2025

SCIENCE FOR CONSERVATION 342

The climate and weather of Campbell Island / Motu Ihupuku: historic observations and projected changes

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Department of Conservation
Te Papa Atawhai

Te Kāwanatanga o Aotearoa
New Zealand Government

Cover: Instrumentation at Campbell Island Automatic Weather Station. Picture taken towards the east. Temperature instruments are located within a Stevenson screen (left), while rainfall gauges and solar instruments can be seen in the centre of the picture. Anemometers attached to a 10 m mast are not shown in this photo. *Photograph: Andrew Harper.*

Science for Conservation is a scientific monograph series presenting research funded by the Department of Conservation (DOC). Manuscripts are internally and externally peer reviewed; resulting publications are considered part of the formal international scientific literature.

This publication is available for download from the DOC website. Refer www.doc.govt.nz under *Publications*.

ISSN 1177–9241 (web PDF)
ISBN 978–1–0670480–3–7 (web PDF)

This report was prepared for publication by Te Rōpū Ratonga Auaha, Te Papa Atawhai/Creative Services, Department of Conservation; editing by Nicki Frances and layout by Sarah Elworthy. Publication was approved by Michelle Crowell, Biodiversity and Climate System Manager, Department of Conservation, Christchurch, New Zealand.

Published by Department of Conservation Te Papa Atawhai, PO Box 10420, Wellington 6143, New Zealand.

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The climate and weather of Campbell Island/Motu Ihupuku: historic observations and projected changes

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Abstract

Observed and projected climate change for mainland New Zealand continues to be addressed thoroughly, but there is less information for New Zealand's subantarctic islands. This report investigates previous and future climate change at Campbell Island/Motu Ihupuku. Meteorological observations were available from 1941 to 2023. These show that the annual mean daily temperature has increased by 0.12 ± 0.03°C per decade. The annual mean daily maximum temperature has increased faster than the equivalent minimum temperature. Annual total rainfall has increased by 47 ± 17 mm per decade. Campbell Island's past and future climate change was modelled. The resolution of available climate models is insufficient to include the influence of the island's terrain on the local weather. However, they are suitable for deriving the broadscale changes for the region. These projections show that annual mean daily temperature increases range from 0.70°C (by 2040 under an intermediate greenhouse gas emissions scenario) to 2.29°C (by 2090 under a very high greenhouse gas emissions scenario). They also show annual total rainfall increases ranging from 3% to 14% (under these same scenarios). The projected climate changes may have implications for conservation management on Campbell Island. Areas of interest for future research include managing the threat of heavy rainfall and slips on nesting birds, and determining whether thresholds of heat stress for birds found on Campbell Island might be exceeded.

Keywords: Campbell Island, climate change, weather, subantarctic, conservation management

Macara G, Gibson PB. 2025. The climate and weather of Campbell Island/Motu Ihupuku: historic observations and projected changes. Wellington: Department of Conservation. Science for Conservation 342.

1. Introduction

Climate change threatens New Zealand's unique natural landscapes and nature. Increases in the concentration of greenhouse gases in the atmosphere have contributed to widespread and rapid changes, including warming of the atmosphere, oceans, and land, diminishing of ice and snow, and sea-level rise (IPCC 2021). Climate change is a significant risk that affects every aspect of the Department of Conservation's (DOC's) work (DOC 2023).

There are already comprehensive observations of the effect of climate change in mainland New Zealand (e.g., MfE and Stats NZ 2023), as well as projections for future changes (e.g., MfE 2018). However, there is a lack of such information for New Zealand's subantarctic islands. Information on observed and projected climate change for these islands is necessary to inform DOC's biodiversity impact assessments, and adaptation planning, which will subsequently contribute to climate change resilience.

Campbell Island / Motu Ihupuku is in the southernmost of New Zealand's five groups of subantarctic islands (Fig. 1). It is located approximately 740 km south of Dunedin. The terrain is steep and rugged with a precipitous western coastline, and the island is covered by extensive areas of peat. The land rises to a maximum elevation of 569 m at Mount Honey. Perseverance Harbour cuts into the island's eastern side (Fig. 2).

Campbell Island is located within New Zealand's subantarctic World Heritage site, and is home to endemic plants, rare birds and marine mammals (DOC 2022). Six species of albatross (*Diomedeidae*) are found there, including toroa, the Southern royal albatross (*Diomedea epomophora*) (DOC 2022). McGlone et al. (2007) provides a detailed description of the island's history, environment and vegetation cover.

Campbell Island is situated north of the latitudes usually traversed by the centres of southern ocean cyclonic storms, and south of the paths usually taken by anticyclones of subtropical latitudes (de Lisle 1964). As a result, strong and persistent westerly winds prevail over the area. It is frequently cloudy over Campbell Island, due to the relatively high humidity of local airmasses and the orographic lifting as they pass over the land.

There is an 83-year history of meteorological observations at Campbell Island. Regular observations began in 1941 at the head of Tucker Cove (Fig. 2), when the New Zealand government established a coastwatching station to report on the presence of enemy shipping (de Lisle 1964). At the end of the Second World War, this station was established permanently under the control of the New Zealand Meteorological Service, and provided regular reports of surface and upper air meteorological conditions (de Lisle 1964). A shelter to protect the instruments from rain and sunshine (a Stevenson screen) was used from at least 1 March 1946 onwards (New Zealand Meteorological Office 1946).

In 1957, the meteorological instruments were shifted to a site located approximately one kilometre to the southeast on a spur in Perseverance Harbour, approximately 600 m south of the summit of Beeman Hill (Fig. 2). The same location is used presently (Figs. 3 and 4); automatic instrumentation was deployed from 1991 onwards, when an automatic weather station was established alongside the preexisting manual observation site.

This report provides:

- a detailed assessment of contemporary climate and weather characteristics on Campbell Island – and any changes in climate that have already occurred – from recorded observations, and
- projected changes to the climate for the area encompassing Campbell Island over the twenty-first century.

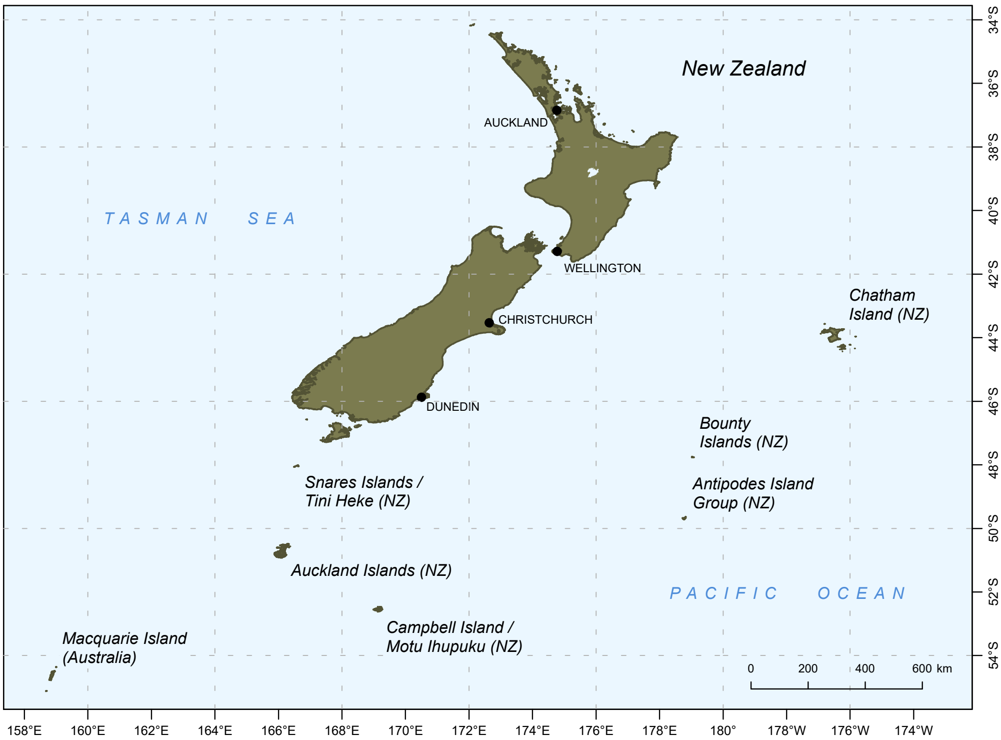

Figure 1. Location of Campbell Island/Motu Ihupuku. *Map: Geraldine Moore, DOC GIS.*

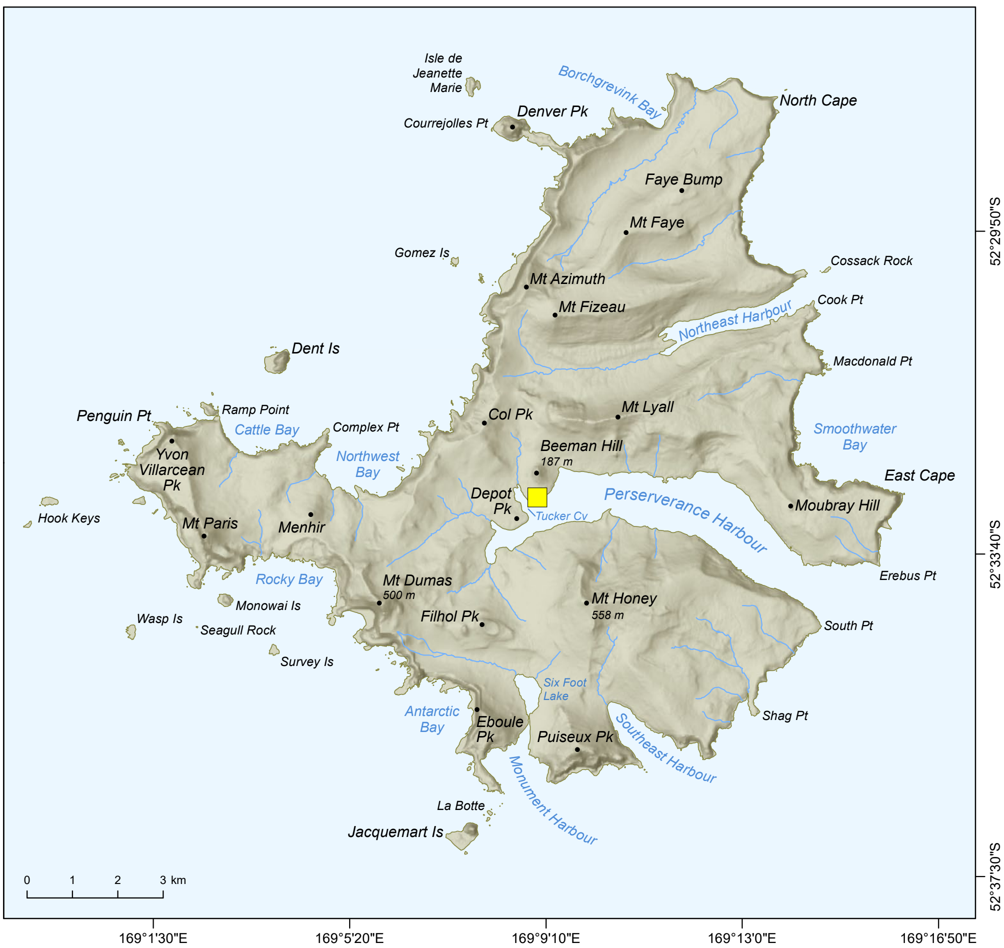

Figure 2. Detailed map of Campbell Island/Motu Ihupuku. The yellow square represents the current location of the weather and climate monitoring station. *Map: Geraldine Moore, DOC GIS.*

Figure 3. Campbell Island Automatic Weather Station looking towards the north. The instruments are located on the relatively flat land in the centre of the picture. The conical Beeman Hill is a prominent feature to the north of the site. *Photo: Andrew Harper.*

