Pacific Region Infrastructure Facility

Guidance for Managing Sea Level Rise Infrastructure Risk

in Pacific Island Countries

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Abbreviations

ADB	Asian Development Bank
APCP	Australian Pacific Climate Partnership
AR5	IPCC 5th Assessment Report
AR6	IPCC 6th Assessment Report
CD	Chart Datum
CMIP6	Coupled Model Intercomparison Project Phase 6
CSIRO	Commonwealth Scientific and Industrial Research Organization
ENSO	El Niño Southern Oscillation
FSM	Federated States of Micronesia
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
IPCC	Intergovernmental Panel on Climate Change
IOC	Intergovernmental Oceanographic Commission
IPO	Interdecadal Pacific Oscillation
LIDAR	Light Detection and Ranging
MfE	Ministry for the Environment – New Zealand
NAP	National Adaptation Plan
NDC	Nationally Determined Contribution
NID	Nauru Local Datum
NIWA	National Institute of Water and Atmospheric Research - New Zealand
PACCSAP	Pacific-Australia Climate Change Science and Adaptation Programme
PIC	Pacific Island Country
PRIF	Pacific Region Infrastructure Facility
RCP	Representative Concentration Pathway
RMI	Republic of the Marshall Islands
SOPAC	South Pacific Applied Geoscience Commission
SPC	Secretariat of the Pacific Community
SPCZ	South Pacific Convergence Zone
SPREP	Secretariat of the Pacific Regional Environment Programme
SSP	Shared Socioeconomic Pathways
UNESCO	United National Educational, Scientific and Cultural Organization
WACOP	Changing Waves and Coasts in the Pacific

Executive Summary

Sea level rise, which is experienced throughout the Pacific, is adversely affecting infrastructure and, consequently, communities. Combined with ongoing intensification of coastal development and future projections of higher rates of sea level rise for Pacific Islands Countries (PICs), the risk and liability exposure are increasing.

Near-term sea level projections to 2050, which are mostly a result of past emissions, indicate a global rise of 0.19–0.24m.[1] The increase is projected to change the permanent exposure of PIC coastal margins and significantly increase vulnerability to extreme events. Post-2050 exposure continues to increase as a function of sea level rise, which is dependent on emission decisions by the global community. By 2150, sea levels could be as high as 0.68–1.98m and up to 5.0m should ice shelves break up faster than expected.

Many of the low-lying regions within PICs are likely to exceed adaptation limits from sea level rise well before the end of this century, even in a low greenhouse gas emission pathway. Regardless of the effectiveness of mitigation and adaptation pathways, under all future emission scenarios most of the low-lying regions may face adaptation limits beyond 2100.[2]

In recognition of the pressure on infrastructure in the coastal margins from sea level rise, strategic long-term planning is required to ensure that risk is managed. Long-term planning in PICs needs to reconcile the uncertainty associated with future climate change with variability in social, cultural, economic, environmental values and capacity to cope.

Effective long-term management of infrastructure, which is ultimately a function of community needs, goals, and aspirations, is based on robust controls on the quality of construction and, importantly, where infrastructure should, or should not, be developed. Throughout PICs, there is limited or inconsistent guidance on these controls.

To assist PIC planners and decision makers, guidance for dynamic adaptative management plans for critical infrastructure and communities is provided, with the outcome being operational infrastructure plans that are sensitive to climate change triggers, and with clear and pre-agreed short-term actions and long-term pathways defined to manage risk.

In recognition that the adaptative management journey is often protracted due to the complexity of issues, transitional guidance to manage risk based on fixed values of sea level rise and projections is provided. The transitional guidance, which is based on a balanced risk profile built around the IPCC 6th Assessment Report (AR6) sea level rise projections, is designed to support or be integrated into the longer-term land use plans or alternatively PIC codes and standards.[3]

PICs have a low adaptative capacity to climate change, and a holistic approach to infrastructure management that considers the full range of plausible climate change and natural hazard outcomes is required. PICs are encouraged to start the adaptative management process by engaging with the community as a vehicle to educate and gain community buy-in to potential adaptative pathways and align aspirations with wider multi-development partner programs.

Due to the rate of sea level rise, high near-term infrastructure exposure and limited adaptative capacity, urgent adaptative planning and engineering design controls are required for each PIC to manage future risk.

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[1] IPCC. 2021. Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, edited by V. Masson-Delmotte, et al. Cambridge: Cambridge University Press (in press).

[2] IPCC. 2019. *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate*, edited by H.-O. Pörtner, et al. Geneva: IPCC.

[3] IPCC. 2021. Climate Change 2021.

1. Introduction

Climate change is impacting low-lying Pacific islands, with cascading and compounding risks that are expected to increase throughout the 21st century and beyond. Vulnerable communities, especially in Pacific coral reef environments, may exceed adaptation limits well before the end of this century, even in a low greenhouse emission pathway.[4] Regardless of the effectiveness of mitigation and adaptation pathways, under all future emission scenarios, most of the low-lying regions may face adaptation limits beyond 2100.

Future rates of global sea level rise are strongly dependent on decisions by the global community. Climate projections show that the rate of sea level rise at the end of the century is expected to be faster under all possible scenarios, including those compatible with achieving the long term temperature goal set out in the Paris Agreement.[5] By 2100, the global mean sea level is projected to rise by 0.28m to 1.02m with a higher likelihood towards the upper end of the range based on current Nationally Determined Contribution (NDC) targets which is currently tracking to a world that is 2.4 °C to 2.7 °C warmer above preindustrial levels.[6]

1.1 Why is Guidance Required?

Hazard risk from sea level rise is compounding in coastal areas because impacts are occurring more frequently as seas rise, while, at the same time, coastal development intensifies. Sea level is expected to keep rising for at least several centuries, posing an ongoing challenge for Pacific Island Countries (PICs) to maintain sustainable coastal communities.[7]

Sea-level-rise-induced hazards impact on a wide range of social, cultural, and economic values, as well as affecting the natural and physical environment. Acceptable solutions for adapting to the changes vary from place to place, and for some communities will be made more complex by greater risks, greater vulnerability, and a lower ability to cope. There is no one-size-fits-all solution. PIC national and local governments face the enduring question of how to achieve the aspirations of local communities while making sometimes unpopular decisions that will enable them to adapt to a changing climate.

The rate of current sea level rise and the wide range of scenarios for future sea levels presents a challenge when considering new and existing critical infrastructure. Effective risk management requires controls on where infrastructure is developed or currently maintained while considering the increased hazards from climate change. Internationally, this is commonly achieved through integrated Building Acts and national adaptation and natural hazard strategies and plans. However, most PICs have limited or non-existent development controls and plans/legislation to support long-term risk management.

For new development, sea level rise risk is commonly addressed via engineering design codes and standards and are based on fixed values of projected sea level rise as a function of design life. Consideration of sea level rise is restricted to the individual asset, making the application of codes and standards alone insufficient to manage infrastructure regionally. Due to the uncertainty of climate change, and level of direction contained within existing codes and standards there is high variability in the application of sea level rise projections and magnitudes of sea level rise throughout PICs.

The combination of limited long-term land use planning in conjunction with inconsistent application of sea level rise projections and magnitudes provides the opportunity to accept unintended risk or, alternatively, overestimate risk, resulting in overdesigned infrastructure. In recognition of the limitations, revised sea level rise projections and guidance to manage infrastructure risk are proposed.

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[4] IPCC. 2019. *IPCC Special Report on the Ocean and Cryosphere.*

[5] Ibid. The Paris Agreement has a goal is to limit global warming to well below 2 °C, preferably 1.5 °C compared to preindustrial levels. To achieve this long-term temperature goal, countries aim to reach global peaking of greenhouse gas emissions as soon as possible to achieve a climate-neutral world by 2050. Recent analysis completed for the 6th Assessment Report has concluded that a more aggressive Very low emissions (SSP1–1.9) pathway is required, which is well below the current global NDC to limit global temperature increase to 1.5 °C above preindustrial levels.

[6] IPCC. 2021. Climate Change 2021.

[7] Ibid.

1.2 About this Guidance Note

Sea level rise in combination with extreme sea level events (e.g., storm surges) and non-climate drivers such as subsidence are increasing PIC community and infrastructure vulnerability and exposure. The associated risk from sea level rise is dynamic and varies widely due to the localized nature of inundation, scale of coastal infrastructure, community livelihoods, and habitability.

Section 2 of this guidance note summarizes the approach to sea level rise planning and includes potential generic responses when considering infrastructure development. The concept of dynamic adaptive pathways is introduced, and a framework is proposed to help manage sea level risk.

The IPCC 6th Assessment Report (AR6) has introduced a new set of climate scenarios and projections that differ from prior assessments. To assist infrastructure practitioners and decision makers, projections of sea level rise for each PIC have been compiled based on the latest AR6 analysis and presented in **Section 3**. The projections incorporate statistical long-term vertical land movement rates and have been extended to provide decadal estimates to the year 2150.

In lieu of finalized adaptation plans, transitional guidance is provided based on fixed levels of sea level rise and/or selected projections for various infrastructure types. The guidance is intended to complement existing planning processes and design codes or standards to provide immediate direction in defining acceptable level of risk. Recommended minimum projections of sea level rise for infrastructure planning and development are provided in **Section 4**.

There are several components that make up sea level with varying magnitudes under ambient and extreme conditions. To support local definition of sea level rise hazard, **Section 5** presents a summary of each component based on recorded tide gauge data for each PIC. Trends of past sea level rise are presented in association with observed vertical land movement. Considering near-term estimates of sea level rise, changes to exposure of the coastal margin is quantified for both ambient and extreme conditions. Links to key resources to support sea level assessments are provided in **Appendix 1**.

Recommendations to progress sea level rise infrastructure risk assessment and future planning are provided in **Section 6** with an emphasis on data gap filling and progressing adaptation planning.

This guidance note has retained the language and terminology that is used by the IPCC to ensure that the guidance outcomes are transferable. Critical terms shown in *italics* include the following:

- *Most likely* is defined as the range of outcomes that are bounded by the 5th and 95th percentiles of the relevant variable representing a probability of occurrence of 90%.
- *Likely* is defined as the range of outcomes that are bounded by the 17th and 83rd percentiles of the relevant variable representing a probability of occurrence of 66%. The likely values are presented in brackets, e.g., (0.05–0.20).
- *High confidence:* based on robust evidence and high agreement.
- *Medium confidence:* based on medium evidence and medium agreement.
- *Low confidence:* based on limited evidence and low agreement.

