CLIMATE RISK COUNTRY PROFILE

MARSHALL ISLANDS

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This profile is part of a series of Climate Risk Country Profiles that are developed by the World Bank Group (WBG). These profiles synthesize the most relevant data and information on climate change, disaster risk reduction, and adaptation actions and policies at the country level. The profile is designed as a quick reference source for development practitioners to better integrate climate resilience in development planning and policy making. This effort is co-led by Veronique Morin (Senior Climate Change Specialist, WBG) and Ana E. Bucher (Senior Climate Change Specialist, WBG).

This profile was written by Alex Chapman (Consultant, NEF Consulting), Denyse Dookie (Consultant,), William Davies (Consultant, NEF Consulting), Ciaran Downey (NEF Consulting) and MacKenzie Dove (Senior Climate Change Consultant, WBG). Technical review of the profiles was undertaken by Robert L. Wilby (Loughborough University). Additional support was provided by Megumi Sato (Junior Professional Officer, WBG), Jason Johnston (Operations Analyst, WBG) and Yunziyi Lang (Climate Change Analyst, WBG). This profile also benefitted from inputs of WBG regional staff and country teams.

Climate and climate-related information is largely drawn from the Climate Change Knowledge Portal (CCKP), a WBG online platform with available global climate data and analysis based on the current Intergovernmental Panel on Climate Change (IPCC) reports and datasets. The team is grateful for all comments and suggestions received from the sector, regional, and country development specialists, as well as climate research scientists and institutions for their advice and guidance on use of climate related datasets.

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FOREWORD

Climate change is a major risk to good development outcomes, and the World Bank Group is committed to playing an important role in helping countries integrate climate action into their core development agendas. The World Bank Group is committed to supporting client countries to invest in and build a low-carbon, climate-resilient future, helping them to be better prepared to adapt to current and future climate impacts.

The World Bank Group is investing in incorporating and systematically managing climate risks in development operations through its individual corporate commitments.

A key aspect of the World Bank Group's Action Plan on Adaptation and Resilience (2019) is to help countries shift from addressing adaptation as an incremental cost and isolated investment to systematically incorporating climate risks and opportunities at every phase of policy planning, investment design, implementation and evaluation of development outcomes. For all IDA and IBRD operations, climate and disaster risk screening is one of the mandatory corporate climate commitments. This is supported by the World Bank Group's Climate and Disaster Risk Screening Tool which enables all Bank staff to assess short- and long-term climate and disaster risks in operations and national or sectoral planning processes. This screening tool draws up-to-date and relevant information from the World Bank Group's Climate Change Knowledge Portal, a comprehensive online 'one-stop shop' for global, regional, and country data related to climate change and development.

Recognizing the value of consistent, easy-to-use technical resources for client countries as well as to support respective internal climate risk assessment and adaptation planning processes, the World Bank Group's Climate Change Group has developed this content. Standardizing and pooling expertise facilitates the World Bank Group in conducting initial assessments of climate risks and opportunities across sectors within a country, within institutional portfolios across regions, and acts as a global resource for development practitioners.

For developing countries, the climate risk profiles are intended to serve as public goods to facilitate upstream country diagnostics, policy dialogue, and strategic planning by providing comprehensive overviews of trends and projected changes in key climate parameters, sector-specific implications, relevant policies and programs, adaptation priorities and opportunities for further actions.

It is my hope that these efforts will spur deepening of long-term risk management in developing countries and our engagement in supporting climate change adaptation planning at operational levels.

Bernice Van Bronkhorst
Global Director
Climate Change Group (CCG)
The World Bank Group (WBG)

KEY MESSAGES

- The Republic of the Marshall Islands' (RMI) island groups have experienced warming of around 0.6°C since 1980.
- Future trends in warming are obscured by the inability of climate models to accurately simulate trends at sufficiently small spatial scales. Warming is likely to take place at a rate slightly lower than the global average. On the highest emissions pathway (RCP8.5) warming of around 2.8°C is projected by the end of the century.
- RMI faces a diverse set of risks from climate change; however, data and reliable model projections are lacking, presenting challenges for decision makers.
- Potential threats to human well-being and natural ecosystems include increased prevalence of heat wave, intensified cyclones, saline intrusion, wave-driven flooding, and permanent inundation.
- Biodiversity and the natural environment of RMI face extreme pressure, and loss of some species of fish, coral, bird, and terrestrial species is likely without very effective conservation measures.
- RMI faces a potential long-term threat from permanent inundation and wave-driven flooding, and some studies have suggested that many of its low-lying islands will become uninhabitable within the 21st century.
- Other research has suggested that the risk of large-scale net loss of land may previously have been overstated and if natural processes and assets, such as coral reefs are conserved, human inhabitancy might be sustained over the long-term.
- RMI's population already lives in a dynamic ecosystem, to which it has adapted, but climate change is likely to increase its variability, pose new threats, and place stress on livelihoods.
- Communities are likely to need support to adapt and manage disaster risks facing their wellbeing, livelihoods, and infrastructure. Geographic isolation and economic vulnerabilities, including dependence on remittance and foreign aid, will increase the challenges faced by communities and decision makers.

COUNTRY OVERVIEW

As part of the larger island grouping of Micronesia, the Republic of the Marshall Islands (RMI) consists of two groups of atolls and islands in the Central North Pacific Ocean about 3,200 kilometres (km) away from both Honolulu and Tokyo.[1] 22 of the 29 atolls and four out of the five small raised coral islands are inhabited; the atoll islands are rarely more than 200 metres (m) in width and almost all of the land is below 2 m.[1] The Marshall Islands has a moist, tropical climate, heavily influenced by the north-east trade wind belt. Annual rainfall varies considerably from north to south within the archipelago, with atolls in the south receiving 300–340 centimetres (cm) rainfall annually, perhaps as much as 3 times more than northern atolls. The average annual temperature and monthly means are generally consistent at around 27°C, with a maximum daily variation of about 7°C.[1] Most of the RMI's population of approximately 59,194 persons (2020),[2] live in the capital city, Majuro. 92% of the population identifies as Marshallese, and the official language, Marshallese, is spoken by more than 98% of people.

[1] Subbarao, S. & Mucadam, R. (2015). Second National Communication of the Republic of the Marshall Islands. United Nations Development Program/Global Environment Facility. Suva, Fiji. URL: https://unfccc.int/sites/default/files/resource/mhlnc2.pdf [accessed 10/07/2019]

[2] World Bank (2021). Development Indicators. DataBank. URL: https://databank.worldbank.org/source/world-development-indicators [accessed 10.19/2021]

The RMI has a unique and close relationship with the United States (US). In 1944, the US gained military control of the country from Japan, and assumed administrative control of the country under United Nations auspices as part of the Trust Territory of the Pacific Islands following the end of World War II.[3] In 1983, the RMI signed a Compact of Free Association with the US and gained independence in 1986 with the Compact's entry into force. Under this Compact, the US provided defence, subsidies and access to social services, and in 2003, this agreement was amended to provide around US$70 million each year over the period 2004–2024.[1,3] Since independence, external assistance and grants have formed 60% of government revenue.[1]

In addition to this dependence on external assistance, the RMI faces a variety of social vulnerabilities, much like many other small island developing states (SIDS). Issues of geographical remoteness, a small sparsely-distributed population, distance to international import and export markets, and associated high costs of transportation, small domestic market, challenges of achieving economies of scale of production, and very high energy costs, as well as few natural resources, all hinder economic development potential.[1] The RMI is heavily reliant on imports – agricultural production is primarily subsistence-based, and small-scale industry is limited to handicrafts, tuna processing and copra.[1] Although tourism is not a major source of foreign exchange, as it is in other Pacific island countries, the industry accounts for about 10% of the local labor market.[1] While many official basic indicator data are not available for the RMI (**Table 1**), using 2011 census data it was estimated that 37% of the total population live below the "basic-needs income line".[4] While 30% of residents in the two main urban centres (Majuro and Ebeye) are estimated below this line, these numbers could double in the outer islands. Such deepening poverty, amidst "growing concerns over high unemployment, financial hardship, hunger and poor nutrition",[4] are noted in the context of a vulnerability to "transnational threats, natural disasters, and the potential effects of climate change".[3]

The Marshall Islands face a high risk of cyclones, and the low-lying islands are susceptible to coastal floods and tsunamis.[5] Extreme heat and drought conditions have also recently affected the islands. In late 2015/early 2016, below average rainfall, exacerbated by El Niño, induced local drought conditions and water shortages. EM-DAT data estimates that the drought affected more than half the population, with resulting economic damages estimated at just under US$5 million.[6] While this event remains the most severe disaster for the country, the potential for disaster risk in the RMI is high due to the combination of economic and physical vulnerability, and the islands' proneness to natural hazards (it is also noted that previous nuclear testing on some of the atolls have made them uninhabitable[7]), and is further exacerbated by climate change and variability. The risks faced by the Marshall Islands have been set out in several communications to the United Nations, including republic's Second National Communication to the UNFCCC (2015); the RMI is also noted for being the first country to submit its ambitious Second Nationally Determined Contribution (2020) to the Paris Climate Agreement.[8]

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3 US Department of State (2018). U.S. Relations with Marshall Islands. URL: https://www.state.gov/u-s-relations-with-marshall-islands/ [accessed 15/07/2019]

4 Johnson, J. (2016). ADB report: Poverty rate high in Marshall Islands. Marianas Variety online April 19 2016. URL: http://www.mvariety.com/regional-news/88542-adb-report-poverty-rate-high-in-marshall-islands [accessed 15/07/2019]

5 GFDRR (2016). ThinkHazard! Profile for the Marshall Islands. URL: http://thinkhazard.org/ [accessed 15/07/2019]

6 EMDAT (2019). Emergency Events Database. URL: https://www.emdat.be/ [accessed 15/07/2019]

7 Dvorsky, G. (2019). Radiation Levels at the Marshall Islands Remain Disturbingly High. 15/07/2019. URL: https://gizmodo.com/radiation-levels-at-the-marshall-islands-remain-disturb-1836382678 [accessed 15/07/2019]

8 Mead, L. (2018). Marshall Islands Becomes First Country to Submit Second, More Ambitious NDC. 28/11/2018. URL: https://sdg.iisd.org/news/marshall-islands-becomes-first-country-to-submit-second-more-ambitious-ndc/

Green, Inclusive and Resilient Recovery

The coronavirus disease (COVID-19) pandemic has led to unprecedented adverse social and economic impacts. Further, the pandemic has demonstrated the compounding impacts of adding yet another shock on top of the multiple challenges that vulnerable populations already face in day-to-day life, with the potential to create devastating health, social, economic and environmental crises that can leave a deep, long-lasting mark. However, as governments take urgent action and lay the foundations for their financial, economic, and social recovery, they have a unique opportunity to create economies that are more sustainable, inclusive and resilient. Short and long-term recovery efforts should prioritize investments that boost jobs and economic activity; have positive impacts on human, social and natural capital; protect biodiversity and ecosystems services; boost resilience; and advance the decarbonization of economies.