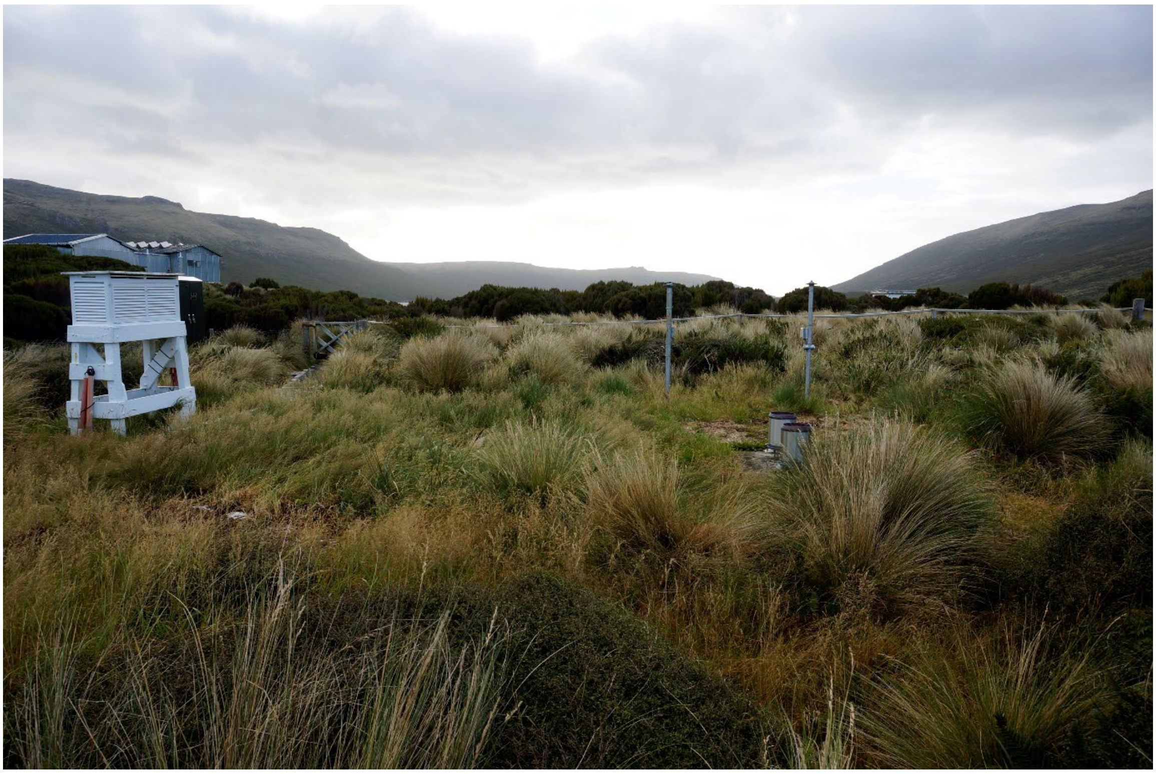

Figure 4. Instrumentation at Campbell Island Automatic Weather Station. Picture taken towards the east. Temperature instruments are located within a Stevenson screen (left), while rainfall gauges and solar instruments can be seen in the centre of the picture. Anemometers attached to a 10 m mast are not shown in this photo. *Photo: Andrew Harper.*

2. Methods

2.1 Compiling historic climate observations

All historic data for Campbell Island were extracted from New Zealand's National Climate Database (CliDB). This database is maintained by the National Institute of Water and Atmospheric Research (NIWA). Daily temperature, rainfall, and sunshine data are available from two distinct weather stations in CliDB:

- Campbell Island Aws (network number K94402, automatically collected data available from 1991 to 2024)
- Campbell Is (network number K94400, manually collected data available from 1941 to 1995).

The temperature and rainfall data were combined to create a single timeseries of daily data from 1941 to 2023. Campbell Island Aws data were used for the period 1991–1995 where data availability from the two stations overlapped. Mean daily temperatures for these historic data were calculated as the average of the corresponding daily maximum and minimum temperatures. Manually collected sunshine data were available from 1941 to 1995 via the Campbell Is station, with no sunshine data collected at the automatic Campbell Island Aws station. These sunshine data were measured using a Campbell–Stokes instrument.

2.2 Data homogeneity

This assessment considered two techniques described in the World Meteorological Organization guidelines for data homogenisation (Aguilar et al. 2003): metadata analysis and quality control, and the use of a reference time series. Sensor and site histories were used to inform a statistical assessment of data homogeneity at Campbell Island. These histories were obtained from New Zealand's National Climate database, CliFlo (https://cliflo.niwa.co.nz/) and the station documentation held at NIWA (see https://sims.niwa.co.nz/sims/).

2.2.1 Metadata analysis and quality control

Inbuilt data-checking systems are in place to safeguard the quality of data in CliDB. As observed values are transferred into permanent data tables in CliDB from temporary input tables, they are automatically inspected for errors. Gross errors occurring when values fall outside of prescribed extreme thresholds are not transferred into CliDB. These are flagged for further investigation. Potential errors defined through statistical distributions (e.g., beyond the 1st or 99th percentiles for that place or time) are uploaded to the data archive but appear on automated daily error reports until they are confirmed or corrected by a trained technician. Systematic audits of the climate database data tables are conducted from time to time to identify, report and resolve any residual data quality issues.

Additional data quality checks were performed manually during this study using the quality control diagnostic plots generated by the *Climpact* software. This included simple sense checks, for example: ensuring the highest daily maximum temperatures were observed in Austral summer, and that the lowest daily minimum temperatures were observed in Austral winter. Daily temperature ranges were also checked to ensure no values were less than zero, i.e., if the daily maximum temperature was recorded as lower than the daily minimum temperature. We found several instances where the daily temperature range was less than zero. This suggests previous human error in reading or transcribing the temperature data; these daily data were excluded from further analyses.

2.2.2 Comparison of overlapping data

Overlapping observations for the period 1991–1995 enabled a comparison of temperature and rainfall data measured at the two distinct Campbell Island stations. According to the sensor and site histories in the CliFlo database, the Campbell Island Aws (network number K94402) sensors were all installed within the existing enclosure of the Campbell Is manual climate station (network number K94400).

We found slight discrepancies when comparing the data. The mean daily maximum temperature for the Campbell Island Aws station was 0.06°C lower. The mean daily minimum temperature was 0.10°C higher. The average daily rainfall total (where daily rainfall > 0 mm) was 0.15 mm higher. These discrepancies are very small. This shows that there is a good match between datasets. Inhomogeneity between the two distinct Campbell Island stations is unlikely.

2.2.3 Statistical homogeneity tests

The penalised maximal *t* test was used within the *RHtestsV4* software package (Wang and Feng, 2013) to perform statistical homogeneity tests on the data. Descriptions of the relevant methods implemented in this package are found in Wang (2008a, 2008b), Wang et al. (2010) and Vincent et al. (2012). Note that such tests may detect shifts which cannot be traced to events documented in a station's history. These could simply be due to natural variation rather than artificial changes (Wang and Feng 2013). The results of such tests should therefore be interpreted with caution.

Raw, unadjusted temperature data were assessed. The precipitation data were log-transformed before assessment, as precipitation data is typically non-Gaussian (Wang and Feng 2013). The nominal confidence level of the *RHtestsV4* software was set to its default value of 95% for all applications of the penalised maximal *t* test in this report.

No shifts were detected in the monthly mean daily minimum temperatures. For the monthly mean daily maximum temperatures, a statistically significant shift of -0.49°C was detected in November 1990 (Fig. 5). Sensor and site histories from the CliFlo database indicate that the Campbell Island Aws station opened on 1 November 1990, and its temperature and humidity instruments shared a large screen with the manual instruments from this time. These metadata suggest a valid inhomogeneity, so the raw daily maximum temperatures prior to November 1990 were adjusted by -0.49°C.

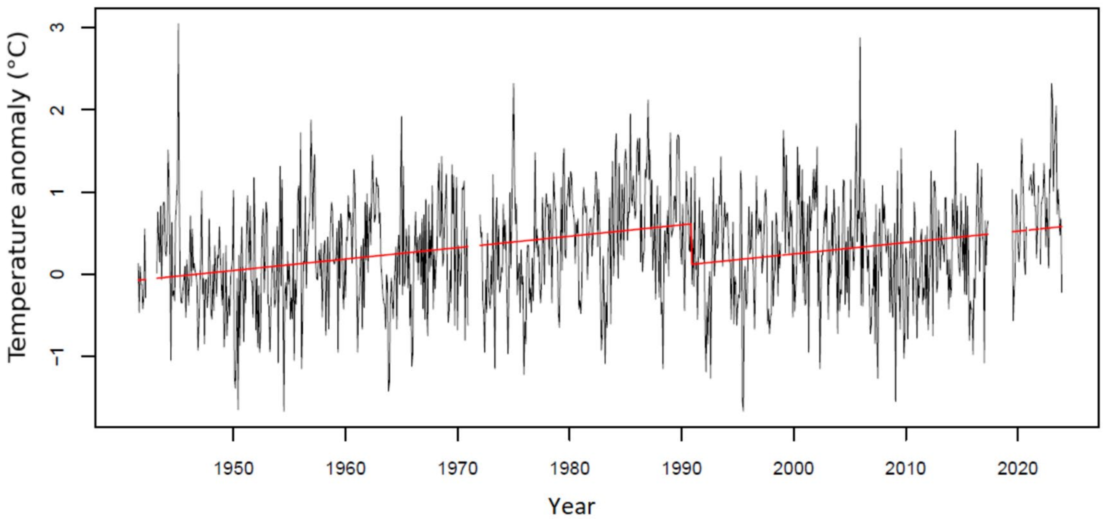

Figure 5. Monthly mean daily maximum temperature anomaly series and regression fit for Campbell Island (1941–2023).

Macquarie Island is situated approximately 720 km southwest of Campbell Island. There is no land mass between the two islands, and they are situated at a similar latitude within the 'Furious Fifties'. Strong westerly airflows prevail throughout the year, and the two islands are exposed to similar weather patterns. Macquarie Island monthly rainfall (BoM 2024) was therefore used as a reference time series to analyse the homogeneity of rainfall observations at Campbell Island. This is a suitable reference series because the rainfall data there have been assessed as homogenous (Jovanovic et al. 2012). Three statistically significant mean shifts were detected with reference to observations at Macquarie Island (Fig. 6) between 1948–2023:

- a 34.0% decrease from May 2011 to January 2016
- a 0.97% decrease from October 1976 to April 2011, and
- a 13.4% increase from July 1941 to September 1976.

Sensor and site histories from the CliFlo database show that the rainfall sensor failed in late-June 2011, with a switchover made to a backup instrument. This timing is broadly consistent with the mean shift identified from May 2011. The station's rain gauge was replaced in January 2012, but it is unclear how long the backup instrument was in use. There is no relevant metadata corresponding to the remaining two mean shifts. In lieu of comprehensive metadata support, the mean shifts from Macquarie Island's homogenous rainfall data suggest the inhomogeneities are valid. Raw daily rainfall data at Campbell Island were therefore adjusted according to these mean shifts, e.g., daily rainfall data from May 2011 to January 2016 were increased by 34.0%.

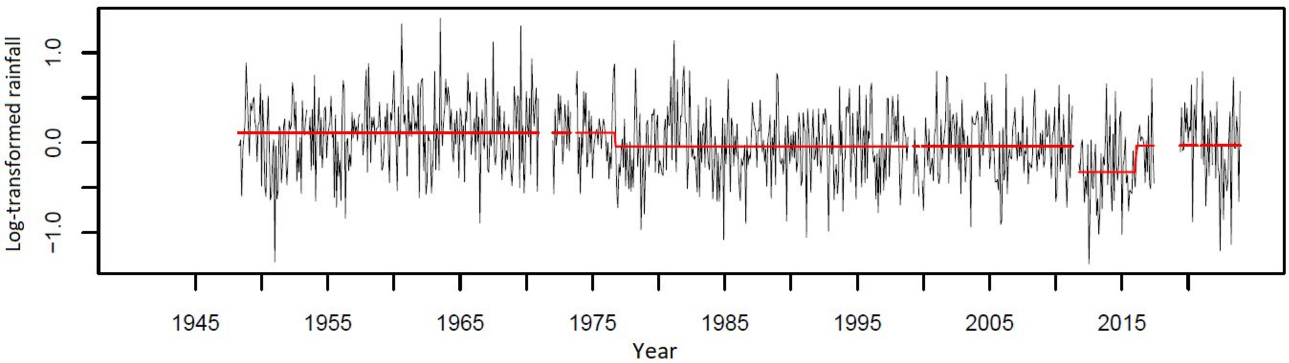

Figure 6. Log-transformed monthly rainfall totals: Campbell Island minus Macquarie Island (black line) (1948–2023). The mean difference between Campbell Island and Macquarie Island is shown by the red line.

2.3 Trend analysis in historic climate observations

The *Climpact* software was used to calculate measures of weather and climate ('indices') and understand trends in historic climate data. *Climpact* permits a maximum of three missing days in any month and a maximum of 15 missing days in any year. If any of these thresholds are exceeded, then the monthly or annual indices are not calculated. For Campbell Island, this meant most annual indices were not calculated for the period 2017–2021, as well as 1941.

