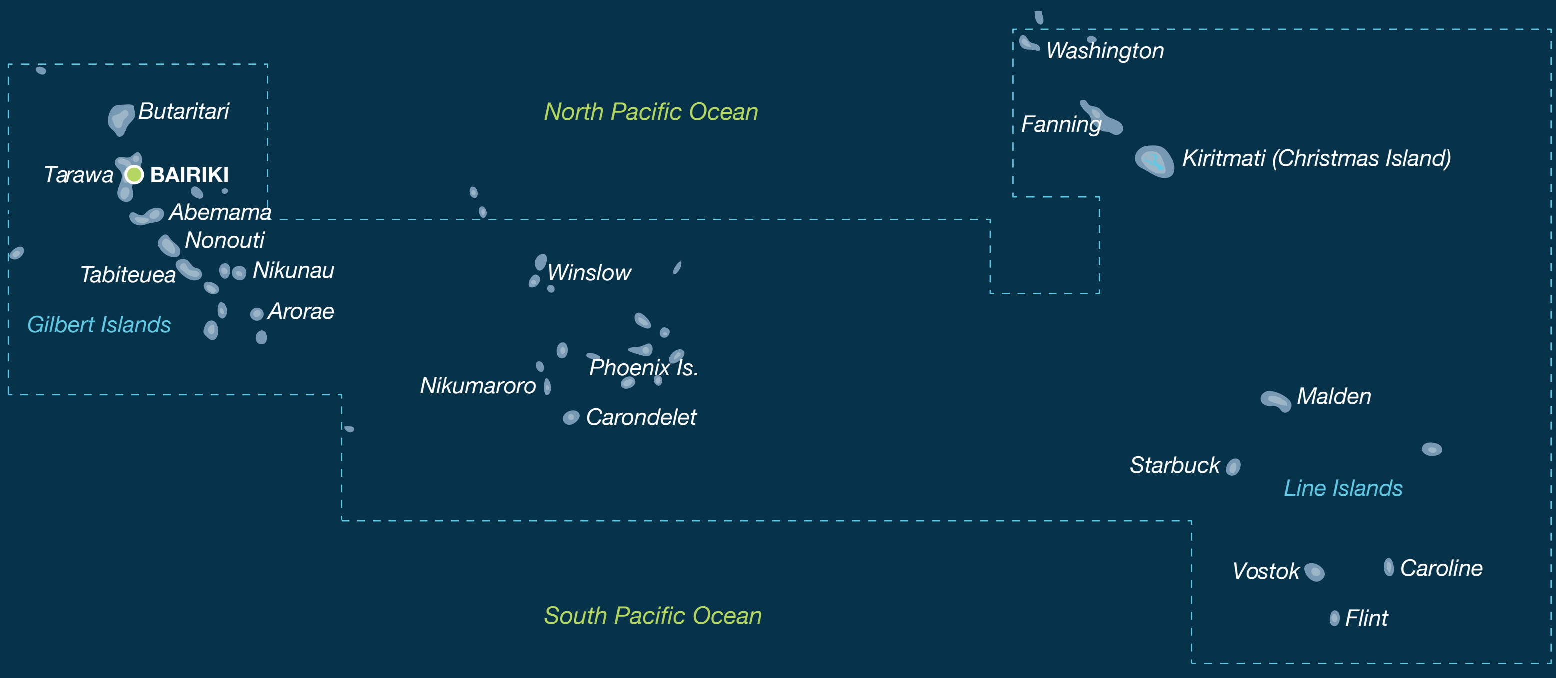

‘NextGen’ Projections for the Western Tropical Pacific:

Current and Future Climate for **Kiribati**

Technical Report

October 2021

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Contents

Executive Summary

This report presents information about average temperature and rainfall change in Kiribati, including historical change, interpretation of climate projections, understanding projections as they relate to 'global warming levels', and a set of future climate scenarios for Kiribati using storylines. It also gives a summary of important new projections information on tropical cyclones, extreme rainfall and sea level rise, and gives a preview of the emerging set of new generation climate modelling.

This is a technical report for the Australia-Pacific Climate Partnership (APCP), as part of the APCP-funded project entitled 'Next Generation Climate Projections for the Western Tropical Pacific'. Technical reports of this type are being prepared for 15 Pacific Island countries, upon which a suite of more user-friendly (and where possible non-technical) knowledge products have been developed for communication, capacity development and general outreach to target users in the region. These users variously include national/sub-national governments, national met services and sectors, regional organisations and sectors, regional/national universities, consultancies, international donors and other development partners to inform climate-related policy development and risk assessments, adaptation and disaster risk management planning and associated decision-making. These reports, along with other project collateral including case study reports and project publications etc are available online at www.rccap.org.

This report uses much of the same underlying datasets and information from Pacific-Australia Climate Change Science and Adaptation Planning (PACCSAP) reports (CSIRO, Bureau of Meteorology and SPREP, 2014) but presents the information in new and more salient ways, with more context and detail; thereby making the underpinning science more relevant to decision-makers for application at a sectoral level. This report describes changes in average climate, which is superimposed upon natural year-to-year climate variability, partly related to the El Niño Southern Oscillation. The key findings for Kiribati are summarised as follows:

Analysis of observed and future temperature

- Warming of the climate is clear and ongoing. From the 1850-1900 period (chosen to represent 'pre-industrial' climate), Kiribati likely experienced around 0.6°C warming up to the 1986-2005 baseline and also around 0.6°C warming up to the 2011-2020 baseline period. The estimate is uncertain due to poor data early in the record.
- Observed warming trends from 1995 to today are 'tracking' within the range of 2030 temperature projections described in the PACCSAP reports, suggesting that the PACCSAP projections are a reliable guide to the ongoing temperature trend.
- There is a long-term warming trend, but over the next ten years there may be a slight cooling trend or a rapid warming trend due to natural climate variability offsetting or enhancing the long-term trend.
- The effect of warming is similar by 2030 regardless of the greenhouse gas emissions pathway (1.4°C from 1850-1900, or 0.8°C from 1986-2005), but later in the century, there is a growing and notable difference: less change under a low emissions pathway (RCP2.6) and much higher change under a high emissions pathway (RCP8.5). By 2050 it's around 0.9°C (RCP2.6) to 1.5°C (RCP8.5), and by 2070 it's 0.9°C (RCP2.6) to 2.3°C (RCP8.5), relative to 1986-2005, but slightly less in the Line Islands.
- Step-like changes in temperature through time have occurred in the past, including an apparent step-increase since 2000, and we should expect there to be step-like changes in future.

Analysis of observed and future rainfall

- Historical rainfall trends are unclear given poor data coverage and very high climate variability. Also, the projected direction and magnitude of rainfall change is less clear than for temperature.
- There is a range of possible future changes in annual and seasonal rainfall, from slightly drier or little change in annual rainfall through to a dramatic increase in rainfall, largely determined by the strength of the 'enhanced equatorial response' of warming along the equator. To plan for these possibilities, it is useful to assess the impact of both a slightly drier and a much wetter future – these are described in the standard climate scenarios with storylines (section 6).

Projections of change for 'global warming levels'

Projections for Kiribati are presented for a range of 'global warming levels' (defined as the warming of the global average temperature since the pre-industrial era), including the 1.5°C and 2°C limits from the Paris Agreement. In summary:

- During 2011-2020, the world was around 1.1°C warmer than in 1850-1900 (over land-only by around 1.6°C). Global warming could reach 1.5°C from the late 2020s or early 2030s.Whether we reach global warming levels higher than 1.5°C later in the century depends on the emissions pathway – from a very low pathway where the 2°C limit may not be crossed, to a very high pathway where 4°C or more is possible late in the century.
- In Kiribati, observed and projected warming suggests that 2°C global warming relates to 1.5 to 2.2°C, i.e. Kiribati warms at a similar amount or slightly less than the global warming rate. However, this doesn't mean impacts are lower than other nations – high temperature extremes emerge faster in the tropics (Frame et al. 2017) and Kiribati is vulnerable to climate change in many ways, so risk assessment is needed.
- A range of possible changes in average rainfall magnitude and direction are possible under all global warming levels, from little change to a dramatic increase, and the range of possible change is larger under higher global warming levels compared to lower levels.

Sea level

Research since 2014 that was assessed in the IPCC Special Report on Oceans and Cryosphere in a Changing Climate (SROCC, IPCC 2019) indicates that under a high global emissions pathway, the Antarctic ice sheet may contribute to greater sea level rise this century than previously thought. This means a higher high range of projected change is estimated – for Kiribati this means an updated projection by 2090 under very high emissions of 0.55 to 1.00 m consistent with the SROCC. Results are not as different for lower emissions pathways.

Preview of emerging emissions pathways and climate modelling

A set of new standard global emissions pathways are now defined, and a new set of coordinated global climate modelling is nearly finalised, emerging in 2021-2022. Important features of these new developments include:

- **Emissions Pathways:** we currently use the Representative Concentration Pathways (RCPs), but soon most work will move to the new Shared Socio-economic Pathways (SSPs), which include detailed emissions pathways based on the latest research but also include a global socio-economic dimension.
- **New models (CMIP6):** many climate projections use the CMIP5 set of global climate models, and a new set of CMIP6 models is emerging in 2021 and 2022. The new models show improvements at simulating the climate of the western Pacific. This means the confidence in projections may be a little higher in some instances – however many issues remain, and the projections still show a wide range of possible change, so we still need to take a scenario approach and consider different future possibilities when planning climate adaptation.
- **Climate sensitivity:** the new set of models has a wider range of 'climate sensitivity' (the response of the climate to changes in greenhouse gases) than the existing set, with some models showing very high values and high temperature projections, but others showing very low climate sensitivity and low temperature change. These models are being assessed, and we may need to use this set of models differently than CMIP5 to produce projections to account for this broader range.

Standardised scenarios with storylines

For Kiribati, a set of four representative future climate scenarios for 2050 is presented as a simple and effective means to represent the range of possibilities. The four scenarios are shown below in a 2x2 matrix with two dimensions:

- **Rows:** the range of possible emissions pathways the world follows, noting the likely socio-economic pathway. From a very low emissions pathway with a socio-economic pathway of 'sustainability' (top row) to a very high emissions pathway with a socio-economic pathway of 'fossil-fuelled development' (bottom row)
- **Columns:** two different but plausible changes in the regional climate for each of the emissions pathways, from warmer and slightly drier (left column) to hotter and much wetter (right column), determined by the dominant physical climate 'storyline' the region follows –how strong the equatorial response is.

These four scenarios can be used as a simple starting point for considering the possible future climate in any risk assessment. Studies can compare the top and bottom rows (high and low emissions) indicating the benefits of following a low emissions pathway rather than a high pathway. Studies can also compare the climate scenario columns showing quite different possible outcomes for each emissions pathway.

The projected changes reported here can be applied to historical daily and monthly climate datasets representing the local conditions to examine the impact of climate change. Various analyses are possible, such as:

1. Subtracting past changes to examine change at different periods in the past
2. Adding on projected future changes to examine future scenarios, such as:
    - The complete range of plausible temperature change to 2050
    - Changes in temperature and rainfall for the four standardised scenarios
    - Changes in temperature and rainfall when the world reaches 2°C global warming since the pre-industrial era

Standardised scenarios for Kiribati for the period 2040-2059 relative to 1986-2005 for low and high emission pathways and two climate change scenarios defined by the physical change 'storyline'.

	Scenario 1 Weaker equatorial warming	Scenario 2 Stronger equatorial warming
Low emissions (RCP2.6)	***Warmer & drier*** • Annual temperature: +0.8°C • Annual rainfall: 0 to -5% • More heatwaves • Less humidity • More solar radiation • Heavier rainfall events • Sea level rise: 17-29 cm	***Much warmer & wetter*** • Annual temperature: +1.0-2.0°C • Annual rainfall: +30% • More heatwaves • More humidity • Less solar radiation • Much heavier rainfall events • Sea level rise: 17-29 cm
High emissions (RCP8.5)	***Much warmer & drier*** • Annual temperature: +1.0°C • Annual rainfall: 0 to -5% • More heatwaves • Less humidity • More solar radiation • Heavier rainfall events • Greater tropical cyclone impacts • Sea level rise: 20-36 cm	***Hotter & much wetter*** • Annual temperature: +2.1°C • Annual rainfall: +60% • Many more heatwaves • More humidity • Less solar radiation • Much heavier rainfall events • Greater tropical cyclone impacts • Sea level rise: 20-36 cm

1 Introduction

This report presents new analyses and explanatory descriptions of historical and projected future temperature and rainfall to improve the interpretation and translation of climate change information in policy and sectoral planning. The focus is on delivering climate projections for Kiribati and Pacific Island Countries (PICs) in the form of more contextualised science-based services using presentation styles tailored specifically for policy and sectoral user needs. This aims to facilitate appropriate and more extensive use of science-based evidence for on-ground applications.

This work has been undertaken as part of the project entitled 'Next Generation Climate Projections for the Western Tropical Pacific' funded by the Australian Government through the Australia-Pacific Climate Partnership (APCP) and delivered by the CSIRO Climate Science Centre (CSC) in partnership with the SPREP Pacific Met Desk Partnership.

The research builds upon existing climate projections, data and information developed previously through the Pacific Climate Change Science Program (PCCSP; Australian Bureau of Meteorology and CSIRO 2011) and the Pacific-Australia Climate Change Science and Adaptation Planning (PACCSAP) program (CSIRO, BoM and SPREP 2014). This report describes changes in average climate, which is superimposed upon natural year-to-year climate variability, partly related to the El Niño Southern Oscillation.

The work addresses new needs from climate projections, and it uses new research findings from updated observed datasets and draws on lessons from a series of sectoral engagements within Kiribati and other PICs. Initial plans and results for the updated projections were presented at a number of forums, including a Pacific-regional workshop in Kiribati, and national and sub-national workshops in Kiribati. These engagements identified new and emerging data and information needs for informing climate risk and associated decision-making at the national level, and this was used to guide final analyses and production of this report.

New analyses of the average annual temperature and seasonal rainfall include:

- **Historical variability and change:** as far back as the 'pre-industrial' baseline 1850-1900
- **Change between different historical periods (baselines)**
- **Climate stripes:** visualisation of change from blue years (cooler than average) to red years (warmer than average)
- **'Tracking' projections:** assessing projections from a 20-year period centred on 1995 (1986-2005) to a 20-year period centred on 2030 (2020-2039) presented in PACCSAP
- **Near-term projected variability and change:** considering climate over the next 10 years
- **Projected change:** projections from different baselines and under different emissions pathways
- **Step-like projected changes:** assessing the possibility of step-like changes in the past and future
- **An example of applying these changes to regional analysis**

Other highlights:

- Projected changes are also presented for different 'global warming levels' from pre-industrial, including what the 1.5 and 2°C limits from the Paris Agreement mean for Kiribati.
- Standardised future climate scenarios for 2050 with attached 'storylines' (descriptions of the factors that determine the future climate of the region).

The report also gives a brief overview of new developments in tropical cyclone (TC), extreme rainfall and sea level projections and gives an initial assessment of the new global emissions scenarios and climate modelling currently emerging.

Kiribati

Kiribati is an archipelago of 32 low lying atolls and one raised limestone island near the equator in the Pacific Ocean, at 5 °N to 12 °S Latitude and 168 °E to 152 °W (208 °E) Longitude (Figure 1.1). For this report, Kiribati is divided into three sub-regions, and from west to east these are: Gilbert Islands, Phoenix Islands and Line Islands. Long-term climate records are available at a few sites, including Betio on Tarawa Atoll, Kirimati, Banaba, Tabuaeran, Beru and Kanton. Analysis of gridded observations and models reported here are average values calculated over the entire exclusive economic zone of Kiribati including land and ocean, in the three sub-regions (Figure 1.1, bottom). All three sub-regions of Kiribati have a wet season from November to April and dry season from May to October (Figure 1.2).

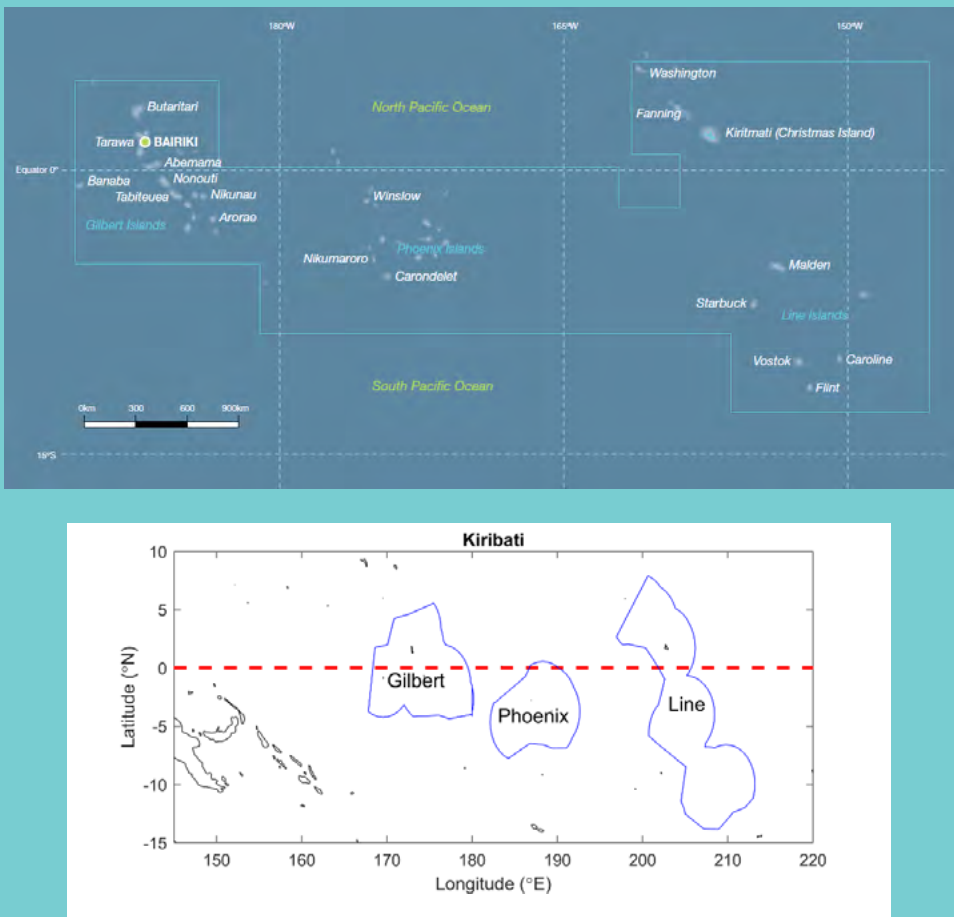

Figure 1.1. Map of Kiribati (top) and the mask areas (bottom) for calculating areal averages from gridded observational data and climate models' outputs.