This document aims to summarise the climate risks faced by the Marshall Islands. This includes rapid onset and long- term changes in key climate parameters, as well as impacts of these changes on communities, livelihoods and economies, many of which are already underway. This is a high-level synthesis of existing research and analyses, focusing on the geographic domain of the Marshall Islands, therefore potentially excluding some international influences and localized impact. The core climate projections presented are sourced from the Pacific-Australia Climate Change Science and Adaptation Planning Program,[9,10] as well as the World Bank Group's Climate Change Knowledge Portal (CCKP), incorporating climate projections from the Coupled Model Inter-comparison Project Phase 5 (CMIP5). This document is primarily meant for WBG staff to inform their climate actions. The document also aims to direct the reader to many useful sources of secondary data and research.

[9] Australian Bureau of Meteorology and CSIRO (2014). Climate Variability, Extremes and Change in the Western Tropical Pacific: New Science and Updated Country Reports. Pacific-Australia Climate Change Science and Adaptation Planning Program Technical Report, Australian Bureau of Meteorology and CSIRO, Melbourne, Australia. URL: https://www.pacificclimatechangescience.org/wp-content/uploads/2014/07/PACCSAP_CountryReports2014_WEB_140710.pdf

[10] The NextGen projections for the Pacific region under CMIP5 are expected to be available from late 2021. These will provide an update on the PACCSAP 2014 projections referenced in this profile. The process for providing the new NextGen CMIP6 projections for the Pacific is still in the planning phase.

TABLE 1. Key indicators

Indicator	Value	Source
Population Undernourished[11]	N/A	FAO, 2020
National Poverty Rate[12]	N/A	ADB, 2020a
Share of Wealth Held by Bottom 20%[13]	N/A	World Bank, 2021
Net Annual Migration Rate[14]	N/A	UNDESA, 2019
Infant Mortality Rate (Between Age 0 and 1)[15]	N/A	UNDESA, 2019
Average Annual Change in Urban Population[16]	0.6% (2015–20)	UNDESA, 2019
Dependents per 100 Independent Adults[17]	N/A	UNDESA, 2019
Urban Population as % of Total Population[18]	78% (2020)	CIA, 2020
External Debt Ratio to GNI[19]	32.8% (2018)	ADB, 2020b
Government Expenditure Ratio to GDP[20]	60.1% (2018)	ADB, 2020b

CLIMATOLOGY

Climate Baseline

Overview

The Republic of the Marshall Islands has a warm, tropical climate year-round, with average temperatures around 27°C and annual precipitation of approximately 350 cm. Two seasons are recognised: a wet season that occurs between May and November and a drier season between December and April. Climate in this part of the Pacific is governed by a number of factors, including the trade winds and the movement of the South Pacific Convergence Zone (SPCZ), a zone of low-pressure rainfall that migrates across the Pacific south of the equator, which is also the

[11] FAO, IFAD, UNICEF, WFP, WHO (2020). The state of food security and nutrition in the world. Building Resilience for peace and food security. FAO. Rome. URL: http://www.fao.org/documents/card/en/c/ca9692en/

[12] ADB (2020a). Basic Statistics 2020. URL: https://www.adb.org/publications/basic-statistics-2020

[13] World Bank (2021). Income share held by lowest 20%. URL: https://data.worldbank.org/indicator/SI.DST.FRST.20 [accessed 10/19/2021]

[14] UNDESA (2019). World Population Prospects 2017. URL: https://population.un.org/wpp/Download/Standard/Population/ [accessed 15/02/2021]

[15] UNDESA (2019). World Population Prospects 2019. URL: https://population.un.org/wpp/Download/Standard/Population/ [accessed 15/02/2021]

[16] UNDESA (2019). World Urbanization Prospects 2019. URL: https://population.un.org/wup/Download/ [accessed 15/02/2021]

[17] UNDESA (2019). World Population Prospects 2019. URL: https://population.un.org/wpp/Download/Standard/Population/ [accessed 15/02/2021]

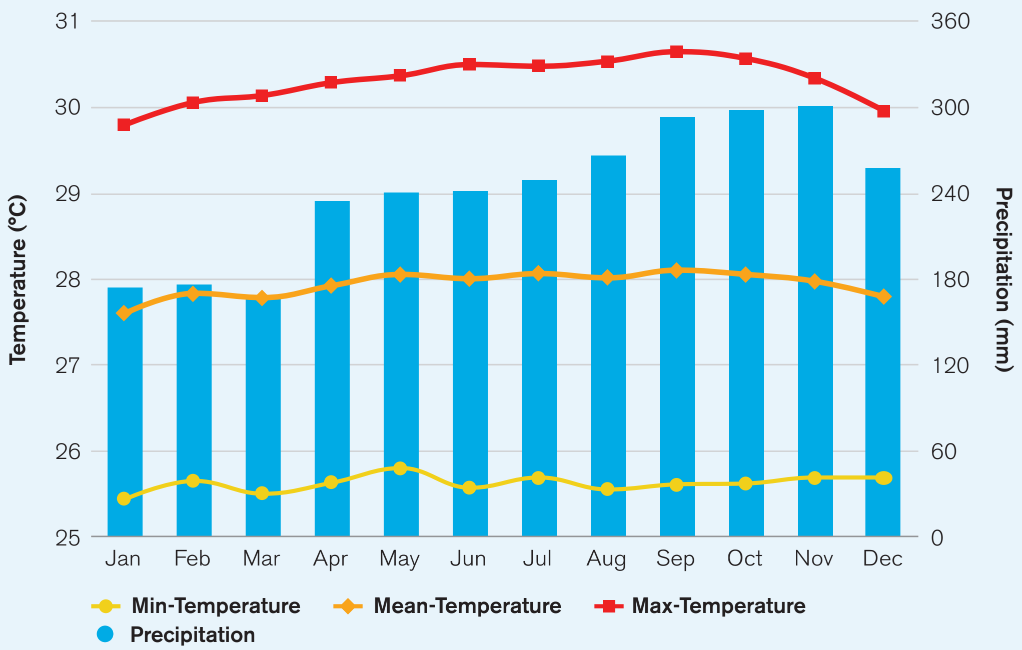
[18] CIA (2020). *The World Factbook*. Central Intelligence Agency. Washington DC. URL: https://www.cia.gov/the-world-factbook/

[19] ADB (2020b). Key Indicators for Asia and the Pacific 2020, 51st Edition. Asian Development Bank. Manila. URL: https://www.adb.org/sites/default/files/publication/632971/ki2020.pdf

[20] ADB (2020b). Key Indicators for Asia and the Pacific 2020, 51st Edition. Asian Development Bank. Manila. URL: https://www.adb.org/sites/default/files/publication/632971/ki2020.pdf

largest and most persistent spur of the Inter-tropical Convergence Zone (ITCZ).[21] Year-to-year variability in climate is also strongly influenced by the El Niño conditions in the southeast Pacific, which bring drought conditions to the Republic of the Marshall Islands.[10] **Figure 1** shows the most recent climatology for observed temperature and precipitation across the seasonal cycle , for the latest climatology, 1991–2020.

FIGURE 1. Average monthly mean, max, and min temperatures and rainfall in the Marshall Islands, 1991–2020[22]



Key Trends

Temperature

RMI's Second National Communication to the UNFCCC suggests evidence of warming trends across the islands; these trends are consistent with global warming trends.[1] There have been observed increases in the annual and half-year mean temperatures at Majuro (southern Marshall Islands) since 1955 and at Kwajalein (northern Marshall Islands) since 1952, which are statistically significant at the 5% level. Maximum and minimum temperature trends at Kwajalein are much stronger compared to Majuro, although it seems that the rate of change has been faster at Majuro. Additionally, the frequency of Warm Days for the region has increased while the number of Cool Nights has decreased at both Majuro and Kwajalein. For the Pacific region, data from the World Bank's Climate Change Knowledge Portal, summarises that mean temperatures across the South Pacific have increased by approximately 1°C since 1970, at an average rate of 0.3°C per decade, and the number of hot days and hot nights has increased significantly across the Pacific.[22] The Berkeley Earth Dataset on historical warming shows a significant increase in

[21] Linacre, E. & Geerts, B. (1998). Movement of the South Pacific Convergence Zone. URL: http://www-das.uwyo.edu/~geerts/cwx/notes/chap12/spcz.html [accessed 16/07/2019]

[22] World Bank Climate Change Knowledge Portal (2021). Marshall Islands. Available at: https://climateknowledgeportal.worldbank.org/country/marshall-islands

the rate of warming post-1980, suggesting that the over the subsequent 40 year period the climate in the vicinity of the Marshall Islands warmed by approximately 0.6°C.[23]

Precipitation

Based on the RMI's Second National Communication to the UNFCCC, there is evidence of a decreasing trend in annual rainfall at Majuro (southern Marshall Islands), statistically significant at the 5% level, since 1954.[1] The report indicates that this could be due to a shift in the mean location of the ITCZ away from Majuro and/or a change in the intensity of rainfall associated with the ITCZ. As well, there has also been a decrease in the number of Very Wet Days since 1953. Notable inter-annual variability associated with the El Niño-Southern Oscillation (ENSO) phenomenon is evident in the observed rainfall records for Majuro since 1954 and Kwajalein since 1945. The remaining annual, seasonal and extreme rainfall trends at Majuro and Kwajalein show little change.

Climate Future

RCPs

The Representative Concentration Pathways (RCPs) represent four plausible futures, based on the rate of emissions reduction achieved at the global level. Four RCPs (i.e. RCP2.6, RCP4.5, RCP6.0, and RCP8.5) were selected and defined by their total radiative forcing (cumulative measure of GHG emissions from all sources) pathway and level by 2100. In this analysis, RCP2.6 and RCP8.5, the low and high emissions pathways, are the primary focus; RCP2.6 represents a very strong mitigation scenario, whereas RCP8.5 assumes a high-emissions scenario. For reference, **Table 2** provides information on all four RCPs over two-time horizons. In subsequent analysis RCPs 2.6 and 8.5, the low and high emissions pathways, are the primary focus. RCP2.6 would require rapid and systemic global action, achieving significant emissions reduction throughout the 21st century. RCP8.5 assumes annual global emissions will continue to increase throughout the 21st century. Climate changes under each emissions pathway are presented against a reference period of 1986–2005 for all indicators. For more information, please refer to the RCP Database.

A Precautionary Approach

Studies published since the last iteration of the IPCC's report (AR5), such as Gasser et al. (2018), have presented evidence which suggests a greater probability that earth will experience medium and high-end warming scenarios than previously estimated.[24] Climate change projections associated with the highest emissions pathway (RCP8.5) are presented here to facilitate decision making which is robust to these risks.