The Sen's slope approach was used to estimate linear trends, with a confidence level of 95% applied. Sen's slope is a nonparametric estimate of slope, and is insensitive to outliers (Theil 1950; Sen 1968). This means it provides a more robust estimate of trends in the data than a least-squares estimate.

It is useful to define a baseline of conditions likely to be experienced at a given location, and this can be used to compare with any observed or modelled trends of change. The 1961–1990 period was used as a 30-year average benchmark (the 'climate normal'), as this baseline is recommended by the World Meteorological Organization for historical comparison and climate change monitoring (WMO 2023).

2.4 Climate projections

Climate projections for Campbell Island were generated using greenhouse gas emission scenarios called Shared Socioeconomic Pathways (SSPs; see box for more details). The projections are generated using a suite of global climate model data, generated during the sixth phase of the Coupled Model Inter-comparison Project (CMIP6).

Two scenarios were chosen: an intermediate emissions scenario, SSP2–4.5, and a very high emissions scenario, SSP5–8.5. This is broadly consistent with the approach of New Zealand's National Climate Change Risk Assessment, where moderate (RCP4.5) and high (RCP8.5) pathways for future atmospheric greenhouse gas concentrations were used (MfE 2020).

Five indices representing temperature, rainfall and wind were selected for this assessment (Table 1). These indices were calculated at annual, summer (December, January and February) and winter (June, July and August) timescales. All available CMIP6 model outputs were considered. These are stored on the New Zealand eScience Infrastructure (NeSI) High Performance Computing resource under the project 'niwa02916'. Different CMIP6 models were used for different indices. For example, approximately 20 available models provide daily maximum and minimum air temperatures, while approximately 40 available models provide mean air temperature. Note that the particular models used for a given index are kept the same across the SSP2–4.5 and SSP5–8.5 scenarios for consistency.

Ensemble average values (i.e., the average of all available model projections) were calculated for each index. The 10th and 90th percentile values of all model data were also calculated for each index. These percentile calculations provide insight into the variability (and therefore uncertainty) of projections associated with the global climate models.

Future changes were calculated for the mid century (2040, averaged over the period 2031–2050) and the late century (2090, averaged over the period 2080–2099). The historic baseline used to calculate future changes was 1995 (averaged over the period 1986–2005). These time periods are consistent with previous climate change assessments published by NIWA (e.g., Macara et al. 2021).

Table 1. Climate projection indices selected from the global climate models for this study.

INDICES	DESCRIPTION
Mean daily temperature	Near-surface (2 m elevation) average of the daily mean air temperature (°C). Daily mean is the average from a model's sub-daily timesteps. These timesteps vary between each model, but the temporal resolution is at least hourly, if not sub-hourly.
Mean daily maximum temperature	Near-surface (2 m elevation) monthly average of the daily maximum air temperature (°C).
Mean daily minimum temperature	Near-surface (2 m elevation) monthly average of the daily minimum air temperature (°C).
Total precipitation	Rainfall, calculated as the monthly average of the daily precipitation rate (mm/day).
Eastward wind	Near-surface (10 m elevation) monthly average of the eastward component of wind speed (m/sec). Also known as the zonal wind, which is the prevailing component of wind observed at Campbell Island.

The Shared Socioeconomic Pathways emissions scenarios

Assessing possible changes for our future climate due to human activity is challenging because climate projections depend strongly on estimates of future greenhouse gas concentrations. In turn, those concentrations depend on future global greenhouse gas emissions and these are driven by factors such as: economic activity, population changes, technological advances, and policies for mitigation and sustainable resource use. This uncertainty has been dealt with by the Intergovernmental Panel on Climate Change (IPCC) through the consideration of 'scenarios' that describe concentrations of greenhouse gases in the atmosphere. The wide range of scenarios is associated with possible economic, political and social developments during the twenty-first century.

In the IPCC Sixth Assessment Report, some of these scenarios are called the Shared Socioeconomic Pathways (SSPs). This is a new range of pathways compared to those defined during earlier IPCC reporting. SSP emissions scenarios cover the range of possible future development of anthropogenic drivers of climate change (IPCC 2021).

The SSP emissions scenarios start in 2015. Their names are abbreviated to SSP1–1.9, SSP1–2.6, SSP2–4.5, SSP3–7.0 and SSP5–8.5, in the order of increasing greenhouse gas emissions scenarios. The scenarios represent the outcomes of a range of twenty-first-century climate policies. The following definition of each scenario is adapted from IPCC (2021).

- SSP1–1.9 and SSP1–2.6 are scenarios with very low and low greenhouse gas emissions, with carbon dioxide (CO_2) emissions declining to net zero around or after 2050, followed by varying levels of net negative CO_2 emissions.
- SSP2–4.5 is an intermediate greenhouse gas emissions scenario, with CO_2 emissions remaining around current levels until the middle of the century.
- SSP3–7.0 and SSP5–8.5 are high and very high greenhouse gas emissions scenarios, with CO_2 emissions that roughly double from current levels by 2100 and 2050, respectively.

In this study, we consider the results from scenarios SSP2–4.5 and SSP5–8.5.

2.5 Limitations and caveats

As with any modelling exercise, there are limitations on the results and use of the data. The following should be considered when using this report.

Global climate models are based on a coarse-resolution grid, which ensures the size of the computation and outputs are manageable. Raw CMIP6 global models were used based on extracting data from the closest available grid cell to Campbell Island.

While the model resolution has typically increased from CMIP5 to CMIP6, the average global model resolution is still around 100–150 km in CMIP6. This means Campbell Island is too small to be recognised as a land point in any of the CMIP6 models used for this report. Therefore, the projections should be interpreted to represent the broad conditions surrounding the island over the water. Any way in which the physical presence of the island influences the local temperature, precipitation and winds cannot be captured by the CMIP6 models used in this study. This means that the projections should only be viewed as broadscale changes to the region.

All available CMIP6 models were used in the analysis to enable a robust estimate of uncertainty in the projections. Subsets of models were not selected based on historical performance and historical performance was not analysed here.

Also, the process of compiling and homogenising observational data contains a degree of subjectivity. This is due to factors such as incompleteness of metadata and the emphasis placed on objective versus subjective information (Jovanovic et al. 2012). To minimise the effect of subjective decisions, data were only adjusted when points to change were identified by objective statistical tests. A lack of proximate records is another limitation when homogenising data from geographically isolated sites (Jovanovic et al. 2012), as is the case for Campbell Island.

Although there are some limitations and caveats in the approach used here, considerable effort has been made to generate historic and climate change projection data for this area, and to ensure their plausibility. Thus, the data provide a good basis for understanding both observed and projected climate change at Campbell Island, and may be used to inform risk assessments and adaptation plans.

3. Observed climate and weather

This section provides an assessment of contemporary climate and weather characteristics in Campbell Island – and any changes in climate that have already occurred – from recorded observations.

3.1 Temperature

Both daily and annual temperature variations are relatively small at Campbell Island (Fig. 7). This suppressed variation reflects the island's small size, the moderating influence of the surrounding sea, and its location within the zone of strong and persistent westerly winds.

July is the coolest month, with a mean daily temperature of 4.9°C, mean daily maximum temperature of 6.9°C, and a mean daily minimum temperature of 2.9°C. January is the warmest month, with a mean daily temperature of 9.5°C. The mean daily maximum temperature in January is 12.0°C, whilst the mean daily minimum temperature is 6.9°C.

The lowest temperature on record is -8.0°C, recorded in July 2011. The highest temperature on record is 21.2°C, recorded in January 1995 and February 2023. The daily maximum temperature reached at least 20°C on Campbell Island four times: in January 1965, January 1986, January 1995, and February 2023.

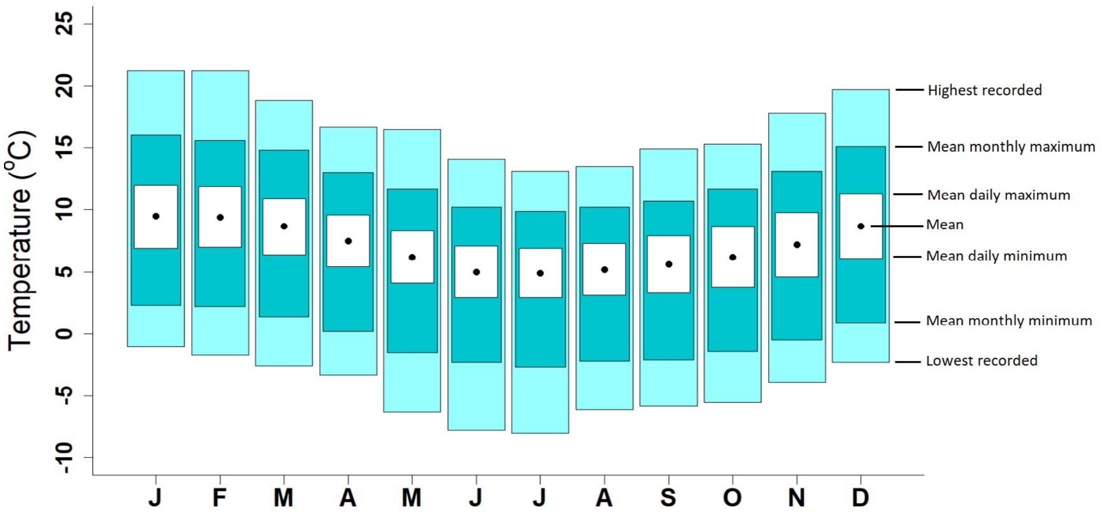

Figure 7. Monthly variation in air temperatures at Campbell Island (1941–2023). See Appendix for detailed data on monthly temperature variation.

Over the 83-year period of records at Campbell Island, statistically significant trends have emerged in several temperature indices.

- The annual mean daily temperature for the climate normal used in this study (the 1961–1990 observations) was 7.0°C. This has increased at a rate of 0.12 ± 0.03°C per decade (Fig. 8).
- The annual mean daily maximum temperature for the climate normal period was 9.4°C. This has increased at a rate of 0.14 ± 0.04°C per decade (Fig. 9).
- The annual mean daily minimum temperature for the climate normal period was 4.6°C. This has increased at a rate of 0.11 ± 0.03°C per decade (Fig. 10).
- The annual number of cold days – meaning the daily minimum temperature was less than the 10th percentile daily minimum temperature for 1961–1990 – decreased at a rate of 1.5 days per decade (Fig. 11).
- The annual number of warm days – meaning the daily maximum temperature was greater than the 90th percentile daily maximum temperature for 1961–1990 – increased at a rate of 5.6 days per decade (Fig. 12).

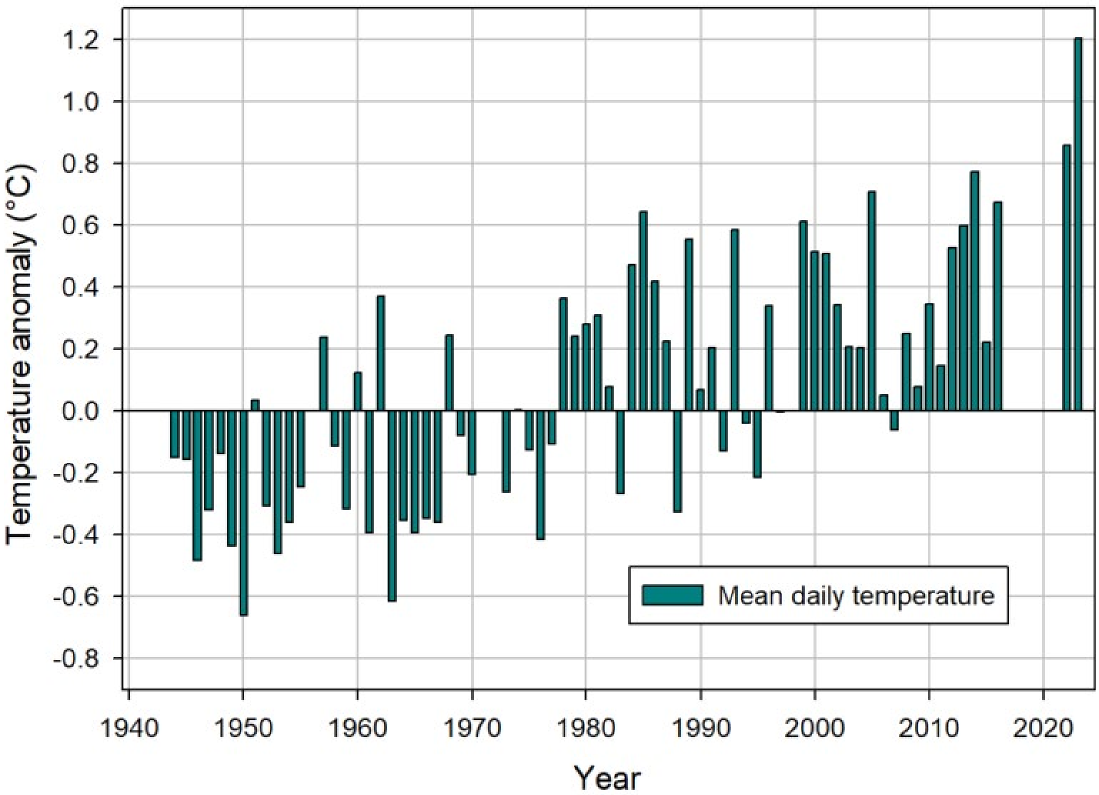

Figure 8. Annual mean daily temperature at Campbell Island (1941–2023) presented as an anomaly from the 1961–1990 period (climate normal for this study).

