that due to the large number of files, and file sizes, an account though NeSI is currently (at the time of writing this report) required for accessing this data. The NetCDF file format is commonly used for efficiently storing very large gridded geophysical datasets. Various commonly used modern scripting languages and software can be used to query, analyse and visualize these files, including Python, R, NCL, ArcGIS and others.

4 Summary and Conclusions

This report provides summary information and guidance for users of the CMIP6 downscaled data for Aotearoa New Zealand produced by NIWA. The downscaling methodology is described in detail in this report. This includes how GCMs were selected for downscaling and how the downscaling was performed with CCAM, alongside additional comparisons with other regional models. We also summarize the main methodological differences between these newly updated CMIP6 downscaled projections and the previous CMIP5 downscaled projections.

Model evaluation of the downscaled output from CCAM is described through the perspective of 'added value'. This assesses the biases in the downscaled output relative to the raw GCM output and shows the relative strengths and weaknesses of downscaling. Remaining biases in the downscaled output were then targeted through bias correction, producing a final national product at 5-km resolution for key climate variables at daily temporal resolution. Lastly, guidance is provided on the use and format of the different datasets produced. These include GIS-based change maps and data for key climate indicators, daily bias corrected fields from CCAM, and the raw (i.e. non-bias corrected) CCAM model output.

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6 Glossary of abbreviations and terms

CMIP6	Coupled Model Intercomparison Project Phase 6
IPCC	Intergovernmental Panel on Climate Change
AR6	Sixth Assessment Report (produced by IPCC)
SSP	Shared Socioeconomic Pathway
CORDEX	Coordinated Regional Climate Downscaling Experiment
AMIP	Atmospheric Model Intercomparison Project
CCAM	Conformal Cubic Atmospheric Model
GCM	Global Climate Model
RCM	Regional Climate Model
VCSN	Virtual Climate Station Network
ECS	Equilibrium Climate Sensitivity
SST	Sea surface temperature
SIC	Sea ice concentration
HPC	High-Performance Computing
NeSI	New Zealand eScience Infrastructure
CSIRO	The Commonwealth Scientific and Industrial Research Organisation

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