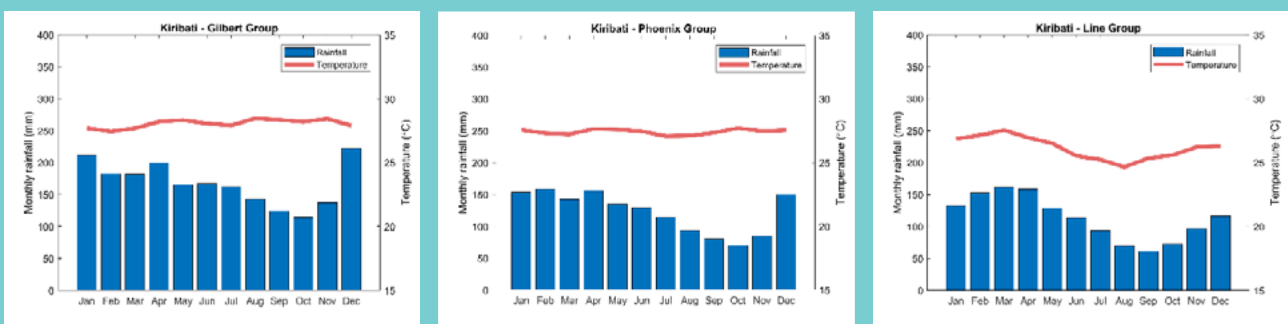

Figure 1.2. Mean annual cycle of rainfall and temperature in Kiribati in 1981-2010 (rainfall uses ERA5, temperature uses HadCRUT5, see Methods in Section 8).

2 Historical and projected temperature

For Kiribati, a projected average temperature change of around 0.8°C (0.4 to 1.2°C uncertainty range) from the 1986-2005 period out to 2020-2039 under all emissions pathways was reported (Australian Bureau of Meteorology and CSIRO, 2014). By 2090, Kiribati is projected to warm by 2.0 to 4.5°C for very high emissions (RCP8.5) and 0.5 to 1.5°C for very low emissions (RCP2.6), with only slight differences between the three sub-regions. What does this mean in the context of natural variability we have seen in the past, and how may this projection play out in the future?

Historical change and observed variability (Figure 2.1): average annual temperature has year-to-year variability mostly related to the El Niño Southern Oscillation (ENSO), with cooler years such as 2008 and 2011 and warmer years such as 2015 and 2019, but there is a warming trend over the 1850-2020 period as a whole. There were periods of steady warming such as the 1960s to today, and less rapid warming or even cooling such as around 1945 to 1960. Be aware that weather station data in the region are sparse before 1950, so the data from these earlier periods are less reliable.

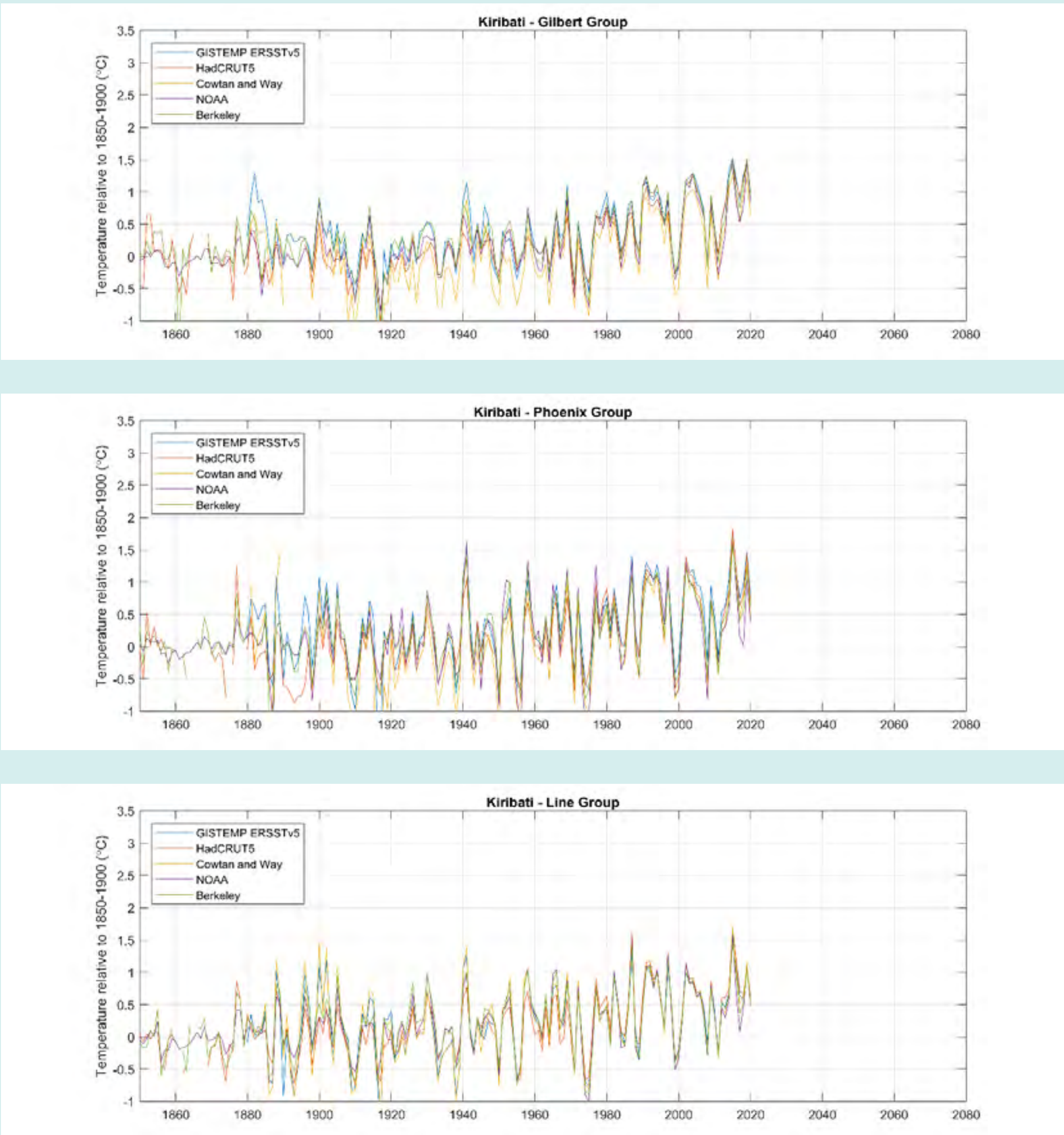

Figure 2.1. Average annual temperature of the Kiribati regions relative to 1850-1900 in five global datasets (see Methods, Section 8 for details).

Different baselines (Figure 2.2): The temperature of the Kiribati region has risen, and at a faster rate in recent decades. This can be seen in increasingly warm temperatures through commonly used historical periods (or 'baselines').

This change between different baseline periods is important in three ways:

- It shows warming is underway and ongoing – we can't assume temperature is stable over time, and we must report any changes in context of the baseline used.
- The early pre-industrial baseline of 1850-1900 is now used widely to approximate a pre-industrial climate, so we must allow for warming that has already occurred since that time.
- Warming in Kiribati has been less than the global average – from the 1850-1900 baseline up until the last 10 years, the world (land and ocean) warmed by around 1.1°C and land by around 1.6°C, but Kiribati warmed by around 0.6 to 0.7°C.

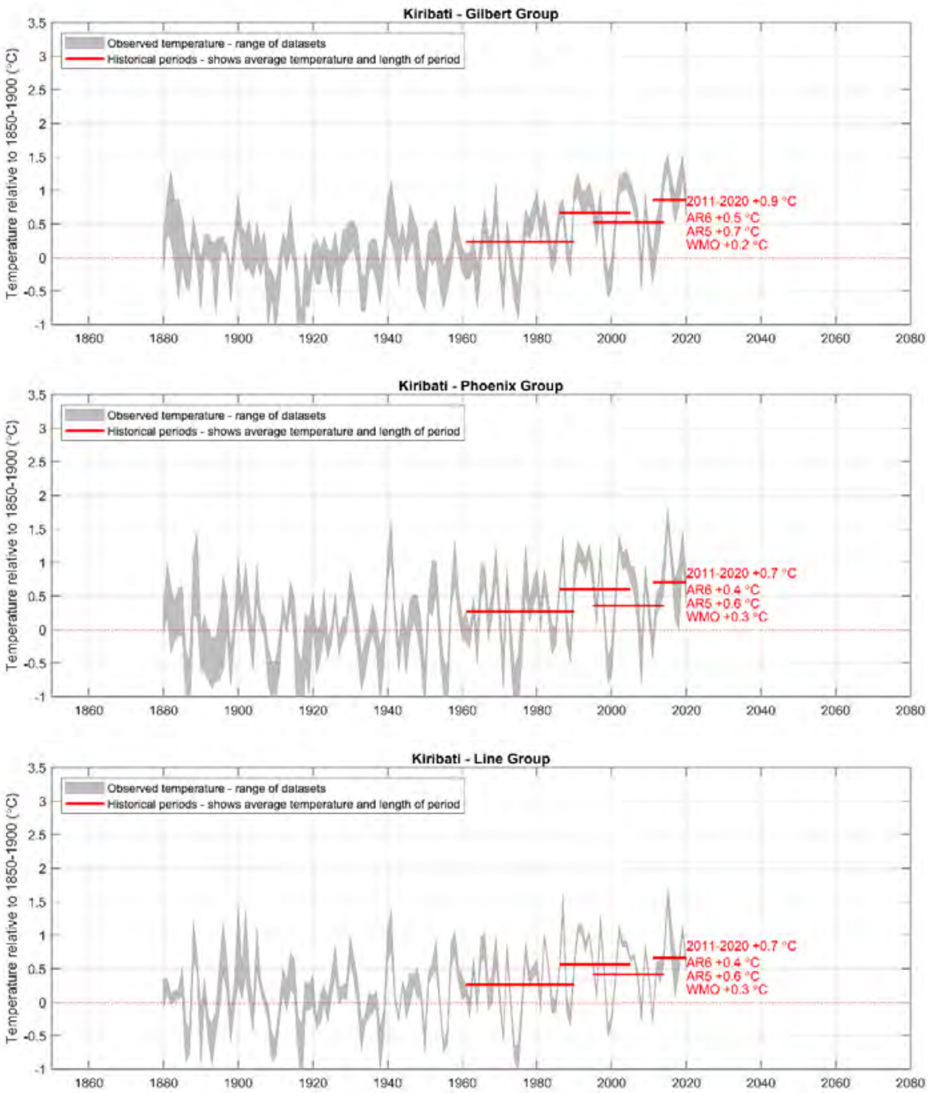

Figure 2.2. Average annual temperature of Kiribati regions relative to 1850-1900 (°C; grey band indicates the range of five global temperature datasets) and the climate average for four different historical periods (baselines), as marked:

- WMO 1961-1990 is a common baseline used by the World Meteorological Organisation
- AR5 1986–2005 is the baseline used in the IPCC 5th assessment report (AR5), and PACCSAP
- AR6 1995-2014 is the new baseline that has been used in the IPCC 6th assessment report (AR6)
- 2011-2020 is a recent ten-year period

Climate stripes (Figure 2.3): The stripe pattern developed by Hawkins (2018) gives an indication of the variability, or ups and downs, in the temperature record. For Kiribati, we see a clear change from more blue (cooler than average) to more red (warmer than average) years since 1850, with more red bars, especially since the 1990s.

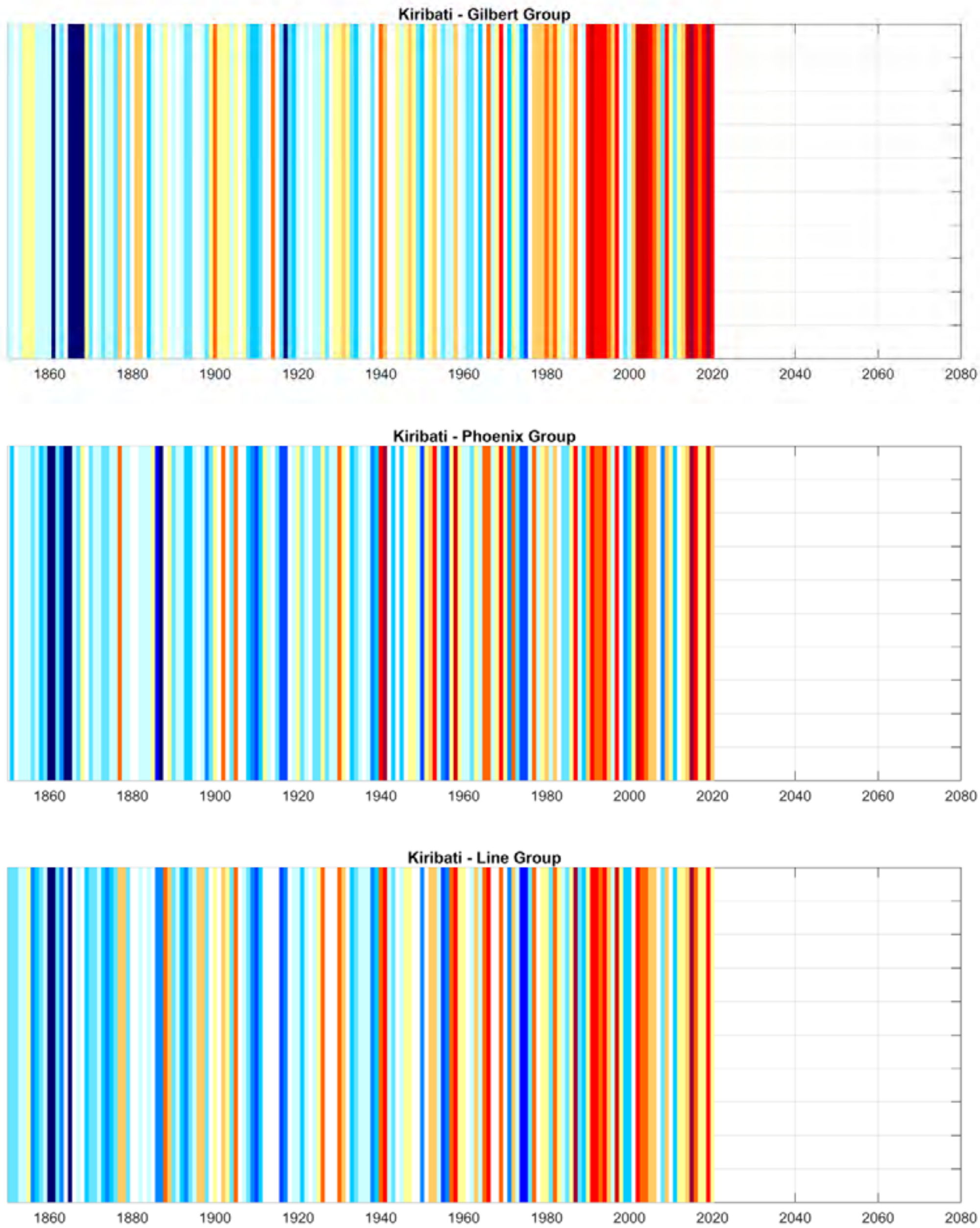

Figure 2.3. Kiribati regions temperature relative to 1961-1990 through time presented as 'climate stripes' devised by Hawkins (2018): red = hotter, blue = cooler (using the Berkeley dataset).

'Tracking' projections from PACCSAP (Figure 2.4): temperature projections presented in the PACCSAP report are relative to the 1986-2005 historical period (or 'baseline'), a period centred on 1995. We can ask the question "are the projections getting it right so far?" This graph shows that since 1995, the observed temperature change is at the lower end or below the projected change. Climate variability is high in Kiribati, and the trend over the next ten years may bring the observations within the projected range or may not - we will need to wait until 2030 to see.