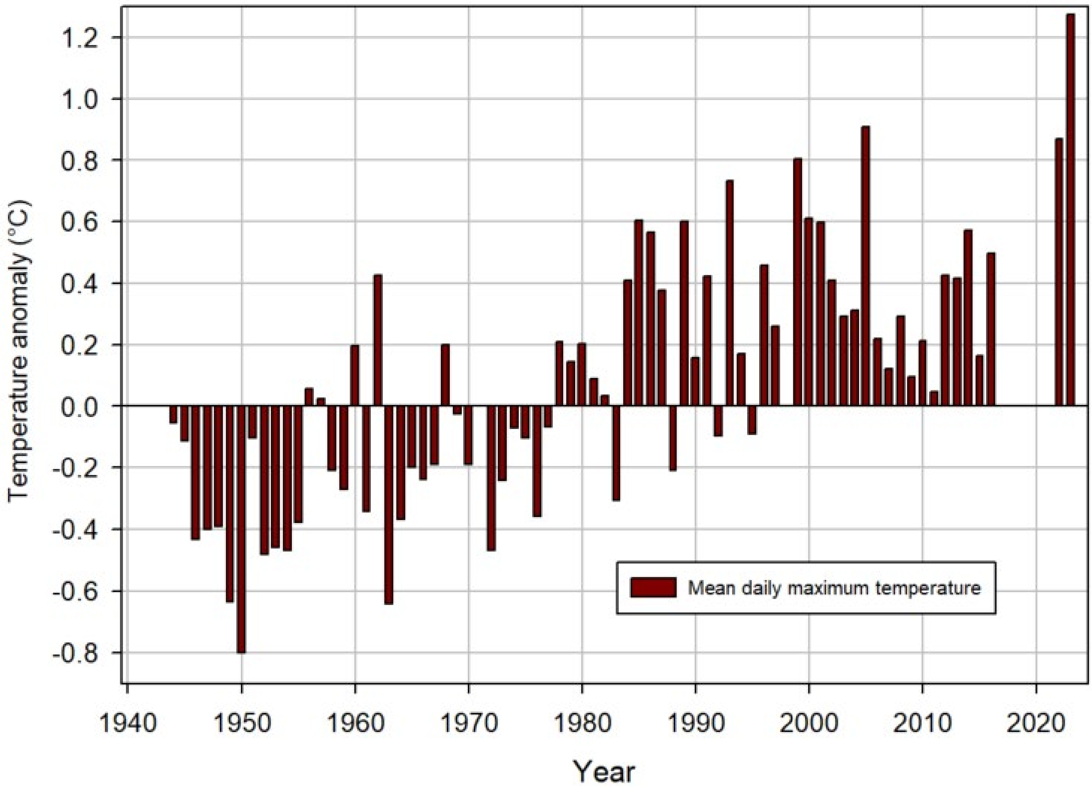

Figure 9. Annual mean daily maximum temperature at Campbell Island (1941–2023) presented as an anomaly from the 1961–1990 climate normal period.

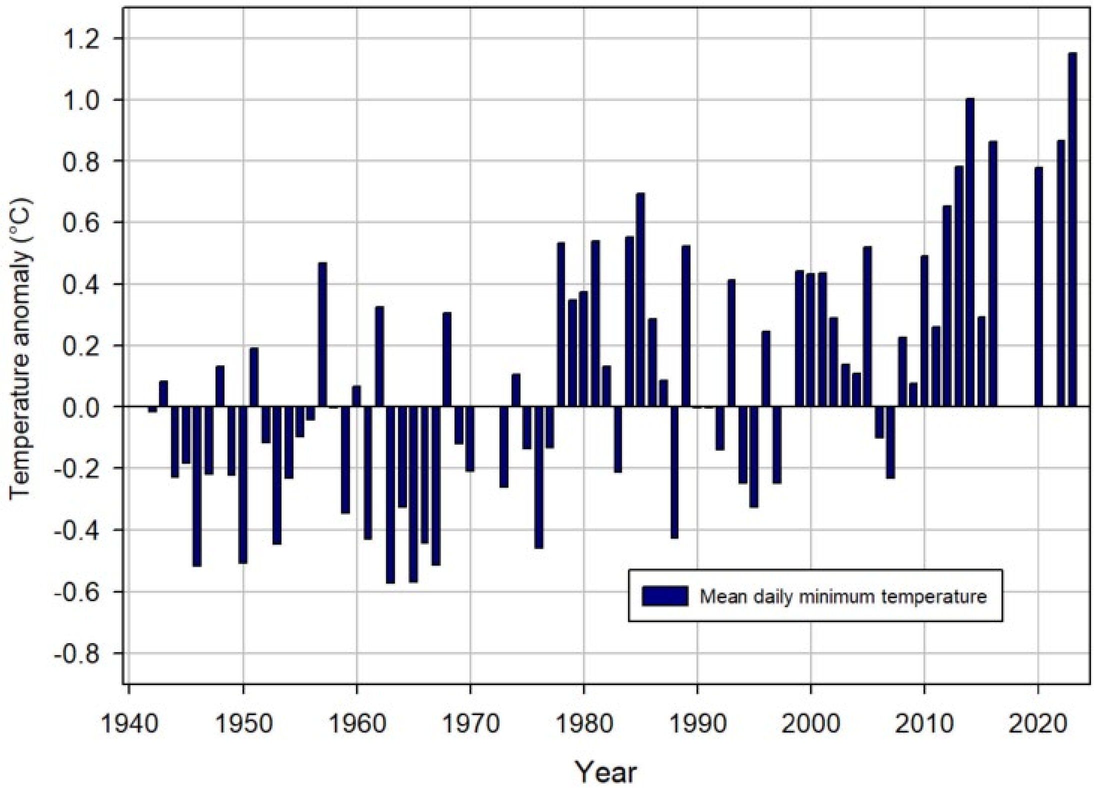

Figure 10. Annual mean daily minimum temperature at Campbell Island (1941–2023) presented as an anomaly from the 1961–1990 climate normal period.

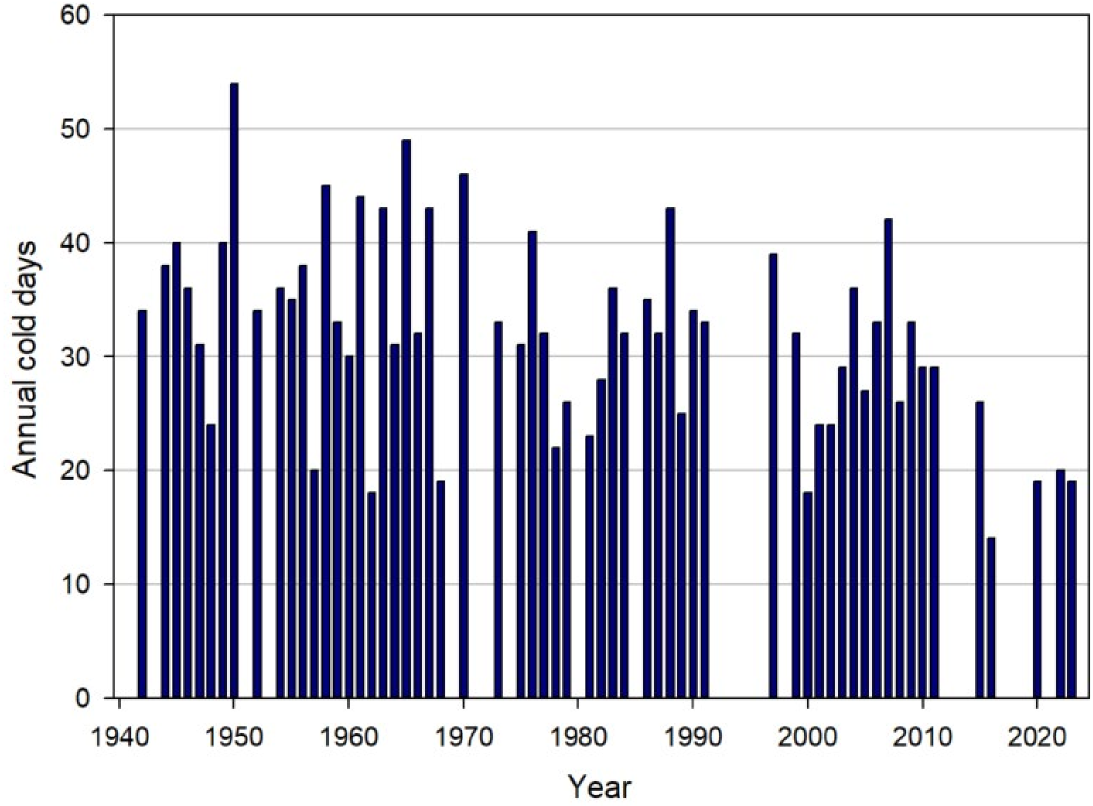

Figure 11. Annual number of cold days for Campbell Island (1941–2023). Cold days are defined as days where the daily minimum temperature is lower than the 10th percentile daily minimum temperature for the period 1961–1990.

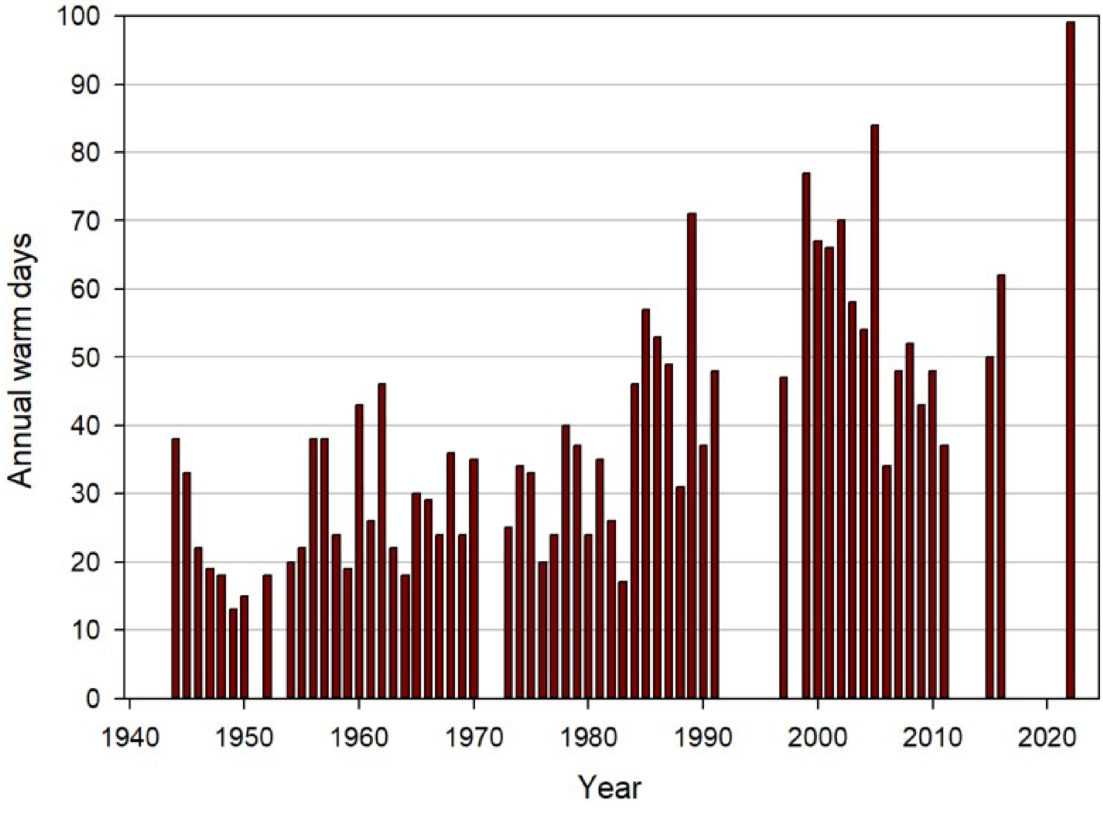

Figure 12. Annual number of warm days for Campbell Island (1941–2023). Warm days are defined as days where the daily maximum temperature is higher than the 90th percentile daily maximum temperature for the period 1961–1990.