[23] Carbon Brief (2018). Mapped: How every part of the world has warmed – and could continue to warm. [26 September 2018]. URL: https://www.carbonbrief.org/mapped-how-every-part-of-the-world-has-warmed-and-could-continue-to-warm [accessed 25/10/2019]

[24] Gasser, T., Kechiar, M., Ciais, P., Burke, E. J., Kleinen, T., Zhu, D., . . . Obersteiner, M. (2018). Path-dependent reductions in CO2 emission budgets caused by permafrost carbon release. Nature Geoscience, 11, 830–835. URL: https://www.nature.com/articles/s41561-018-0227-0?WT.feed_name=subjects_climate-sciences

TABLE 2. An overview of temperature change projections (°C) in the Marshall Islands under four emissions pathways. Projected changes over the 1986–2005 baseline are given for 20-year periods centred on 2050 and 2090 with the 5th and 95th percentiles provided in brackets.[9]

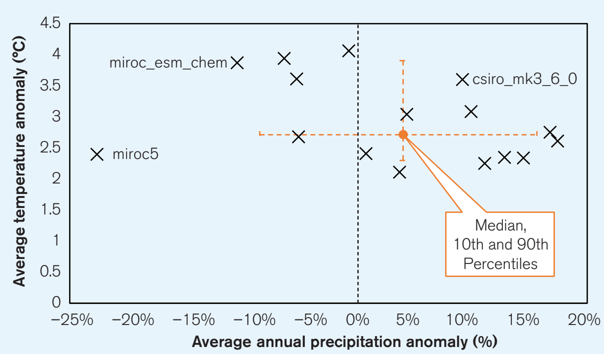
	Mean Surface Air Temp (Annual)		Max Temp (1-in-20 Year Event)		Min Temp (1-in-20 Year Event)	
Scenario	2050	2090	2050	2090	2050	2090
RCP2.6	0.8 (0.6, 1.2)	0.8 (0.5, 1.2)	0.8 (0.4, 1.3)	0.8 (0.4, 1.2)	0.9 (0.5, 1.3)	0.9 (0.2, 1.3)
RCP4.5	1.1 (0.7, 1.4)	1.5 (1, 2.1)	1 (0.6, 1.4)	1.4 (0.8, 2)	1.1 (0.7, 1.4)	1.5 (0.8, 2)
RCP6.0	1 (0.7, 1.4)	1.9 (1.4, 2.6)	NA	NA	NA	NA
RCP8.5	1.5 (1, 1.9)	3.1 (2.2, 4.2)	1.6 (0.9, 2.2)	3.3 (1.9, 4.4)	1.7 (0.9, 2.3)	3.4 (1.9, 4.7)

Model Ensemble

Due to differences in the way global circulation models (GCMs) represent the key physical processes and interactions within the climate system, projections of future climate conditions can vary widely between different GCMs. This is particularly the case for rainfall related variables and at sub-national scales. Exploring the spread of climate model outputs can assist in understanding uncertainties associated with climate models. The range of projections from 16 GCMs on the indicators of average temperature anomaly and annual precipitation anomaly for the Marshall Islands under RCP8.5 is shown in **Figure 2**.

The majority of the models from which outputs are presented in this report are from the CMIP5 round of standardization and quality assurance. Unfortunately, models of this generation operate at large spatial scales and are not well equipped to simulate the future climate of small islands. Typically, the changes projected will relate more to the expected changes over nearby ocean than the island itself. Caution should therefore be applied in interpreting results. This highlights a major area for future development, a research opportunity, and an urgent need from the perspective of policy makers planning for climate change.

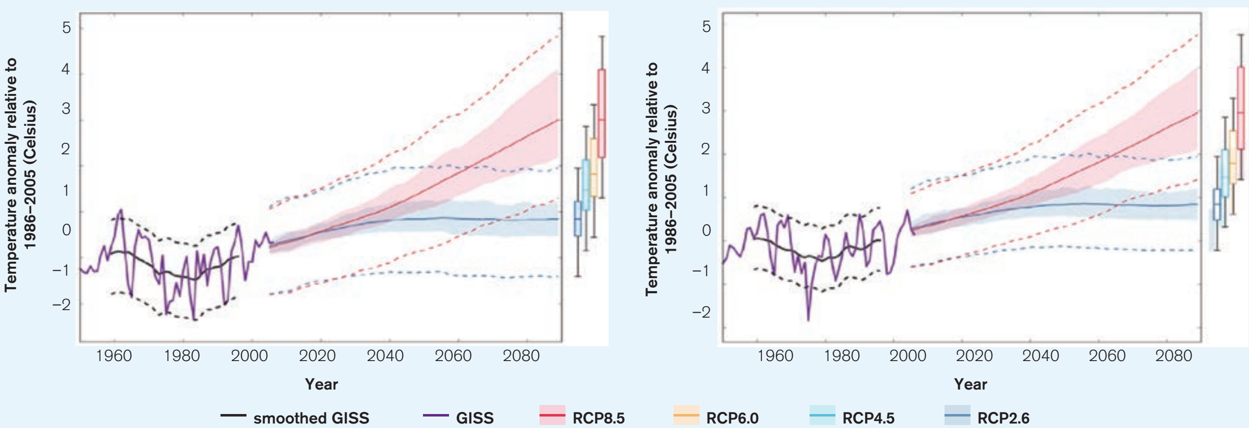
FIGURE 2. 'Projected average temperature change' and 'projected annual rainfall change' in the Marshall Islands. Outputs of 16 models within the ensemble simulating RCP8.5 over the period 2080–2099. Models shown represent the subset of models within the ensemble which provide projections across all RCPs and therefore are most robust for comparison.[22] Three models are labelled.



Temperature

Projections of future temperature change are presented in three primary formats. Shown in **Table 2** are the changes (anomalies) in maximum and minimum temperatures over the given time period, as well as changes in the average temperature. **Figures 2** and **3** display only the average temperature projections. While similar, these three indicators can provide slightly different information. Monthly and annual average temperatures are most commonly used for general estimation of climate change, but the daily maximum and minimum can explain more about how daily life might change in a region, affecting key variables such as the viability of ecosystems, health impacts, productivity of labor, and the yield of crops, which are often disproportionately influenced by temperature extremes.

FIGURE 3. Historical and simulated surface air temperature time series for the region surrounding the northern (left) and southern (right) Marshall Islands. The graph shows the anomaly (from the base period 1986–2005) in surface air temperature from observations (the GISS dataset, in purple), and for the CMIP5 models under the very high (RCP8.5, in red) and very low (RCP2.6, in blue) emissions scenarios. The solid red and blue lines show the smoothed (20-year running average) multi-model mean anomaly in surface air temperature, while shading represents the spread of model values (5–95th percentile). The dashed lines show the 5–95th percentile of the observed interannual variability for the observed period (in black) and added to the projections as a visual guide (in red and blue). This indicates that future surface air temperature could be above or below the projected long-term averages due to interannual variability. The ranges of projections for a 20-year period centred on 2090 are shown by the bars on the right for RCP8.5, 6.0, 4.5 and 2.6. (Australian BoM and CSIRO, 2014)[9]



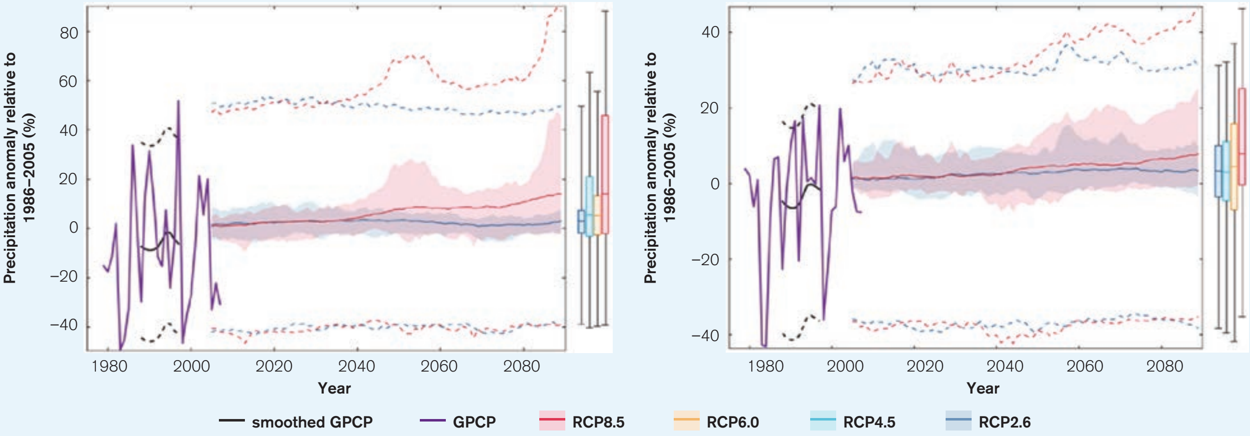
Across the Pacific, temperatures are projected to increase between 1.4°C and 3.1°C[22] As shown in **Figure 3**, localised temperature increases are expected across the Marshall Islands, with warming differences varying widely across RCPs, especially after 2030. For instance, as indicated in **Table 2**, relative to the 1986–2005 baseline, a warming of 0.5°C–1.2°C for RCP2.6, and 2.2°C–4.2°C for RCP8.5 is projected by the 2090s. While there is *very high confidence* that temperatures in the Marshall Islands will rise, based on theory and observational evidence, there is *medium confidence* in the model average temperature changes.[9] As explained in Australian BOM & CSIRO (2014), this is possibly due to differences in model estimations of temperature changes in the recent past in the Marshall Islands as well as in other places, and/or a possible bias in the simulation of sea-surface temperatures and the ITCZ for this region. It is noted that this could likely affect projection uncertainty in both rainfall and temperature. It is also noted that because of natural climate variability there will still be relatively warm and cool years and decades, although likely projections indicate a warmer climate to influence more warm years and decades on average.[9]

It is noted that future temperature rises in RMI may likely be below the global average – the mean annual surface air temperature under the highest emissions pathway is projected to reach around 3.1°C by the 2090s, compared to around 3.7°C globally. This difference may reflect the moderating effect of large amounts of nearby ocean cover, but considering that ocean cover can also distort model simulations, and the current iteration of global models does not have the spatial accuracy to reliably capture climate processes over small island states, these projections should be approached with caution.