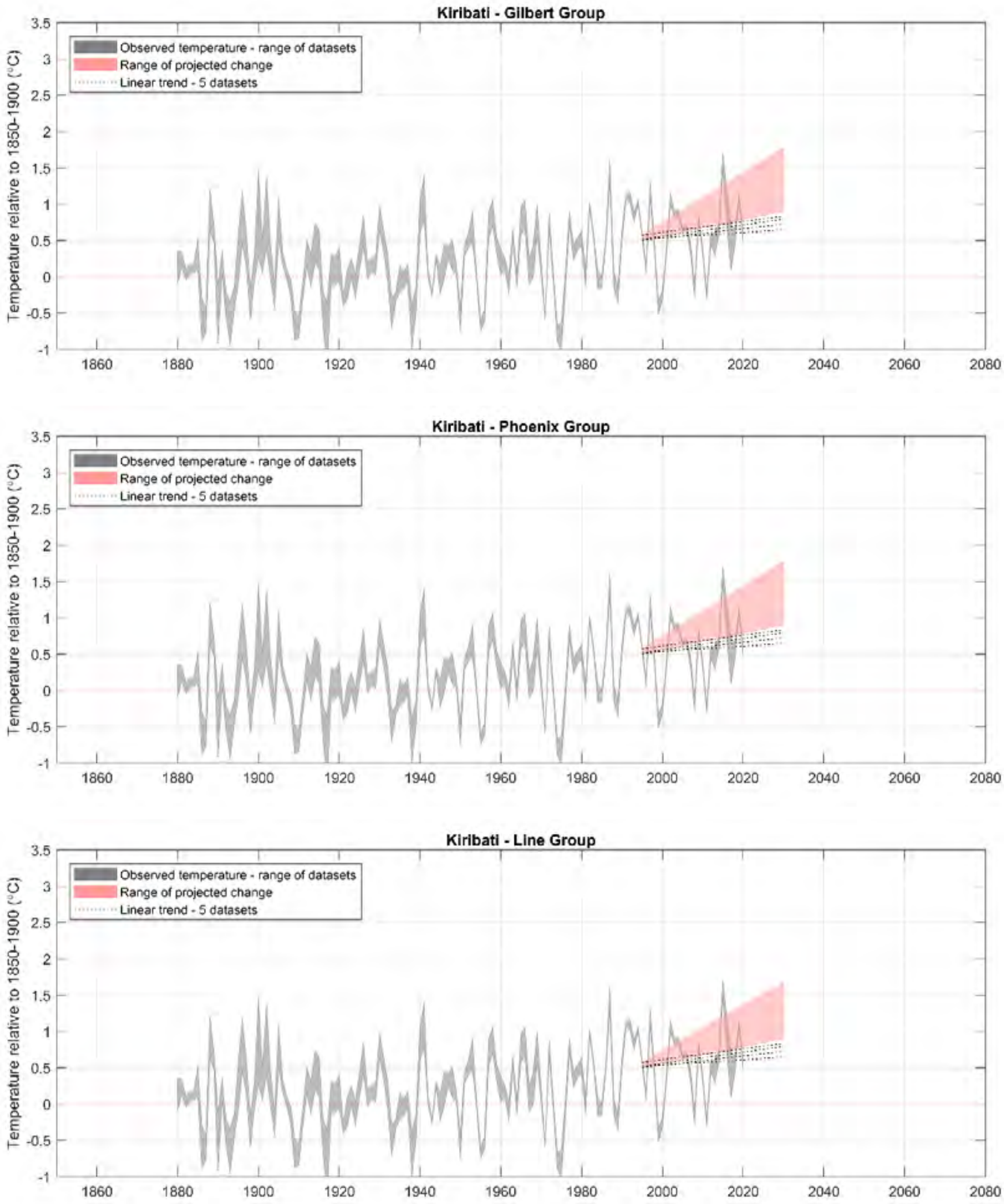

Figure 2.4. Average annual temperature of the Kiribati regions relative to 1850-1900 (°C; grey band indicates range of five global temperature datasets), the reported range of projected change from PACCSAP is shown as a red wedge (the starting point allows for the difference between the five datasets) and the linear trend of smoothed observations for 1995-2020 plotted and extrapolated forward to 2030 (one dotted line for each dataset).

Near-term projected variability and change (Figure 2.5): as with the past climate, in future there always will be climate variability (ups and downs) at all time scales – including daily, monthly, yearly, 10-yearly and so on. We know that there is an ongoing warming trend, but that variability will occur as well. Two contrasting examples of how variability and the warming trend could unfold in Kiribati Gilbert Islands (results are similar for Line and Phoenix) are shown using two separate climate model simulations – these have a consistent underlying warming trend but a different sequence of climate variability.

The top plot shows a simulation where the linear trend in temperature in 2020-2030 is offset compared to the long-term trend, and in fact shows cooling. In contrast, the bottom panel shows a model simulation where the variability creates an enhanced temperature trend in 2020-2030 compared to the long-term trend. Note, these are not predictions of the next ten years, they are simulations shown to illustrate hypothetical cases. They emphasise the fact that we should always expect climate variability to enhance or offset the long-term trend.

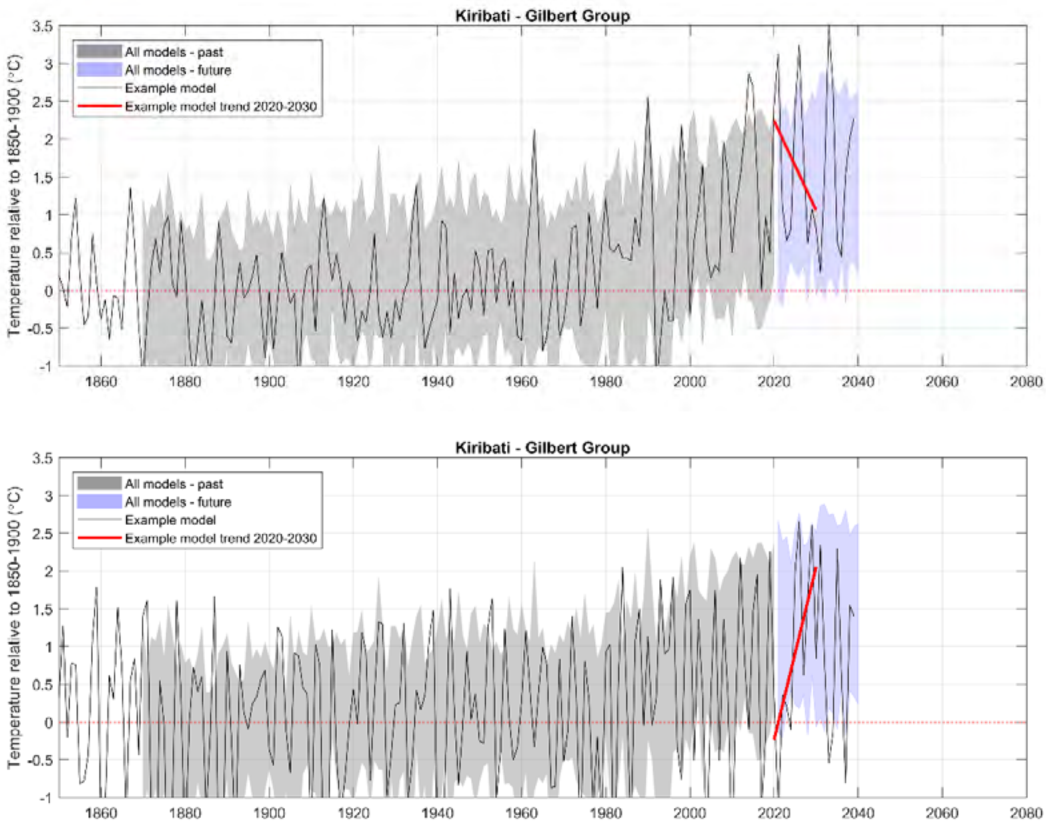

Figure 2.5. Average annual temperature in Kiribati Gilbert Islands relative to 1850-1900 (°C) simulated in CMIP5 models, showing the range of all models (historic; grey band, future; blue band) and example model simulations (black line) with the linear trend for 2020-2030 marked (red line); top: an example with suppressed warming in 2020-2030 due to climate variability, bottom: an example where variability enhances the warming trend in 2020-2030.

Projected change – near term, medium term and long term (Figure 2.6): this graphic shows change under a very high emissions pathway in the pink shaded band (RCP8.5), and a very low emissions pathway in green (RCP2.6), with the model averages shown as thick lines. In the near term (2020-2039) the range of projected temperature change is similar for both emissions pathways, but in the medium term (2040-2059) the pathways begin to separate, and by the long term (2060-2079) the pathways give very different outcomes. By 2080 there is almost no overlap. By 2030, the warming is 0.8°C (all RCPs), by 2050 it's 0.9°C (RCP2.6) to 1.5°C (RCP8.5), and by 2070 it's 0.9°C (RCP2.6) to 2.3°C (RCP8.5), relative to 1986-2005, but slightly less in the Line Islands (Table 4.1). Values are smaller from the recent baseline due to the historical warming already in place. Greenhouse gases have a long lifetime in the atmosphere, so early and sustained action taken to reduce emissions by the global community will reduce the climate change impacts experienced later.

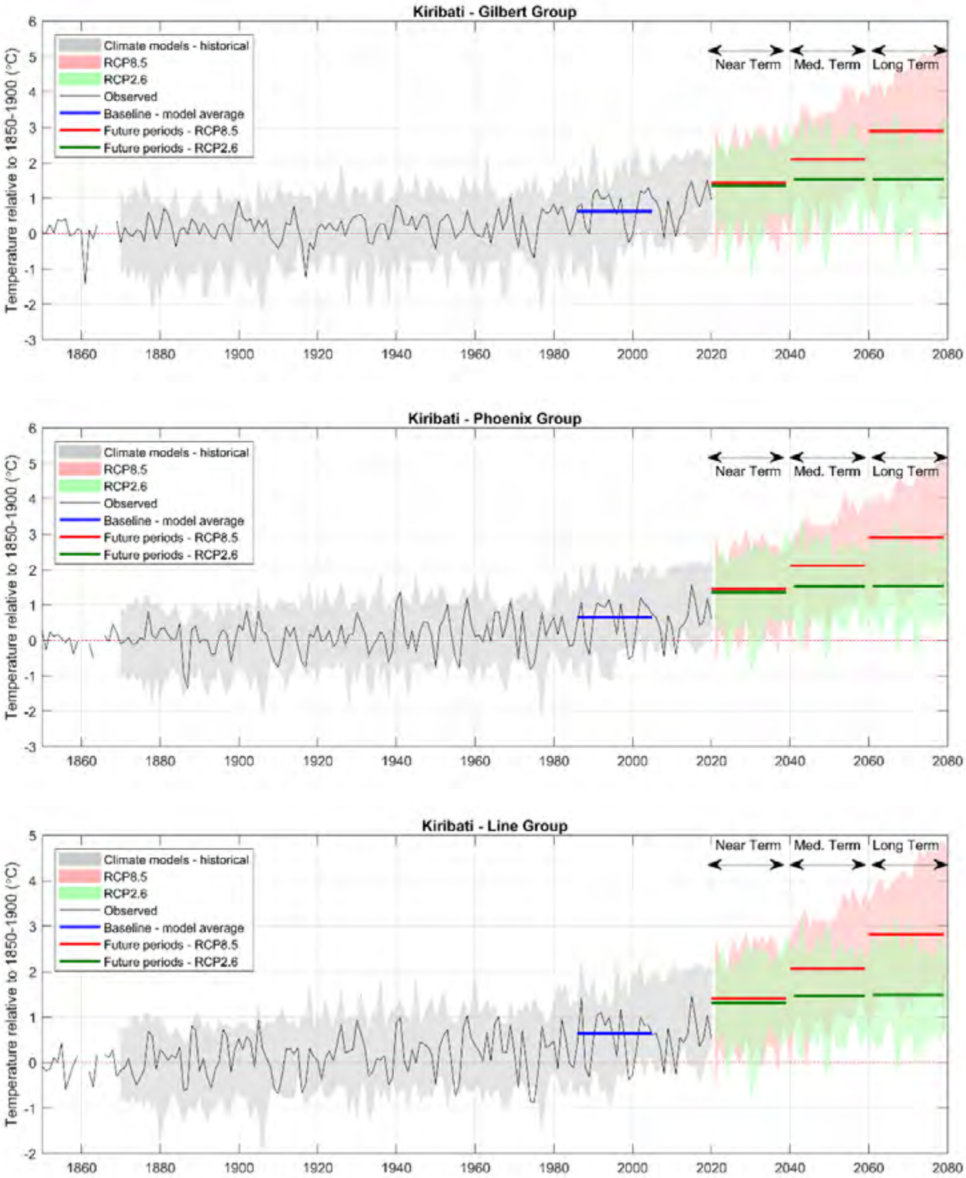

Figure 2.6. Average annual temperature in the Kiribati sub-regions relative to 1850-1900 (°C) derived from observations (Berkeley shown; grey solid line) and simulated in CMIP5 models, showing the range of all models for the past period (grey band), the future under a very high emissions pathway (pink band) and a very low emissions pathway (green band). Thick horizontal lines show the mean of all models in 20-year periods of the baseline 1986-2005 (blue) and future 20-year periods centred on 2030, 2050 and 2070 (RCP8.5; red horizontal lines, RCP2.6; green horizontal lines).

Step-like changes (Figure 2.7): As well as year-to-year variability, and different 10-year trends (see above), there can be what look like 'steps' in the time series of mean annual temperature. As an example, in Kiribati Line Islands (results are similar for Gilbert and Phoenix), statistical tests detect two abrupt, step-like changes in the observed series of average temperature since 1850, making three 'eras' (shown as different colours in the plot), as well as a short period in the 1975 to 1976 of cool years. The most recent, warmest era is all years since this cool spell ending in 1976. Similarly, in model simulations we see apparent step-like changes and different eras in the past and future – with more steps and shorter eras during periods of more rapid background warming. Model simulations won't predict the exact timing of these apparent steps but can indicate the kind of steps that may occur.

This illustrates that temperature change isn't necessarily smooth, and this concept can help us better manage variability and change. We shouldn't expect every year to be hotter than the last, and we should expect there to be not only variability year-to-year and between ten-year periods, but we should also expect what look like jumps or steps in the temperature record. This suggests that the climate system may have different stable states separated by abrupt changes or tipping points (Bathiany et al., 2018). The effect of these different apparent eras in the temperature series may be able to be seen in changes or impacts in the region.

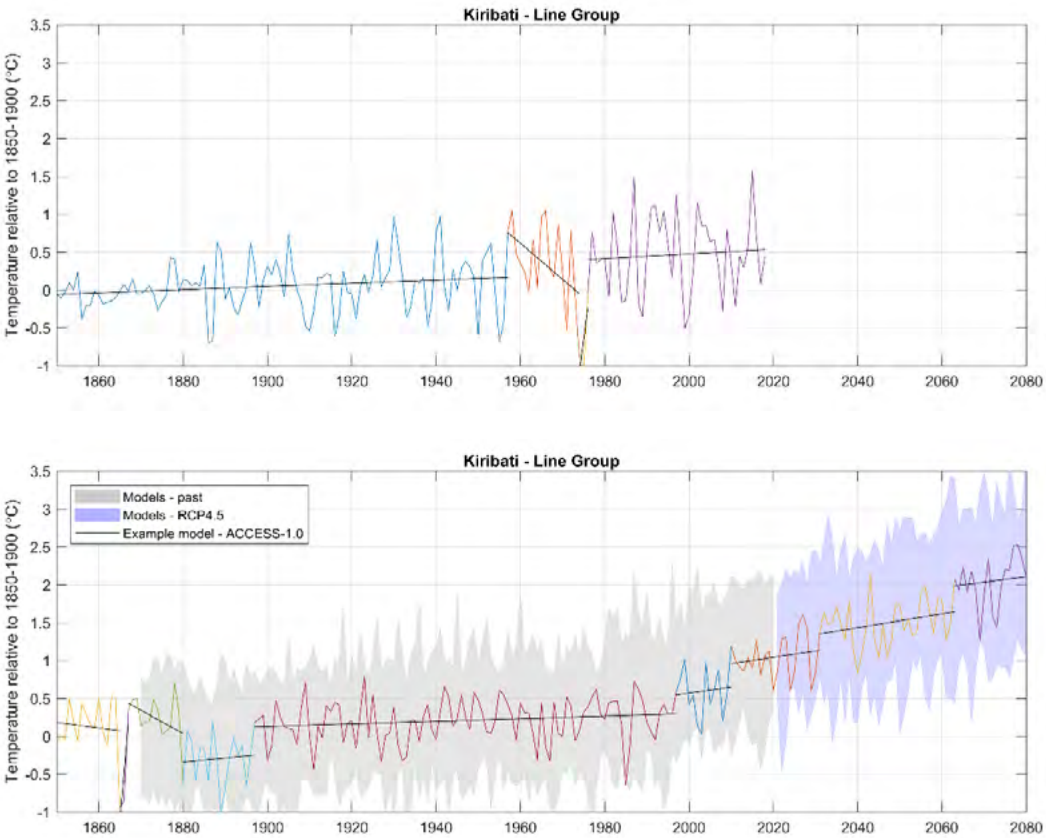

Figure 2.7. Annual average temperature of Kiribati Line Islands relative to the 1850-1900 (°C) baseline showing detected eras separated by breakpoints (see Data and Methods): top: in observations (Cowtan and Way 2014) showing three eras, early in the time series (blue), then 'jump' to a warmer period through mid to late 20th Century (orange), and the warmer 2000s (yellow); and bottom: an example model simulation, showing step-like changes throughout the past and future. Example model simulation is from ACCESS-1.0 under moderate emissions RCP4.5 (results are similar but with lower background warming in RCP2.6, and higher background warming in RCP8.5).

3 Historical and projected rainfall

Variability and percent change (%) in annual rainfall is examined here. PACCSAP reported rainfall projections for Kiribati ranging from little change to a dramatic increase, with a multi-model average suggesting an increase on average. Changes are potentially larger under higher emissions scenarios toward the end of the century. For example, in the Phoenix Group, the projected change for annual rainfall to 2030 ranges from -4 to +34% in all RCPs, but by 2070 the range is -8 to 40% under very low emissions (RCP2.6), and 1 to +92% under very high emissions (RCP8.5) (Table 4.1).

What does this mean in the context of natural variability we have seen in the past, and how will this play out in the future? Given the lack of a clear trend in observations, and the lack of clear projected direction of change, we don't show the 'tracking' or step-like change analyses, and just give a simple analysis of projections.

Observed variability and change (Figure 3.1): Annual total rainfall shows extremely large year-to-year variability, partly related to the El Niño Southern Oscillation, and no significant trends since 1960 (Australian Bureau of Meteorology and CSIRO, 2014). Similarly, there are no significant trends in gridded rainfall datasets for the entire region of Kiribati including surrounding oceans.

The average of all climate models considered (see Methods, Section 8) shows an increase in annual rainfall for all three Kiribati sub-regions between the pre-industrial baseline of 1850-1900 to the 1961-1990 baseline and then to the 1986-2005 baseline, but it is difficult to evaluate this against observations. Also, some individual models show an increase, some show little change. This suggests there is possibly a climate change signal in rainfall trends to date, but it is much less than annual and decadal variability.