3.2 Rainfall

Rainfall occurs throughout the year in Campbell Island (Fig. 13). The average of the monthly rainfall totals observed across all years is between 98 mm (the average for February) and 123 mm (the average for May). Across all available data, the average annual rainfall total is 1,194 mm. The driest month on record was July 1941, with 20 mm of rain. The wettest month on record was June 2023, with 244 mm of rain. From 1941–2023, Campbell Island's annual total rainfall has increased at a rate of approximately 47 ± 17 mm per decade, although most of the increase appears to have occurred from the early 1970s (Fig. 14). The rate of increase in annual total rainfall from 1970–2023 was 79 ± 27 mm per decade.

Several other rainfall indices were calculated. These provide additional insights of the rainfall characteristics of Campbell Island.

- The most rainfall occurring in a single day for each year of observation was noted. The average of these for 1941–2023 is 41 mm (Fig. 15).
- The maximum number of consecutive dry days in each year was calculated. A dry day is recorded when the daily rainfall total is less than 1 mm. The average for 1941–2023 is eight days per year. The highest number of consecutive dry days on record is 14 days, which occurred in three different years. The lowest number of consecutive dry days on record is four days, which occurred in two different years (Fig. 16).
- The maximum number of consecutive wet days in each year was calculated. A wet day is recorded when the daily rainfall total is at least 1 mm. The average for 1941–2023 is 17 days per year. The highest number is 36 days, which occurred in 1993. The lowest is nine days in 1983 (Fig. 17).
- The number of days in each year when precipitation is less than or equal to 10 mm was noted. The average is 27.9 days for the climate normal period used in this study (the 1961–1990 observations). From 1941–2023, this increased at a statistically significant rate of 2.2 ± 0.7 days per decade.
- We divided the annual total precipitation by the number of wet days for each year to give the average daily rainfall on wet days for each year. The average for the climate normal period is 5.3 mm/day. From 1941–2023, this increased at a statistically significant rate of 0.14 ± 0.04 mm/day per decade.

The wettest day on record at Campbell Island was 107 mm on 22 May 1982. This contributed to a three-day rainfall total of 161 mm from 21–23 May 1982, which is 38 mm higher than the average monthly total rainfall for May (123 mm). The following description from Graeme Taylor (Principal Science Advisor, DOC) highlights some of the notable implications of this exceptional rainfall:

> "I was not there at the time but there were records about it in the station logs. The rain was torrential and caused massive slips all over the island. These were still obvious on Mount Honey across from the base in 1984 and ran from the high points down to sea level. A huge slip came down from Col Ridge (separates Northwest Bay from Tucker Cove) and damaged buildings in the old Tucker Cove camp. Slips must have taken out a lot of nesting albatrosses on various parts of the island that year. There was so much debris washed down that apparently Perseverance Harbour was covered in floating tussocks and peat. The old Garden Cove hut got washed into the harbour intact and when the debris thinned out after a few tides the Met [New Zealand Meteorological Service] crew launched their small boat and towed it back to shore."
> *(G. Taylor, pers. comm., 28 March 2023.)*

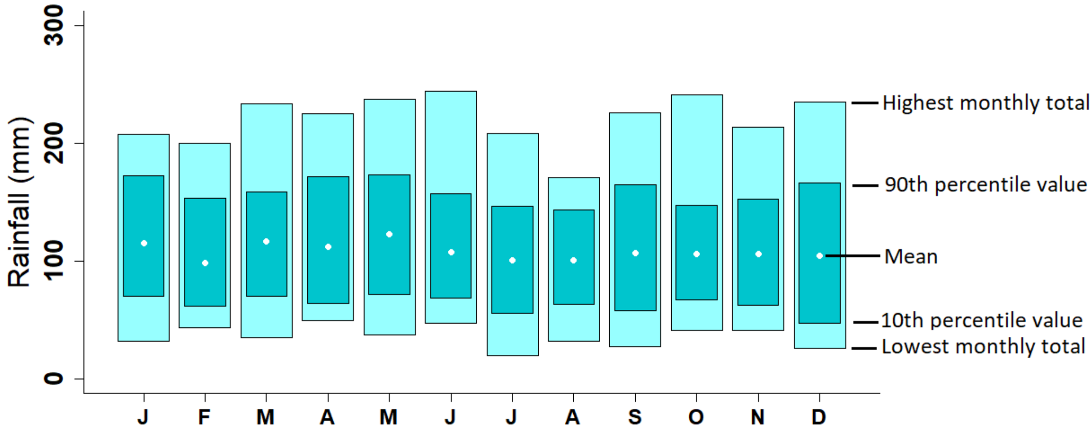

Figure 13. Monthly variation of rainfall for Campbell Island (1941–2023). See Appendix for detailed data on monthly rainfall variation.

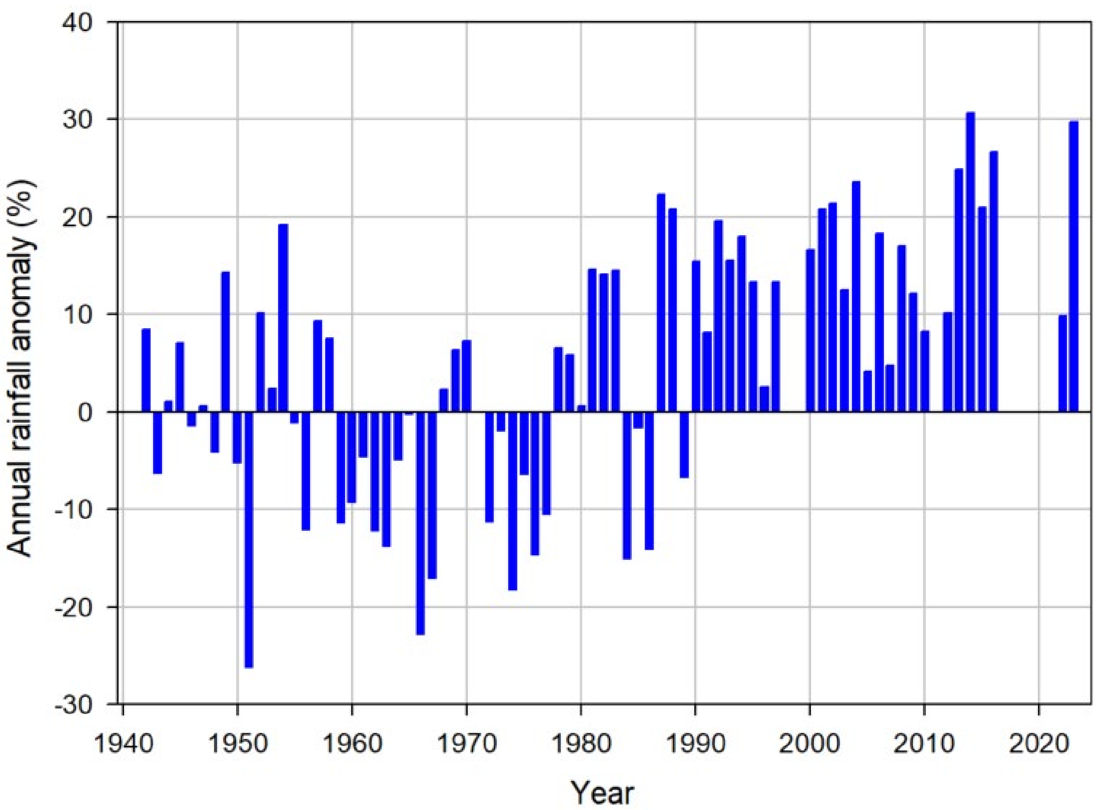

Figure 14. Annual total precipitation for Cambell Island (1941–2023) as a percentage anomaly from the 1961–1990 annual average.

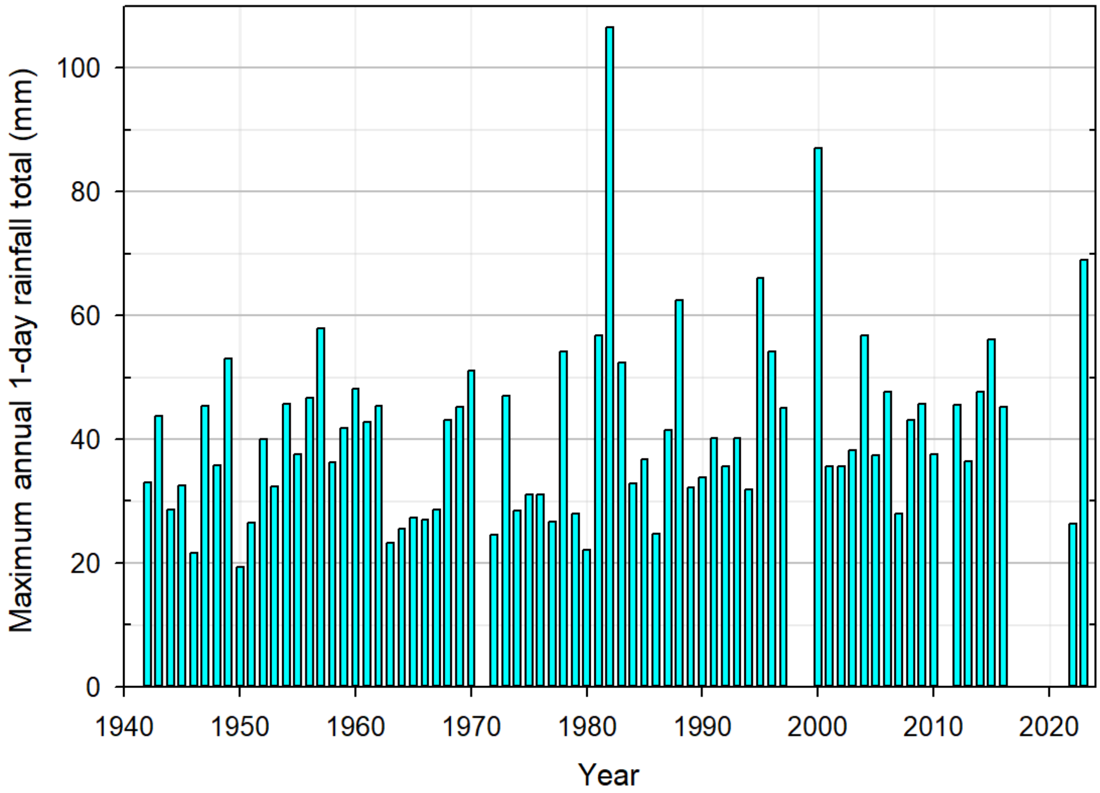

Figure 15. Maximum rainfall in one day for each year on Campbell Island (1941–2023).