Precipitation

As shown below in **Figure 4**, the climate model ensemble's best estimate is of an increase in long-term average rainfall across the Marshall Islands, with increases more evident in higher emission scenarios in longer term scenarios, and across both wet and dry seasons.[9] However, as shown in **Figure 2** there is disagreement between precipitation models in this long-term increasing trend, due to the complexity of modelling tropical rainfall. Issues including ITCZ intensity and uncertain ENSO influence means certainty in the model average rainfall change is limited. Although there is expected natural variability of rainfall resulting in wet and dry years and decades, and the

FIGURE 4. Historical and simulated annual average rainfall time series for the region surrounding the northern (left) and southern (right) Marshall Islands. The graph shows the anomaly (from the base period 1986–2005) in rainfall from observations (the GPCP dataset, in purple), and for the CMIP5 models under the very high (RCP8.5, in red) and very low (RCP2.6, in blue) emissions scenarios. The solid red and blue lines show the smoothed (20-year running average) multi-model mean anomaly in rainfall, while shading represents the spread of model values (5–95th percentile). The dashed lines show the 5–95th percentile of the observed interannual variability for the observed period (in black) and added to the projections as a visual guide (in red and blue). This indicates that future rainfall could be above or below the projected long-term averages due to interannual variability. The ranges of projections for a 20-year period centred on 2090 are shown by the bars on the right for RCP8.5, 6.0, 4.5 and 2.6.[9]



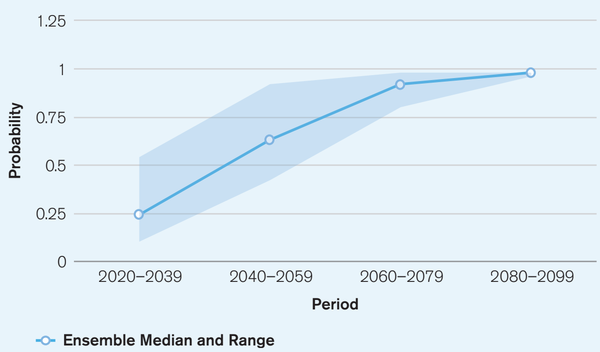
long-term average is likely to be wetter, climate change impacts on short- and medium-term rainfall are unclear. In terms of extreme rainfall events, a warmer atmosphere is likely to lead to an increase in their frequency and intensity. However, the magnitude of such changes in extreme rainfall is not as certain due to possible underestimation and difficulty to capture certain process related to extreme rainfall events.[9]

CLIMATE RELATED NATURAL HAZARDS

Heat Waves

Heat waves are defined as a period of 3 or more days when the daily temperature remains above the 95th percentile.[22] **Figure 5** shows the projected change in heat wave probability (compared to 1986–2005), highlighting the daily probability of a sudden heat wave in subsequent time periods. For the Marshall Islands, this probability approaches a value of 1 by 2100. It is noted that the tropics are expected to see a particularly extreme rise in the probability of heat waves, when a heat wave is measured against a historic temperature baseline. The stability of past temperatures means even a small temperature rise can result in temperatures which would be considered a heat wave according to the above definition.

FIGURE 5. Projected change in probability of heat waves in the Marshall Islands (compared to 1986–2005)[22]



The Marshall Islands regularly experiences relatively high temperatures, with a mean annual temperature of around 27.6°C and highest temperatures in September at an average of 27.7°C (see **Figure 1**). Ensemble-based mean annual temperatures anomalies in the Marshall Islands are projected to reach even up to 3.1°C by 2100 (**Table 2**), with a projected ensemble mean change in the maxima of daily maximum temperature of 3.3°C, compared to the historical mean (**Figure 6a**). This rise will push temperatures to levels uncomfortable for the human body, especially when measured through 'heat index,' (a function of combined temperature and humidity) which also considers the impact of humidity levels. By 2100, the projected change in the Heat Index 35 for the Marshall Islands is 356.9 days per year by the 2090s, under RCP8.5 (**Figure 6b**) – this Index represents a change in the total count of days where the daily mean heat index rose above 35°C relative to the reference period (1986–2005). While noted instances of Heat Index 35 may be primarily found in monsoon regions as well as some subtropical locations with high humidity,[25] in general the values vary between 0 and +150 days. The projected change for the Marshall Islands

[25] Im, E. S., Pal, J. S., & Eltahir, E. A. (2017). Deadly heat waves projected in the densely populated agricultural regions of South Asia. Science advances, 3(8), e1603322. URL: https://advances.sciencemag.org/content/3/8/e1603322

FIGURE 6A. Projected change in maxima of daily max temperature[22]

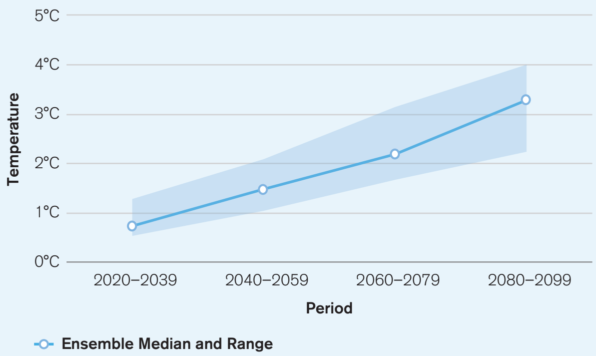
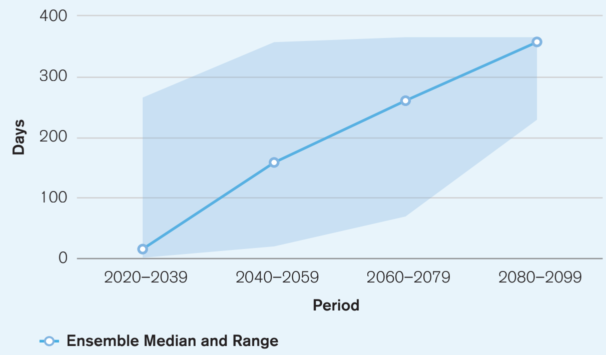


FIGURE 6B. Projected change in Heat Index 35[22]



likely signals the potential for extremely uncomfortable conditions, with local impacts and repercussions. However, it is noted that further research is required to better understand the implications of climate change, and its interaction with the ENSO phenomenon, for its future regime and potential heat waves.

An additional factor for consideration is the potential for marine heat waves. Research has shown that "from 1925 to 2016, global average marine heat wave frequency and duration increased by 34% and 17%, respectively, resulting in a 54% increase in annual marine heat wave days globally".[26] While such research has not specifically identified the Marshall Islands under threat, the consequences of these trend may be serious for marine ecosystems in the region, which are adapted to survive under very stable temperature regimes, as well as the livelihoods dependent on them.

Drought

Drought conditions have contributed to the worst natural hazard-based disasters affecting the Marshall Islands. Events in 2013 and 2015 affected 27,384 persons, just over half of the current-day population of more than 59,194 people,[2] with an estimated economic damage cost of around US$5 million.[6]

Drought can be expressed in many ways, from looking at simple precipitation deficits to complex estimates of remaining soil moisture. Research done for the report on "Climate Variability, Extremes and Change in the Western Tropical Pacific 2014", defines projected changes in the frequency and duration of mild, moderate, severe and extreme meteorological droughts using the Standardised Precipitation Index (SPI).[9] This index is based solely on rainfall (i.e. periods of low rainfall are classified as drought), and does not take into account factors such as evapotranspiration or soil moisture content. (It is noted that the SPI is commonly used in many regions including the Pacific due to the relative simplicity with which it is calculated, as well as its relevance across temporal and spatial scales).[9] These SPI drought projections for very low and very high emissions (RCP2.6 and 8.5), and for both the northern and southern Marshall Islands, show that the overall proportion of time spent in drought is

[26] Oliver, E. C., Donat, M. G., Burrows, M. T., Moore, P. J., Smale, D. A., Alexander, L. V., . . . & Holbrook, N. J. (2018). Longer and more frequent marine heatwaves over the past century. Nature communications, 9(1), 1324. URL: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5893591/

expected to decrease under all scenarios. However, it should be noted that complex processes relating to rainfall projections, including the limited consensus of future ENSO influence for the region, hinder the confidence of these projections of drought frequency and duration.[9]

Another lens through which to view drought risk is the standardised precipitation evapo-transpiration index (SPEI), which is computed over 12-month periods and captures the cumulative balance between gain and loss of water across the interannual time scale by incorporating both precipitation input variations as well as changes in the loss of water through evapotranspiration. It is widely used today as a global measure for drought monitoring over various cumulative time intervals.

The likelihood for severe drought analyses the frequency at which prolonged dry conditions are expected, and as shown in **Figure 7**, the map shows the probability for change in projected by the 2050s compared to the reference period (1986–2005) under the highest emissions pathway, RCP 8.5. Brown/Yellow areas are more likely to experience severe drought compared to the baseline period, while Blue/Green areas are less likely to experience severe drought – as such, the projection shows that southern atolls are more likely to face severe drought compared to northern atolls in the Marshall Islands in the near long term.

Figure 8 adds further context to this likely forecast by looking at the projected changes in the annual mean drought index for the Marshall Islands in subsequent time periods, compared to 1986–2005. Since positive values indicate positive water balance (or wet) conditions and negative values indicate negative water balance (or dry) conditions, this signals that SPEI trends to 2100 in the RMI may vary widely, however overall confidence is very low and as such, further research is required.

FIGURE 7. Change in annual likelihood of severe drought (CMIP5 RCP8.5 ensemble projection for 2050) for RMI[22]

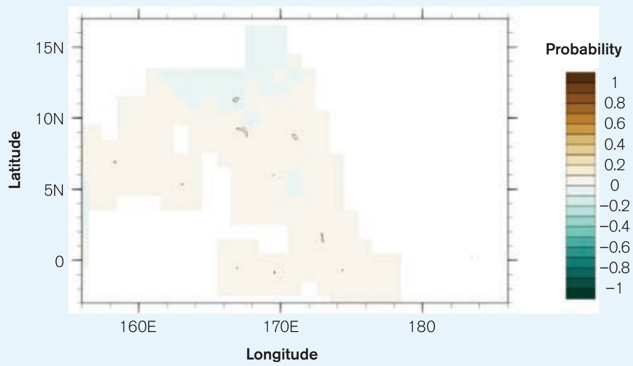
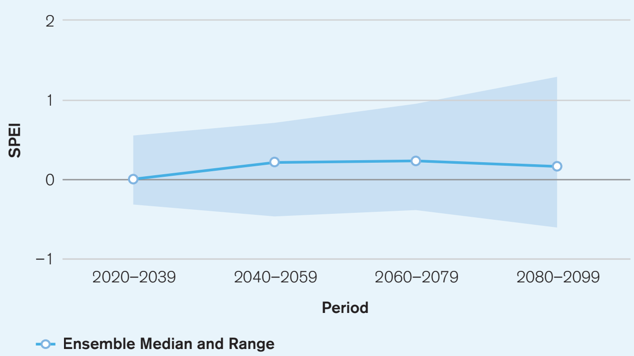


FIGURE 8. Projected change in Annual Mean Drought Index for RMI[22]



Flood, Cyclones, and Storm Surge

Analysis from the CCKP highlights that the most extreme rainfall episodes can lead to significant floods in the Marshall Islands.[22] Individual daily rainfall is often linked to flash-floods of limited spatial extent, but multi-day rainfall generally has a broader spatial footprint and thus more extensive flooding can be expected. Rare precipitation events are often referred to as events of a certain return level, and the 5-day cumulative rainfall indicator focuses on the maximum rainfall amount over any 5-day period that can be expected once in an average 25-year period.

Changes in this indicator may have potentially significant impacts on infrastructure and endanger life and property through direct physical effects and perhaps through water quality issues. As such, any significant changes in their magnitudes would need to be understood.