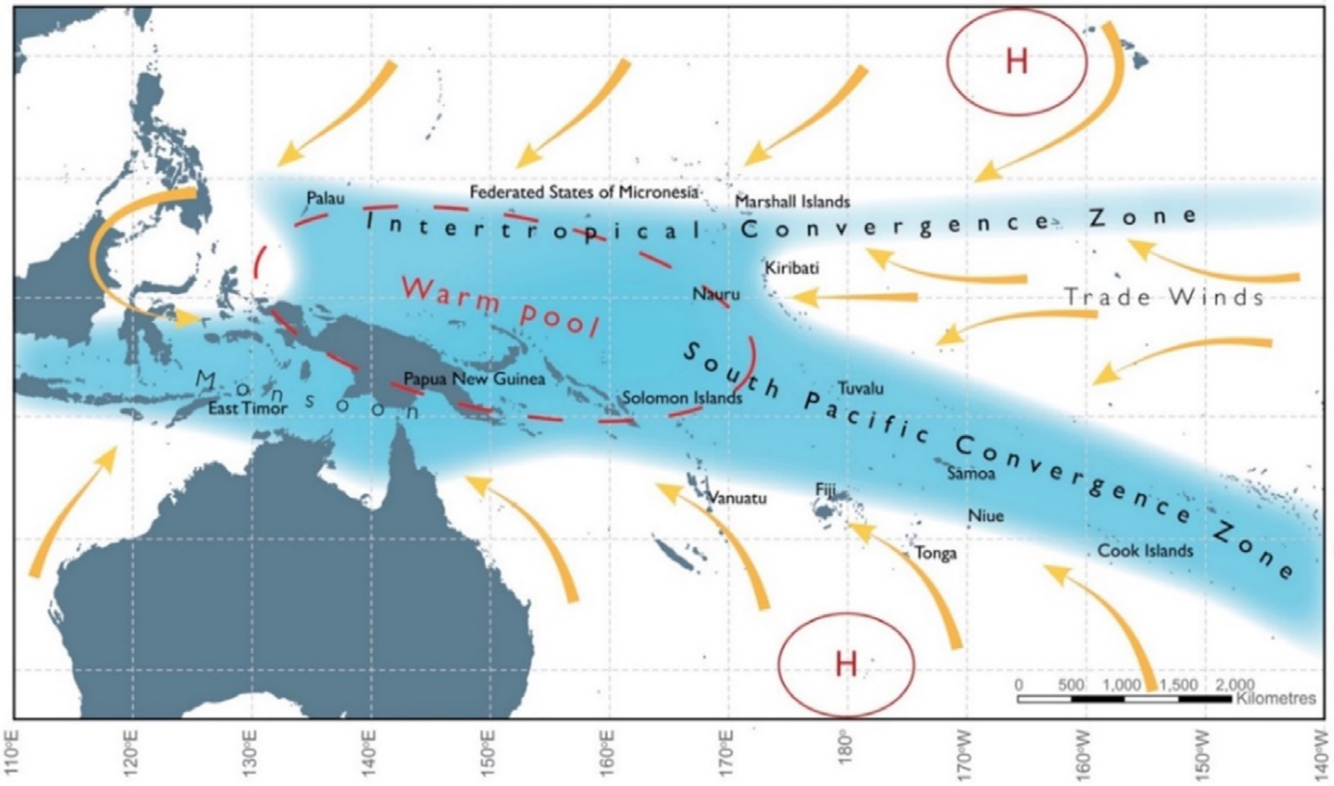
This guidance does not intend to replace codes, standards, or guidance manuals that are in existence. The guidance has been developed to assist infrastructure planners and developers in understanding the quantum of the future sea level rise and how it should be considered when developing new or managing existing infrastructure in lieu of established guidance. For aspects of the guidance that require specialist assessment, it is recommended that a suitably qualified professional be utilized.

1.3 Geographic Coverage

The geographic extent of the guidance is confined to the Cook Islands, Federated States of Micronesia (FSM), Samoa, Tonga, Fiji, Kiribati, Nauru, Palau, Republic of the Marshall Islands (RMI), Niue, Tuvalu, Solomon Islands, and Vanuatu. Locations with reference to dominant Pacific climate processes that influence global climate change effects for the region are presented in Figure 1.1.

Infrastructure throughout these locations is particularly susceptible to the impacts from natural variability of regional climate processes from year to year and season to season and have significant effect on the environment and communities. These large-scale climate processes include El Niño Southern Oscillation (ENSO), the South Pacific Convergence Zone (SPCZ), the West Pacific Monsoon, and the Intertropical Convergence Zone, and the zone of influence is presented in Figure 1.1. Longer-term climate change and variability compound these processes, which, in turn, increases vulnerability to natural climate disasters.

Figure 1.1: Weather and Climate Processes that Influence PICs between November and April



Notes:
1. Pacific Island Country (PIC).
2. Yellow arrows indicate near surface winds.
3. Red dashed region indicates the typical location of the Pacific Warm Pool (i.e., during years classed as the Neutral phase of the El Niño/Southern Oscillation).
4. High pressure systems are indicated by H.

Source: 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 Commonwealth Scientific and Industrial Research Organization, Melbourne, Australia.

2. Planning for Sea Level Rise

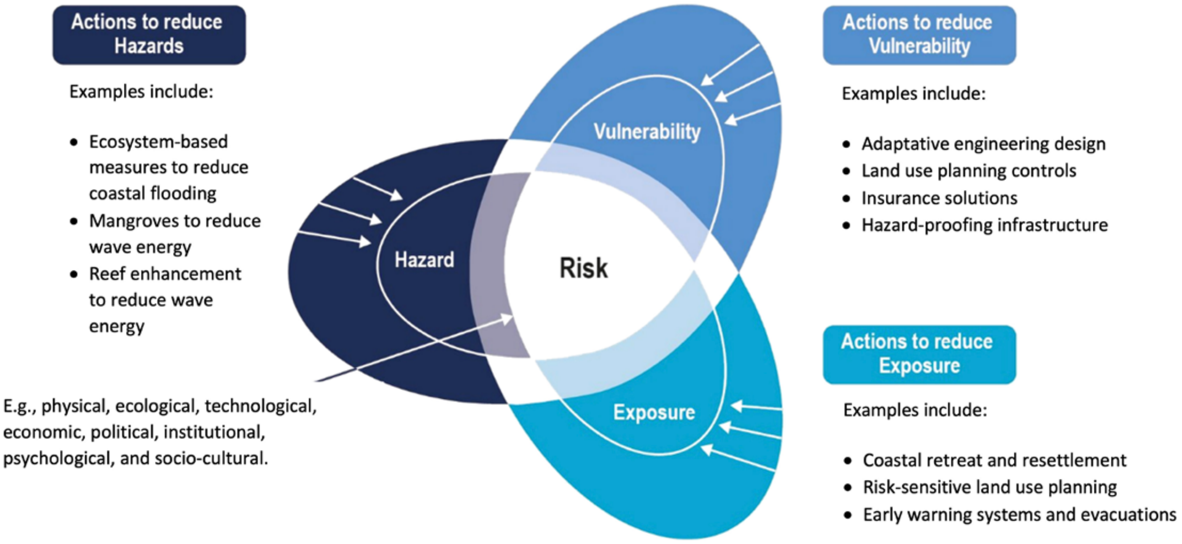
When developing or managing infrastructure, decision makers are required to consider the range of hazards that infrastructure is subject to, the exposure and vulnerability, and the inherent uncertainty associated with sea level rise. The range of hazards from sea level can be diverse (Table 2.1) and depend on infrastructure type, design, and location.

Because of climate uncertainty, it is necessary to consider a range of plausible future states. Since planning of greenfield development or new infrastructure will lock in a level of risk, consideration of management options to address future sea level rise, and wider climate change variables is required.

The principles of managed risk and "no regrets", or precautionary decision making, are common throughout PICs when considering major new development. However, when considering sea level rise and wider climate change impacts, the scale of the potential impact makes the decision-making framework complex, with potential consequences persisting well into the future and potentially compounding risk.

Beyond mitigation, adaptation is a key avenue to reducing risk (Figure 2.1). Adaptation efforts can reduce existing and future vulnerability, exposure, and, where possible, hazards. Addressing the different risk components (hazards, exposure, and vulnerability) involves assessing and selecting options for policy and action. Such decision-making entails evaluation of the effectiveness, efficiency, efficacy, and acceptance of actions. Adaptation requires capacity, which is particularly challenging in PICs, due to limited available land, complex land ownership and economic funds to commit to a particular strategy.

Figure 2.1: Components of Risk



Source: IPCC, 2019: *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate.*

Throughout PICs, National Adaptation Plans (NAPs) have been, or are being, developed, albeit at a high level that considers generic adaptation responses to sea level rise, as presented in Box 2.1. However, considering adaptative capacity, most PICs have yet to define the risk and develop long-term land use and adaptation plans at a national or community (local) level to manage sea level rise risk. Furthermore, for project development there remains a wide range of codes and standards throughout PICs that provide inconsistent or limited guidance on sea level rise risk and magnitude with respect to asset design life.

Box 2.1: Responses to Sea Level Rise

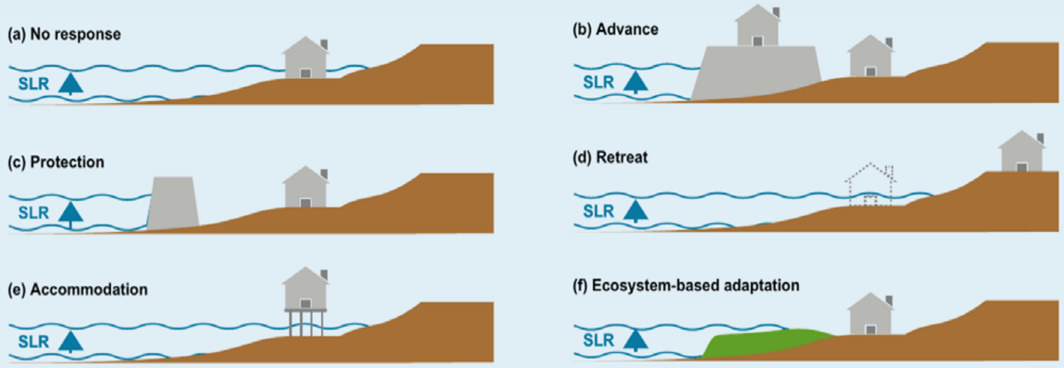
Advance creates new land by building seaward, reducing coastal risks for the hinterland and the newly elevated land. This includes land reclamation above sea levels, planting vegetation with the specific intention to support natural accretion of land and surrounding low areas with stop banks/dikes. Advance also requires drainage and often pumping systems to address increased catchment-based flooding.

Protection reduces coastal risk and impacts by blocking the inland propagation and other effects of mean or extreme sea levels. This includes: i) hard protection such as dikes, seawalls, breakwaters, barriers, and barrages to protect against flooding, erosion, and saltwater intrusion; ii) soft protection such as beach and shore nourishment, dunes; and iii) ecosystem-based adaptation (see below). The three subcategories are often applied in combination as hybrid measures.