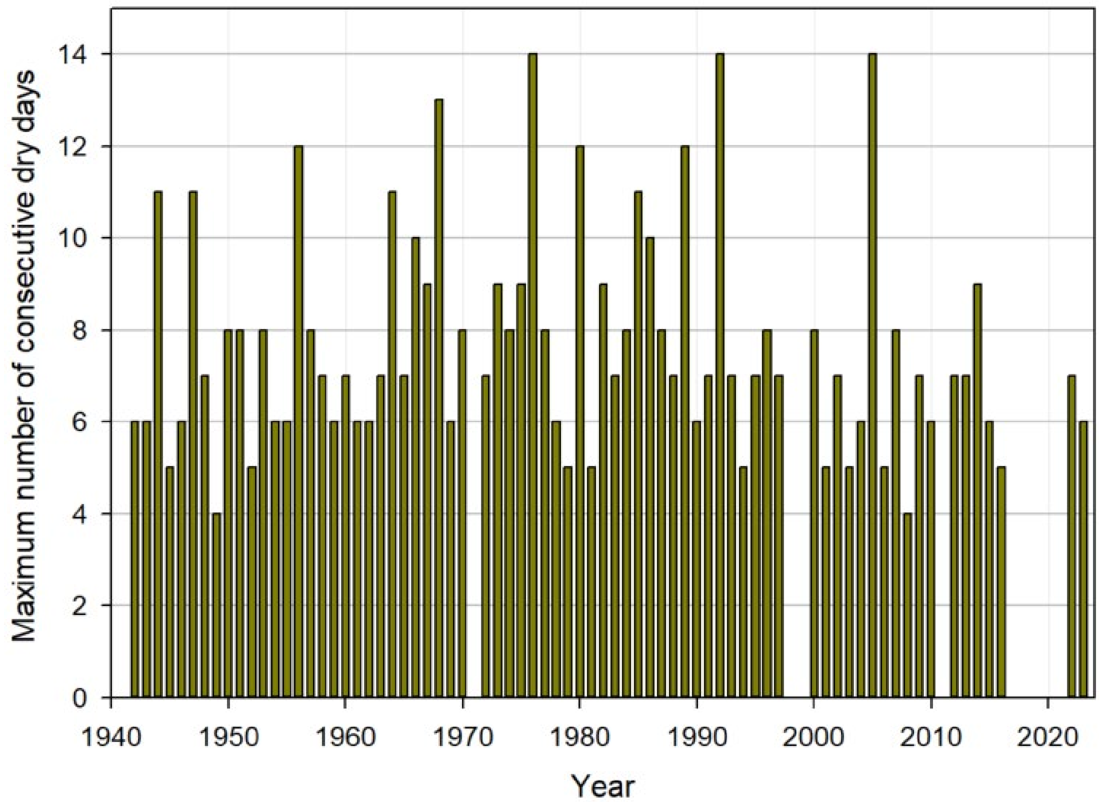

Figure 16. Maximum number of consecutive dry days per year on Campbell Island (1941–2023).

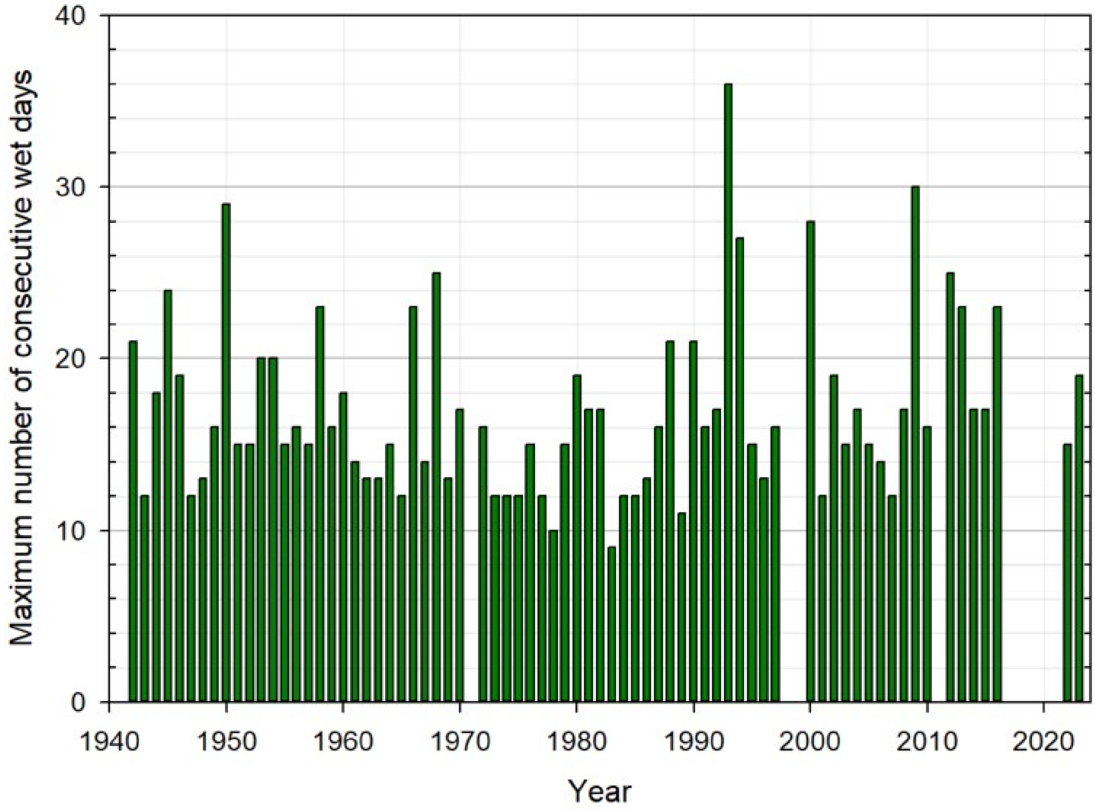

Figure 17. Maximum number of consecutive wet days per year on Campbell Island (1941–2023).

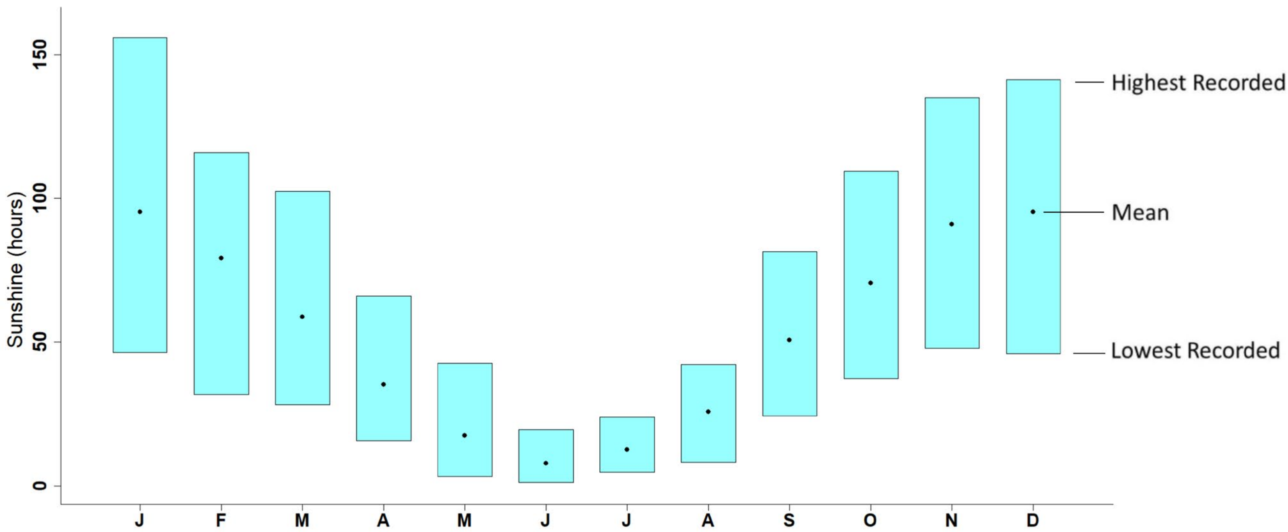

Figure 18. Monthly variation of sunshine for Campbell Island (1941–1995). See Appendix for detailed data on monthly sunshine variation.

3.3 Sunshine

Cloudiness increases considerably to the south of New Zealand. Campbell Island increases its own cloudiness through the orographic lift of moist airmasses over its elevated terrain (de Lisle 1964). Overcast conditions are frequently observed over the island, although clear skies and good visibility do occur in the right atmospheric conditions (typically requiring high atmospheric pressure and a dry airmass overhead). The average annual total of sunshine in Campbell Island is 639 hours. For context, Invercargill averages 1,834 hours of sunshine per year, while Christchurch averages 2,141 hours of sunshine per year (Macara 2018).

The monthly mean, maximum and minimum recorded sunshine hours for Campbell Island are shown in Fig. 18. As expected for a mid-latitude location, sunshine hours are higher in the summer months and lower in the winter months, due to the seasonal variability of daylight hours at the latitude of Campbell Island.

December and January are the equal sunniest months at Campbell Island, with an average of 95 hours of sunshine. The fewest sunshine hours are typically recorded in June, with an average monthly total of eight hours of sunshine and a minimum total of 1.3 hours (June 1992). Campbell Island's sunniest month of 156 sunshine hours occurred in January 1972.

4. Climate change projections

This section describes projected changes to the climate for the area encompassing Campbell Island over the twenty-first century.

4.1 Temperature

Modelled historic (1950–2014) and future (2015–2099) annual, summer and winter temperatures under the scenarios SSP2–4.5 (intermediate emissions) and SSP5–8.5 (very high emissions) were generated for Campbell Island. The projected mean daily temperature, the mean daily maximum temperature, and the mean daily minimum temperature are shown in Fig. 19. Table 2 summarises the projected changes by 2040 (2031–2050) and 2090 (2080–2099) compared to 1995 (1986–2005). Temperatures are projected to increase under both scenarios, with greater increases under the SSP5–8.5 scenario.

Table 2. Projected temperature changes (°C) for Campbell Island relative to 1995.

		2040		2090	
		SSP2–4.5	SSP5–8.5	SSP2–4.5	SSP5–8.5
Changes in mean daily temperature	Annual	+ 0.70	+ 0.79	+ 1.36	+ 2.29
	Summer	+ 0.67	+ 0.73	+ 1.32	+ 2.18
	Winter	+ 0.74	+ 0.84	+ 1.38	+ 2.42
Changes in mean daily maximum temperature	Annual	+ 0.67	+ 0.74	+ 1.33	+ 2.34
	Summer	+ 0.59	+ 0.64	+ 1.25	+ 2.21
	Winter	+ 0.73	+ 0.81	+ 1.38	+ 2.49
Changes in mean daily minimum temperature	Annual	+ 0.60	+ 0.69	+ 1.28	+ 2.28
	Summer	+ 0.56	+ 0.62	+ 1.22	+ 2.16
	Winter	+ 0.64	+ 0.75	+ 1.31	+ 2.40