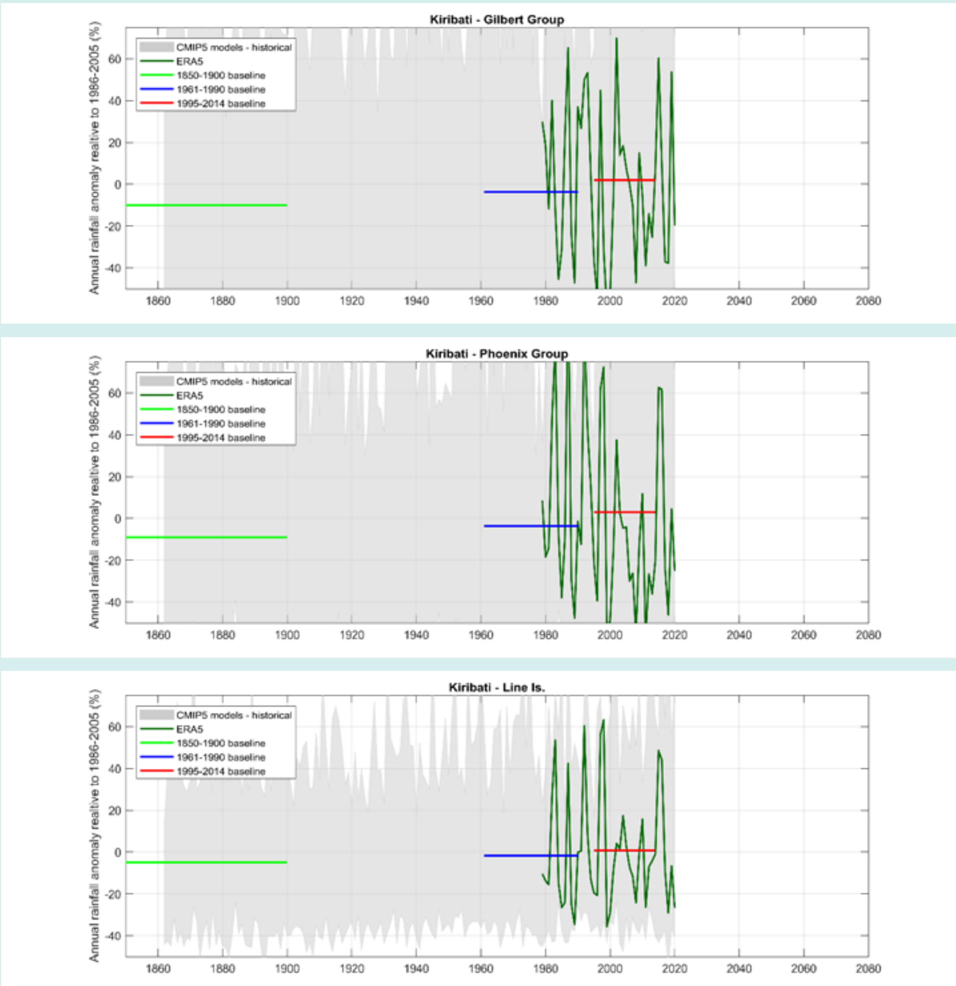

Figure 3.1. Area-average of Kiribati sub-region annual rainfall (%) relative to the 1986-2005 period from gridded observations (ERA5 shown, results are similar from GPCP, CMAP and ERA5), the range of CMIP5 models (grey band). Coloured horizontal bars show the average of all models for the baseline periods described in the legend.

Near-term variability and change (Figure 3.2): large variability and no clear long-term trend means the 10-year trend in 2021-2030 could be for no change, decrease or increase. This is illustrated by the time series in two examples of model runs for Kiribati Line Islands (results are similar for Gilbert and Phoenix).

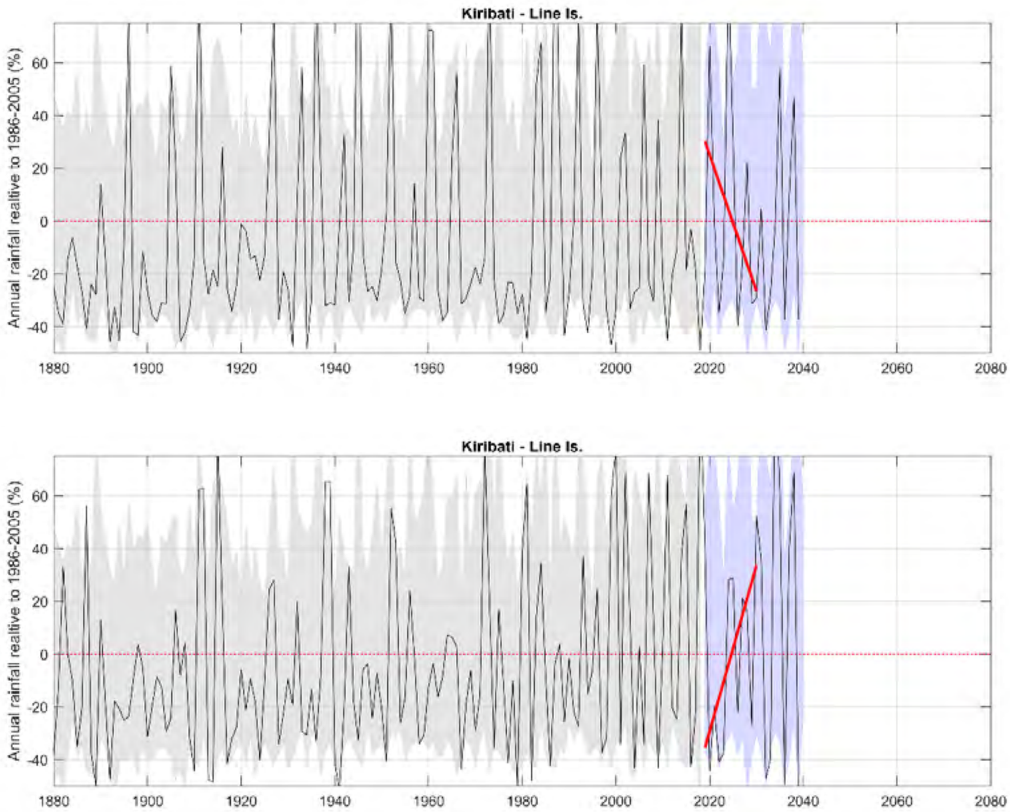

Figure 3.2. Mean annual rainfall of Kiribati region relative to 1986-2005 (%) from the group of CMIP5 models (grey band: historic, blue band: future), with an example model run shown in each panel (black line) highlighting the different possible trend in 2021-2030: (top) a model showing a decrease (red trend line in the top panel), and (bottom) a model showing an increase (red trend line in the bottom panel).

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Projected change – near and long term (Figure 3.3): In contrast to temperature, there is a large range of possible change in mean rainfall from little change to a dramatic increase, and this change appears within very high rainfall variability. Kiribati in particular has very large variability in rainfall, making the definition of long-term trends unclear over shorter periods. While the multi-model mean is for a strong rainfall increase for the near, medium and long term under both emissions pathways, this is the mid-point between some models projecting little change and others projecting a dramatic increase. Climate models has persistent biases in the equator region, meaning the rainfall projections are not given with high confidence, and the very strong projected rainfall increases at the high end (values over 100% increase) may not be plausible.

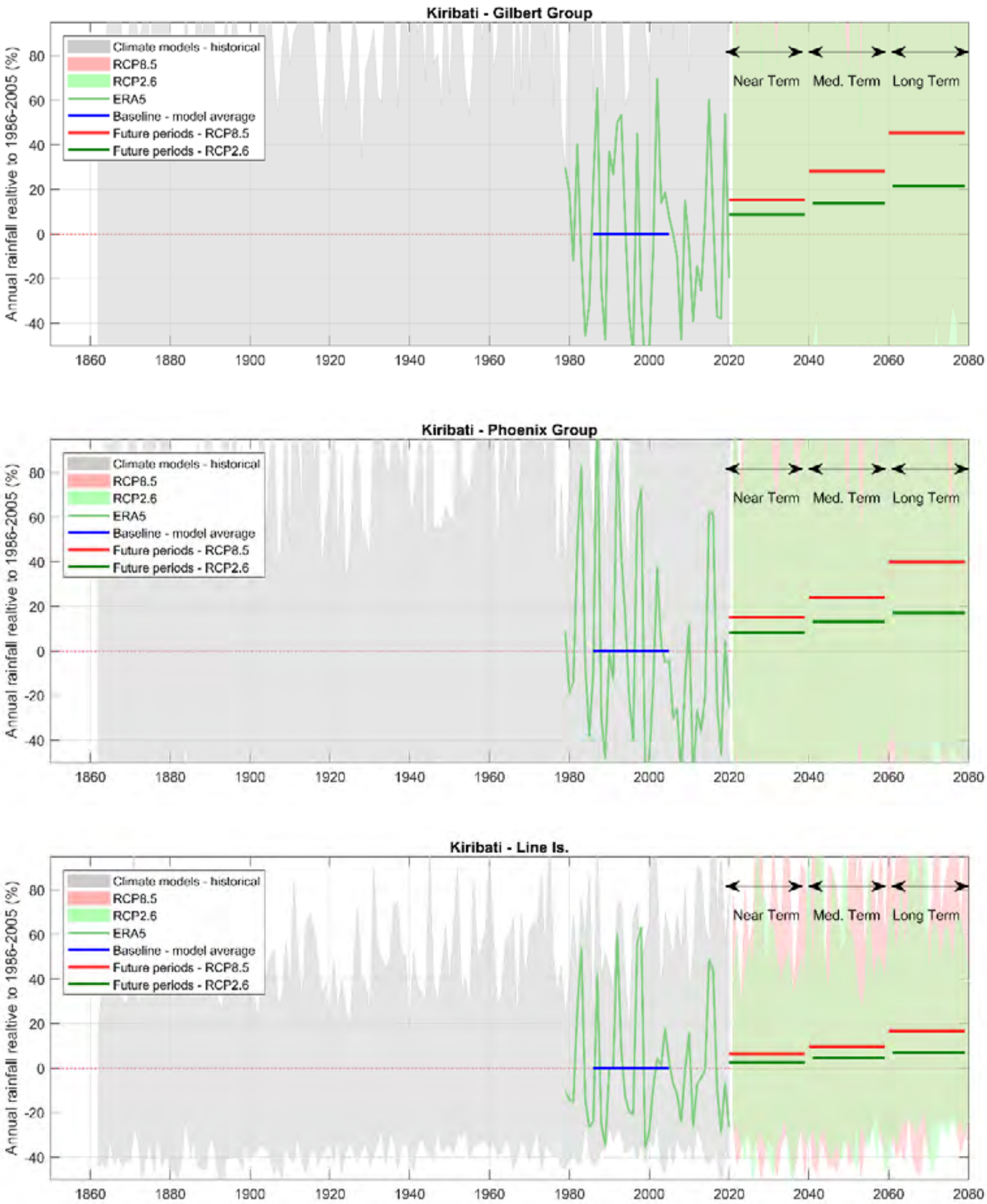

Figure 3.3. Average annual rainfall in the Kiribati sub-regions relative to 1850-1900 (%) in ERA5 and simulated in CMIP5 models, showing the range of all models for the past period (grey), the future under a very high emissions pathway (pink band) and a very low emissions pathway (green band), note the range goes off scale on some panels. Thick lines show the mean of all models in 20-year periods: the baseline 1986-2005 (blue) and future 20-year periods centred on 2030, 2050 and 2070 (RCP8.5; red lines, RCP2.6; green lines).

4 Projections for global warming levels

It has been a common approach to describe future climate change in terms of what may occur by a defined future time-period, e.g. 'By 2030 warming for Kiribati is projected to be around 0.7°C'. Recently there has been a growing focus on climate change according to different global warming levels – the amount that the world has warmed since the start of the industrial revolution. For example, the Paris Agreement aims to keep global warming to well below the level of 2°C since pre-industrial (1850-1900).

Global warming levels are measured as the global average surface temperature increase above the 1850–1900 baseline. The average global temperature for 2011-2020 is 1.1°C above this baseline, and a global warming of 1.5°C could occur in the window of the late 2020s to 2050 if warming continues at the current rate, and it will take dramatic emission reductions to avoid reaching it. Reaching higher global warming levels depends on the emissions pathway the world follows, the size of the global warming response to those emissions and the natural climate variability. This is shown by comparing the very low (top panel) and the very high (bottom panel) emissions pathways illustrated in Figures 4.1 and 4.2.

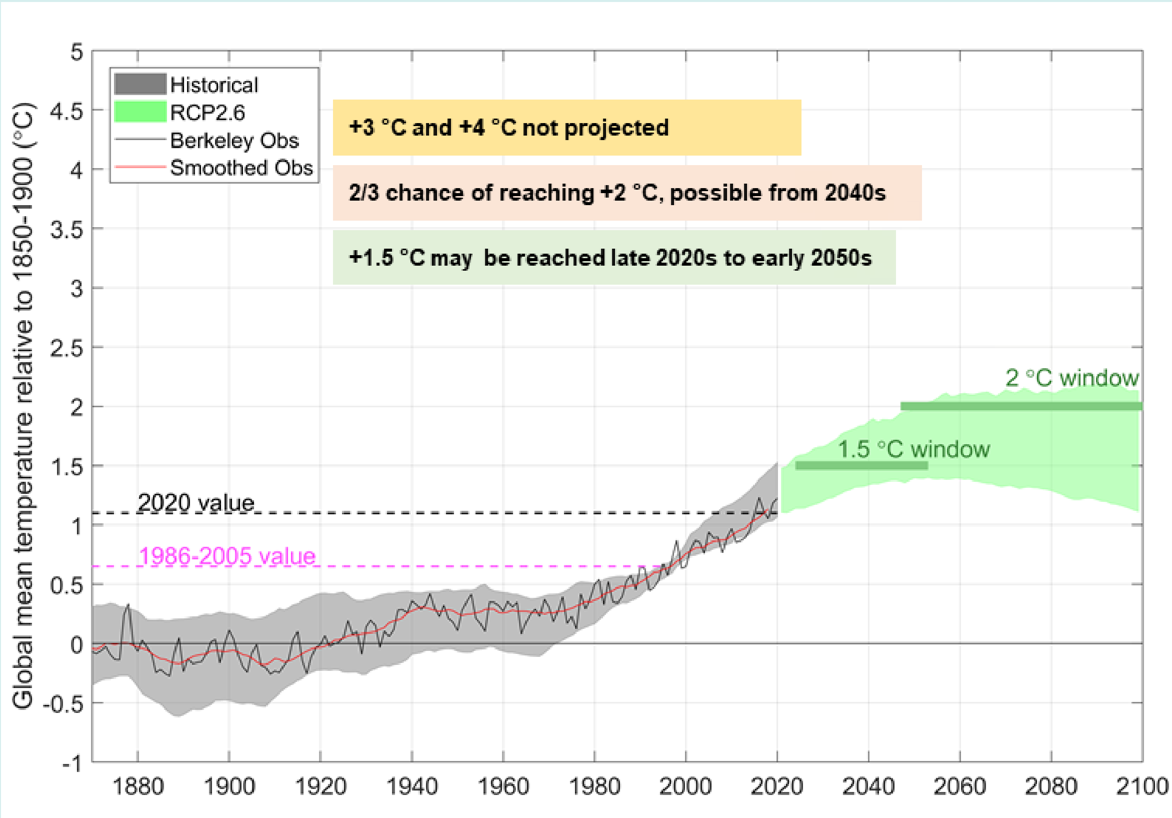

Figure 4.1. Global average surface temperature relative to 1850-1900 in Berkeley observations (grey line: annual value, red line: 41-year Lowess smoother), in the CMIP5 models for historical (grey band) and future under RCP2.6 (green band). The rough time window when global warming levels could be reached is shown by dark horizontal bars. Note models are calibrated relative to the 1986-2005 baseline and the observed change between 1850-1900 and 1986-2005 is added.

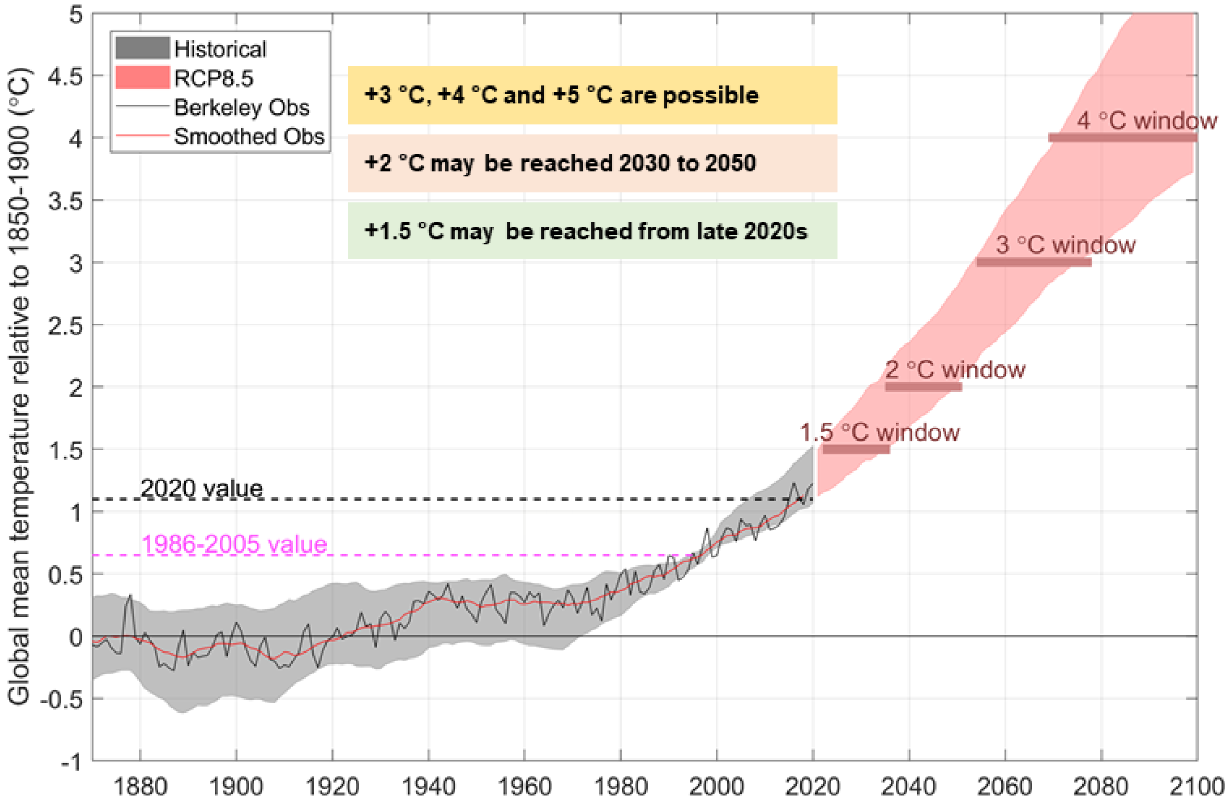

Figure 4.2. As for Figure 4.1 but showing a future under the very high emissions pathway (RCP8.5)

Because the projected warming rate varies by region, when the global average warming is at a defined level, some regions of the world will show warming lower than this average, some higher. The warming for Pacific Islands is projected to be lower than the global average, in contrast to the large continents and the Arctic that are projected to be much warmer. The maps below show the multi-model mean regional warming for the 1.5°C, 2°C, 3°C, and 4°C global warming levels (Figure 4.3).