Retreat reduces coastal risk by moving exposed people, assets, and human activities out of the coastal hazard zone. This includes the following three forms: i) Migration, which is the voluntary permanent or semi-permanent movement of people; ii) Displacement, which refers to the involuntary and unforeseen movement of people due to environment related impacts; and iii) Relocation, also termed resettlement, managed retreat, which is typically initiated, supervised, and implemented by governments from national to local levels and usually involves small sites and/or communities. The need for retreat and other response measures can be reduced by avoiding new development commitments in areas prone to severe sea level rise hazards.

Accommodation includes diverse biophysical and institutional responses that mitigate coastal risk and impacts by reducing the vulnerability to coastal residents, human activities, ecosystems, and the built environment, thus enabling the habitability of coastal zones despite increasing levels of hazard occurrence. Accommodation measures for erosion and flooding include building codes, land use planning, raising infrastructure, and designing infrastructure so that it can be modified in the future to reduce risk.

Ecosystem-based Adaptation combines Protection and Advance benefits based on the sustainable management, conservation, and restoration of ecosystems. Examples include the conservation or restoration of coastal ecosystems such as wetlands and reefs. Ecosystem-based adaptation protects the coastline by (i) attenuating waves, and, in the case of wetlands storm surge flows, acting as obstacles and providing retention space; and (ii) raising elevation and reducing rates of erosion through trapping and stabilizing coastal sediments, as well as building up of organic matter and detritus. Ecosystem-based adaptation is also referred to by various other names, including Natural and Nature-based Features, Nature-based Solutions, Ecological Engineering, Ecosystem-based Disaster Risk Reduction or Green Infrastructure. Within Pacific Island countries, common forms of Ecosystem-based Adaptation that feature in many of the National Adaptation Plans include mangrove planting and coral reef restoration.



Different Types of Responses to Coastal Risk and Sea Level Rise
SLR = sea level rise.
Source: IPCC, 2019: *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate.*

2.1 Adjacent Sea Level Rise Impacts

Critical climate variables and related hazards that can impact infrastructure are presented in Table 2.1. While this guidance is focused on sea level rise, it is important to recognize its interconnectivity with other climate variables. For example, while sea level rise can actively change the exposure of an asset to tidal forces, the increased water levels are likely to increase river tailwater levels, enhancing catchment flooding during periods of high rainfall. It is important to consider the interconnectivity of each hazard and approach the adaptation planning and development process holistically to ensure a robust outcome.

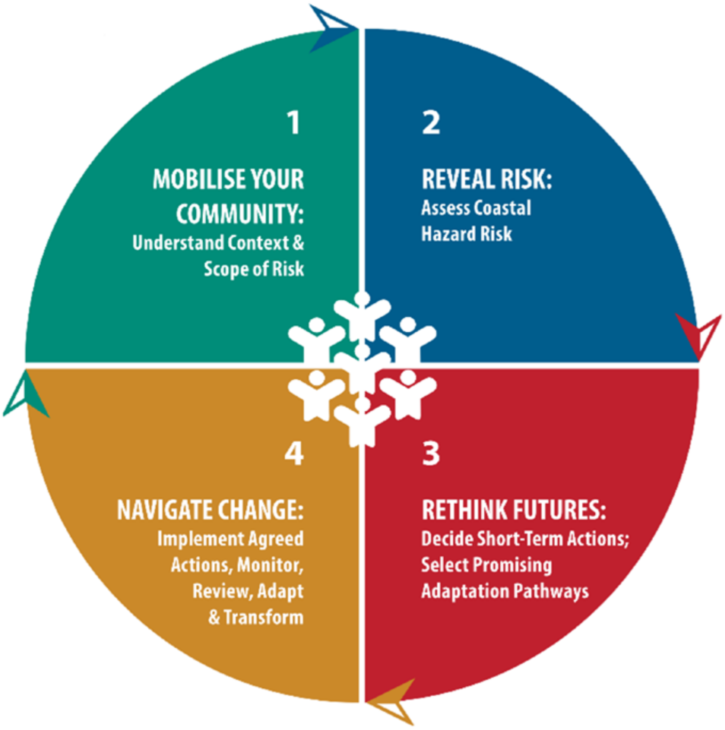
Table 2.1: Climate-induced Hazards on Infrastructure

Climate variable	Climate related hazard/effect
Rainfall	• Higher or lower mean annual rainfall • Changes in rainfall seasonality • Interannual variability, such as El Niño Southern Oscillation • Changes in extreme rainfall resulting in increased intensity and persistence • Floods (fluvial and pluvial) • Rain induced landslides • Changes in sedimentation from catchment runoff • Changes in groundwater depths
Storminess and wind	• Changes in mean wind speed/direction • Changes in wind seasonality • Interannual variability, such as El Niño Southern Oscillation • Changes in extreme wind speed • Increase in frequency and intensity of tropical cyclones
Coastal change: sea level rise, waves, and ocean circulation	• Relative sea level rise (incl. land movement) • Change in tidal range or increased water depth • Permanent increase in high tide inundation • Permanent and episodic saline intrusion • Rising groundwater from sea level rise • Changes in waves/swell persistence and intensity • More frequent coastal flooding (storm tide, waves) • Coastal and cliff erosion • Changes in sedimentation (estuaries/harbor) • Increased nearshore wave energy
Rising temperatures	• Higher day and night temperatures • More heatwaves and warm spells • Fewer frosts or cold days • Changes in seasonality • Interannual variability (e.g., El Niño Southern Oscillation) • Freshwater and estuaries: higher mean temperatures • Marine/coastal waters: higher mean temperatures • Marine/coastal waters: heatwaves
Dryness and drought	• Increase in dry spells • Higher drought frequency and persistence • Fire weather (harsher, prolonged season) • Changes in seasonality • Interannual variability (e.g., El Niño Southern Oscillation) • Low river flows, lake, and groundwater levels
Snow and ice	• Changes in global snow and glacial melt resulting in sea level rise
Ocean changes	• Changes in ocean nutrient cycling – upwelling and carbon • Ocean acidification (pH decreasing) • Ocean circulation changes

2.2 Adaptative Planning

Adaptative planning is a relatively new approach that is well suited to management of sea level rise as it incorporates uncertainty and risk and places community engagement at the center of decision-making processes (Figure 2.2). The approach is called Dynamic Adaptive Pathways Planning and identifies ways forward (pathways) despite uncertainty, while remaining responsive to change should this be needed (dynamic).

Figure 2.2: Sea Level Rise and Coastal Hazard Planning Framework



Source: IOC-UNESCO. 2021. *Community Guide for Community Members Interested in Risk Reduction Efforts. How to Reduce Coastal Hazard Risk in your Community: A Step-By-Step Approach.* IOC Manuals and Guides 85(2). Paris: UNESCO.

In the adaptive planning approach, a range of responses to climate change are tested against possible scenarios, which is further addressed in Section 3 . Pathways are mapped that will best manage, reduce, or avoid risk. A plan is developed, with short-term actions and long-term options, and includes pre-defined points (triggers) where decisions can be revisited. This flexibility allows the agreed course of action to change if the need arises, such as if rates of sea level rise occur faster than projected or if new climate change information becomes available.

This iterative approach helps avoid locking in investments that could make future adjustments difficult and costly. As such, it assists both longer-term sustainability and community resilience. The Dynamic Adaptive Pathways Planning approach is a powerful process for managing and adapting to climate change. It recognizes that, first, climate change effects vary from place to place, and second, that decision-makers face unavoidable uncertainty about ongoing sea level rise. It is usually not possible, practical, or sensible for them to wait until uncertainties are reduced before making decisions.

To support the NAP process, which is wide-ranging and considers the full range of climate change effects, specific national and community (local) land use plans and policies are required to manage infrastructure risk built around the principles of Dynamic Adaptive Pathways Planning. The intent and outcome of the plans is to provide clear cascading guidance on where it is appropriate to locate infrastucture and provide adaptation options at a national and community level to respond to ongoing sea level rise and associated hazards. Key principles to consider when assessing sea level rise risk and developing adaptative management plans are outlined in Box 2.2.

Box 2.2: Key Principles in Managing Sea Level Rise Risk

When developing or planning for future infrastructure, the following principles should be considered:

- Use the most up-to-date and robust science to determine regional sea level rise projections.
- No one particular climate future can be determined due to uncertainty in global emissions and the emergence of polar ice sheet instabilities, which can affect the rate of sea level rise. Therefore, planning and development in coastal areas needs to consider the range of potential climate scenarios. Due to the uncertainties a definitive likelihood cannot be defined for a particular planning horizon. However, for infrastructure design a risk-based approach is required to determine the level of risk that is acceptable, which is commonly defined by codes and standards. Accordingly a precautionary approach should be adopted for given planning timeframes erring to higher projections of sea level rise.
- Decision makers should not presume that sea level rise will follow one sea level projection scenario outlined in this guidance. Rather hazard analysis and vulnerability and risk assessments should be completed to determine how different scenarios or increments of sea level rise affects design, level of service, maintenance, and viability before making decisions on the acceptable risk profile or adaptative management options.
- Decision makers should evaluate a range of pathways to address uncertainty and develop a range of outcomes that can be implemented in adaptative manner at defined trigger/decision points.
- Flexibility is required to account for the degree of risk, likelihood of future consequences including criticality of the infrastructure and sensitivity to coastal hazards, permanence of the activity, and adaptive capacity of the community and assets.
- To align with design standards and codes that consider infrastructure importance, the magnitude of sea level rise to consider in design needs to recognize the risk, which is a function of likelihood and consequence. Accordingly, PIC climate projections presented in this guidance are based on a precautionary approach and erred to projections that are consistent with existing rates of level of sea level rise (High and Very high emissions projections).
- For anticipated long life or greenfield developments and critical new infrastructure, a planning timeframe of 100 years should be considered in association with the Very High Emissions - Low confidence (SSP5-8.5H+) projection, which is consistent with the upper bound of likely sea level rise via the Very high emission scenario (SSP5-8.5).
- It is prudent to stress test future climate sensitivity and adaptative capacity of the activity, policy options or land use plan, including existing and new development, greenfield development, and major new upgraded infrastructure projects. Accordingly, it is advised that a precautionary approach is applied utilizing sea level rise projections for Intermediate and Very high emission scenarios and the implications for the upper likely bound of the projections (83rd percentile).
- No sea level rise scenario should be extrapolated on past trends as the future states are a result of different drivers. Any extrapolation will underestimate the level of risk and ultimately the magnitude of coastal hazards.
- Sea level rise projections are mathematically smooth, whereas, in reality, seasonal, annual and decadal climate fluctuations result in variability. This needs to be recognized in hazard assessment, adaptative planning and development of design basis.
- It is essential for decision makers to distinguish between global mean sea level and local (relative) mean sea level. For the Pacific, the effect of regional subsidence is resulting in higher sea level rise rates. It is noted that several PICs such as Samoa, Tonga, and Vanuatu are subject to frequent seismic activity, which further affects local sea level rise rates.
- It is important to recognize that sea levels will continue to rise for several centuries, and the rate or rise is dependent on global decisions on management of greenhouse gas emissions over the next decades.
- It is recommended that a suitably qualified professional is involved in the quantification of local sea level rise and delineation of risk and development of adaptation options for infrastructure.