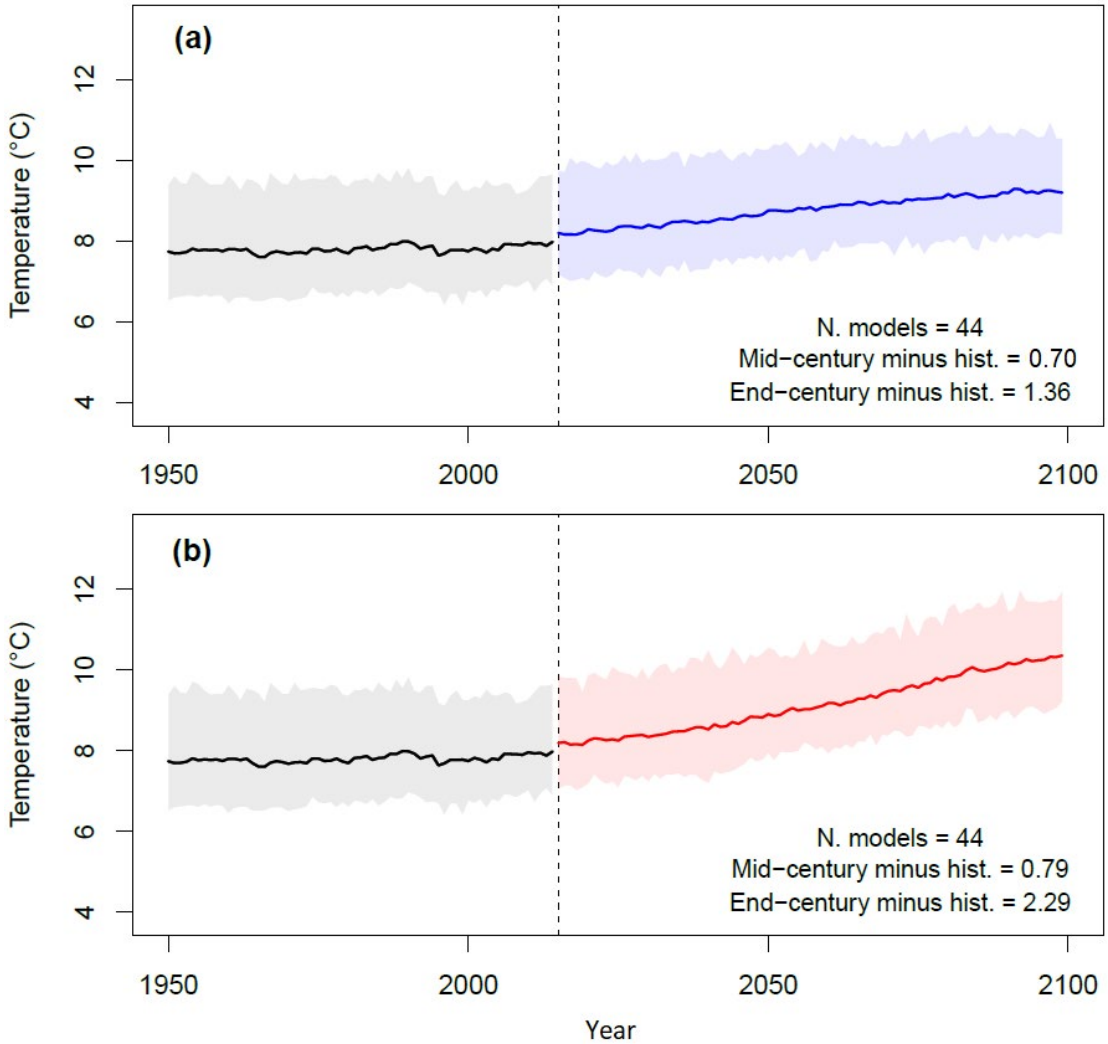

Figure 19. Modelled historic and future annual mean daily temperature for: (a) the SSP2–4.5 scenario, and (b) the SSP5–8.5 scenario. The historic period covers 1950–2014. The scenario-based projections begin in 2015 (indicated by the vertical dashed line). Solid lines represent the ensemble average, with the number of contributing models indicated by 'N. models'. Highlighted areas represent the 10th to 90th percentiles. Changes by 2040 (mid-century) and 2090 (end-century) are calculated relative to 1995.

4.2 Annual and seasonal rainfall

Modelled historic (1950–2014) and future (2015–2099) total annual rainfall under scenarios SSP2–4.5 (intermediate emissions) and SSP5–8.5 (very high emissions) are shown in Fig. 20. For the modelled historic period, the average annual total rainfall is 2.99 mm/day (equivalent to 1,092 mm per year). Summer and winter projections were also generated, and these are summarised in Table 3.

Rainfall is projected to increase under both scenarios, with greater increases under SSP5–8.5. Projected increases in rainfall are higher in winter than in summer.

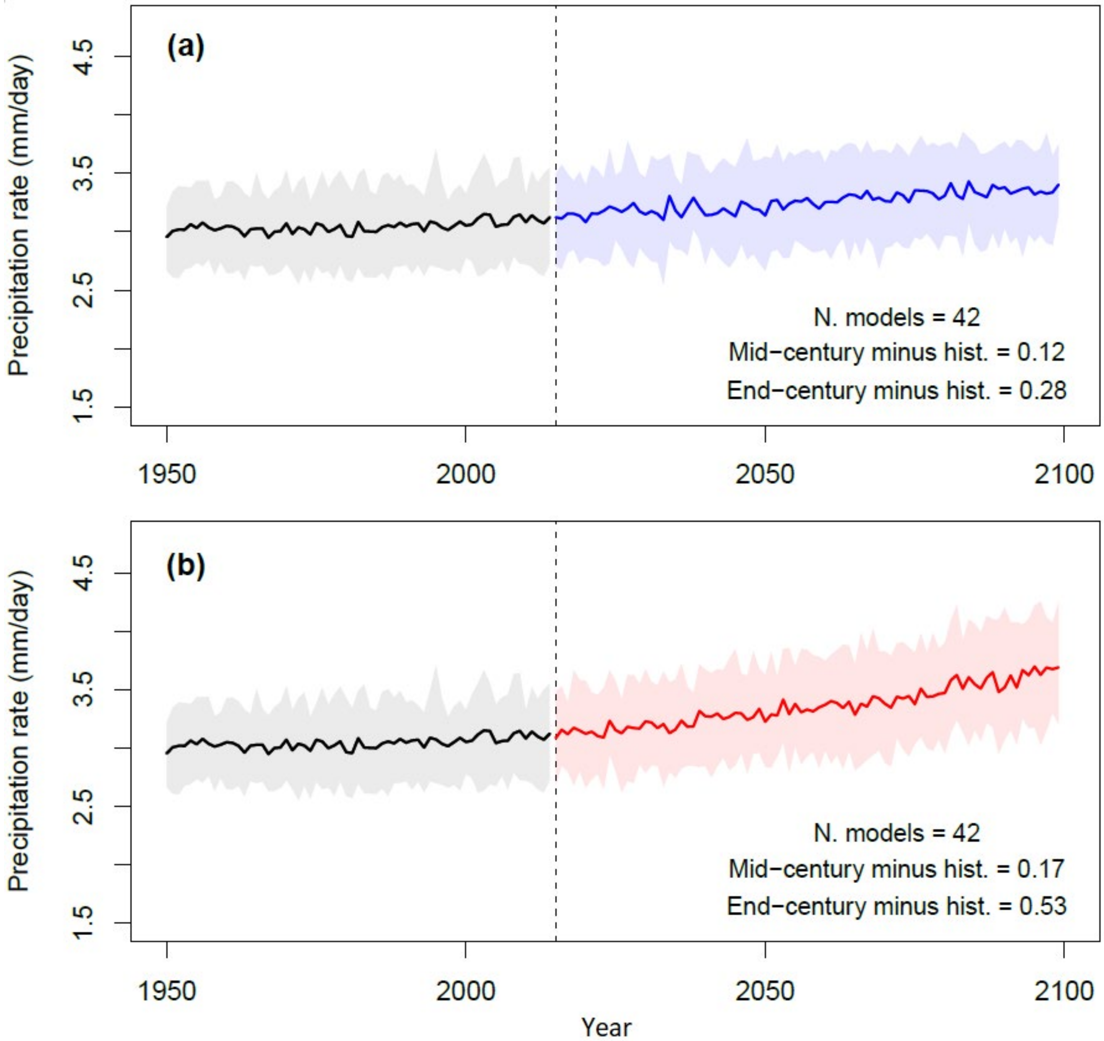

Figure 20. Modelled historic and future annual rainfall on Campbell Island (1950–2100) calculated as the average daily precipitation rate (mm per day) for (a) the SSP2–4.5 scenario, and (b) the SSP5–8.5 scenario. The historic period covers 1950–2014. The scenario-based projections begin in 2015 (indicated by the vertical dashed line). Solid lines represent the ensemble average, with the number of contributing models indicated by 'N. models'. Highlighted areas represent the 10th to 90th percentiles. Changes by 2040 (mid-century) and 2090 (end-century) are calculated relative to 1995.

Table 3. Projected rainfall changes (mm/day) for Campbell Island relative to 1995. The projected changes are also shown as a percentage.

		2040		2090	
		SSP2–4.5	SSP5–8.5	SSP2–4.5	SSP5–8.5
Total rainfall changes	Annual	+ 0.12 (3%)	+ 0.17 (4%)	+ 0.28 (7%)	+ 0.53 (14%)
	Summer	+ 0.06 (2%)	+ 0.14 (4%)	+ 0.21 (5%)	+ 0.34 (9%)
	Winter	+ 0.15 (4%)	+ 0.24 (6%)	+ 0.36 (10%)	+ 0.75 (21%)

4.3 Wind

Modelled historic (1950–2014) and future (2015–2099) zonal (eastward) wind under scenarios SSP2–4.5 and SSP5–8.5 are shown in Fig. 21. Summer and winter projections were also generated. These are summarised in Table 4. Zonal wind is projected to increase under both scenarios, with greatest increases by 2090 under scenario SSP5–8.5.

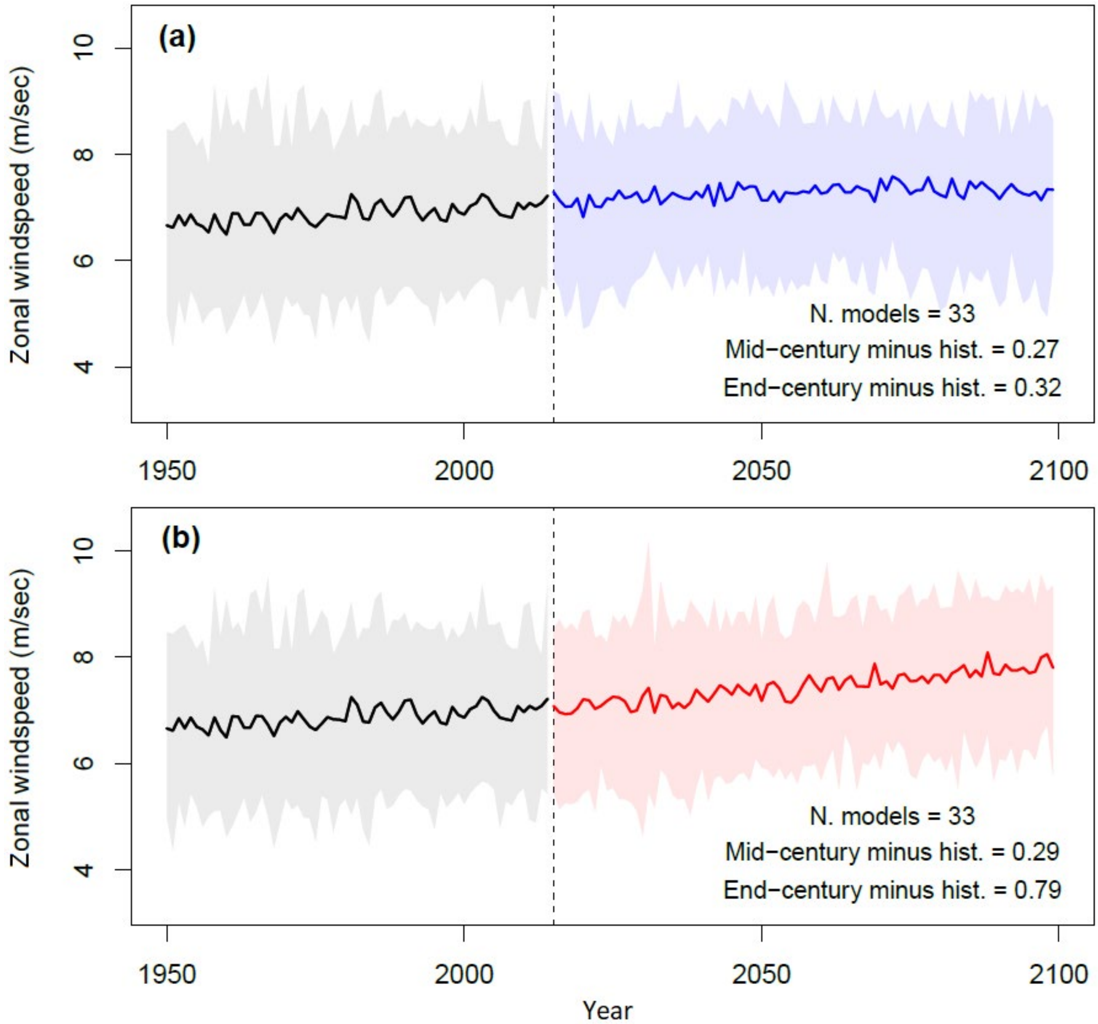

Figure 21. Modelled historic and future annual zonal (eastward) wind for (a) the SSP2–4.5 scenario, and (b) the SSP5–8.5 scenario. The historic period covers 1950–2014. The projections begin in 2015 (indicated by the vertical dashed line). Solid lines represent the ensemble average, with the number of contributing models indicated by 'N. models'. Highlighted areas represent the 10th to 90th percentiles. Changes by 2040 (mid-century) and 2090 (end-century) are calculated relative to 1995.

Table 4. Projected eastward wind changes (m/sec) for Campbell Island relative to 1995.

		2040		2090	
		SSP2–4.5	SSP5–8.5	SSP2–4.5	SSP5–8.5
Zonal wind changes	Annual	+ 0.27	+ 0.29	+ 0.32	+ 0.79
	Summer	+ 0.29	+ 0.33	+ 0.37	+ 0.55
	Winter	+ 0.21	+ 0.19	+ 0.29	+ 0.97

5. Discussion

5.1 Historic observations

The annual mean daily temperature at Campbell Island has increased at a rate of 0.12 ± 0.03°C per decade. This is marginally higher than the rate of increase observed from 1909 to 2022 over New Zealand's mainland: 1.11 ± 0.24°C per century, or 0.11°C per decade on average (NIWA 2023).