The boxplot in **Figure 9** shows recorded 5-Day Cumulative Rainfall for 1986–2005 and projected 5-Day Cumulative Rainfall 25-yr Return Level by 2050 under all RCPs of CIMP5 ensemble modelling for the Marshall Islands. From this, it is noted that compared to the historical value there is a minor increase (<10%), but these are associated with great uncertainty. Looking at further future projections, **Figure 10** highlights the projected change in annual maximum 5-day rainfall of a 25-year return level. Projected ensemble median changes seem to be close to 0 initially then increase closer to 2100, but the range of values is quite broad and needs to be further contextualised and understood.

FIGURE 9. 5-day precipitation – historical and projected scenarios of 25-year return level in RMI for period 2040–2059[22]

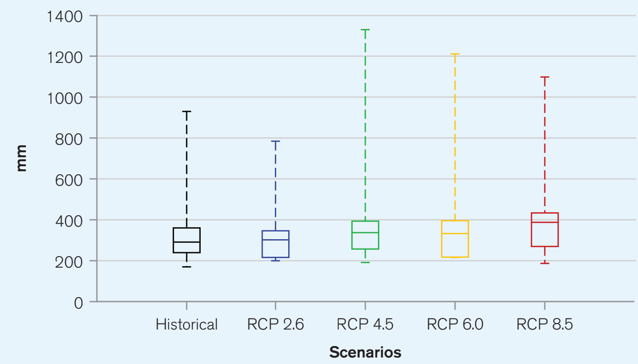
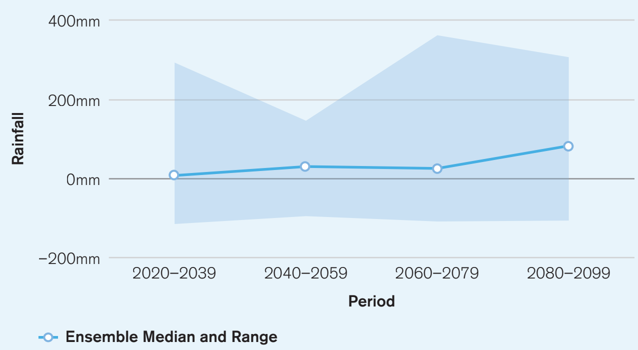


FIGURE 10. Projected change in annual maximum 5-day rainfall (25-year return level) for the RMI[22]



Tropical cyclones have historically affected the Marshall Islands. The tropical cyclone archive of the Northern Hemisphere indicates that between the 1977 and 2011 seasons, 78 tropical cyclones developed within or crossed the Marshall Islands EEZ, and 18% of these became severe events (Category 3 or stronger). This represents an average of 22 cyclones per decade, although there is large interannual variability.[27] Tropical cyclones were most frequent in El Niño years (50 cyclones per decade) and least frequent in La Niña years (3 cyclones per decade); the neutral season average is 18 cyclones per decade. Although there have been notable recent storms, such as Bavi and Nangka in 2015, Tropical Storm Zelda in 1991 remains on record for causing significant damage to homes and livelihoods, affecting almost 6000 persons.[6] In 1997, Typhoon Paka caused US$80 million of damage to crops and affected 70 percent of houses on Ailinglaplap Atoll and it is estimated that during a 20-year period, cyclones in the Marshall Islands caused on average US$63 million per cyclone.[28]

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[27] Australian Bureau of Meteorology and CSIRO (2014). Climate Variability, Extremes and Change in the Western Tropical Pacific: New Science and Updated Country Reports. Pacific-Australia Climate Change Science and Adaptation Planning Program Technical Report, Australian Bureau of Meteorology and CSIRO, Melbourne, Australia. URL: https://www.pacificclimatechangescience.org/wp-content/uploads/2014/07/PACCSAP_CountryReports2014_WEB_140710.pdf

[28] GFDRR (2015). Country Note: Marshall Islands. URL: https://www.gfdrr.org/sites/default/files/publication/country-note-2015-pcrafi-marshallislands.pdf [accessed 22/07/2019]

According to available information compiled by the Global Facility for Disaster Reduction and Recovery (GFDRR) ThinkHazard! web-based tool, the risk of cyclone (hurricane/typhoon) hazard is classified as *high* in the Marshall Islands.[5] This means that there is more than a 20% chance of potentially-damaging wind speeds for the country in the next 10 years. However, climate change is expected to interact with cyclone hazard in complex ways which are currently poorly understood. Known risks include the action of sea-level rise to enhance the damage caused by cyclone-induced storm surges, and the possibility of increased wind speed and precipitation intensity. Modelling of climate change impacts on cyclone intensity and frequency conducted across the globe points to a general trend of reduced cyclone frequency but increased intensity and frequency of the most extreme events.[29] Further research is required to better understand potential changes in cyclone seasonality and routes, and the potential for cyclone hazards to be experienced in unprecedented locations. As such, given this global context, the current projection for the Marshall Islands is for a decrease in tropical cyclone genesis (formation) frequency for the northern basin, with *low confidence*.[9]

Wind-waves in the Marshall Islands are influenced by trade winds seasonally, and the El Niño–Southern Oscillation (ENSO) interannually. The wind-wave climate of the Marshall Islands shows spatial variability between the northern and southern islands, but generally, wave heights are greater in December–March than June–September. While available data are not suitable for assessing long-term trends, ThinkHazard! information for the RMI shows that there is a *high* risk of coastal floods and *medium* risk of tsunamis.

CLIMATE CHANGE IMPACTS

Natural Resources

Water

As with many other island nations, the RMI have uniquely fragile water resources due to their small size, lack of storage, and limited freshwater.[1] The main sources of fresh water are rainfall harvesting and groundwater – urban centres utilise rainwater, groundwater, desalination and imports, while the outer islands use mainly rainwater and groundwater. Wet season rainfall generally supplies the majority of freshwater to the RMI, and according to RMI's Census 2011, the main source of drinking water in the country is rainwater catchments and tanks which are used by almost four-fifths of households.[30] The 2011 census also notes that 88% of the population has access to improved drinking water source.

Despite relatively high rainfall, the limited storage capacity and aging reticulated water system means the public water supply is rationed – under non-drought, normal operating conditions, the public water operates three days a week for four hours a day.[19] There is an urgent need to upgrade and improve the city water system in order to

[29] Walsh, K., McBride, J., Klotzbach, P., Balachandran, S., Camargo, S., Holland, G., Knutson, T., Kossin, J., Lee, T., Sobel, A., Sugi, M. (2015) Tropical cyclones and climate change. WIREs Climate Change: 7: 65–89. DOI: https://doi.org/10.1002/wcc.371
[30] RMI (2016). Republic of Marshall Islands State of the Environment Report 2016. Apia, Samoa: SPREP. URL: https://www.sprep.org/attachments/VirLib/Marshall_Islands/state-of-environment-report-2016.pdf [accessed 22/07/2019]

make water more available, but the country has made limited investments in water management and infrastructure rehabilitation for water and waste water. This is also hampered by the typical constraints of small island nations (isolation, fragile natural variability, and a limited human, financial, and capital resource base).[1] Staggering increases in population on the two urban islands, as well, poses a significant challenge to meeting future water needs.[1]

Furthermore, limited attention has been offered to the potential effects of climate-related extremes on current water resources, especially with regards to salt-water intrusion, which negatively affect the limited freshwater lens on some of the lower-lying islands and atolls.[1] On the Majuro atoll, water supplies rely on the Laura freshwater lens and the airport runway catchment area, which pipes water to the city's principal reservoir. Rising temperatures could lead to increased evaporation from the reservoir, thus reducing already limited freshwater supplies. With sea level rise, the fresh water lens which floats above a mixed salt water base will be elevated, and its slope and head will increase.[1] This is likely to result in increased lateral saline mixing, increased evaporation through taro pits and wells, increased loss of fresh water by coastal leakage, saline water being brought within the reach of coconut and other tree crop roots or well and pump intakes, and generally a loss of the fresh water resource. If sea level rise is accompanied by increased storm surges, which will favour island building, such wash processes will render groundwater saline until a state of stability returns. Such stability is possible only when sea level rise ceases. Hygiene and sanitation continue to be a concern and a particular challenge is to manage a sewage system without contaminating the ground-water lens. Already, some of the country's freshwater lens has been contaminated with brine.

El Niño conditions in this part of the Pacific can shift rainfall patterns, bringing significantly less rainfall than in normal years and leading to drought conditions.[19] Should this association of lower rainfall with higher temperatures persist with global warming, the ground water resources of these atolls would decrease, with less rain-fed recharge, increased evaporation and increased water demand.[1] Water crises during El Niño-driven droughts are becoming increasingly common on smaller and more remote northern atolls that rely primarily on rainwater and have limited harvesting capacity and high costs to serve from a centralized government. Droughts are especially damaging in the atolls lacking sufficient rain-water harvesting/storage capacity to withstand dry periods, as is the case with most of the outer atolls of the dry North. The 1998/1999 El Niño event was one of the most pronounced drought periods in RMI, bringing only 8% of normal rainfall in a four-month period and leading the government to declare the entire archipelago a disaster area, and severely impacting Laura atoll's fresh-water lens. During this event, it is noted that public water supplies were exhausted to the extent that Reverse Osmosis (RO) Units had to be brought in to help relieve the water crisis. It is noted that the RO units are expensive to operate and maintain, economically unsustainable and produce harmful CO2 emissions.[19] More frequent El Niño events could increase the intensity and occurrence of these drought events, with important implications for disaster management and response in the RMI.

The Coastal Zone

Sea-level rise threatens significant physical changes to coastal zones around the world. Global mean sea-level rise was estimated in the range of 0.44 meter (m) —0.74 m by the end of the 21st century by the IPCC's Fifth Assessment Report,[31] but some studies published more recently have highlighted the potential for greater rises (**Table 3**).