Source: Adapted from New Zealand Ministry of Environment (MfE). 2017. *Coastal Hazards and Climate Change – Guidance for Local Government.*

2.3 Development of Adaptative Infrastructure Plans

To support adaptative infrastructure management planning, an implementation procedure adapted from IOC-UNESCO[8] and AS5334:2013 is provided in the following sections. It is acknowledged that the process for developing comprehensive adaptative management plans is protracted due to the complexity and uncertainty of sea level rise coupled with PIC-specific community and institutional constraints. Accordingly, the adaptation plan process includes the implementation of transitional guidance (Section 4) to manage infrastructure risk while dynamic adaptative plans are developed.

2.3.1 Step 1 – Mobilize the Community, Understand Context and Scope of Risk

Due to the complexity and extent of potential sea level rise on communities and infrastructure, a multidisciplinary team is required to carry out preparatory tasks. Tasks involved in Step 1 include:

1) **Formation of the adaptation planning team and agreement on the best way to work together and secure funding and a mandate to act.**
    - Skill sets will include inputs from across various government functions and sectors, such as environmental, social safeguards, transport, utilities, energy, insurance, banking, etc.
    - Where appropriate, work with Development partners to align parallel programs of work and funding streams.

2) **Establish the need to reduce sea level rise risk.**
    - Define the communities and/or the specific infrastructure shaping risk.
    - Define priority areas that are likely to be subject to sea level rise risk and associated hazards, such as low-lying coastal areas, areas prone to coastal erosion, and areas that are susceptible to groundwater and drainage effects.
    - Complete screening based on existing infrastructure risk exposure information and prioritize communities, infrastructure type (e.g., buildings, roads, utilities, energy generation and transmission, etc.) and critical infrastructure (e.g., airport or port) where adaptation plans are required.

3) **Agree on how the team will engage with the community.**
    - Identify who should participate, integrating community leaders and stakeholders in the process.
    - Understand the community views on sea level rise and coastal hazard risk.
    - Reflect on community values, vision, objectives, and goals and how to work together to reduce risk.

4) **Agree on a plan to reduce risk and mobilize resources.**
    - Based on the range of communities such as highly developed towns versus villages, decide on the appropriate plan to reduce risk. This could include tailoring the assessment and adaptative approach to suit local constraints.
    - Secure a planning mandate across national and local government, including key community leaders.
    - Raise awareness and inform local communities.

5) **Review respective legislation and land use planning controls to identify gaps in current practices to manage risk.**
    - Review existing infrastucture development controls to ensure infrastucture development in areas subject to natural hazards and climate change are suitably managed. Where provisons are not defined, implement a program to amend legislation. It is recommended that development of infrastructure should be avoided in areas that are likely to be affected by sea level rise and associated natural hazards within a 100-year time frame.

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[8] IOC-UNESCO. 2021. Community Guide for Community Members Interested in Risk Reduction Efforts. How to Reduce Coastal Hazard Risk in your Community: A Step-By-Step Approach. *IOC Manuals and Guides*, 85(2) (English). Paris: UNESCO. https://unesdoc.unesco.org/ark:/48223/pf0000375768.

- Review existing local government administration functions that control where development is located and managed and, where needed, enhance systems/departments to manage development via a consent approval process.
- Review infrastructure codes and standards that inform the quality of construction and provide minimum standards to accommodate natural hazards and sea level rise.

6) **Implementation of transitional controls for planning and infrastructure design.**

- To minimize risk until adaptative pathways are implemented, fixed sea level scenarios must be defined. Bespoke precautionary controls are provided in Section 4 of this guidance.

7) **Complete stock-take of available information and data.**

- Complete a stock-take of available information and, where data at the site of interest are not available, prepare data collection and study programs. Required data are outlined in Table 2.2. Of importance is detailed topographic, bathymetric, infrastructure data and aerial imagery to assist delineation of hazards and visualizing the consequence for community engagement, with the first two preferably sourced from laser scanning Light Detection and Ranging (LIDAR) methods.

Table 2.2: Required Data for Infrastructure Risk Assessment

Data	Derived information	Use
GIS Infrastructure Type and location	GIS spatial information of infrastructure type, extent, and location	• Mapping to define risk exposure • Quantification of vulnerability • Development of adaptation options
Sea level record	– Tidal elevations – Storm surge – Sea level maxima – Establishment of datums	• Land-sea boundary definition • Boundary conditions or calibration data for numerical models • Component of probabilistic sea level analysis
LIDAR Topography and Bathymetry	Land and seabed levels	• Input for hydrodynamic numerical models • Geographic information system hazard mapping • Definition of coastal features
Aerial photography	Maps	• Shoreline and land use change
Wave record	Wave height period and direction	• Boundary conditions or calibration data for numerical models • Extreme wave frequency-magnitude distribution • Input to empirical wave setup and runup models • Monitor wave climate variability and climate change effects on waves
Beach profile records	Beach slope, position, and volume	• Input to wave setup and run up models • Input to beach erosion models and validation of post storm effects
Historical storm tide and elevation	Coastal hazard markers and elevation	• Verification data for coastal storm inundation and beach erosion models
Meteorology	Wind velocity, air pressure and rainfall	• Input to hydrodynamic or empirical storm surge and wave models
Sediment composition	Sediment grain size	• Beach erosion models
Piezometer	Ground water levels	• Groundwater level and salinity response to sea level change.

GIS = Geographic Information System ; LIDAR = Light Detection and Ranging.
Source: Adapted from MfE (2017).

At the end of Step 1, you will have:

- established, at the national and community level, the need to reduce sea level rise and coastal hazard risk;
- agreed how the government and community will work together to reduce this risk;

- decided on the appropriate collaborative risk assessment and adaptive approach for the respective community and/or infrastructure type, and mobilized resources and your community, to initiate risk reduction;
- implemented transitional sea level rise planning and engineering guidance until adaptive pathways and plans are defined and implemented; and
- defined a program of work to fill necessary data and sea level rise risk information gaps.

2.3.2 Step 2 - Reveal Risk, Assess Sea Level Rise, and Coastal Hazard Risk

The assessment of risk from sea level rise requires quantification and delineation of hazards exacerbated by sea level rise and the subsequent effects on coastal systems and infrastructure at national/regional and local (community) levels. The following tasks are recommended:

1) **Describe possible hazards and occurrence.**
    - Identify possible hazards exacerbated by sea level rise (Table 2.1) and potential scenarios (Section 3).
    - Depending on mandate, consider additional natural hazards that are not climate change-related, such as seismic or tsunami effects, to provide a holistic assessment of infrastructure hazard risk.
    - Assess the potential risk from the various sea level rise scenarios for infrastructure via risk-based assessment methods.
    - Develop maps of hazards exacerbated by sea level rise that delineate the spatial extent of future risk and captures the potential impacts on existing infrastructure (Section 5.6.1).

2) **Assess the vulnerability to sea level rise and exacerbation of coastal hazards.**
    - Assess community infrastructure exposure including implications at a national or regional level.
    - Assess susceptibility to loss and damage that considers economic, social, and environmental values.
    - Assess implications to community connectiveness, particularly associated to critical infrastructure (airports, ports, energy generation, etc.).
    - Assess capacity to reduce vulnerability via existing adaptation management options.

3) **Involve the community in defining risk to enhance local understanding of the risk and aligning with local community values, vision, goals, and objectives.**
    - Assess risks utilizing community knowledge and perception of current sea level rise and coastal hazards.
    - Seek community feedback on the range of potential risks that could occur locally from the effects of sea level rise. Of particular importance is capturing interrelated and cascading hazards that can affect infrastructure (Table 2.1).
    - Educate and inform the community of the potential sea level rise impacts and threats to the community and infrastructure.

At the end of Step 2, you will have:

- described the plausible sea level rise scenarios and the associated change to coastal systems and hazards and considered the implications;
- assessed the national/regional and community infrastructure vulnerability to the effects of sea level rise;
- informed, educated, and involved the community in assessing the risks it faces.

2.3.3 Step 3 - Rethink Futures and Develop Adaptative Pathways

The adaptation pathways approach is based on defining a range of possible adaptation responses that are considered appropriate for defined levels of sea level rise. The range of pathways is dependent on the adaptative capacity of the local environ, which is generally limited for PICs. To assist development of adaptative plans the following tasks are recommended:

1) **Prepare for the potential range of future sea level scenarios (Section 3) and the related changes to coastal systems and hazards.**
    - Consider possible futures for communities and infrastructure built around the range of adaption options (Box 2.1) and the adaptive capacity of each PIC.
    - Identify priority infrastructure risks and determine acceptable levels of risk.
    - Identify barriers and enablers to improve infrastructure resilience.

2) **Identify and compare potential infrastructure risk reduction strategies.**
    - Identify risk reduction strategies and measures.
    - Compare advantages and disadvantages.
    - Identify and select most promising intervention options.

3) **Definition of adaptation measures and pathways for sustained risk reduction.**
    - Consider community values, vision, and goals.
    - Identify and assess adaptation thresholds, signals, and triggers for various adaptation options.
    - Evaluate interventions and pathways considering adaptive capacity, economic, social, and environmental constraints.
    - Define adaptation pathways with set triggers to switch to alternative pathways and interventions.
    - Design monitoring and evaluation processes to retest pathways and trigger thresholds.

4) **Prepare infrastructure management strategy that provides the basis for ongoing collaborative sea level rise risk reduction.**
    - Prepare adaptation plan than defines and prioritizes risks, identifies, compares, and selects preferred sea level rise risk reduction strategies, measures, and pathways.
    - Secure formal government approval for the plan and define how the plan will be operationalized as part of local government processes.

At the end of Step 3, you will have:

- identified and compared risk reduction strategies and measures and selected the most promising intervention options to manage sea level rise risk;
- developed a robust adaptation pathway plan; and
- secured formal government approval and approved pathway for operation of the plan(s).

2.3.4 Step 4 – Navigate Change, Implement and Monitor

The effectiveness of any dynamic adaptive plan is dependent on ensuring that it is fully mainstreamed into local government processes, community decision making and is subject to regular monitoring and update. Due to the uncertainty of climate change, unexpected events are likely to occur and short-term actions need to be taken along temporary pathways to work progressively towards the community's shared vision and long-term goals. To maintain the currency of the adaptative plans the following tasks are recommended:

1) **Implement government-endorsed adaptation plan.**
    - Implement agreed roles and responsibilities and coordinating mechanisms to operationalize the plan within local government.
    - Integrate the plan within existing planning controls and local government provisions to ensure compliance and enforce provisions and regulations.
    - Mainstream the adaptation approach to proactively reduce sea level rise risk and improve adaptive capacity and resilience.