Warming is less over the ocean regions than over land, so warming is lower over Kiribati than over the large continents of Eurasia, North America and the Arctic (Figure 4.4). However, climate variability in the tropical Pacific is also lower than in many places, so in fact the 'signal to noise' ratio is similar to or higher than many other places. This means that unfamiliar climates, and higher temperature extremes can 'emerge' (become clear above natural variability) sooner (Frame et al. 2017; Hawkins et al. 2020). Also, it should be stressed the level of impact is determined by the climate hazards experienced, including extreme weather and climate events, but also on the current exposure and vulnerability of the country. In many ways Kiribati is more vulnerable to the impacts of climate change than many other places.

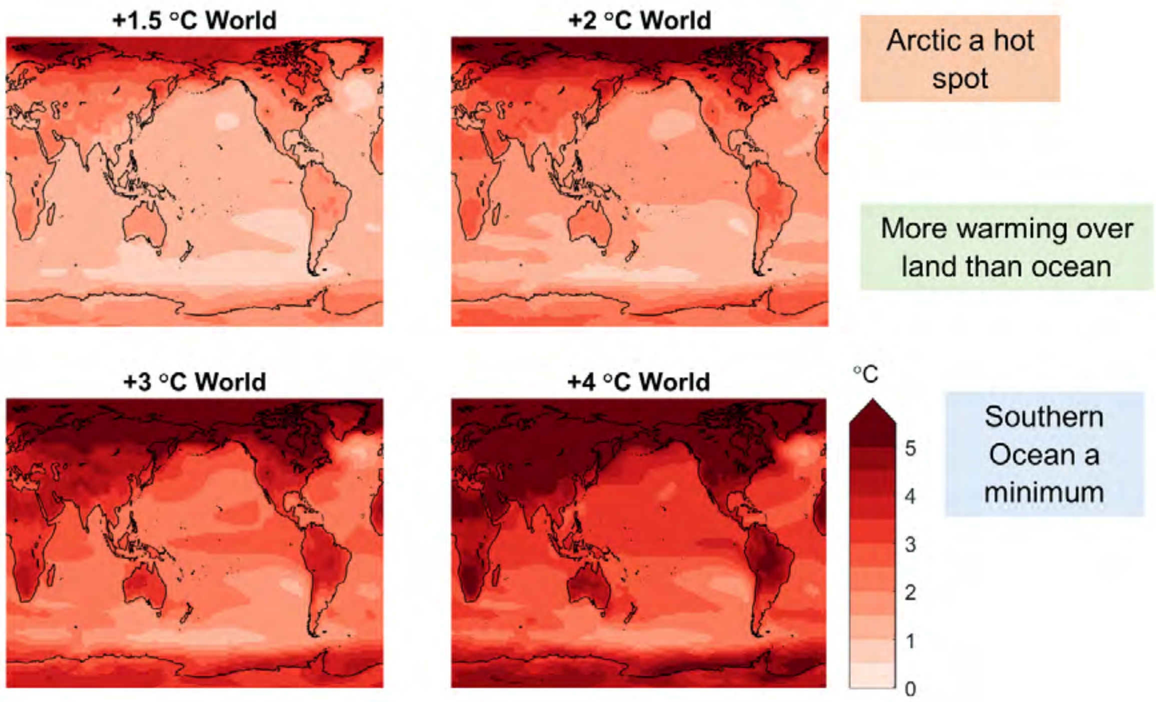

Figure 4.3. The multi model average projection of temperature change across the world when the global average warming reaches 1.5, 2, 3 and 4°C above the 1850-1900 baseline.

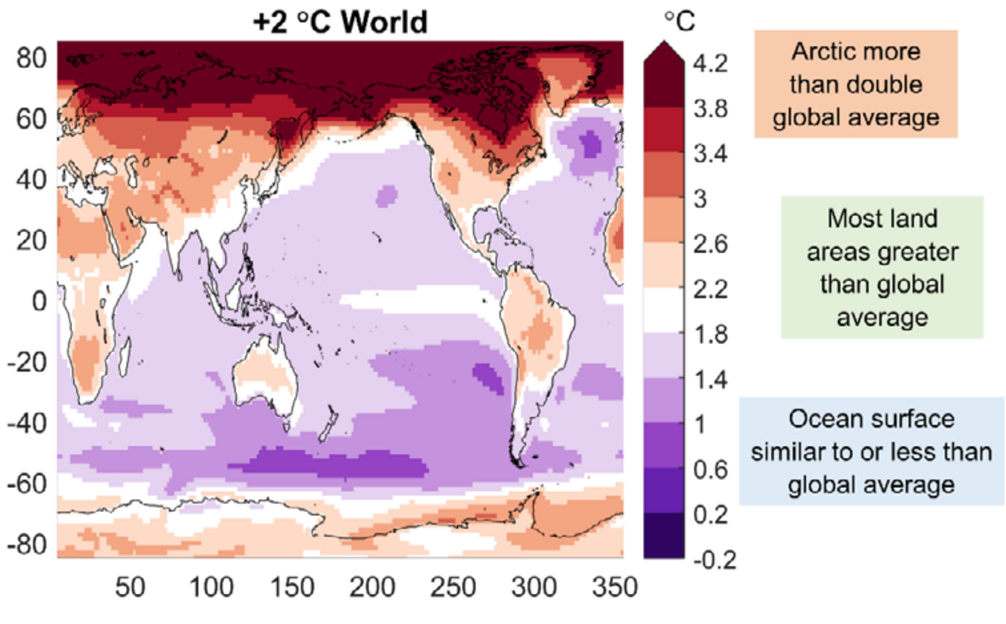

Figure 4.4. As for the 2°C panel in Figure 4.3, but with a narrower colour scale that is centred on +2°C, with hotter than global average in red and cooler in purple.

Temperature change

The maps above show the multi-model average, but there is a range of regional temperature changes possible for each global warming level - suggested by different climate models. In a 2°C warmer world, Kiribati is projected to be similar to or a little less than this global average: 1.5 to 2.2°C warmer compared to the pre-industrial baseline (or 0.8 to 1.6°C from the 1986-2005 baseline). The ratio is similar for other warming levels, shown by the bars below (Figure 4.5, Table 4.1).

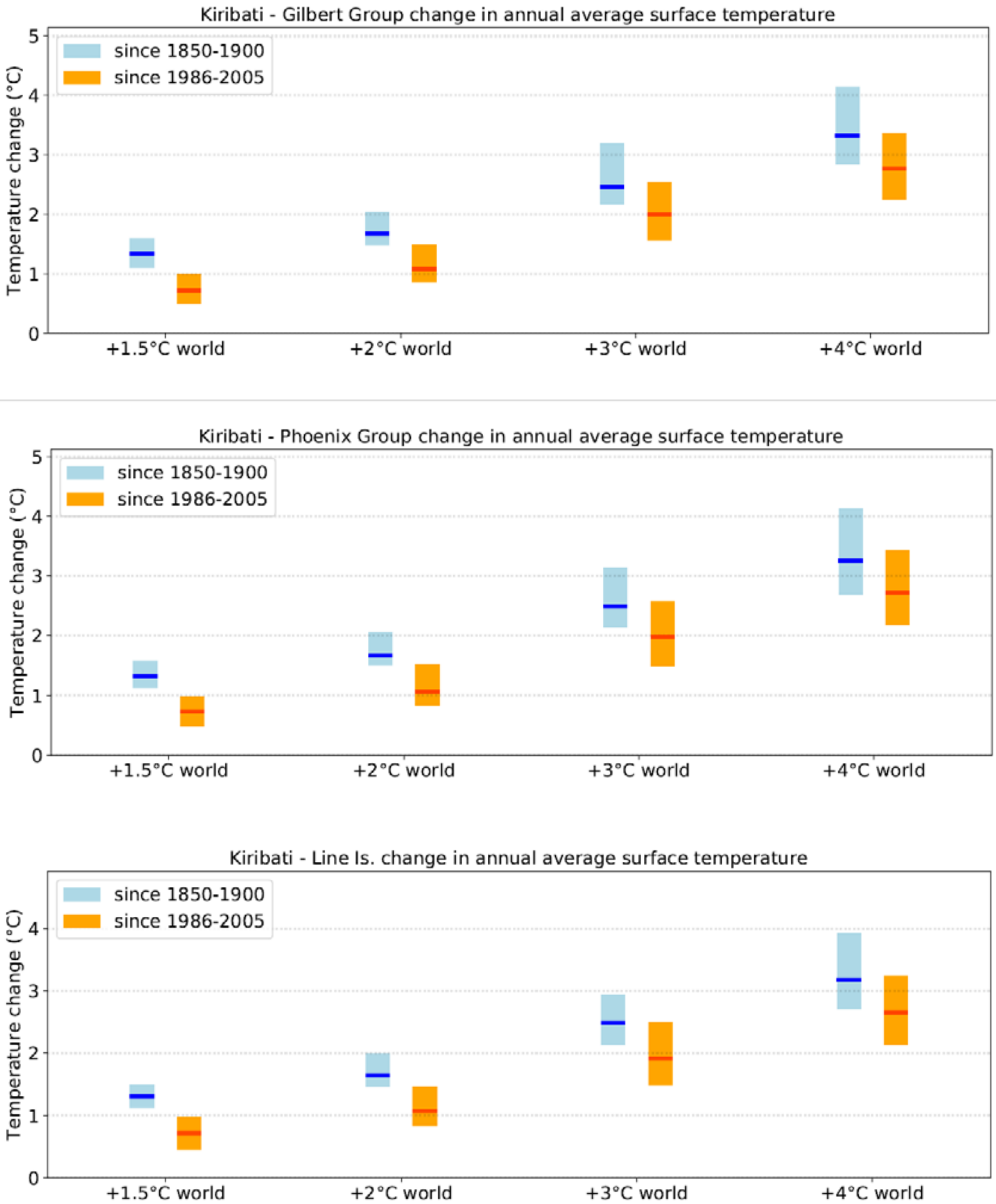

Figure 4.5. Change in the average annual temperature of Kiribati sub-regions at different global warming levels, from the 1850-1900 baseline, and from the more recent baseline of 1986-2005. The bars represent multi-model median and 10th-90th percentile range.

Rainfall change

We can examine rainfall projections for different global warming levels relative to the recent baseline period of 1986-2005. There is a range of future possibilities, with the median projection of increase in rainfall for annual and 6-month season rainfall under any warming level, with some seasonal differences between the three sub-regions (Figure 4.6). Values of the high end of rainfall increase are very large at the higher warming levels of 3 and 4°C (values go off scale), but as mentioned above these may be unrealistic. This higher range of possible change at higher at higher warming levels is consistent with the projections by timeframe and emissions pathway – where higher emissions pathways and further time periods bring higher global warming levels (Table 4.1).

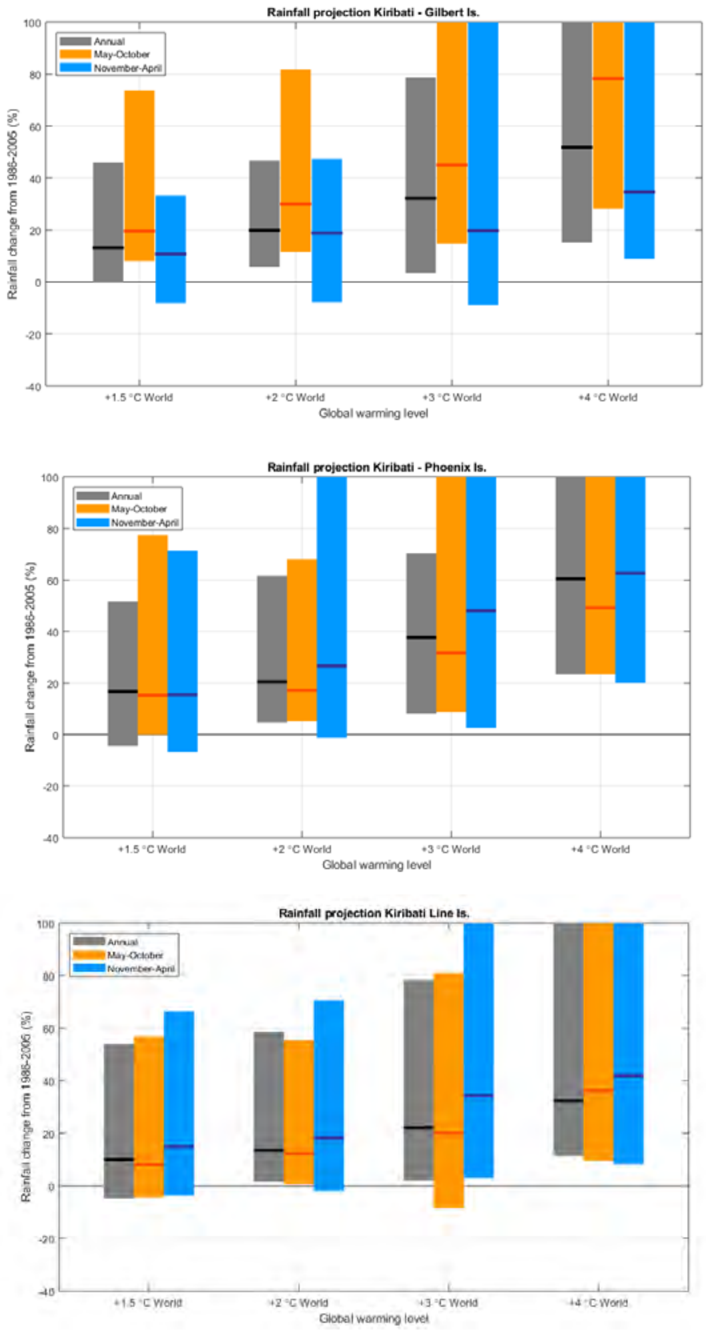

Figure 4.6. Change in the average annual and 6-month seasonal rainfall in the Kiribati regions at different global warming levels relative to the 1986-2005 baseline. The bars represent multi-model median and 10th-90th percentile range.

Table 4.1a Projected changes for the Kiribati Line Islands average annual temperature, as well as annual and seasonal rainfall. Median changes are given, with the 10-90 percentile uncertainty range in brackets. Changes are for 20-year periods centred on 2030, 2050 and 2070, relative to 1986-2005, for low emissions (RCP2.6: green) and high emissions (RCP8.5: red). In 2030, changes are similar for low and high emissions.

	2030	2050	2070	1.5°C global warming	2°C global warming	3°C global warming	4°C global warming
Temperature from 1986-2005 (°C)	0.7 (0.4 to 1.1)	0.8 (0.6 to 1.3) 1.4 (1.0 to 2.0)	0.8 (0.5 to 1.3) 2.2 (1.5 to 3.2)	0.7 (0.4 to 1.0)	1.1 (0.8 to 1.5)	2.0 (1.5 to 2.4)	2.7 (2.1 to 3.2)
Annual rainfall from 1986-2005 (%)	4 (-5 to 16)	5 (-4 to 14) 9 (-2 to 19)	6 (-2 to 14) 13 (0 to 26)	10 (-5 to 54)	14 (2 to 59)	22 (2 to 78)	32 (11 to 113)
May-Oct rainfall from 1986-2005 (%)	2 (-10 to 13)	2 (-9 to 12) 5 (-4 to 14)	4 (-8 to 14) 9 (-7 to 20)	8 (-4 to 57)	12 (1 to 55)	20 (-9 to 81)	36 (10 to 103)
Nov-Apr rainfall from 1986-2005 (%)	5 (-8 to 17)	7 (-5 to 15) 11 (-1 to 26)	8 (2 to 17) 16 (2 to 31)	15 (-4 to 67)	18 (-2 to 71)	34 (3 to 110)	42 (8 to 194)

Table 4.1b Projected changes for the Kiribati Gilbert Group average annual temperature, as well as annual and seasonal rainfall. Median changes are given, with the 10-90 percentile uncertainty range in brackets. Changes are for 20-year periods centred on 2030, 2050 and 2070, relative to 1986-2005, for low emissions (RCP2.6: green) and high emissions (RCP8.5: red). In 2030, changes are similar for low and high emissions.

	2030	2050	2070	1.5°C global warming	2°C global warming	3°C global warming	4°C global warming
Temperature from 1986-2005 (°C)	0.8 (0.4 to 1.2)	0.9 (0.6 to 1.5) 1.5 (1.0 to 2.2)	0.9 (0.5 to 1.4) 2.3 (1.5 to 3.5)	0.7 (0.5 to 1.1)	1.1 (0.9 to 1.5)	1.9 (1.6 to 2.7)	2.8 (2.2 to 3.4)
Annual rainfall from 1986-2005 (%)	15 (-9 to 34)	16 (-3 to 44) 30 (-2 to 70)	21 (-1 to 59) 48 (-4 to 124)	13 (0 to 46)	20 (6 to 47)	32 (4 to 79)	52 (15 to 164)
May-Oct rainfall from 1986-2005 (%)	18 (-3 to 58)	20 (2 to 50) 36 (7 to 87)	25 (-8 to 69) 64 (10 to 155)	20 (8 to 74)	30 (12 to 82)	45 (15 to 147)	78 (28 to 221)
Nov-Apr rainfall from 1986-2005 (%)	14 (-21 to 36)	13 (-12 to 37) 25 (-7 to 73)	17 (-5 to 52) 34 (-8 to 107)	11 (-8 to 33)	19 (-8 to 47)	20 (-9 to 113)	35 (9 to 168)

Table 4.1c Projected changes for the Kiribati Phoenix Group average annual temperature, as well as annual and seasonal rainfall. Median changes are given, with the 10-90 percentile uncertainty range in brackets. Changes are for 20-year periods centred on 2030, 2050 and 2070, relative to 1986-2005, for low emissions (RCP2.6: green) and high emissions (RCP8.5: red). In 2030, changes are similar for low and high emissions.