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[31] Church, J. a., Clark, P. U., Cazenave, A., Gregory, J. M., Jevrejeva, S., Levermann, A., . . . Unnikrishnan, A. S. (2013). Sea level change. In Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 1137–1216). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press. URL: https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter13_FINAL.pdf

TABLE 3. Estimates of global mean sea-level rise by rate and total rise compared to 1986–2005 including likely range shown in brackets, data from Chapter 13 of the IPCC's Fifth Assessment Report with upper-end estimates based on higher levels of Antarctic ice-sheet loss from Le Bars et al. (2017).[32]

Scenario	Rate of Global Mean Sea-Level Rise in 2100	Global Mean Sea-Level Rise in 2100 Compared to 1986–2005
RCP2.6	4.4 mm/yr (2.0–6.8)	0.44 m (0.28–0.61)
RCP4.5	6.1 mm/yr (3.5–8.8)	0.53 m (0.36–0.71)
RCP6.0	7.4 mm/yr (4.7–10.3)	0.55 m (0.38–0.73)
RCP8.5	11.2 mm/yr (7.5–15.7)	0.74 m (0.52–0.98)
Estimate inclusive of high-end Antarctic ice-sheet loss		1.84 m (0.98–2.47)

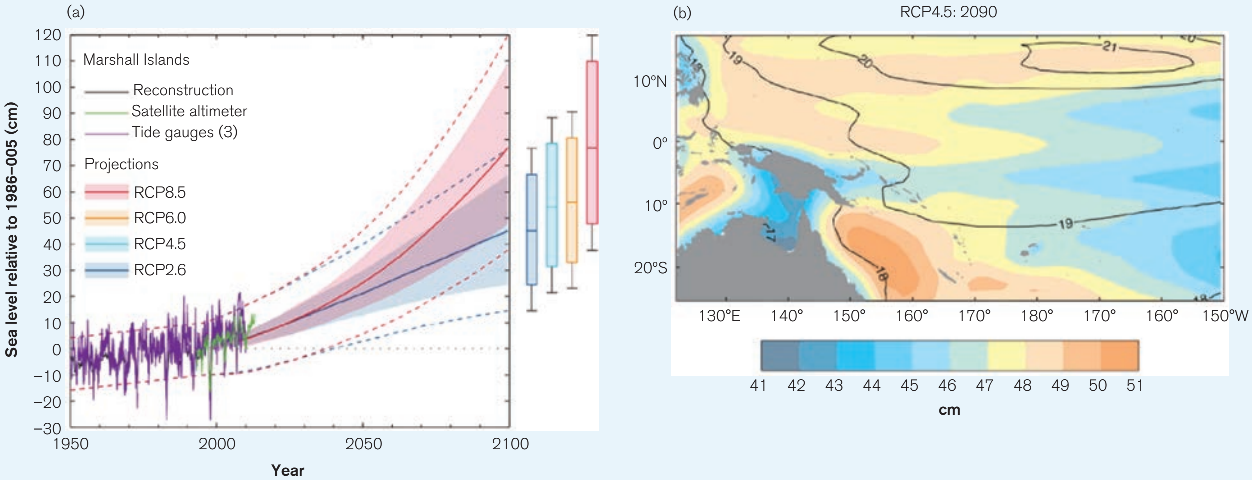
According to its Second National Communication to the UNFCCC, the Republic of the Marshall Islands is one of four countries that consist entirely of low-lying atolls and islands, and which face perhaps the most urgent and daunting of climate change challenges in the world.[1] Of these challenges, one of the main threats of immediate concern includes sea level rise in combination with storm surges causing flooding. Local sea-levels can show variation and are influenced by ENSO. A continued increase in mean sea level for the Marshall Islands is projected to 2100, with a high degree of confidence, and with similar values across different RCPs (see **Figure 11**).[9] Uncertainty in the projections of changes in the Antarctic ice sheet limit the certainty of knowledge of the range of this mean sea level change. There has also been a historical interannual variability of sea levels of about 20 cm (5%–95% range, after removal of the seasonal signal), which is expected to be quite similar through 2100.[9]

Increased wave height and increased storminess are both likely to cause erosion of unstable coastlines in the RMI as they have in the past.[1] In some islands, coastline stability is greater than on other atoll islands because of the extensive fringe sandy or conglomeratic beach rock, and the existence of natural beach rock accumulations. These deposits will offer temporary resistance to the erosion likely to be caused by rising sea level, but in time is still expected to succumb to this erosion.

Shoreline erosion caused by sea level rise is already a significant problem across the Marshall Islands[22]. Erosion of the coastline of Majuro is occurring at a considerable rate as coconut trees and coastal vegetation fall over as the soils are washed away from underneath them. This situation is not helped by the amount of dredging and sand mining that is happening especially around the airport area.[1]

[32] Le Bars, D., Drijhout, S., de Vries, H. (2017) A high-end sea level rise probabilistic projection including rapid Antarctic ice sheet mass loss. Environmental Research Letters: 12:4. URL: https://iopscience.iop.org/article/10.1088/1748-9326/aa6512

FIGURE 11. (a) The observed tide-gauge records of relative sea-level (since the late 1970s) are indicated in purple, and the satellite record (since 1993) in green. The gridded (reconstructed) sea level data at the Marshall Islands (since 1950) is shown in black. Multi-model mean projections from 1995–2100 are given for the RCP8.5 (red solid line) and RCP2.6 emissions scenarios (blue solid line), with the 5–95% uncertainty range shown by the red and blue shaded regions. The ranges of projections for four emission scenarios (RCPs 2.6, 4.5, 6.0, 8.5) by 2100 are also shown by the bars on the right. The dashed lines are an estimate of interannual variability in sea level (5–95% uncertainty range about the projections) and indicate that individual monthly averages of sea level can be above or below longer-term averages. (b) The regional distribution of projected sea level rise under the RCP4.5 emissions scenario for 2081–2100 relative to 1986–2005. Mean projected changes are indicated by the shading, and the estimated uncertainty in the projections is indicated by the contours (in cm).[9]



In addition to long-term inundation, the Marshall Islands must prepare for rapid onset events. Potentially-damaging waves are currently expected to flood the coast at least once in every 10 years, and there is more than a 10% chance of a potentially-damaging tsunami occurring in the next 50 years.[5] Both phenomena will be exacerbated by sea-level rise. Strong winds, wave run-up, and overtopping of beach berms and protective structures are significant sources of flooding and damage across the RMI.[1] Such was the case in 2008, when a combination of factors, including three major storms in two weeks and high tides, together flooded (via storm surges) a large part of the Majuro atoll, damaging more than 300 homes and forcing 10% of the population to temporary shelters, and in total affecting at least 600 persons.[6]

Sea-level rise is not just a threat due to long-term encroachment on coastal areas, but also due to the projected increase in the frequency of extreme sea-level events.[33] The return period of exceptionally high sea-levels, driven by climate circulations, is expected to reduce and low-lying Pacific island nations are particularly at risk.[34] Studies

[33] Widlansky, M. J., Timmermann, A., & Cai, W. (2015). Future extreme sea level seesaws in the tropical Pacific. Science Advances, 1(8). DOI: https://doi.org/10.1126/sciadv.1500560

[34] Vitousek, S., Barnard, P. L., Fletcher, C. H., Frazer, N., Erikson, L., & Storlazzi, C. D. (2017). Doubling of coastal flooding frequency within decades due to sea-level rise. Scientific Reports, 7(1), 1399. https://doi.org/10.1038/s41598-017-01362-7

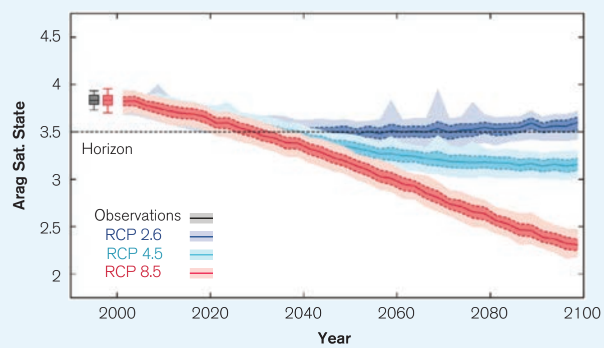
have shown that the extent of wave-driven flooding is impacted by coral reef height and health, highlighting the importance of coral conservation as an adaptation.[35] Without successful adaptation some studies have estimated that wave-driven flooding will make many atoll islands uninhabitable by the mid 21st century.[36] According to a study done by the National Oceanic and Atmospheric Administration of the United States (NOAA) as far back as 1992, a three foot rise in sea levels would completely inundate the Majuro atoll, and defence mechanisms to protect the atoll from a one-in-fifty year storm event would be impossible.[22] It is generally recommended that a "full retreat of the entire population of the Majuro atoll and the Marshall Islands must be considered in planning for worst-case sea level rise scenarios".[1] However, the scientific field lacks consensus on the gravity of the threat. Other studies have shown that atoll islands have potential to sustain and even grow despite sea-level rise thanks to geomorphological processes which build land.[37] The future picture is likely one of a dynamic ecosystem which will demand adaptive lifestyles and livelihoods from inhabitants.

Coral Reefs and Fisheries

Calcium carbonite is used for the external skeletons of multiple marine organisms – for instance, plankton, coral reefs, and shell-fish. Increases in atmospheric carbon dioxide are understood to lead to reduced levels of calcium carbonite saturation on the ocean's service via an increase in ocean acidification and by decreasing carbonite ion concentrations. As a result, there are serious concerns that if carbonite minerals, such as aragonite, become under saturated, it could undermine current ocean ecosystems.[38] **Figure 12** shows the projected aragonite saturation state under three emission scenarios for the Marshall Islands. Worryingly under RCP4.5 and RCP8.5 the saturation state is expected to decrease below the threshold needed to sustain healthy coral reefs.

It is well understood that a warming ocean is expected to increase the risk of coral bleaching, but the projected rate of this change for the Marshall Islands is not certain due to challenges in ascertaining the rate

FIGURE 12. Projected changes in aragonite saturation state in the Southern Marshall Islands from CMIP5 models under RCP2.6, 4.5 and 8.5. Shown are the median values (solid lines), the interquartile range (dashed lines), and 5% and 95% percentiles (light shading). The horizontal line represents the threshold at which transition to marginal conditions for coral reef health typically occurs.[9]



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35 Beetham, E., Kench, P. S., & Popinet, S. (2017). Future Reef Growth Can Mitigate Physical Impacts of Sea-Level Rise on Atoll Islands. Earth's Future, 5(10), 1002–1014. URL: https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1002/2017EF000589

36 Storlazzi, C. D., Gingerich, S. B., van Dongeren, A., Cheriton, O. M., Swarzenski, P. W., Quataert, E., . . . McCall, R. (2018). Most atolls will be uninhabitable by the mid-21st century because of sea-level rise exacerbating wave-driven flooding. Science Advances, 4(4). URL: https://pubmed.ncbi.nlm.nih.gov/29707635/

37 Kench, P. S., Ford, M. R., & Owen, S. D. (2018). Patterns of island change and persistence offer alternate adaptation pathways for atoll nations. Nature Communications, 9(1), 605. URL: https://www.nature.com/articles/s41467-018-02954-1

38 Orr, J. C., Fabry, V. J., Aumont, O., Bopp, L., Doney, S. C., Feely, R. A., . . . & Key, R. M. (2005). Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. Nature, 437(7059), 681. URL: https://pubmed.ncbi.nlm.nih.gov/16193043/

of sea surface temperature changes and changes at the reef scale.[9] Beginning in 2014, during an unprecedented 36-month heat wave and global bleaching event,[39] the Marshall Islands experienced one of its worse mass coral bleaching episodes, which affected up to 75% of smaller corals and 25% of the larger varieties at some sites.[40] Coral bleaching risk calculations show that if severe bleaching events occur more often than once every five years, the long-term viability of coral reef ecosystems becomes threatened, although it should be noted that this calculation does not account the impact of other potential stressors. Rising ocean temperatures and ocean acidification (via increased concentration of carbon dioxide), in combination with extreme low tides, as well as sedimentation and pollution, may have significant adverse impacts upon coral reefs such as coral bleaching, coastal ecosystems, and migratory fish stocks such as tuna, which represent a substantial economic resource for RMI.