2) **Regularly review, monitor, and evaluate interventions.**
    - Review and refine the monitoring and evaluation program including currency of defined adaption options and appropriate sea level rise trigger levels.
    - Gather and assess monitoring data as part of a broader annual state of the environment monitoring approach.
    - Communicate findings and actively engage with local communities that are affected by the plan.

3) **Review and revise the plan to match changed national, local and community aspirations or changes in technology or rate of climate change.**
    - Actions in response to signal alert or trigger points.
    - Actions to reduce vulnerability and risk and improve resilience.

At the end of Step 4, you will have:

- implemented the adaptation plan;
- completed monitoring and tested the plan for robustness and currency;
- updated the plan for changes in aspirations or unexpected events; and
- institutionalized a community led adaptation approach to improve infrastructure resilience.

2.3.5 Summary

Effective infrastructure planning requires controls to guide where development is appropriate and the level of sea level rise risk that needs to be addressed in engineering design. Adaptative planning is a cost-effective process to manage risk while recognizing the inherent uncertainty of future sea level rise.

Implementing the adaptation planning process within the PIC context is complicated due to the scale of the issue, lack of adaptative capacity, magnitude of infrastructure that is susceptible and the expense of the process. Accordingly, implementing of Steps 1 and 2 of the adaptation plan process built around operationalizing the transitional guidance in Section 4 is considered a priority to immediately improve infrastructure risk decisions.

An example of the dynamic adaption management process is presented in Section 2.3.5.1 that assesses potential pathways for Majuro atoll in RMI. The assessment presents the outcomes from Steps 1 and 2 of the adaptation planning process and has identified potential adaptation pathways (Step 3) of which decisions have yet to be made on which path to action. Due to the low-lying nature of Majuro and limited adaptative capacity, the range of defined adaption options to address sea level rise are applicable to all PICs.

2.3.5.1 Case Study – Majuro Atoll (Marshall Islands)

Faced with an existential threat from climate change, and specifically the effects of sea level rise, the Republic of the Marshall Islands (RMI), in conjunction with support from the World Bank, is developing a National Adaption Plan for Majuro. Long-term adaptation is critical to giving the Marshallese the choice to continue living in the places they have called home for centuries, even as sea levels rise.

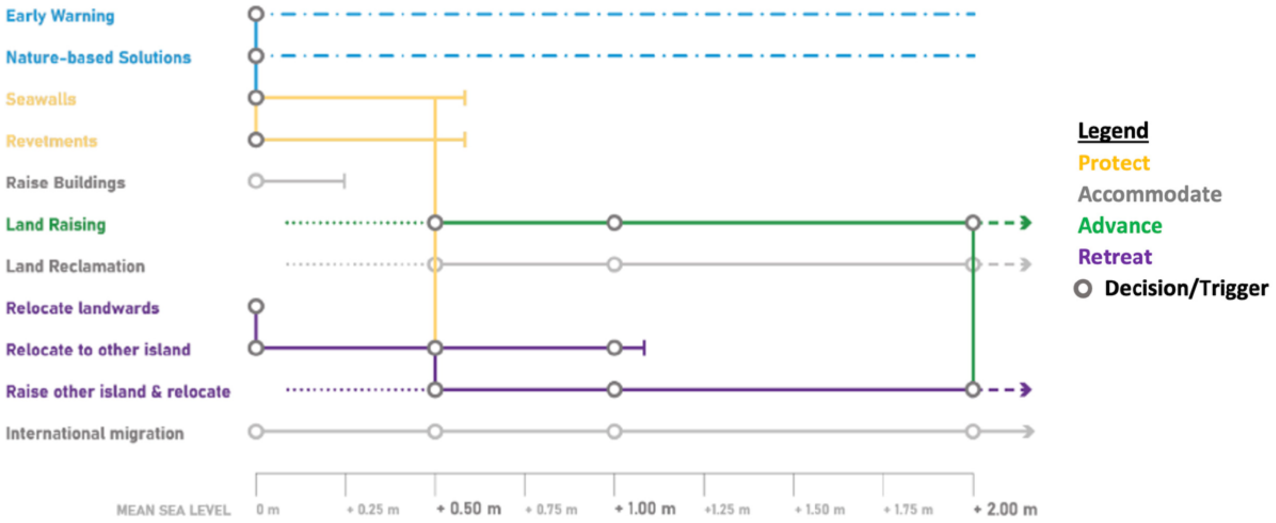
Majuro, the capital of RMI is located in the Northern Pacific and consists of a low-lying atoll with the majority of land situated 1–2m above mean sea level. The atoll has a population of approximately 30,000 and is densely developed, with 5,664 buildings and supporting transport, water, and utility infrastructure.

In recognition of the range of uncertainty in future sea levels, infrastructure risk was assessed for a set amount of sea level rise (0.25m, 0.5m, 1m, and 2m) independent of any specific future climate change scenario or planning horizon. This set spans a broad range of potential impacts from low emission to high emission climate outcomes, which may be linked to different short and long-term adaptation options. Based on a comprehensive inundation assessment, the proportion of Majuro's at-risk building stock from sea level rise was quantified to be 8.5%, 37.1%, and 92.4% for sea level rise increments of 0.5m, 1.0m, and 2.0m, respectively.

Considering the limited adaptative capacity of Majuro, the Protect, Advance, Accommodate and Retreat pathways, in association for early warning systems and nature-based solutions, were considered viable (Box 2.1). Protecting urban atolls from the effects of sea level rise requires both non-structural and structural measures with variable design lives that may fail sooner as conditions change.

The Dynamic Adaptive Policy Pathways approach using a Metro-map decision tree to visualize multiple pathways is presented in Figure 2.3. Each adaptation pathway has a limit to their effectiveness, or tipping point, before transitioning to a different pathway. Adaptation pathways can be followed sequentially or simultaneously.

Figure 2.3: Dynamic Adaptative Pathways for Majuro



Source: World Bank – World Bank PREP-II (Pacific Resilience Program) Adapting to rising sea levels in Marshall Islands.

While certain pathways can withstand extreme sea level rise scenarios of 2m or more, they are usually very expensive to implement. It is important to weigh the trade-offs between different adaptation pathways and consider the sequence of investments to make the right transition around tipping points while retaining the flexibility to respond to changing rates of sea level rise. For example, prioritizing robust but costly actions early on may turn out to be an overinvestment or may lock in strategies with negative environmental and cultural impact.

For Majuro, one pathway that needs to be financed and implemented in the short term is Protect. This involves strategies to reinforce the coastal edges of urban atolls to withstand moderate sea level rise and the elevated risk of coastal flooding. The measures under Protect, such as seawalls and revetments, are only effective for low to intermediate levels of sea level rise. With 0.5m sea level rise, around 80km of Majuro shoreline need to be protected. As sea levels continue to rise, and coastal inundation increases, it is likely that more transformational resilience measures will be needed in the medium to long term. Protect is a considered a short-term adaptation strategy that buys time to plan for and invest in pathways like Raise, Reclaim, or Relocate. These are expensive but robust pathways that can withstand sea level rise of 1–2m, or more.

Photo: Majuro atoll and Majuro town in Marshall islands. Source: Getty Images.

3. Future Sea Level Rise Projections

Future projections of climate change are regularly assessed by the Intergovernmental Panel on Climate Change (IPCC) at 7–8-year intervals, with the 5th Assessment Report (AR5) published in 2014 and the AR6 being progressively released through 2021–2022. Most of the existing PIC future sea level guidance is based on AR5. AR6 is fundamentally different from AR5 and forms the new basis for climate and sea level rise assessment. This section provides a summary of the AR6 assessment with emphasis on the new set of scenarios and provides updated sea level projections for each PIC.

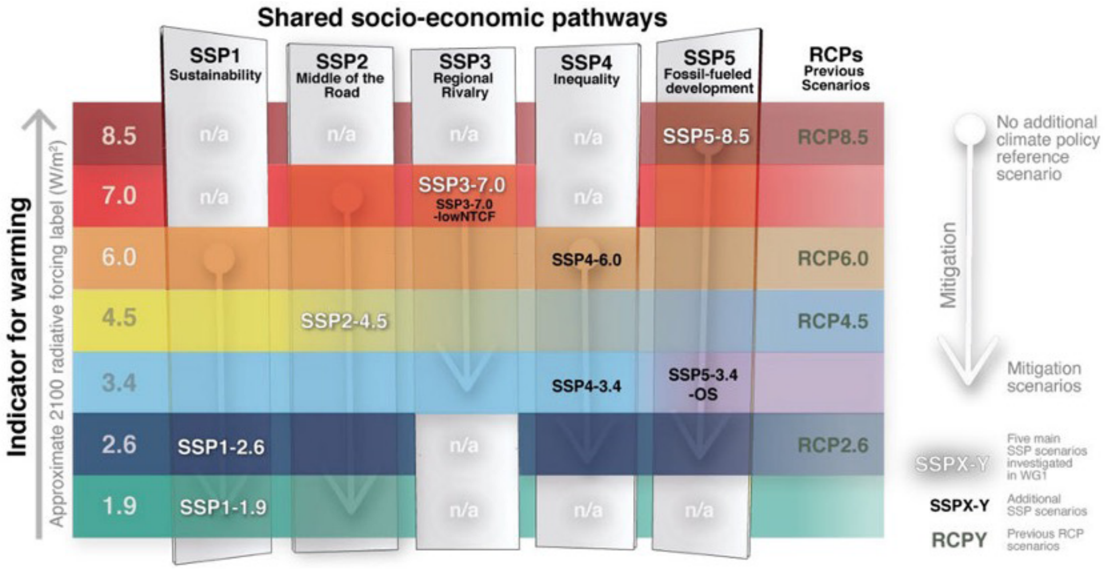
3.1 Climate Scenarios

The AR6 assessment uses the output from the latest generation of global climate models, produced as part of the sixth Coupled Model Intercomparison Project (CMIP6). These coordinated efforts consist of simulations of around 100 distinct climate models being produced by various research groups around the world.

AR6 has used a new set of scenarios derived from Shared Socioeconomic Pathways (SSPs). The SSP consist of five broad narratives of future socioeconomic development used to develop scenarios of energy use, air pollution control, land use, and greenhouse gas emissions to which Representative Concentration Pathways (RCPs) are applied to achieve an approximate radiative forcing level at the end of the 21st century. This contrasts with AR5, which was based on a fixed socioeconomic pathway whereby various RCPs were applied. The AR6 SSP suite is considered more representative of potential climate futures.