The rate of increase in annual mean daily maximum (0.14 ± 0.04°C per decade) and mean daily minimum (0.11 ± 0.03°C per decade) temperature at Campbell Island is higher than that observed at Macquarie Island. At Macquarie Island, the annual mean daily maximum and minimum rate of temperature increase is 0.08 ± 0.06°C per decade and 0.07 ± 0.06°C per decade, respectively (Jovanovic et al. 2012). The discrepancy between the rates of change at each island may be partly due to the different observation period assessed. Rates of temperature change at Macquarie Island were calculated for the period 1948–2011. Meanwhile, Campbell Island's three warmest years on record have each occurred after 2011, which likely contributes to a larger overall rate of change compared to Macquarie Island. Both locations observed a faster rate of increase in maximum temperature compared to minimum temperature.

Annual total rainfall has increased at a rate of 47 ± 17 mm per decade. This is equivalent to an increase in annual total rainfall of 390 mm over the 83 years of observations, which is 33% of the average annual rainfall over the entire period. The rate of increase in rainfall is higher than observed at Macquarie Island, which is 30 ± 18 mm per decade (Jovanovic et al. 2012). Again, the difference in observation periods may be contributing to this discrepancy, as Campbell Island's four wettest years on record each occurred after 2011. Elevated rates of increase in annual average rainfall compared to the overall average are observed since the early 1970s at both Campbell Island (Fig. 14) and Macquarie Island (Jovanovic et al. 2012). The increase in annual rainfall in recent decades may be related to the positive trend of the Southern Annular Mode (SAM, a ring of climate variability circling the South Pole and extending to New Zealand), as a positive SAM is associated with increased storm activity over the Southern Ocean (NIWA 2024a).

Campbell Island has experienced an increase in the annual average rainfall recorded per wet day. There is also an increase in the annual number of days with at least 10 mm of rain. This suggests that the increase in annual rainfall may be driven by wetter days (i.e., rainfall events becoming heavier), which was also apparent at Macquarie Island (Jovanovic et al. 2012).

The lower sunshine hours recorded in the winter months likely reflects the lower position of the sun in the sky at this time of year, as opposed to signalling an increase in cloudiness during those times – although increased cloudiness during winter may also be a contributing factor. This is particularly relevant because of elevated terrain north of the climate station site (clearly seen in Fig. 3). This elevated terrain obscures the sun from reaching the site at certain times of the day, reducing the total sunshine hours possible compared to if the horizon was unobstructed. Sunshine data were only available at Campbell Island from 1941–1995. An improved understanding of contemporary and future sunshine at Campbell Island could be achieved by installing an electronic Kipp & Zonen sunshine recorder. These instruments are more sensitive than a Campbell–Stokes instrument (Srinivasan et al. 2019). They would therefore be more suitable for the measurement of sunshine duration at Campbell Island.

5.2 Future projections

Air temperatures are projected to increase in all indices and scenarios presented in this report. For mean daily temperatures, slightly higher increases are projected for winter compared to summer, according to the ensemble mean. A qualitative examination of mainland New Zealand projections show a similar feature of seasonal projected change for some coastal and southern parts of New Zealand, including Invercargill and Stewart Island/Rakiura (NIWA 2024b). The opposite is true for inland areas of mainland New Zealand (i.e., higher increases in summer mean daily temperatures compared to winter), where maritime climate characteristics are less pronounced. The variability of projected annual mean daily temperature between individual models, as indicated by the 10th to 90th percentile range (Fig. 19), is approximately 2.5°C. Both the 10th and 90th percentiles increase relative to the historic period across both SSP2–4.5 and SSP5–8.5 scenarios, which indicates consistency across all models in the projected increase in future temperatures.

Annual, summer and winter rainfall are projected to increase at Campbell Island. Greater increases are projected for winter compared to summer. This matches the pattern of change projected for southern and western parts of the South Island (NIWA 2024b). Inter-model variability indicates that the direction of change for summer (both scenarios) and winter (SSP2–4.5) is not consistent across all models. This is an important caveat when interpreting the ensemble mean projections. This caveat is not limited to the present study area, as uncertainty in the sign of long-term changes in precipitation over the New Zealand mainland is well documented (e.g., MfE 2018; Gibson et al. 2024). There is a consistent projected increase in winter rainfall across all models by the end of the twenty-first century under SSP5–8.5.

Changes to extreme rainfall are an important consideration for Campbell Island, particularly considering the observed effects of historic extreme rainfall, including slips and water-transported debris. Changes to extreme rainfall at Campbell Island were not assessed specifically using the climate projections in this report, although this may be possible in future using higher spatial resolution (downscaled) outputs from the CMIP6 global climate models. A warmer atmosphere can store more water vapour; increasing temperatures from climate change will likely contribute to increased intensity and severity of extreme rainfall events.

The frequency and intensity of very extreme precipitation events (defined as events with a recurrence interval of two years or more) are projected to increase throughout New Zealand. Percentage increases per degree of warming range from 5% for five-day duration events to 14% for one-hour duration events (MfE 2018). Whilst these data were calculated for mainland New Zealand, the underlying concept of increases to very extreme precipitation is applicable to Campbell Island.

Zonal (eastward) winds are projected to increase in Campbell Island, with generally greater increases in summer compared to winter. This may indicate a continuation of the contemporary trend of more positive than negative phases in the Southern Annular Mode (SAM), which is associated with increased windiness over the Southern Ocean (NIWA 2024a).

5.3 Comparison of historic observations and modelled data

The spatial resolution of the CMIP6 global climate models is too coarse to recognise Campbell Island as a land point. This means any topographic influence on the local weather and climate regime cannot be captured by the CMIP6 models used in this study. This limitation means a comprehensive quantitative assessment of the climate model performance for the study area was not warranted. Nevertheless, a simple comparison of the modelled historic period with observations is justified to provide further context for the model projections.

The modelled historic annual mean daily temperature is 7.8°C, which is higher than the observed value of 7.0°C. The modelled annual mean daily maximum temperature is 8.5°C, whereas the observed value is 9.3°C. The modelled annual mean daily minimum temperature (7.0°C) is considerably higher than the observed value (4.7°C). The supressed diurnal variation observed in the modelled historic data is consistent with the coarse spatial resolution of the model. This coarse resolution results in an inability to capture the terrestrial influence of daily temperature regimes on Campbell Island. The modelled historic annual average rainfall is 1,092 mm, which is 102 mm less than the observed value of 1,194 mm. This discrepancy is expected given the orographic influence on airmasses passing over Campbell Island.

Projected increases to mean daily temperature by 2090 under scenarios SSP2–4.5 and SSP5–8.5 are equivalent to a rate of 0.14°C and 0.24°C per decade, respectively. These exceed the rate of increase in Campbell Island's historical record (0.12 ± 0.03°C per decade). The projected increases to annual mean daily maximum and annual mean daily minimum temperatures by 2090 under SSP5–8.5 are equivalent to a rate of 0.25°C and 0.24°C per decade, respectively. These projections indicate the area can expect accelerated increases in temperature under future climate change.

Rainfall is projected to increase by 2090 under scenarios SSP2–4.5 and SSP5–8.5 at a rate of 10.8 mm and 20.4 mm per decade, respectively. This is lower than the observed rate of increase in Campbell Island's historical record (47 ± 17 mm per decade). These projected rates of increase may be supressed because the models don't capture the orographic effect of Campbell Island, so any future improvements to model resolution will offer an interesting point of comparison to these projections.

6. Summary and conclusions

This report presents observed and projected climate data for Campbell Island. Historic climatic conditions provide a context for future changes. The future changes discussed in this report consider differences between the historical period 1986–2005 and two future time-slices representing 2040 (averaged over 2031–2050) and 2090 (averaged over 2080–2099).

It is internationally accepted that further climate changes will result from increasing amounts of anthropogenically produced greenhouse gases in the atmosphere. The influence from anthropogenic greenhouse gas contributions to the global atmosphere is the dominant driver of climate change. In addition, the climate will vary from year to year and decade to decade due to natural variability.

Notably, future climate changes depend on the pathway taken by the global community (e.g., through mitigation of greenhouse gas emissions, or ongoing high emissions). The global climate system will respond differently to future pathways of greenhouse gas concentrations. The approach taken here reflects this variability through the consideration of two greenhouse gas emission scenarios (i.e., SSP2–4.5, the intermediate scenario, and SSP5–8.5, the very high scenario). The use of all available global climate models to project Campbell Island's future climate enables interpretation of the variability (and therefore uncertainty) of the projections. The ensemble average values from these models reduce the overall effect of 'noise' in the climate signal.

From 1941–2023, Campbell Island has observed increases in air temperature and rainfall. These increases are projected to continue through the twenty-first century, with greater increases under the higher greenhouse gas emissions scenario (SSP5–8.5).

6.1 Implications for conservation management

The climate information presented in this report can be used to inform studies of flora and fauna on Campbell Island. Specific considerations for conservation management and areas worthy of further investigation may include the following:

- Extreme rainfall events and slips will potentially have the biggest impact on nesting birds on the island. Can this threat be managed and mitigated?
- What are the heat-stress thresholds for birds found on Campbell Island, and will these threshold temperatures be exceeded due to climate change?
- Sea-level increases due to climate change will continue, so how will this impact beaches where pakake (*Phocarctos hookeri*, New Zealand sea lion) haul-out and breed?
- Does climate change for the New Zealand mainland have implications for Campbell Island and New Zealand's subantarctic islands generally? For example, are there species impacted by climate change on New Zealand's mainland, such as hoiho (*Megadyptes antipodes*, yellow-eyed penguin), that will be reliant on Campbell Island or New Zealand's other subantarctic islands for their future survival? Would this habitat remain viable under climate change projections?

7. Acknowledgements

Jenny Christie, Graeme Taylor, Nicki Frances and three anonymous reviewers are thanked for their reviews of this manuscript, which resulted in an improved final version. Graeme Taylor is thanked for his insights on the potential implications of climate change for conservation management on Campbell Island. The authors carried out this work with DOC funding: GM via his DOC secondment position, and PBG extracted the climate projection data under a commercial contract between DOC and NIWA.

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Appendix

Historic climate data

These tables contain detailed data for Campbell Island's historic climate.

Table B1. Monthly temperature (°C) variation at Campbell Island for the period 1941–2023.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Highest recorded	21.2	21.2	18.8	16.7	16.5	14.1	13.1	13.5	14.9	15.3	17.8	19.7
Mean monthly maximum	16.0	15.6	14.8	13.0	11.7	10.2	9.9	10.2	10.7	11.7	13.1	15.1
Mean daily maximum	12.0	11.9	10.9	9.6	8.3	7.1	6.9	7.3	7.9	8.7	9.8	11.3
Mean	9.5	9.4	8.7	7.5	6.2	5.0	4.9	5.2	5.6	6.2	7.2	8.7
Mean daily minimum	6.9	7.0	6.4	5.4	4.1	2.9	2.9	3.1	3.3	3.8	4.6	6.1
Mean monthly minimum	2.3	2.2	1.4	0.2	-1.5	-2.3	-2.7	-2.2	-2.1	-1.4	-0.5	0.9
Lowest recorded	-1.0	-1.7	-2.6	-3.3	-6.3	-7.8	-8.0	-6.1	-5.8	-5.5	-3.9	-2.3

Table B2. Monthly rainfall (mm) variation at Campbell Island for the period 1941–2023.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Maximum	208	200	234	225	237	244	209	171	226	241	214	235
90th percentile	172	153	159	171	173	157	146	144	165	147	153	166
Mean	115	98	117	112	123	108	101	101	107	106	106	104
10th percentile	71	62	70	64	72	69	56	63	58	67	63	48
Minimum	32	43	35	50	37	47	20	32	27	41	41	26

Table B3. Variation of monthly bright sunshine (hours) at Campbell Island for the period 1941–1995.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Maximum	155.8	115.8	102.5	65.9	42.7	19.6	24.0	42.3	81.5	109.4	135.1	141.2
Mean	95.2	79.1	58.8	35.2	17.5	7.8	12.5	25.7	50.7	70.6	91.0	95.2
Minimum	46.4	31.8	28.2	15.6	3.2	1.3	4.7	8.2	24.4	37.3	47.8	46.0