The fisheries sector, and in particular the tuna fishery of the EEZ of the RMI, is the mainstay of the nation's economy. Fisheries represented 6.1% in GDP growth, and contributed 23% of the total growth, between 2003 and 2017,[41] and the sale of fishing rights generally represents about 14% of the RMI economy.[19] However, there are limiting factors to the continuing viability of the sector including the sustainable yield of the fish stock, the world markets for the products and the effects of climate phenomena such as El Niño/ENSO.[1] It is not known how increased ocean temperatures will affect the tuna fishery industry but it is acknowledged that the tuna fishery is a risky and costly business for the Marshallese. Hence, despite the fact that only about 5% of the potential fisheries revenue is retained in the RMI, the government will continue to look at foreign fishing vessels and companies for the utilisation of its tuna fisheries for some years to come. Subsistence fishery is particularly important and includes reef and lagoon, as well as oceanic fisheries.[1]

There is also concern that the current rate of damage to the corals and coral reef systems from land-based pollution activities is having negative effects on the life cycle of many coral and fish species. Dredging, sand mining and beach erosion are having detrimental effects on the corals and reefs and these are in turn having negative impacts on fisheries resources of the country. Yellowfin and bigeye tuna stock are reported to be nearing full exploitation. El Niño conditions in 2002- 2003 resulted in the principal tuna stock moving out of RMI waters and congregating more in the western hemisphere around Papua New Guinea and its neighbouring countries. This led to decreased catch and less trans-shipments occurring in the RMI. This situation is expected to reoccur under similar conditions in future.[1]

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39 Eakin, C.M., Liu, G., Gomez, A.M., De la Couri, J.L., Heron, S.F., Skirving, W.J., Geiger, E.F., Marsh, B.L., Tirak, K.V., Strong, A.E. (2018). Unprecedented three years of global coral bleaching 2014–17. Sidebar 3.1. [in State of the Climate in 2017]. Bulletin of the American Meteorological Society, 99(8), S74–S75. URL: https://www.climate.gov/news-features/understanding-climate/unprecedented-3-years-global-coral-bleaching-2014%E2%80%932017

40 AFD, 2014. Global warming blamed for Pacific coral bleaching. December 22, 2014. URL: https://phys.org/news/2014-12-global-blamed-pacific-coral.html [accessed 22/07/2019]

41 RMI (2018). Economic Review RMI Fiscal Year 2017. URL: http://www.pitiviti.org/initiatives/economics/rmi.php [accessed 22/07/2019]

Island Ecology

Sea-level rise not only threatens humans residing on Pacific islands, but also their unique ecosystem functions and ecology. Indeed, island biodiversity faces a variety of human pressures.[42] Research has shown that inundation of low-lying islands has the potential to remove important refuges for migrating sea birds.[43] As climate changes so the suitable range for species to inhabit shifts, typically either upslope or away from the equator. In the Island environment the capacity for species to shift is extremely limited and as such loss and extinction are becoming increasingly likely. Major concerns have been raised for the terrestrial ecology of low-lying Pacific islands, for example endemic lizards, which may become trapped in a shrinking habitat.[44] Research has also highlighted the risks to biodiversity in the Pacific through study of tree richness in New Caledonia, where the range sizes of 87%–96% of species was projected to decline, typically by 52%–84%.[45]

Economic Sectors

Agriculture and Food

Agriculture in the Marshall Islands, including the subsistence production of taro, coconuts, breadfruit, pawpaw and the commercial production of copra (the kernel inside of coconuts) are highly dependent on fresh ground water supplies.[1] Similarly, a significant proportion of water used for domestic purposes is taken from ground water aquifers. Any change in ground water resources would have a significant impact on land use in the RMI. Since subsistence agriculture has a more limited role in the Marshall Islands than in most atoll states, the result would not be severe as elsewhere. Nevertheless, although atoll plant species are generally resistant to some salt intrusion, there are unlikely to be any crop or plant species that would benefit from a greater level of salinity. Most of the settlements in the Marshall Islands are necessarily located near the coast. Increased coastal erosion would threaten some of these settlements and make relocation necessary. Unfortunately, this would be virtually impossible in Ebeye and Majuro where the urban areas are almost completely filled-up and where private land tenure prevents some kinds of relocation. Elsewhere, central depressions, and mosquitoes discourage residence at a greater distance from the coasts. Only in a few areas, such as Laura, can relocation be possible, albeit to a very limited extent.[1]

[42] Jupiter, S., Mangubhai, S., & Kingsford, R. T. (2014). Conservation of Biodiversity in the Pacific Islands of Oceania: Challenges and Opportunities. Pacific Conservation Biology, 20(2), 206–220. URL: https://www.publish.csiro.au/pc/pc140206

[43] Reynolds, M. H., Courtot, K. N., Berkowitz, P., Storlazzi, C. D., Moore, J., & Flint, E. (2015). Will the Effects of Sea-Level Rise Create Ecological Traps for Pacific Island Seabirds? PLOS ONE, 10(9), 1–23. DOI: https://doi.org/10.1371/journal.pone.0136773

[44] Taylor, S., & Kumar, L. (2016). Global Climate Change Impacts on Pacific Islands Terrestrial Biodiversity: A Review. Tropical Conservation Science, 9(1), 203–223. URL: https://journals.sagepub.com/doi/full/10.1177/194008291600900111

[45] Pouteau, R., & Birnbaum, P. (2016). Island biodiversity hotspots are getting hotter: vulnerability of tree species to climate change in New Caledonia. Biological Conservation, 201, 111–119. URL: https://agris.fao.org/agris-search/search.do?recordID=FR2017101025

Prolonged periods of drought over the past twenty years have been observed to have adverse effects on the agricultural productivity of the atolls of the Marshall Islands.[1] Both taro and breadfruit production have been affected by the changes to the water table under adversely dry conditions and this situation can only be expected to worsen with future climate change events such as reduced rainfall and more frequent and intensive droughts. Although there is still not a clear understanding of whether increasing temperatures will directly affect subsistence crops in the RMI, observations seem to suggest that subsistence crops will indeed be affected. The scenarios of future temperature change for the middle of the next century indicate a rise of 1.6°C–2.9°C, implying a climate regime that is considerably different from that of the present. Crops like taro and arrowroot are already showing signs of stress under present conditions and are doubtful to survive further increases in temperature. On the other hand, there is strong evidence that rainfall variations directly affect crop yields and production in the RMI. The scenario of higher rates of sea level rise and increased incidence of extreme events such as droughts and tropical cyclones could result in increased salinity of the soils and fresh water lens, thus impairing food security.

Food security is expected to be one of the most challenging problems in the Marshall Islands.[19] The impacts of climate change and human activity are likely the main contributing factors to the declining production of food and food security. The Marshallese people have long been cultivating the land for food, medicinal and other traditional purposes. Today, people depend on imported goods, which have reduced land cultivation and traditional practices of producing local food and medicine, and a recent study conducted on Arno Atoll, indicates that well over 80% of carbohydrates are being imported[19].

A further, and perhaps lesser appreciated, influence of climate change on agricultural production is through its impact on the health and productivity of the labor force. Dunne et al. (2013) suggest that global labor productivity during peak months has already dropped by 10% as a result of warming, and that a decline of up to 20% might be expected by 2050 under the highest emissions pathway (RCP8.5).[46] Like many other small islands, the Marshall Islands likely operates an agricultural system highly dependent on physical labor inputs and hence is potentially vulnerable to higher temperatures without adaptation. In combination, it is highly likely that the above processes will have a considerable impact on national food consumption patterns both through direct impacts on internal agricultural operations, and through impacts on the global supply chain.

Tourism

Unlike many other small islands, tourism provides a small source of foreign exchange in the Marshall Islands and currently employs less than 10% of the labor force.[1] Tourist arrivals in the RMI increased from about 3,000 in the late 1980's to just over 9000 in 2005, and have declined since.[19] Generally, slow growth and in some years decline have characterized the RMI tourism sector since its formal inception in 1997 through the Tourism Amendment Act, so that tourism in the RMI remains in its early stages of development.[1] While the RMI has a small visitor capacity, it continues to struggle to fill its existing capacity and national occupancy rates have remained low over the past decade, with occupancy estimates below 30%.[1] Due to geographic isolation, it is very costly for tourists to visit.[19] Tourist accommodation and infrastructure is limited to about 300 visitors at one time, and the average number of visitors per year is about 5,000.

[46] Dunne, J. P., Stouffer, R. J., & John, J. G. (2013). Reductions in labour capacity from heat stress under climate warming. Nature Climate Change, 3(6), 563–566. URL: http://www.precaution.org/lib/noaa_reductions_in_labour_capacity_2013.pdf

While it is said that the decline in tourism has led to a less diverse economy, and a reduced impact from tourism on the environment, even the current state of tourism causes relative pressure on the environment, and is exacerbated by increased local demand for imported technology, food and consumer items.[19] Nevertheless, tourism development remains a Government priority for sustainable development, and in the past the RMI formulated its National Tourism Development Plan 2008–2011.[1] The United States and Japan remain as the top markets for the RMI, with scuba diving and more recently surfing visitors drawn to the many pristine and remote destinations within the RMI.

Challenges to tourism development include envisaging its development profile, difficulties in doing business in the RMI, untrained and unexposed tourism workers, substandard infrastructures, cumbersome and expensive domestic and international travel, unexplored sea-bed tourism, and weakness in both policy and planning. It is expected that small-scale operations, such as diving and surf company Indies Trader, can have a large and positive impact, but in general it is suggested that as tourism grows, the long-term impact needs to be monitored.

Climate change threatens to place additional hurdles in front of the Marshall Islands' tourism development plans. In the long-term, the dual threats of rising sea levels and coastal erosion could reduce the quantity and quality of available beach space and, without significant adaptation measures, could therefore reduce the attractiveness of the country as a tourist destination. Another area of vulnerability is the burgeoning recreational diving sector, which could be threatened by environmental degradation, loss of reefs, and coastal erosion. In addition to direct physical impacts, climate change may affect the tourism sector in RMI through global efforts to mitigate climate change. One possible manifestation is in the increased cost of international flights. One study estimated that while the cost of achieving an emissions-target compatible tourism sector may be proportionately low (3.6%) the necessary increase in trip costs (estimated at $11 when averaging across every global trip but potentially higher on a long-haul destination such as the RMI) may further reduce RMI's attractiveness as a tourist destination.[47] Further research is required to better constrain the suite of potential climate change impacts on the sector.