Figure 3.1 illustrates how the SSP (columns) combine with the forcing levels (rows), noting that not all forcing levels are possible under each socioeconomic pathway. For example, for an SSP Regional Rivalry (SSP3) *High emissions* scenario with a target radiative forcing at 2100 of 7.0 W/m2, the scenario is referred to as SSP3–7.0. The figure also shows the similar AR5 RCP scenarios, noting they are not directly comparable with SSP. The new widely accepted baseline SSP scenarios span a wide range of plausible societal and climatic futures from potentially below 1.5 °C (best estimate) warming to over 4 °C warming by 2100; these are summarized in Box 3.1 and shown in white in Figure 3.1.

Figure 3.1: Shared Socioeconomic Pathway Scenarios used in this Guidance, Radiative Forcing Categorization, and the Storylines Upon Which They Are Built



RCP = Representative Concentration Pathway, SSP = Shared Socioeconomic Pathway.
Source: IPCC. 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate. In Press. Cross-Chapter Box 1.4, Figure 1.

Box 3.1: Baseline Shared Socioeconomic Pathway (SSP) Climate Scenarios

Very Low emissions scenario (SSP1–1.9): Holds warming to approximately 1.5 °C above 1850–1900 in 2100 "after slight overshoot" and implied net-zero CO2 emissions around the middle of the century.

Low emissions scenario (SSP1–2.6): Stays below 2 °C warming with implied net-zero emissions in the second half of the century. Most consistent with 5th Assessment Report (AR5) Representative Concentration Pathway RCP 2.6.

Intermediate emissions scenario (SSP2–4.5): Approximately in line with the upper end of combined pledges under the Paris Agreement. The scenario "deviates mildly from a 'no-additional climate-policy' reference scenario, resulting in a best-estimate warming around 2.7 °C by the end of the 21st century". Most consistent with AR5 RCP 4.5.

High emissions scenario (SSP3–7.0): A medium-to-high reference scenario resulting from no additional climate policy, with "particularly high non-CO2 emissions, including high aerosols emissions".

Very High emissions scenario (SSP5–8.5): A high reference scenario with no additional climate policy. Emissions as high as SSP5–8.5 are only achieved within the fossil-fueled SSP5 socioeconomic development pathway. Most consistent with AR5 RCP 8.5.

Source: Adapted from IPCC. 2021: Climate Change 2021.

3.2 Global Sea Level Rise Projections

Observations have shown that sea level has risen 0.20m over the period 1901 to 2018 at an average rate of 1.7 mm/year. Rates of sea level rise have been observed to be accelerating, ranging from 2.1 mm/year for the period 1993 to 2002, 2.9 mm/year for the period 2003 to 2012 and increasing to 4.4 mm/year for the period 2013 to 2021. The rate of global mean sea level rise in the 20th century was faster than any other century in the last three millennia and the rate has increased since the 1960s.[9]

The future rise in global mean sea level caused by thermal expansion, melting of glaciers and ice sheets, and land water changes is strongly dependent on efforts to curb global emissions.[10] The latest projections from IPCC[11] suggest that global mean sea level will continue to rise throughout the 21st century. The AR6 assessment is broadly consistent with the prior AR5 assessment. However, AR6 projects nearly twice the sea level rise due to Antarctic melting, resulting in slightly higher projections to 2100 and has introduced a new Mean Sea Level (MSL) baseline period of 1995–2014 to which the projections are referenced.

Unlike other climate variables, sea level response to climatic changes is delayed due to the large heat capacity of the oceans. Accordingly, the effects of historic emissions have yet to be realized and a proportion of projected sea level rise is already committed. If emissions were to stop in 2021, it is likely that sea levels would rise an additional 0.7–1.1m by 2300; taking in account the pledged NDC emissions through to 2030, committed sea level rise increases to 0.8–1.4m.[12]

With reference to the baseline SSP projections (Box 3.1), global mean sea level is expected to rise between 0.18m (0.15–0.23m) for the *Very low emission* (SSP1–1.9) and 0.23m (0.20 to 0.29m) for the *Very high emission* (SSP5–8.5) scenarios by 2050. By 2100, the projected rise is between 0.38m (0.28 to 0.55m) and 0.77m (0.63 to 1.02m) for the *Very low emission* and *Very high emission* scenarios, respectively.

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[9] IPCC. 2021. Climate Change 2021.
[10] IPCC. 2019. *IPCC Special Report on the Ocean and Cryosphere.*
[11] IPCC. 2021. Climate Change 2021.
[12] Ibid.

The likely global mean sea level projections for *High emissions* (SSP3–7.0) and *Very high emissions* (SSP5–8.5) scenarios are consistent with a continuation of the global mean sea level satellite observed rate of 3.25mm/year for the period 1993 to 2018, which would imply a likely rise of 0.24m (0.23–0.25m) by 2050 and 0.73m (0.69–0.77m) by 2100. The extrapolation would also imply a likely rate of global mean sea level rise of 7.5mm/year over 2040–2060 and 11.2 mm/year over 2080–2100.[13]

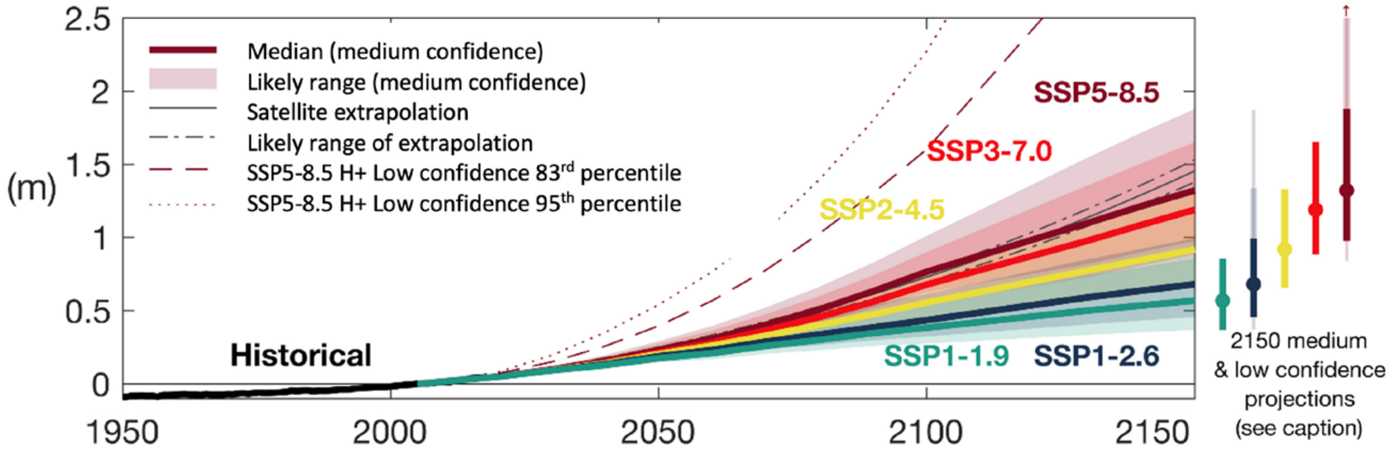
There remains a high level of uncertainty regarding the inputs from Antarctica and, accordingly, a high level of uncertainty with the upper bounds of projections.[14] The IPCC projections do not consider impacts from ice sheet processes that are uncertain. Hence, higher amounts of sea level rise could occur before 2100 should earlier-than-projected disintegration of marine ice shelves, the abrupt, and widespread onset of marine ice shelf instability, and marine ice cliff instability around Antarctica occur.[15] In the *low likelihood* scenario, such processes could add more than an extra meter of sea level rise by 2100 and is shown in Table 3.1 as scenario SSP5-8.5 H+ and the *upper likely* and *very likely* confidence limits are presented in Figure 3.2.[16]

Table 3.1: Global Median Sea Level Rise in metres to the year 2150 above 1995–2014 Mean Sea Level Baseline for selected Shared Socioeconiomic Pathway Scenarios

Year	Low Emissions (SSP1–2.6)	Intermediate Emissions (SSP2–4.5)	High Emissions (SSP3–7.0)	Very High Emissions (SSP5–8.5)	Very High Emissions–Low (SSP5–8.5 H+)a
2030	0.09 (0.08–0.12)b	0.09 (0.08–0.12)	0.09 (0.08–0.12)	0.10 (0.09–0.12)	0.10 (0.09–0.15)
2050	0.19 (0.16–0.25)	0.20 (0.17–0.26)	0.21 (0.18–0.27)	0.23 (0.20–0.29)	0.24 (0.20–0.40)
2090	0.39 (0.30–0.54)	0.48 (0.38–0.65)	0.56 (0.46–0.74)	0.63 (0.52–0.83)	0.71 (0.52–1.30)
2100	0.44 (0.32–0.61)	0.56 (0.43–0.76)	0.68 (0.55–0.90)	0.77 (0.63–1.01)	0.88 (0.63–1.60)
2150	0.68 (0.46–0.99)	0.92 (0.66–1.33)	1.19 (0.89–1.65)	1.32 (0.98–1.88)	1.98 (0.98–4.82)

Notes:
[a] *Very High Emissions- Low* (SSP5-8.5 H+) represents low confidence high consequence scenario.
[b] Bracketed values show *likely* range (17-83%ile).
Source: IPCC. 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate. In Press. Table 9.9.

Figure 3.2: Projected Global Mean Sea Level under Different SSP Baseline Scenarios



Notes:
1. Solid lines present the median (~50%ile) sea level rise for each Shared Socioeconomic Pathway (SSP) with corresponding shading reflecting the and *likely* range (17-83%ile) of potential sea levels. H+ represents low confidence high consequence scenario.
2. Extrapolated sea level based on historic satellite derived sea level rise rates are shown in black.
3. Upper *likely* and *very likely* (95%ile) low confidence SSP-8.5 H+ sea level projections are shown as brown dashes.
Source: IPCC. 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate. In Press. Figure 9.27.