	2030	2050	2070	1.5°C global warming	2°C global warming	3°C global warming	4°C global warming
Temperature from 1986-2005 (°C)	0.8 (0.4 to 1.2)	0.9 (0.6 to 1.4) 1.5 (0.9 to 2.2)	0.9 (0.5 to 1.4) 2.3 (1.6 to 3.4)	0.7 (0.5 to 1.1)	1.1 (0.8 to 1.6)	2.0 (1.6 to 2.7)	2.7 (2.2 to 3.5)
Annual rainfall from 1986-2005 (%)	10 (-4 to 34)	16 (1 to 36) 23 (-1 to 60)	15 (-8 to 40) 34 (1 to 92)	17 (-5 to 52)	21 (5 to 62)	38 (8 to 70)	61 (23 to 193)
May-Oct rainfall from 1986-2005 (%)	7 (-6 to 26)	11 (1 to 22) 16 (-2 to 40)	10 (-7 to 29) 23 (-1 to 59)	15 (0 to 77)	17 (5 to 68)	32 (9 to 142)	49 (23 to 194)
Nov-Apr rainfall from 1986-2005 (%)	15 (-11 to 56)	21 (-1 to 52) 34 (-1 to 116)	20 (-9 to 60) 49 (5 to 147)	16 (-7 to 71)	27 (-1 to 102)	48 (3 to 169)	63 (20 to 276)

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5 Sea level projections

Research since 2014 was assessed in IPCC Special Report on Oceans and Cryosphere in a Changing Climate (SROCC). Under a high global emissions pathway, the research suggested that Antarctic ice sheets may contribute to greater sea level rise this century than previously thought. Sea level projections that incorporate the higher Antarctic contribution have been evaluated for Kiribati and show a rise of between approximately 0.09-0.18 m by 2030 (very similar values for different RCPs and also similar to the PACCSAP projections), and an increase of 0.65 to 1.22 m by 2100 under RCP8.5 (Figure 5.1 and Table 5.1). Compared to the PACCSAP scenarios, the updated median value of sea level rise for RCP 8.5 in 2100 is 0.12 m higher and the upper end of the range is 0.14 m higher. This is because the enhanced Antarctic contribution is expected to be strongest for the highest emission scenario. For RCP 4.5 and 2.6 the range of projected change is generally similar but slightly narrower than PACCSAP projections. Interannual variability of sea level will lead to periods of lower and higher regional sea levels. In the past, this interannual variability (after removal of the seasonal signal) has been about 0.23 m (5–95% range; see dashed lines in Figure 5.2) and it is likely that a similar range will continue through the 21st century. The latest IPCC Sixth Assessment Report (IPCC 2021) emphasises that a 'low likelihood high impact' outcome of much higher sea level rise under the high emissions pathways can't be ruled out.

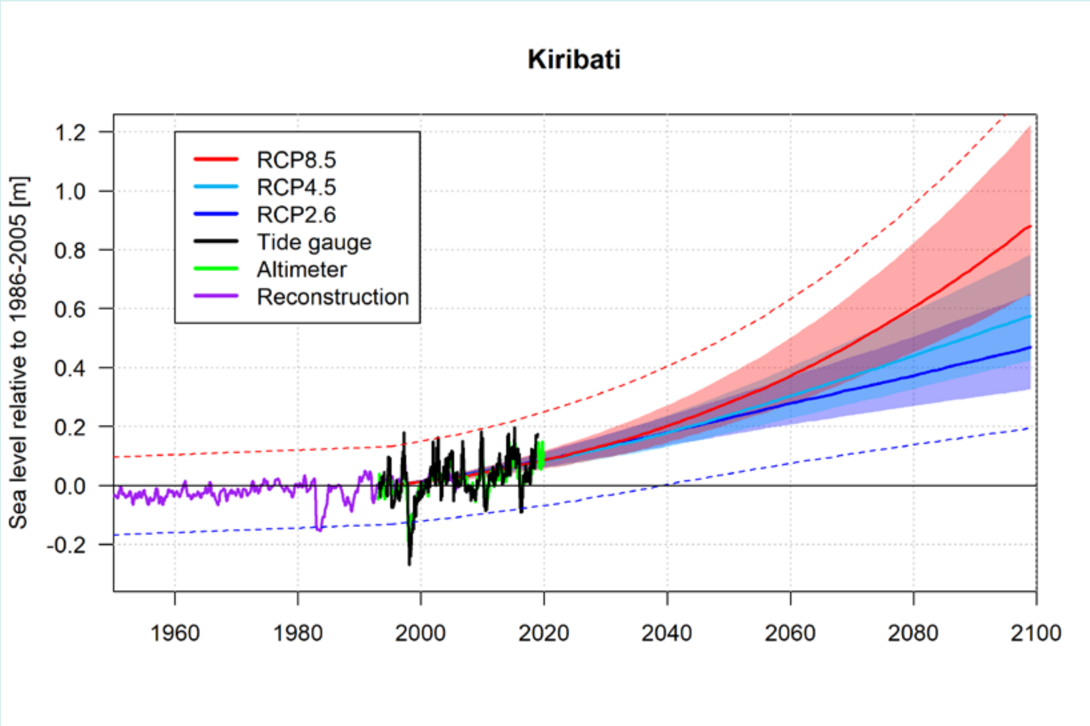


Figure 5.1. Sea level rise projections for Kiribati. The tide gauge record of relative sea level at Tarawa is indicated in black, the satellite record in green and reconstructed sea level data is shown in purple, all are monthly means without seasonal cycles and referenced to mean sea level between 1986-2005. Multi-model-mean projections from 1995–2100 are given for the RCP8.5 (red solid line), RCP4.5 (cyan solid line) and RCP2.6 emissions scenarios (blue solid line), with the 5–95% uncertainty range for RCP8.5 and RCP2.6 shown by the red and blue shaded regions respectively. The dashed lines are an estimate of interannual variability in sea level (5–95% uncertainty range) and indicate that individual monthly averages of sea level can be above or below longer-term averages.

Table 5.1. Median sea level projections for Kiribati with 5-95% range relative to 1986-2005 for RCPs 2.6, 4.5, and 8.5. Units are metres.

	RCP 2.6		RCP 4.5		RCP 8.5	
Year	**Sea level rise**		**Sea level rise**		**Sea level rise**	
2030	0.13	[0.09-0.17]	0.12	[0.09-0.16]	0.13	[0.09-0.18]
2040	0.17	[0.13-0.23]	0.17	[0.13-0.23]	0.19	[0.14-0.26]
2050	0.22	[0.17-0.29]	0.23	[0.17-0.31]	0.27	[0.20-0.36]
2060	0.27	[0.20-0.36]	0.30	[0.22-0.39]	0.36	[0.27-0.49]
2070	0.32	[0.24-0.43]	0.36	[0.27-0.48]	0.47	[0.35-0.63]
2080	0.37	[0.27-0.50]	0.43	[0.32-0.58]	0.59	[0.44-0.80]
2090	0.42	[0.30-0.57]	0.50	[0.37-0.68]	0.73	[0.54-1.00]
2100	0.47	[0.33-0.65]	0.57	[0.42-0.78]	0.88	[0.65-1.22]

Box 1. New emissions pathways

The international research community is set to move away from the Representative Concentration Pathways (RCPs) to the Shared Socio-economic Pathways (SSPs) in 2021. These new pathways are more relevant and up to date (e.g. they start in 2016, rather than in 2006), and they also include a description of the global social and economic factors that can produce each emissions pathway. There are five SSPs, but here we focus on the extreme ends of likely emissions – SSP1 and SSP5:

SSP1 – 'Sustainability', or 'Taking the green road' – higher challenges to mitigation but lower challenges to adaptation compared to some other SSPs. A world shifting to sustainable development with lower material growth, lower energy-intensity and lower resource-intensity, and along with this comes greater equity, inclusiveness, respect for environmental boundaries, education and health. Leads to the lower emissions pathways, so is most compatible with RCP2.6.

SSP5 – 'Fossil-fuelled development' or 'Taking the highway' – lower challenges to mitigation, higher challenges to adaptation compared to other SSPs. A world also investing in health, education and institutions, but one that relies on fossil fuels to drive rapid growth, technology and innovation to maintain energy-intensive and resource-intensive lifestyles. Leads to higher emissions pathways, so is most compatible with RCP8.5.

Others are:

- SSP2 – Middle of the road – medium challenges to mitigation and adaptation
- SSP3 – 'Regional rivalry' or 'A Rocky Road' – high challenges to mitigation and adaptation
- SSP4 – 'Inequality' or 'A Road Divided' – low challenges to mitigation, high challenges to adaptation

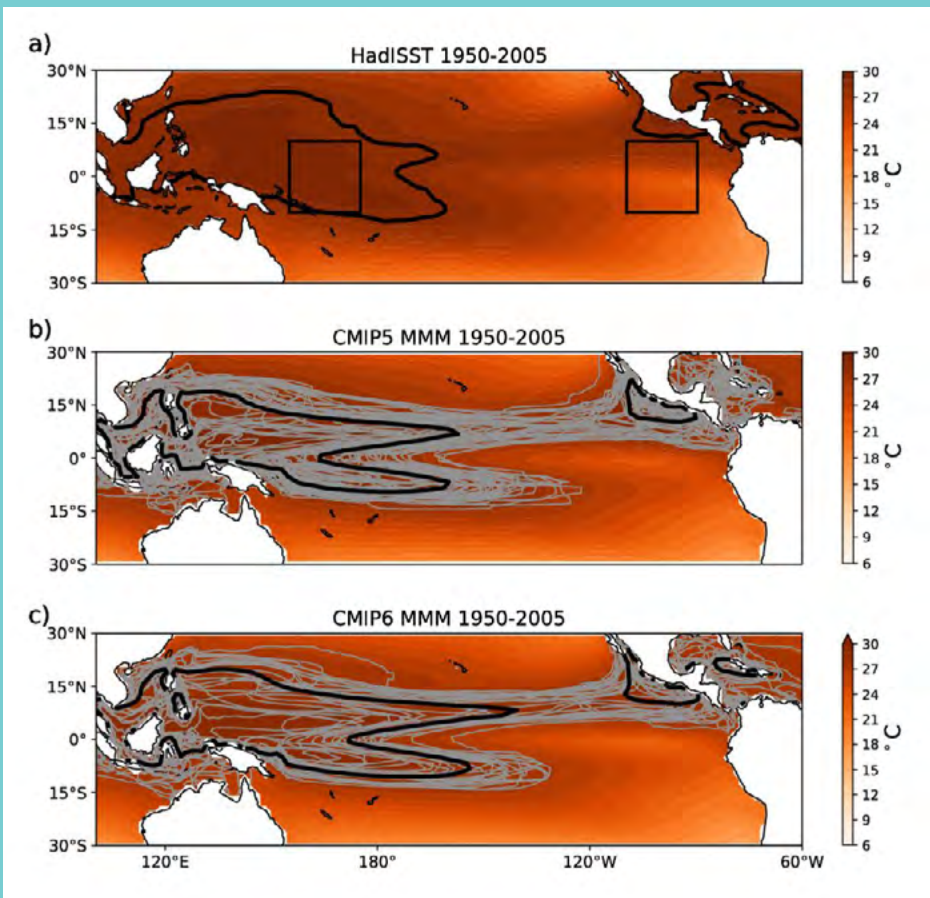
These are global scenarios, and further work is needed to see what they mean for a region or an individual country. For New Zealand and the Pacific, Frame et al. (2018) lay out some analysis of the SSPs and what they might mean for the region.

Box 2. New global climate models

A new group of global climate model simulations from around the world are being evaluated and will start to become the new international standard following the IPCC (2021) Sixth Assessment Report. This means a shift from the Coupled Model Inter-comparison Project phase 5 (CMIP5) to the new phase, CMIP6.

The new models show incremental improvements in the simulation of the climate of the western Pacific, and there will be new insights and new opportunities to understand the future climate using these models. However, the fundamental nature of the models hasn't changed, and the western Pacific remains a challenging area to simulate climate variability and change, and confidence in regional climate projections will remain lower than for some other places.

As an example of the evaluation of models, this plot quantifies the well-known "cold-tongue bias" (the West Pacific warm pool is pinched in at the equator by a tongue of cold water) in the old and the new models:

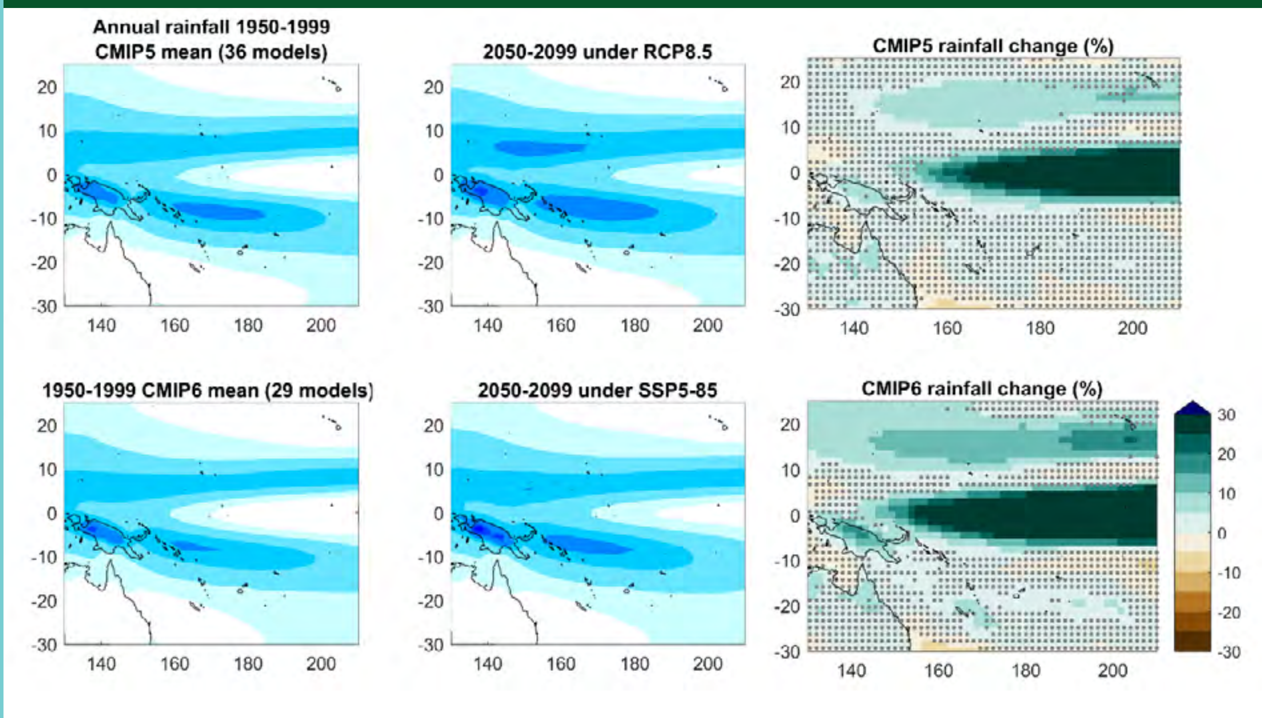


Average sea surface temperature (SST) from 1950 to 2005 for June to November. Top panel shows observations (HadISST1.1) on a colour scale, and the thick black line shows 28.5 °C. The other two maps show the CMIP5 and CMIP6 SST for the same period, and the thin grey lines show the location of 28.5 °C for each individual model, and the thick black line shows the multi-model means. Taken from Grose et al. (2020).

Also, the projected changes in CMIP6 are generally similar to CMIP5 for many features and many climate variables. For example, annual rainfall changes under a very high emissions pathway (RCP8.5 or SSP5-8.5) show many of the same aspects – high model agreement for a strong rainfall increase at the equator, but less certain direction of change for the SPCZ region. There is a group of models with higher temperature projections in CMIP6 compared to CMIP5, and these models are currently being assessed.

In summary, there will be value and new insights from CMIP6 compared to CMIP5, but the nature of the model biases and the projections remain broadly similar to CMIP5.

Projected change to average annual rainfall between 1950-1999 and 2050-2099 under a very high emissions pathway (36 models for RCP8.5 in CMIP5; 29 models available for SSP5-85 in CMIP6), showing the multi-model mean rainfall and change with stippling (dots) indicating where less than two thirds of the models agree on the direction of change – there is high agreement on increase at the equator, but lower agreement elsewhere in both model groups – but perhaps more agreement in CMIP6 in some key regions.



6 Standardised scenario analysis

The future of the climate is determined by three main factors:

1) Ongoing, natural climate variability
2) Greenhouse gas and aerosol emissions pathways due to human activities and
3) The change in the climate that results from the emissions (the 'climate response')

A standardised future climate scenario analysis is a simple and useful way of understanding and quantifying potential ranges of climate change and associated hazards in terms of the emissions pathways and climate responses. This information can then be used in climate impact or risk assessments, in addition to the impact of ongoing climate variability (see, e.g. Sections 3 and 4).

Standardised future climate scenarios need to be both **representative** and **internally consistent:**

- ***Representative*** means covering or sampling the full range of plausible future climates including the range of plausible emissions pathways (RCPs) and the range of plausible climate responses to each emissions pathway – assessed using multiple lines of evidence including the results from different climate models.
- ***Internally consistent*** means that the changes in different climate variables (e.g. temperature and rainfall) make physical sense. When conducting risk assessments, a useful approach is to employ projections of different variables from a single climate model to ensure that projections are internally consistent. Mixing variables from different models (e.g. taking temperature from Model A while rainfall from Model B) into a single scenario may result in physically implausible combinations and is not recommended as best practice.

Here we describe a set of four representative, internally-consistent scenarios for the two regions of the Kiribati for the 2050 period (2040–2059) relative to 1986–2005, covering the full plausible range of emissions pathways and climate responses (temperature and rainfall) as well as a description of the dominant physical 'storyline' of the climate change processes behind each case.