Communities

Poverty, Inequality and Vulnerability to Climate-Related Disaster

Poverty in the Marshall Islands is said to be of urgent concern because of scarce natural resources, high unemployment rates and wealth inequality.[48] Using 2011 census data it was estimated that 37% of the total population live below the "basic-needs income line".[4] While 30% of residents in the two main urban centres (Majuro and Ebeye) are estimated below this line, these numbers could double in the outer islands. Only 39.3% of the population aged 15 years and above is estimated to be employed, and for every one thousand babies born, 30 die before their birthday – the fourth highest in the Pacific region.[37] Such deepening poverty, amidst "growing concerns over high unemployment, financial hardship, hunger and poor nutrition",[4] are noted in the context of a vulnerability to "transnational threats, natural disasters, and the potential effects of climate change".[3]

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[47] Scott, D., Gössling, S., Hall, C. M., & Peeters, P. (2016). Can tourism be part of the decarbonized global economy? The costs and risks of alternate carbon reduction policy pathways. Journal of Sustainable Tourism, 24(1), 52–72. URL: https://www.tandfonline.com/doi/abs/10.1080/09669582.2015.1107080

[48] Yu Tang (2017). Poverty in the Marshall Islands. The Borgen Project. URL: https://borgenproject.org/poverty-in-the-marshall-islands/ [accessed 22/07/2019]

The impacts of climate change and variability is certain to widely affect the economy and local livelihoods. As adverse impacts are expected on local fisheries stocks, and sea level rise and changes in precipitation threaten both locational and food security, the "islander lives" of the Marshallese has been slowly changing.[37] States of Emergency were declared when waves as high as three feet hit the cities, and drought conditions left leaving six thousand people surviving on less than one litre of water per day in 2008 and 2013.[37]

The Marshall Islands are some of the most vulnerable islands to the effects of climate change, and relies on external funding for most of its revenue. The US has offered assistance to perform maritime security functions and strengthen climate resilience through disaster preparedness, in addition to supporting health, education, and infrastructure efforts. It is reported that the US offered as much as US$2.5 million to assist relief efforts in 2016,[3] and a trust fund is under development that the Marshall Islands will rely upon after 2024 when the Compact of Free Association ends.[37] However, reliance on external assistance has perhaps deepened RMI's vulnerability to external shocks and impacts. As for many countries, most of the climate changes projected are likely to disproportionately affect the poorest groups in society. For instance, heavy manual labour jobs are commonly among the lowest paid whilst also being most at risk of productivity losses due to heat stress.[49] Poorer businesses are the least able to afford air conditioning, an increasing need given the projected increase in the need for air conditioning with temperature increases. Poorer farmers and communities are least able to afford local water storage, irrigation infrastructure, and technologies for adaptation. Without action climate change threatens to stall efforts to tackle poverty and deprivation, and may widen social inequalities.

Gender

An increasing body of research has shown that climate-related disasters have impacted human populations in many areas including agricultural production, food security, water management and public health. The level of impacts and coping strategies of populations depends heavily on their socio-economic status, socio-cultural norms, access to resources, poverty as well as gender. Research has also provided more evidence that the effects are not gender neutral, as women and children are among the highest risk groups. Key factors that account for the differences between women's and men's vulnerability to climate change risks include: gender-based differences in time use; access to assets and credit, treatment by formal institutions, which can constrain women's opportunities, limited access to policy discussions and decision making, and a lack of sex-disaggregated data for policy change.[50]

Human Health

Heat-Related Mortality

Research has placed a threshold of 35°C (wet bulb ambient air temperature) on the human body's ability to regulate temperature, beyond which even a very short period of exposure can present risk of serious ill-health and death.[51] Temperatures significantly lower than the 35°C threshold of 'survivability' can still represent a major threat to human health. Climate change will push global temperatures closer to this temperature 'danger zone' both through slow-onset warming via an increase mean annual temperature and the intensity and frequency of heat waves.

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[49] Kjellstrom, T., Briggs, D., Freyberg, C., Lemke, B., Otto, M., Hyatt, O. (2016) Heat, human performance, and occupational health: A key issue for the assessment of global climate change impacts. Annual Review of Public Health: 37: 97–112. URL: https://pubmed.ncbi.nlm.nih.gov/26989826/

[50] World Bank Group (2016). Gender Equality, Poverty Reduction, and Inclusive Growth. URL: http://documents1.worldbank.org/curated/en/820851467992505410/pdf/102114-REVISED-PUBLIC-WBG-Gender-Strategy.pdf

[51] Im, E. S., Pal, J. S., & Eltahir, E. A. B. (2017). Deadly heat waves projected in the densely populated agricultural regions of South Asia. Science Advances, 3(8), 1–8. URL: https://advances.sciencemag.org/content/3/8/e1603322

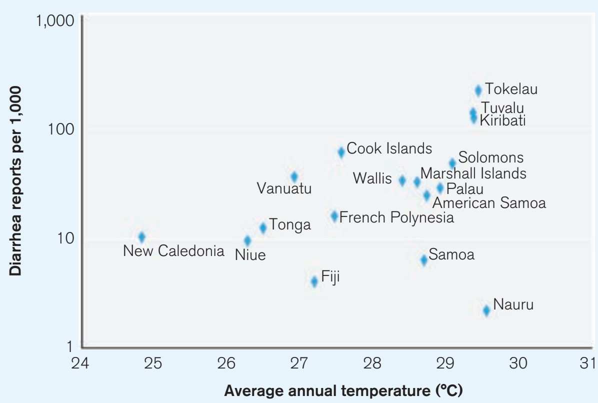
As a result, climate change is expected to resulting in a greater number of people at risk of heat-related medical conditions – the elderly, children, the chronically ill, the socially isolated and at-risk occupational groups are particularly vulnerable to heat-related conditions. Due to the methodological specification, the projected number of heat- related deaths for grids in which sea area is dominant becomes zero. The Marshall Islands, which has very small land areas surrounded by sea, constitutes some of these grids. Based on the climate projections, however, it is safe to say that the number of heat-related deaths is likely to increase in the Marshall Islands if disaster risk reduction efforts are not effectively implemented. It should be noted that the potential reduction in heat-related deaths achievable by pursuing lower emissions pathways is significant, as demonstrated by Mitchell et al. (2018).[52]

Disease and General Health

Some of the world's most virulent infections are also highly sensitive to climate: temperature, precipitation and humidity have a strong influence on the life-cycles of the vectors and the infectious agents they carry and influence the transmission of water and foodborne diseases. Socioeconomic development and health interventions are driving down burdens of several infectious diseases, and these projections assume that this will continue. However, climate conditions are projected to become significantly more favourable for transmission, slowing progress in reducing burdens, and increasing the populations at risk if control measures are not maintained or strengthened.

According to the RMI's 2016 State of the Environment Report,[19] climate change-related health issues are a concern, particularly Non-Communicable Diseases (NCDs) such as diabetes.[53] In addition, loss of a clean water supply can result in water contamination, which will have significant medical concerns. An increase in atmosphere and sea temperatures could also intensify risks in water and vector-borne diseases, such as diarrhoea, dengue fever, disaster-related fatalities, injuries and illnesses, heat stress and conjunctivitis (pink-eye). It is noted that while the interaction between temperature and diarrheal disease is still unclear, one explanation of the association is that rotavirus and other bacteria that cause diarrhoea are able to proliferate in warm marine water. Another possible explanation is that higher temperatures can cause food to spoil more rapidly, and thus cause food poisoning.[54] **Figure 13** shows research by Singh et al. (2001), which demonstrated the link between annual average temperature and average reporting rates of diarrheal disease specifically amongst Pacific island states.[55]

FIGURE 13. Annual average temperature and average reporting rates for diarrheal disease, Pacific islands (1986–1994). $r^2 = 0.49$; $p < 0.05$[43]



[52] Mitchell, D., Heaviside, C., Schaller, N., Allen, M., Ebi, K. L., Fischer, E. M., . . . Vardoulakis, S. (2018). Extreme heat-related mortality avoided under Paris Agreement goals. Nature Climate Change, 8(7), 551–553. URL: https://pubmed.ncbi.nlm.nih.gov/30319715/

[53] Dain, K., & Hadley, L. (2012). Diabetes and climate change—Two interconnected global challenges. Diabetes research and clinical practice, 97(2), 337–339. URL: https://pubmed.ncbi.nlm.nih.gov/22890699/

[54] Bentham, G., & Langford, I. H. (2001). Environmental temperatures and the incidence of food poisoning in England and Wales. *International journal of biometeorology, 45*(1), 22–26. URL: https://pubmed.ncbi.nlm.nih.gov/11411411/

[55] Singh, R. B., Hales, S., De Wet, N., Raj, R., Hearnden, M., & Weinstein, P. (2001). The influence of climate variation and change on diarrheal disease in the Pacific islands. Environmental health perspectives, 109(2), 155–159. URL: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1240636/

National Adaptation Policies and Strategies

- Second Nationally Determined Contribution (2020)
- Nationally Determined Contribution (NDC) (2018)
- Second National Communication (2015)
- Intended Nationally Determined Contribution (INDC) (2015)
- Joint National Action Plan for Climate Change Adaptation & Disaster Risk Management 2014–2018 (2014)
- National Climate Change Policy Framework (2011)
- Initial National Communication (2000)

Climate Change Priorities of the WBG

WBG — Regional Partnership Framework

The WBG has agreed a Regional Partnership Framework (RPF) for Kiribati, Republic of Nauru, Republic of The Marshall Islands, Federated States of Micronesia, Republic of Palau, Independent State of Samoa, Kingdom of Tonga, Tuvalu, and Vanuatu, FY17–FY21. Climate change is one of four key focus areas of the agreement, which states: *"Protecting incomes and livelihoods. A key focus will be on strengthened preparedness and resilience to natural disasters and climate change. Interventions will also help countries strengthen health systems and address NCDs."*

Under the heading of strengthening resilience to natural disasters and climate change, the RPF aims to continue to support regional and single-country activities that help the PIC9 strengthen their resilience against natural disasters and climate change. PICs combine high exposure to frequent and damaging natural hazards with low capacity to manage the resulting risks. Vulnerability is exacerbated by poor planning, which has increased losses and exposure to natural disasters, and by climate change, which is predicted to amplify the magnitude of cyclones, droughts, and flooding. Sea level rise will worsen coastal erosion and salinization of freshwater resources and increase the severity of storm surges, which will be particularly damaging in atoll islands and low-lying areas. All these impacts adversely affect agriculture, fisheries, coastal zones, water resources, health and ecosystems and the communities that rely upon them. The cost of inaction is substantial. Investments in disaster proofing and climate resilience cost substantially less than rebuilding after a disaster. The WBG will ensure that at least 35% of the total portfolio will directly or indirectly support climate-related co-benefits. The RPF further identifies a range of regional and country-specific interventions including vulnerability assessment and disaster risk planning, financing and insurance initiatives for climate risks and natural hazards, as well as support to resilience building interventions in areas such as transport, agriculture and water supply.[56]

[56] WBG (2017). Regional Partnership Framework for Kiribati, Republic of Nauru, Republic of The Marshall Islands, Federated States of Micronesia, Republic of Palau, Independent State of Samoa, Kingdom of Tonga, Tuvalu, and Vanuatu, FY17–FY21. URL: https://elibrary.worldbank.org/doi/pdf/10.1596/28546

CLIMATE RISK COUNTRY PROFILE

MARSHALL ISLANDS

WORLD BANK GROUP