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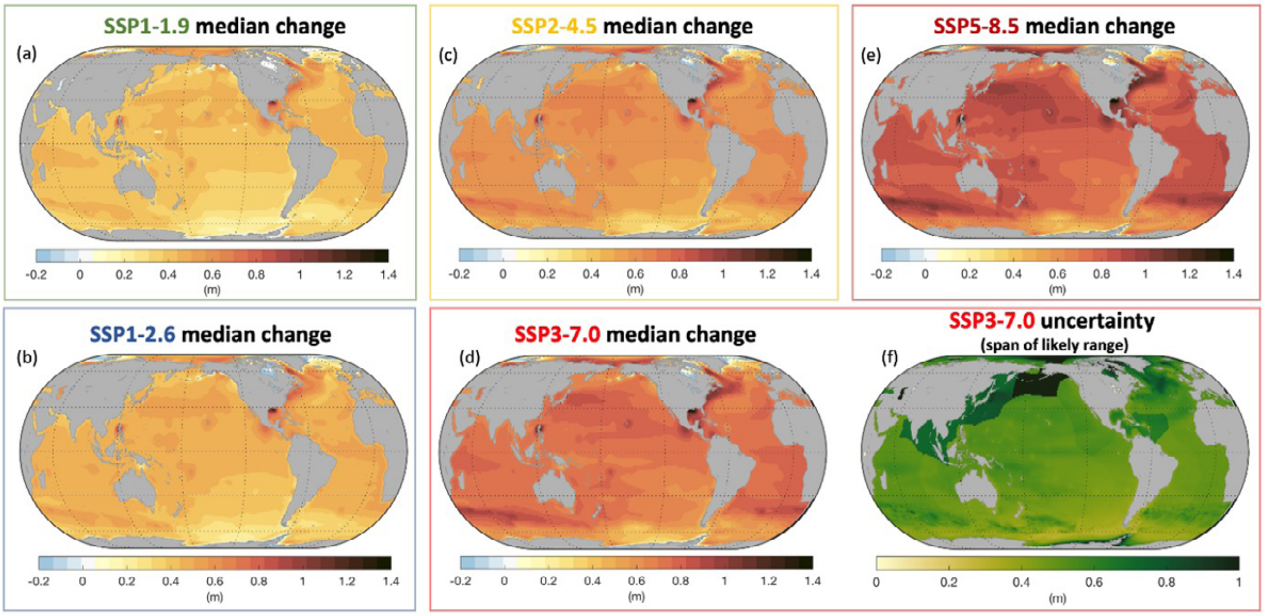
[13] Ibid.
[14] Kopp et al. 2017. Evolving Understanding of Antarctic Ice-Sheet Physics and Ambiguity in Probabilistic Sea Level Projections. Earth's Future, 5(12), 1217–1233
[15] IPCC. 2021. Climate Change 2021; Garner et al. 2017; J.L. Bamber, et al. 2019. Ice Sheet Contributions to Future Sea-Level Rise from Structured Expert Judgment. *Proceedings of the National Academy of Sciences*, 116(23): 11195.
[16] IPCC. 2021. Climate Change 2021.

Beyond 2100, global mean sea level will rise for centuries to millennia and will remain elevated for thousands of years.[17] By 2150, and considering only climate change processes that the IPCC has medium confidence in, global mean sea level is expected to rise between 0.57m (0.37–0.85m) for the *Very low emission* (SSP1–1.9) and 1.32m (0.98 to 1.88m) for *Very high emission* (SSP5–8.5) scenarios relative to the 1995–2014 baseline. For high emission scenarios, should low confidence processes such as marine ice cliff instability occur, the global mean sea level could rise by up to 5m by 2150. By 2300, global mean sea level will rise 0.3–3.1m under *Low emissions* scenarios (SSP1–2.6) and between 1.7–6.8m under *Very high emission* scenario (SSP5–8.5). Should low confidence processes such as marine ice cliff instability occur, the global mean sea level could rise by 16m.[18]

At regional scales such as the Pacific Ocean, additional processes such as vertical land movement, ocean circulation and deformation effects from the redistribution of water from the land to the ocean can affect local sea levels. Overall, coastal locations are expected to experience sea level rise within +/-20% of the global mean sea level change.[19] Projected regional sea level rise to the year 2100 for the various SSP baseline scenarios is presented in Figure 3.3. The regional projections show that sea level rise is variable across the Pacific. Regardless of the SSP scenario, higher magnitudes of sea level rise are expected in the North and South Pacific compared to the Equatorial region driven by projected changes to ENSO.

Figure 3.3: Regional Median Sea Level Change at 2100 for Different Shared Socioeconomic Pathway Scenarios with respect to the 1995–2014 Mean Sea Level



SSP = Socioeconomic Pathway.
Source: IPCC. 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate. In Press. Figure 9.32.

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[17] IPCC. 2021. Climate Change 2021.
[18] Ibid.
[19] Ibid.

3.3 Pacific Sea Level Rise Projections

To reflect the likely range of potential emission pathways, five sea level rise scenarios have been compiled from the AR6 assessment for each PIC; these include SSP1–2.6 to SS5–8.5 (Box 3.1) and are presented in Sections 3.4 to 3.16. An additional ***Very high emissions - low confidence scenario*** (SSP5–8.5H+) has been included that considers the impact of deeply uncertain ice sheet processes and is intended to serve as an upper bound for the expected range of potential sea level rise.

Emphasis has been placed on median values of sea level rise noting that the median magnitudes of the projections for Low emissions (SSP1–2.6) to Very high emissions (SSP5–8.5) are within the likely range of the Intermediate emissions (SSP2–4.5) scenario, which is consistent with current NDC commitments. Furthermore, median sea level rise projections from the Very high emissions scenario (SSP5–8.5 H+), while considered to be of low confidence, are similar to the upper likely bound of the Very high emissions scenario (SSP5–8.5), which is of medium confidence.

Regional projection data have been compiled from the CMIP6 model ensemble for each PIC with respect to the AR6 assessment zones, which include the Northwest tropics, Equatorial Pacific, Southwest SPCZ, and Northeast SPCZ.[20] As infrastructure development timeframes are often more than 100 years, the projections have been extended to 2150 by applying the AR6 long-term global sea level rise rates out to 2150 for each projection. These have subsequently been recast and presented in decadal increments for each PIC and adjusted for the upper bound of the most likely (95%) AR6 long-term average vertical land movement (Table 5.5) to provide a precautionary estimate of future relative sea level rise[21], consistent with observed rates.[22]

Photo: Salesa Nihmei

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[20] Ibid.

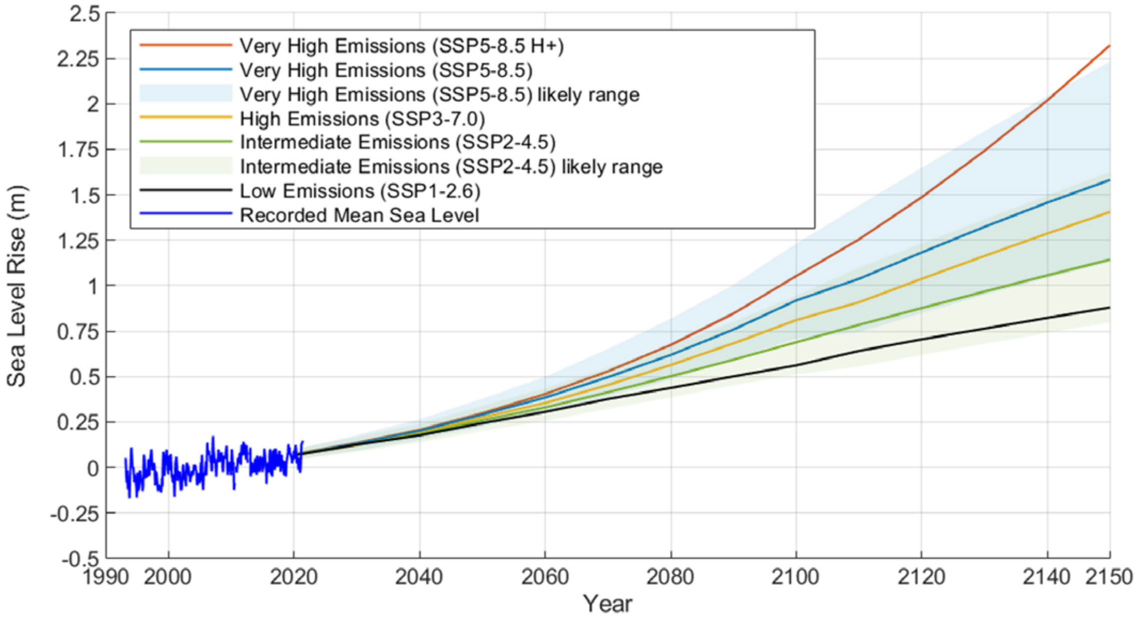
[21] B. Fox-Kemper, et al. 2021. Ocean, Cryosphere and Sea Level Change. In Climate Change 2021: The Physical Science Basis edited by V. Masson-Delmotte, et al. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press (in press).

[22] N. J. Brown et al. 2020. Vertical Motion of Pacific Island Tide Gauges: Combined Analysis from GNSS and Levelling. Record 2020/03. Canberra: Geoscience Australia.

3.4 Cook Islands

Sea level rise projections applicable throughout the Cook Islands are presented in Figure 3.4 and Table 3.2. The projections have been adjusted for the upper bound of the *most likely* long-term vertical land movement,[23] with a constant subsidence rate of -1.0mm/year, noting subsidence at the Avatiu tide gauge of up to -1.2mm/year has been observed since 2002.[24]

Figure 3.4: Sea Level Rise Projections to 2150 for the Cook Islands Relative to 1995–2014 Mean Sea Level



Notes:
1. Shared Socioeconomic Pathway (SSP); H+ represents low confidence high consequence scenario.
2. Projections are given for the 50%ile of the CMIP6 model ensemble unless otherwise defined.

Table 3.2: Decadal Increments for Projections of Sea Level Rise in Meters for the Cook Islands Relative to the 1995–2014 Mean Sea Level

Year	*Low* SSP1–2.6	*Intermediate* SSP2–4.5	*High* SSP3–7.0	*Very High* SSP5–8.5	*Very High – Low* SSP5–8.5 H+
1995–2014	0.00	0.00	0.00	0.00	0.00
2020	0.07 (0.04–0.09)	0.07 (0.04–0.10)	0.07 (0.04–0.10)	0.07 (0.05–0.10)	0.07 (0.05–0.11)
2030	0.13 (0.08–0.18)	0.13 (0.09–0.17)	0.12 (0.08–0.17)	0.13 (0.09–0.18)	0.14 (0.09–0.20)
2040	0.18 (0.12–0.24)	0.18 (0.14–0.24)	0.19 (0.14–0.25)	0.20 (0.15–0.27)	0.21 (0.15–0.33)
2050	0.24 (0.18–0.33)	0.26 (0.20–0.34)	0.28 (0.21–0.36)	0.29 (0.23–0.38)	0.30 (0.22–0.49)
2060	0.31 (0.23–0.41)	0.33 (0.26–0.44)	0.36 (0.27–0.47)	0.39 (0.31–0.50)	0.40 (0.30–0.69)
2070	0.38 (0.29–0.50)	0.41 (0.32–0.55)	0.45 (0.36–0.60)	0.50 (0.39–0.65)	0.53 (0.39–0.93)
2080	0.44 (0.33–0.59)	0.50 (0.39–0.67)	0.56 (0.44–0.74)	0.62 (0.48–0.82)	0.67 (0.48–1.21)
2090	0.50 (0.37–0.69)	0.59 (0.45–0.80)	0.68 (0.53–0.91)	0.76 (0.60–1.01)	0.85 (0.60–1.54)
2100	0.56 (0.40–0.78)	0.69 (0.51–0.95)	0.81 (0.62–1.09)	0.92 (0.71–1.23)	1.05 (0.71–1.89)
2110	0.64 (0.45–0.90)	0.79 (0.56–1.10)	0.91 (0.65–1.24)	1.04 (0.75–1.44)	1.26 (0.75–2.23)
2120	0.71 (0.49–1.00)	0.88 (0.62–1.23)	1.04 (0.75–1.42)	1.18 (0.85–1.65)	1.49 (0.85–2.55)
2130	0.76 (0.52–1.09)	0.97 (0.68–1.37)	1.16 (0.84–1.59)	1.32 (0.95–1.85)	1.74 (0.95–3.31)
2140	0.82 (0.56–1.18)	1.06 (0.74–1.50)	1.29 (0.92–1.77)	1.46 (1.04–2.04)	2.02 (1.04–4.38)
2150	0.88 (0.59–1.28)	1.14 (0.80–1.63)	1.41 (1.01–1.93)	1.58 (1.13–2.23)	2.32 (1.13–5.54)