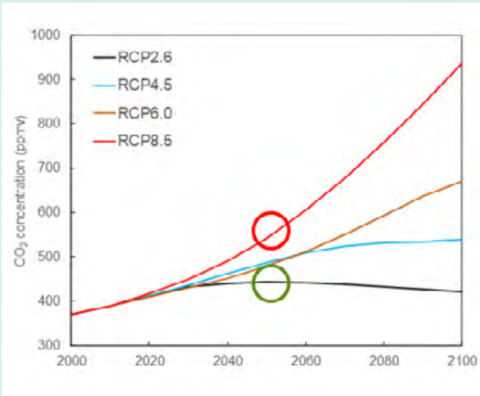
Please note that this is an illustration, it is not suitable for all purposes. A fully developed set of scenarios would need to be co-designed and co-produced between researchers and stakeholders in Kiribati, for the relevant climate variables, timeframe, location and level of impact. The information would then be tailored for a risk assessment by those stakeholders. Please refer to the Pacific Guidelines (CSIRO and SPREP, 2017) on how to use and apply climate change information for impact assessment.

Sampling the range of emissions and socio-economic pathways

To sample each end of the range of global greenhouse gas emissions and global socio-economic changes (also called to 'bookend' or 'bracket' the range), we consider two cases:

- ***High case*** – the world is following a high emissions pathway (RCP8.5) on track for 3-4°C global warming by 2100 (or even more), likely under the global 'Fossil-fuelled development' shared socio-economic pathway SSP5 (see Box 1).
- ***Low case*** – the world is following a pathway to decarbonise the economy leading to net zero emissions by 2070 (RCP2.6), giving a two-thirds chance of staying below 2°C global warming by 2100, likely under the 'Sustainability' SSP1 (see Box 1).

The carbon dioxide concentrations given by different RCPs through the century are indicated by the different coloured lines shown in the below diagram. The circles show the two cases and give perspective on the pathways they represent in terms of carbon dioxide concentrations (a major greenhouse gas).



Sampling the range of climate responses

For the High case and the Low case, the plausible range of change in temperature and rainfall can be assessed by looking at multiple well-performing climate models (Methods, Section 8) and each end of the change can be sampled (to ‘bookend’ or ‘bracket’ the range of possibilities here too).

The projections from all models can be plotted with temperature change on one axis and rainfall change on the other, producing a 2D shape or ‘uncertainty space’. This can be done for both the ***Low Case*** and ***High Case*** emission pathways (Figure 6.1).

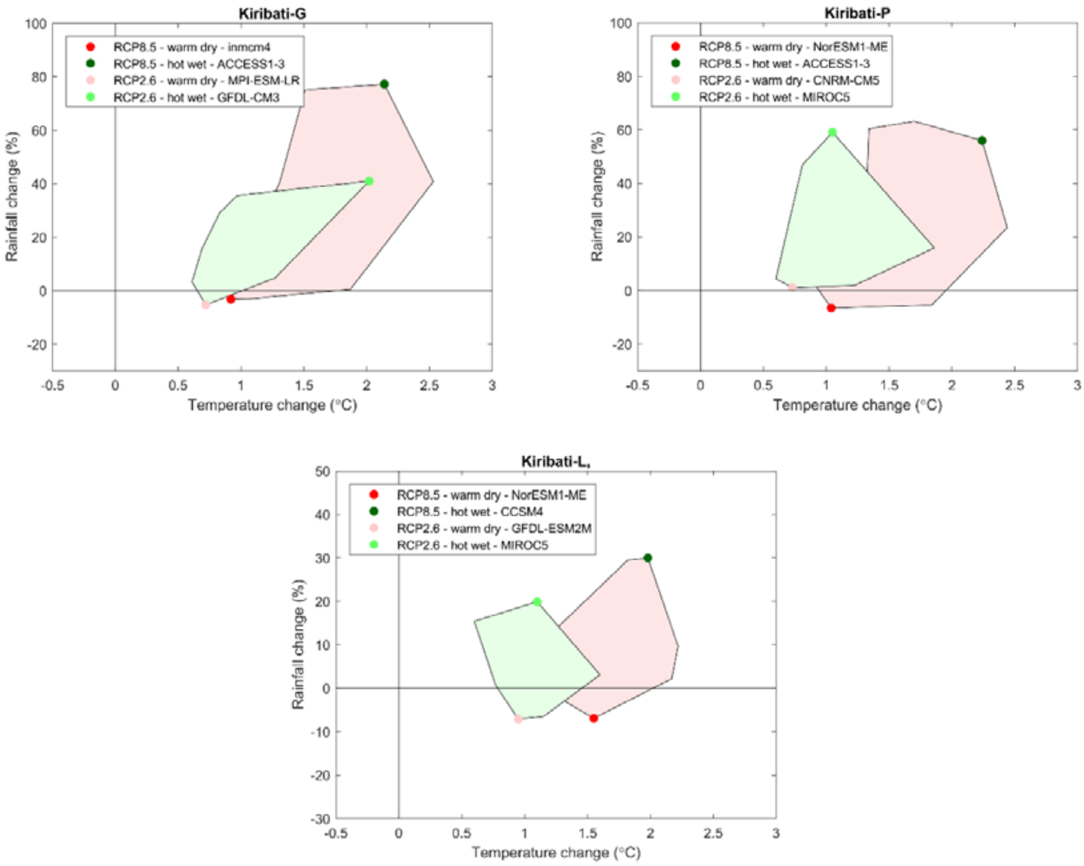


Figure 6.1 Modelled change in annual temperature and rainfall between 1986-2005 and 2040-2059 from CMIP5 models (coloured shapes) in the Kiribati sub-regions (G = Gilbert, P = Phoenix, L = Line), showing the selected models that are representative of a warm dry future and a hot wet future for RCP2.6 (low case RCP2.6: green polygon) and RCP8.5 (high case RCP8.5: red polygon).

Bookending the temperature and rainfall projections requires two scenarios for each emission pathway: (1) warmer and drier, (2) hotter and wetter. Risk assessments often require information about other climate variables such as extreme daily temperature, extreme daily rainfall, extreme daily windspeed, drought, humidity, solar radiation and sea level rise. Internally consistent projections for some of these variables can be included under each scenario (Table 6.1). Changes in annual mean rainfall are typically correlated with changes in annual mean soil moisture, humidity and solar radiation. These are indicative scenarios for an initial scan of impacts, but detailed impact/risk assessments may need to consider a more comprehensive range of scenarios tailored for specific regions, sectors or systems.

For the High Case emissions pathway, the range of change in annual temperature and rainfall can be seen as time series in Figure 6.2). The separation between the time series grows with time.

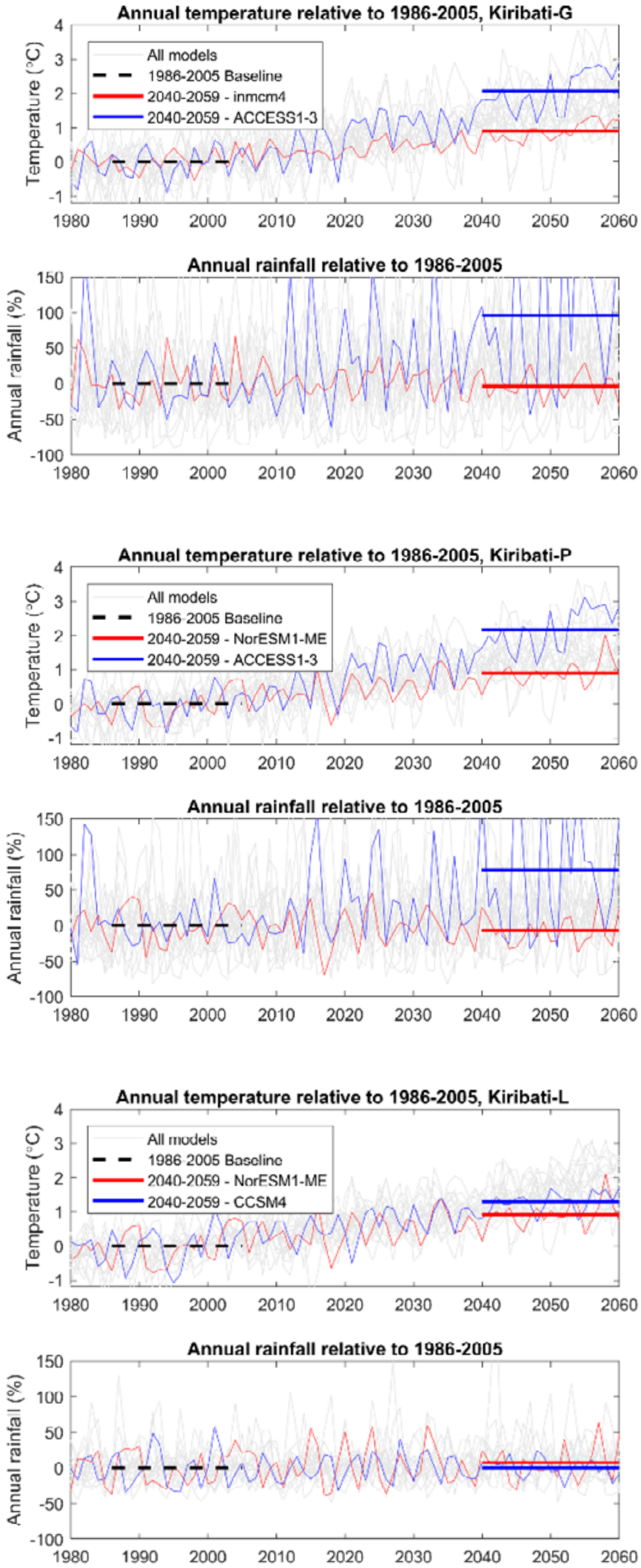


Figure 6.2 Modelled annual temperature (°C) and rainfall (%) changes relative to 1986-2005 from CMIP5 models in the Kiribati sub-regions (G = Gilbert, P = Phoenix, L = Line), showing the selected models that are representative of a warm dry future (red) and a hot wet future (blue).

Table 6.1: Standardised scenarios for Kiribati for the period 2040-2059 relative to 1986-2005 for low and high emission pathways and two climate change scenarios defined by the physical change 'storyline'.

	Scenario 1* Weaker equatorial warming	Scenario 2* Stronger equatorial warming
Low emissions (RCP2.6)	***Warmer & drier*** • Annual temperature: +0.8°C • Annual rainfall: 0 to -5% • More heatwaves • Less humidity • More solar radiation • Heavier rainfall events • Greater tropical cyclone impacts • Sea level rise: 17-29 cm	***Much warmer & wetter*** • Annual temperature: +1.0-2.0°C • Annual rainfall: +30% • More heatwaves • More humidity • Less solar radiation • Much heavier rainfall events • Greater tropical cyclone impacts • Sea level rise: 17-29 cm
High emissions (RCP8.5)	***Much warmer & drier*** • Annual temperature: +1.0°C • Annual rainfall: 0 to -5% • More heatwaves • Less humidity • More solar radiation • Heavier rainfall events • Greater tropical cyclone impacts • Sea level rise: 20-36 cm	***Hotter & much wetter*** • Annual temperature: +2.1°C • Annual rainfall: +60% • Many more heatwaves • More humidity • Less solar radiation • Much heavier rainfall events • Greater tropical cyclone impacts • Sea level rise: 20-36 cm

* These are indicative scenarios for an initial scan of impacts, but detailed impact/risk assessments may need to consider a more comprehensive range of scenarios tailored for specific regions, sectors or systems.

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Climate change storylines

We have more confidence in climate projections if there is a clear and convincing reason why the change would occur, drawing on multiple lines of evidence – this creates a climate 'storyline' of change backed up by evidence (Shepherd et al. 2018). If there is a range of possibilities that we can't currently narrow down, then it is useful to identify the 'storyline' behind each of the categories of possible change. In this way, we can plan for each of the possible future climates, while understanding what would cause them.

For temperature and rainfall change in Kiribati, there is a range of projected change, so we need to identify the plausible 'storyline' for each of the scenarios shown in the previous section. The climate of Kiribati has a similar range of drivers as the other countries very near the equator (see regions in Methods, Figure 8.2). The models that best represent the two storylines for the whole region are CNRM-CM5 for warmer and drier or little change, and ACCESS-1.3 for hotter and much wetter (similar models as used for Kiribati above).

For temperature, the change for a given RCP and timeframe relates largely to the global climate sensitivity (how much the climate responds to a given increase in greenhouse gases). The warmer and drier scenario has lower climate sensitivity and lower warming, while the hotter and much wetter scenario has higher climate sensitivity and so higher warming. However, the change is also partly related to the level of enhanced warming on the equator that will occur.

This level of 'equatorial response' also affects the change in rainfall (Grose et al. 2014a), where a stronger warming along the equator produces a greater rainfall increase (the shapes in Figure 6.1 above have the 'warm dry' to 'hot wet' diagonal orientation).

Looking at the ***High Case*** in Figure 6.3, the warm dry scenario has a lower enhanced equatorial warming and little change in rainfall. In contrast, the hot wet scenario has a much stronger equatorial response and a shift in the boundary of dominant rainbands, so Kiribati moves into a wetter zone.

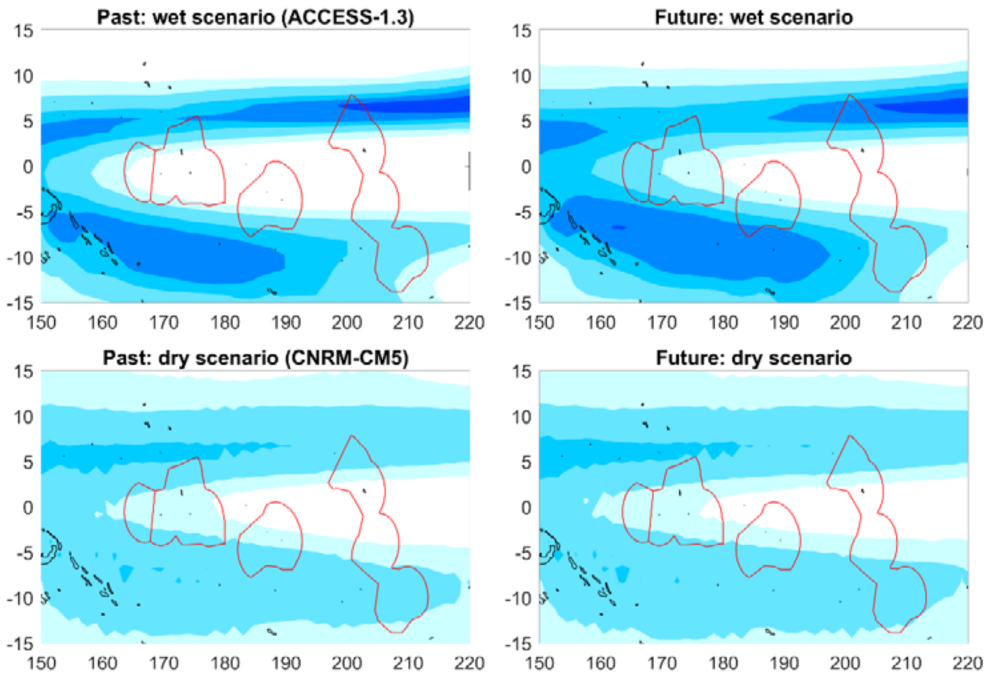

Figure 6.3 The mean annual rainfall of the western tropical Pacific (bluer is wetter) in the 1986-2005 (past) and the 2040-2059 (future) periods as simulated in the models used to represent the warm and dry scenario (top) and the hot and wet scenario (bottom).

The result of these storylines can be seen as either a strong warming and increase on the equator, or a more even warming pattern and little change in rainfall (Figure 6.4). Both scenarios are plausible given our current understanding of processes driving climate change in the region. With further research, we may be able to have more certain projections of the equator, reject non-plausible cases and present a narrower range of projected change. But for the moment we should consider both these scenarios, or anywhere in between, as possible. The scenarios are similar in nature but with smaller changes in the ***Low Case.***

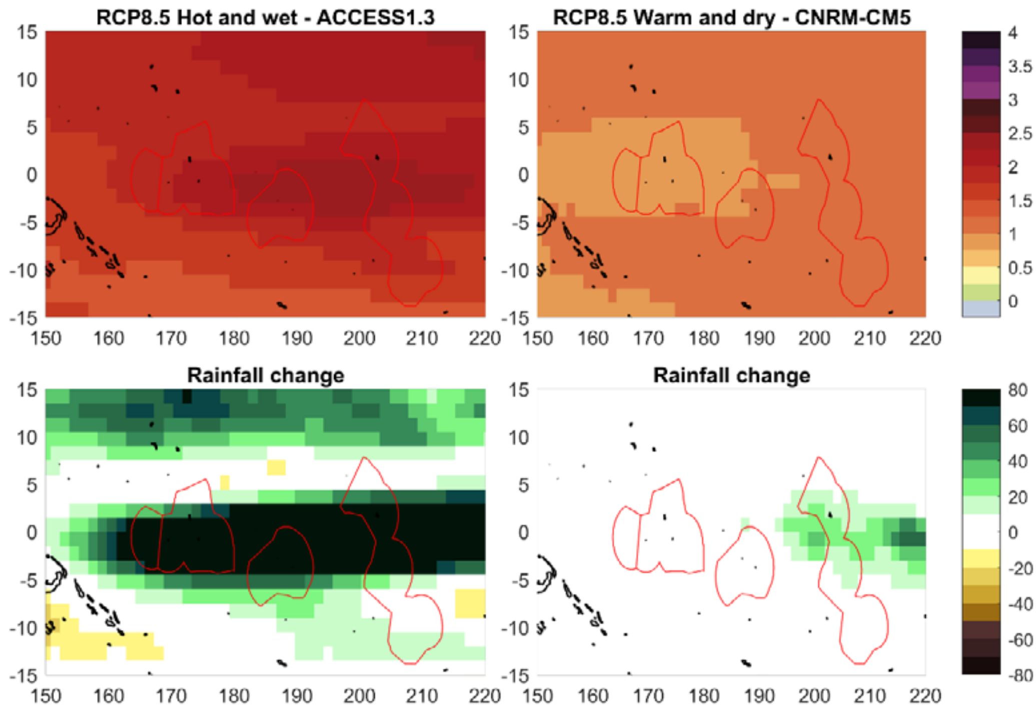

Figure 6.4 Map of projected change for mean annual temperature (left panels, °C) and rainfall (right panels, %) between 1986-2005 to 2040-2059 under RCP8.5 in the two scenarios for the ***High Case***

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7 Assessing impacts using these approaches

There are various historical and projected changes in this report, including:

- Historical changes between different baseline periods
- Future changes for different emissions scenarios and time frames
- Future changes for different global warming levels
- Future change at 2050 using standardised scenarios with storylines and representative climate models.

Here's how you can look in detail at what this means to the average climate of Kiribati.

Observations at a weather station or as gridded data describe the local conditions today. If we want to see what a different average climate looks like, we can use the observed dataset and apply the changes to that – i.e. apply a 'change factor' or 'scaling factor'. This will create a dataset that represents a different climate – warmer or hotter, wetter or drier. A past change can be applied, or else a future projected change. If a particular threshold is important – for example an amount of annual rainfall or a particular average temperature for growing a crop, then this can be compared in the past, present and future climate datasets.

This simple example shows how we can take the annual average temperature of 1986-2005, then apply changes from the report (a 'scaling factor') to this data and see how this changes the area within the 29°C contour line (Figure 7.1). This can be relevant to real questions, for example the ideal growing conditions for a crop or design criteria for infrastructure may be 29°C. In the current climate, Tarawa is close to this level, and would exceed it in future if the world reaches 2°C global warming since pre-industrial (taken as the model average value of around 1.7°C from 1850-1900 or around 1.1°C from 1986-2005 for Gilbert Islands). Tarawa would be above 29°C mean annual temperature at the upper range of plausible warming by 2050.

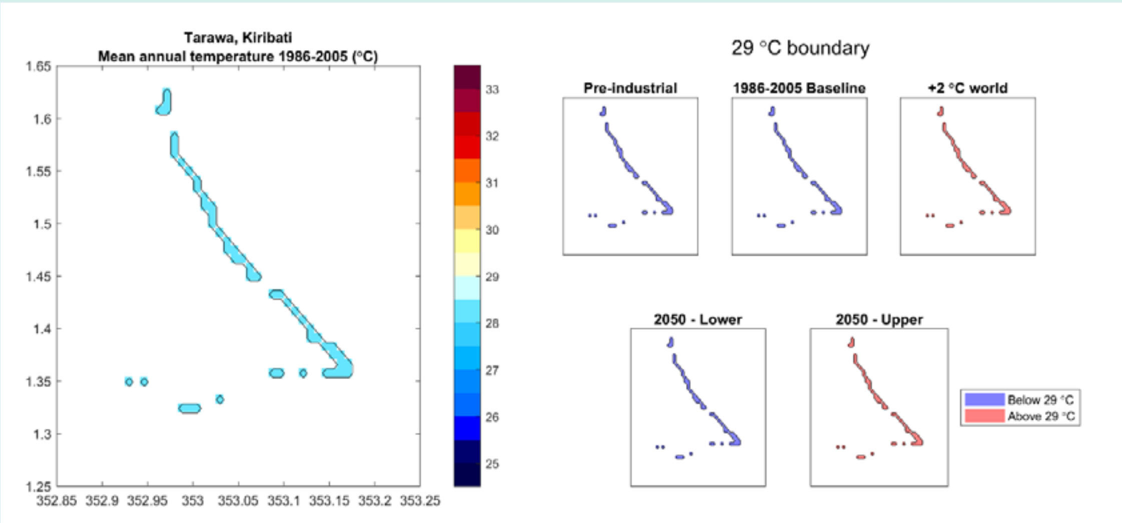
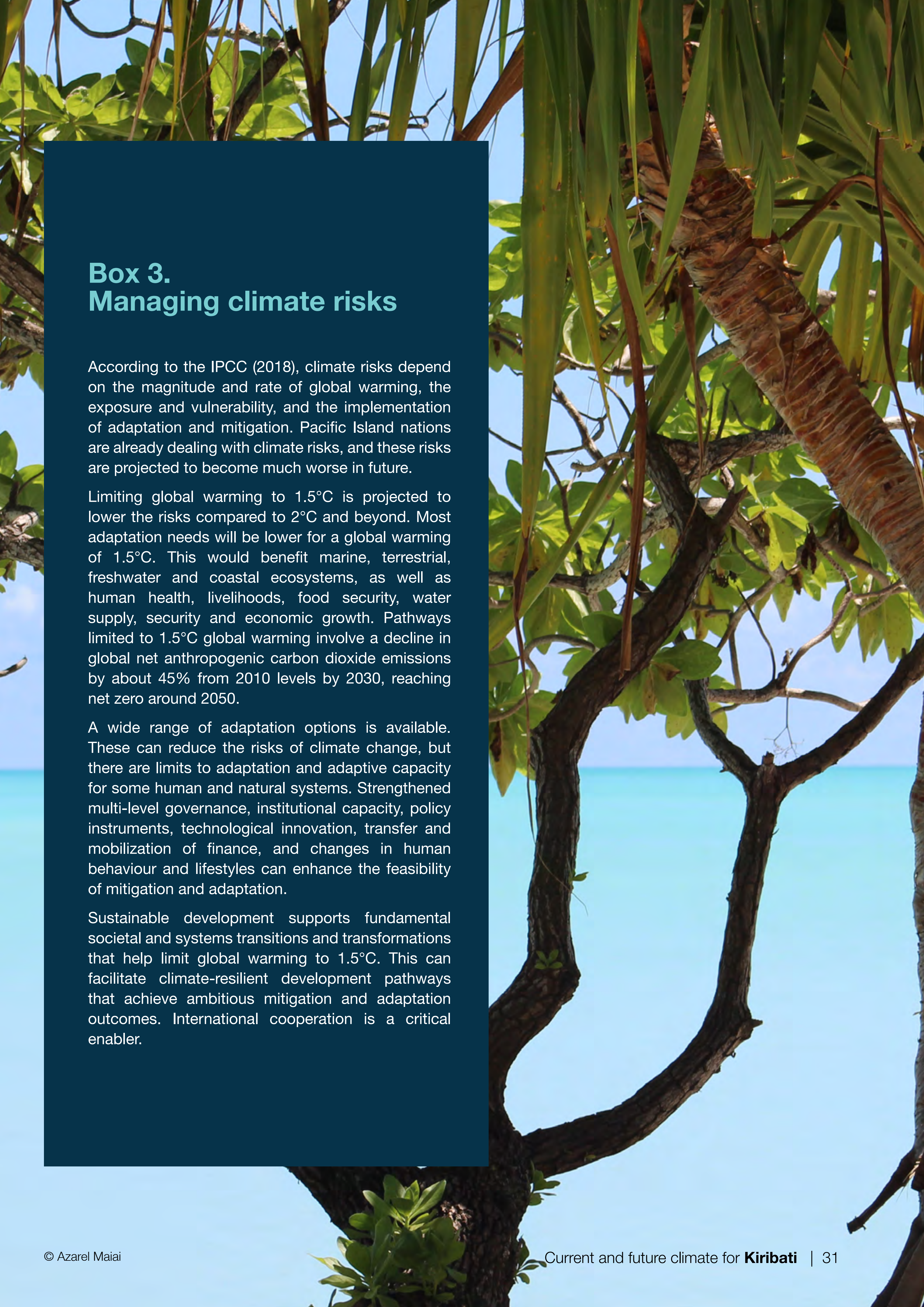


Figure 7.1. The average annual temperature in 1986-2005 in Kiribati (left: the 'WorldClim' high-resolution climate surface adjusted for the baseline used, showing the four land grid cells for the region and the approximate outline of the atoll boundary), and the area of the island above or below the 29°C boundary for various scenarios (right).

In addition to changes in the mean climate, impact assessment requires information about changes to extreme hazards, the exposure (e.g. people, assets, crops affected by the change in hazard) and vulnerability (the susceptibility to damage). For example, if projected changes in average temperature for 2050 are applied to historical daily temperature data, the output represents daily temperature data for 2050 which can be analysed for extreme events such as days over 30°C.

Hazard, exposure and vulnerability can be brought together to understand the impact, evaluate adaptation options and implement actions. This can be co-designed and investigated in a joint program with relevant stakeholders and researchers.



Box 3. Managing climate risks

According to the IPCC (2018), climate risks depend on the magnitude and rate of global warming, the exposure and vulnerability, and the implementation of adaptation and mitigation. Pacific Island nations are already dealing with climate risks, and these risks are projected to become much worse in future.

Limiting global warming to 1.5°C is projected to lower the risks compared to 2°C and beyond. Most adaptation needs will be lower for a global warming of 1.5°C. This would benefit marine, terrestrial, freshwater and coastal ecosystems, as well as human health, livelihoods, food security, water supply, security and economic growth. Pathways limited to 1.5°C global warming involve a decline in global net anthropogenic carbon dioxide emissions by about 45% from 2010 levels by 2030, reaching net zero around 2050.

A wide range of adaptation options is available. These can reduce the risks of climate change, but there are limits to adaptation and adaptive capacity for some human and natural systems. Strengthened multi-level governance, institutional capacity, policy instruments, technological innovation, transfer and mobilization of finance, and changes in human behaviour and lifestyles can enhance the feasibility of mitigation and adaptation.

Sustainable development supports fundamental societal and systems transitions and transformations that help limit global warming to 1.5°C. This can facilitate climate-resilient development pathways that achieve ambitious mitigation and adaptation outcomes. International cooperation is a critical enabler.

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8 Data and Methods

For assessment of historical temperature in the Kiribati region, we use five global observed datasets: HadCRUT5 (1850–2020; Morice et al., 2021), Berkeley Earth (1850–2019; Rohde and Hausfather, 2020), NOAA GlobalTemp (1880–2019; Huang et al., 2020; Zhang et al. 2020), Cowtan and Way (1850–2019; Cowtan and Way, 2014) and GISTEMP (1880–2019; Lenssen et al., 2019). For rainfall, we rely on the CMAP and GPCP merged gauge-satellite monthly precipitation datasets available from 1979 (see Yin et al. 2004 for a discussion and comparison of these), and ERA5 reanalysis rainfall data (1979-2020; Hersbach et al. 2020).

Gridded datasets use records from weather stations, satellite data and other sources, then fill in gaps in space and time. Therefore, the changes and trends in these gridded datasets agree with those in the underlying weather stations in general (see McGree et al. 2019) but are not exactly the same. Early periods include fewer weather observations with fewer supplementary data sources to draw upon, so these rely more heavily on the filling in across time and space and are therefore less reliable.

For the future climate, this report uses climate modelling output from the Coupled Model Inter-comparison Project phase 5 (CMIP5) of Taylor et al. (2012). The outputs from up to 36 climate models are used to show the ranges of possible change (Table 8.1), but detailed analyses and models we choose for scenario analyses are taken from a group of 21 models for RCP8.5 and RCP4.5, and 17 models for RCP2.6 that have passed evaluation tests (see Grose et al. 2014b), and we have information about changes to climate features such as the equatorial warming.

Projections are examined using three of the RCPs from van Vuuren et al., (2011): RCP2.6, RCP4.5 and RCP8.5 (there is also a RCP6.0, not used here). The RCPs are based on future pathways of all the major greenhouse gases, aerosols and land-use changes through the century, and are given a value based on the change in 'radiative forcing' by the year 2100 (Figure 8.1).

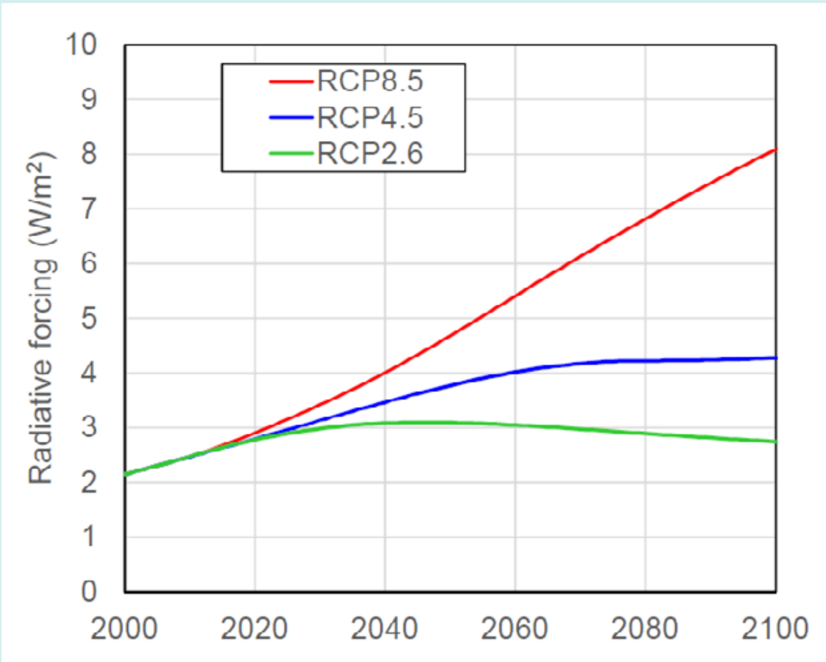

Figure 8.1. The enhanced greenhouse effect (or 'radiative forcing') in the three Representative Concentration Pathways (RCPs) used in this report. The three RCPs can be broadly thought of as a very high pathway with accelerating global emissions (RCP8.5), an intermediate pathway where emissions plateau (RCP4.5), and an ambitious decarbonisation pathway, roughly consistent with the Paris Agreement goal to keep global warming below 2°C (RCP2.6).

Average temperature and rainfall for the Kiribati region are analysed and plotted in different ways to show historical and future context.

- To calculate changes at different 'global warming levels', e.g., 2°C global warming, 'time sampling' methods are employed (see James et al. 2017).
- Break points between different eras were detected by a statistical function that minimises the cost function (Matlab software: https://au.mathworks.com/help/matlab/ref/ischange.html)
- Representative climate scenarios for 2050 are derived from comparing the range of change in temperature and rainfall from the range of climate model outputs, and in understanding the most important drivers of change for this region, as described in the scientific literature. The dominant drivers of rainfall change are examined for the following regions:

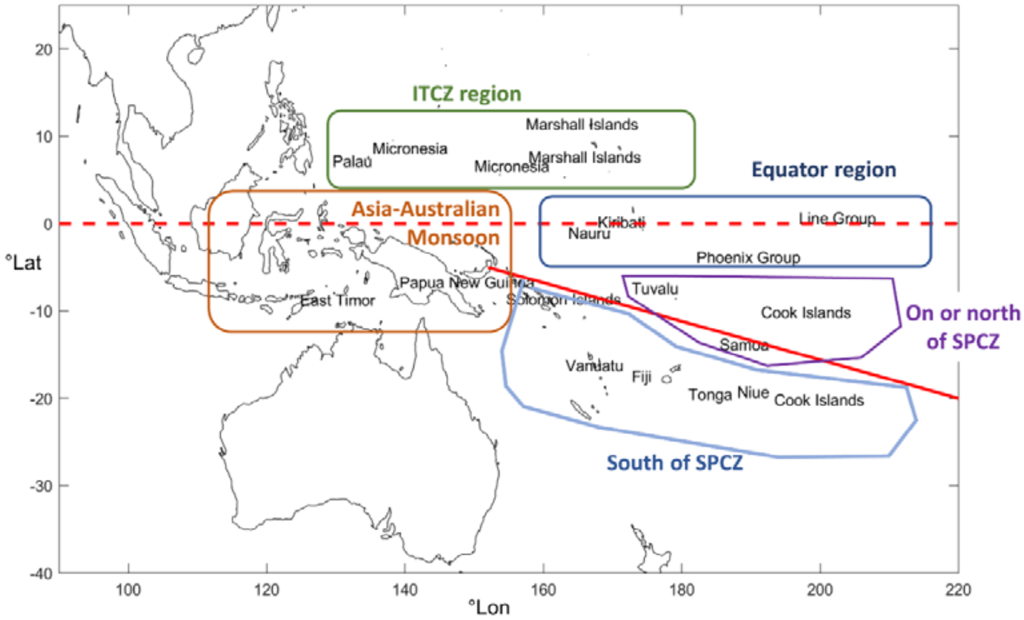

Figure 8.2. Map of the western Pacific showing the sub-regions used for developing representative scenarios with attached storylines. Red line shows the average position of the centre of the SPCZ in the current climate, red dashed line shows the equator. Kiribati is in the "Equator" zone, outlined in dark blue.

Table 8.1. CMIP5 models used in this report. While all models had RCP8.5 simulations available, a subset had RCP2.6 simulations, and the subset of models with evaluation information is also indicated.

No.	Name	Evaluated	RCP2.6	No.	Name	Evaluated	RCP2.6
1	'ACCESS1-0'	Yes		19	'GISS-E2-H'	Yes	Yes
2	'ACCESS1-3'	Yes		20	'GISS-E2-H-CC'		
3	'bcc-csm1-1'	Yes	Yes	21	'GISS-E2-R'	Yes	Yes
4	'bcc-csm1-1-m'		Yes	22	'GISS-E2-R-CC'		
5	'BNU-ESM'		Yes	23	'HadGEM2-AO'		Yes
6	'CanESM2'	Yes	Yes	24	'HadGEM2-CC'	Yes	
7	'CCSM4'	Yes	Yes	25	'HadGEM2-ES'	Yes	Yes
8	'CESM1-BGC'			26	'inmcm4'	Yes	
9	'CESM1-CAM5'		Yes	27	'IPSL-CM5A-LR'	Yes	Yes
10	'CMCC-CESM'			28	'IPSL-CM5A-MR'	Yes	Yes
11	'CMCC-CM'			29	'IPSL-CM5B-LR'		
12	'CMCC-CMS'			30	'MIROC5'	Yes	Yes
13	‘CNRM-CM5’	Yes	Yes	31	'MPI-ESM-LR'	Yes	Yes
14	'FGOALS-s2'		Yes	32	'MPI-ESM-MR'		Yes
15	'FIO-ESM'		Yes	33	'MRI-CGCM3'	Yes	Yes
16	'GFDL-CM3'	Yes	Yes	34	'MRI-ESM1'		
17	'GFDL-ESM2G'	Yes	Yes	35	'NorESM1-M'	Yes	Yes
18	'GFDL-ESM2M'	Yes	Yes	36	'NorESM1-ME'	Yes	Yes

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