Notes:
1. Shared Socioeconomic Pathway (SSP); H+ represents low confidence high consequence scenario.
2. Projections based on IPCC (2021), sourced from AR6 and interpolated to nearest decade and adjusted for the upper bound of the *most likely* vertical land movement as defined by Fox-Kemper et al. (2021).
3. Projections are given for the 50%ile of the CMIP6 model ensemble and *likely* range shown in brackets

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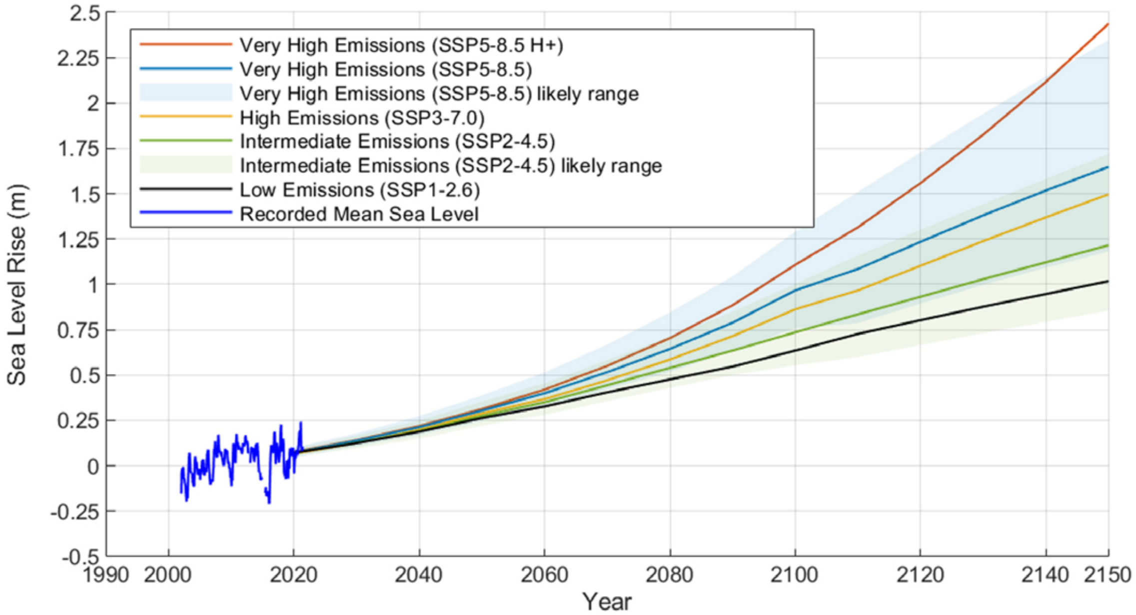
[23] B. Fox-Kemper et al. 2021. Ocean, Cryosphere and Sea Level Change.
[24] N. J. Brown et al. 2020. Vertical Motion of Pacific Island Tide Gauges.

3.5 Federated States of Micronesia

Sea level rise projections applicable throughout FSM are presented in Figure 3.5 and Table 3.3. The projections based on trends at Pohnpei have been adjusted for the upper bound of the *most likely* long term vertical land movement,[25] with an average subsidence rate of -1.3 mm/year. Subsidence at the Pohnpei tide gauge of up to -1.4mm/year has been observed since 2006.[26] It is noted that AR6 long term vertical land movement for other FSM states is lower than assessed for Pohnpei.

Figure 3.5: Sea Level Rise Projections to 2150 for the Federated States of Micronesia Relative to 1995–2014 Mean Sea Level



Notes:
1. Shared Socioeconomic Pathway (SSP); H+ represents low confidence high consequence scenario.
2. Projections are given for the 50%ile of the CMIP6 model ensemble unless otherwise defined.

Table 3.3: Decadal Increments for Projections of Sea Level Rise in Meters for Federated States of Micronesia Relative to the 1995–2014 Mean Sea Level

Year	*Low* SSP1-2.6	*Intermediate* SSP2-4.5	*High* SSP3-7.0	*Very High* SSP5-8.5	*Very High – Low* SSP5-8.5 H+
1995–2014	0.00	0.00	0.00	0.00	0.00
2020	0.07 (0.05–0.10)	0.07 (0.05–0.10)	0.07 (0.04–0.09)	0.07 (0.05–0.10)	0.08 (0.05–0.11)
2030	0.13 (0.09–0.17)	0.13 (0.10–0.17)	0.13 (0.09–0.17)	0.14 (0.11–0.18)	0.14 (0.11–0.21)
2040	0.19 (0.14–0.25)	0.19 (0.15–0.25)	0.20 (0.15–0.26)	0.21 (0.17–0.27)	0.22 (0.17–0.34)
2050	0.26 (0.21–0.34)	0.28 (0.22–0.35)	0.29 (0.24–0.37)	0.30 (0.25–0.39)	0.31 (0.24–0.51)
2060	0.33 (0.26–0.43)	0.35 (0.28–0.45)	0.37 (0.29–0.48)	0.40 (0.33–0.51)	0.42 (0.32–0.72)
2070	0.41 (0.32–0.53)	0.44 (0.36–0.58)	0.47 (0.38–0.61)	0.52 (0.42–0.67)	0.55 (0.42–0.98)
2080	0.48 (0.37–0.64)	0.54 (0.43–0.71)	0.59 (0.47–0.77)	0.64 (0.52–0.85)	0.70 (0.52–1.28)
2090	0.55 (0.42–0.74)	0.64 (0.50–0.85)	0.72 (0.57–0.94)	0.79 (0.63–1.04)	0.89 (0.63–1.62)
2100	0.64 (0.46–0.87)	0.74 (0.55–1.00)	0.86 (0.66–1.16)	0.97 (0.76–1.29)	1.11 (0.76–2.00)
2110	0.73 (0.51–1.01)	0.84 (0.60–1.16)	0.97 (0.69–1.32)	1.09 (0.79–1.51)	1.32 (0.79–2.36)
2120	0.80 (0.56–1.12)	0.93 (0.67–1.30)	1.10 (0.79–1.52)	1.24 (0.90–1.73)	1.56 (0.90–2.69)
2130	0.88 (0.60–1.23)	1.03 (0.73–1.44)	1.24 (0.88–1.71)	1.38 (1.00–1.94)	1.83 (1.00–3.49)
2140	0.95 (0.65–1.34)	1.12 (0.79–1.58)	1.37 (0.97–1.90)	1.52 (1.09–2.15)	2.12 (1.09–4.62)
2150	1.02 (0.69–1.45)	1.22 (0.86–1.72)	1.50 (1.06–2.08)	1.65 (1.18–2.35)	2.44 (1.18–5.85)

Notes:
1. Shared Socioeconomic Pathway (SSP); H+ represents low confidence high consequence scenario.
2. Projections based on IPCC (2021), sourced from AR6 and interpolated to nearest decade and adjusted for the upper bound of the *most likely* vertical land movement as defined by Fox-Kemper et al. (2021).
3. Projections are given for the 50%ile of the CMIP6 model ensemble and likely range shown in brackets.

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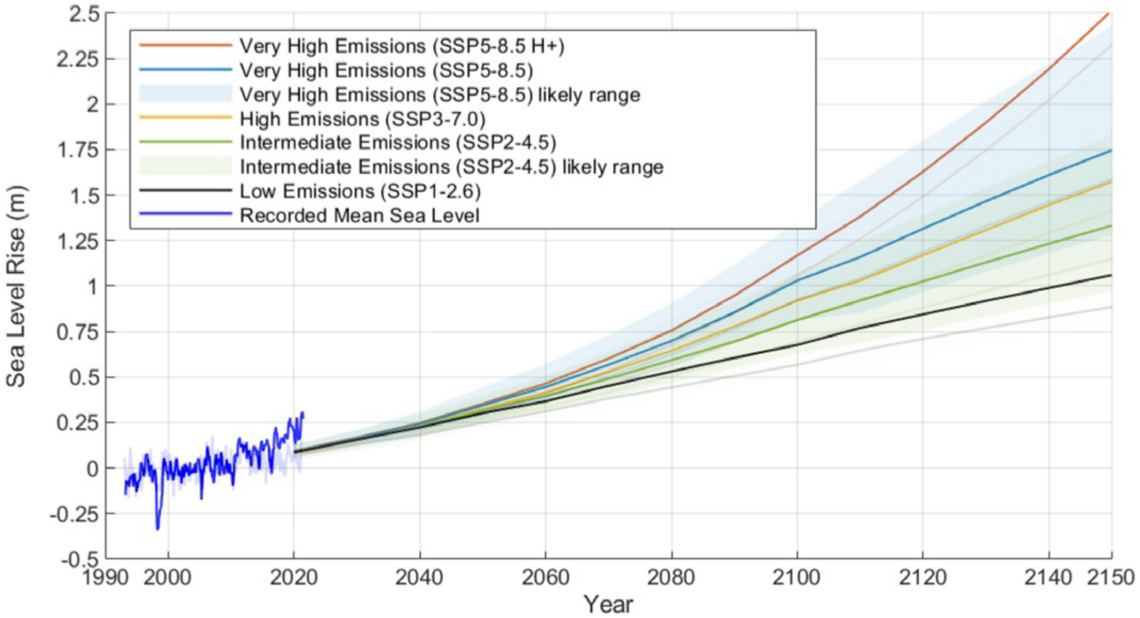
[25] B. Fox-Kemper, et al. 2021, Ocean, Cryosphere and Sea Level Change.
[26] N. J. Brown et al. 2020. Vertical Motion of Pacific Island Tide Gauges.

3.6 Samoa

Sea level rise projections applicable throughout Samoa are presented in Figure 3.6 and Table 3.4. The projections have been adjusted for the upper bound of the *most likely* long term vertical land movement of -2.1mm/year,[27] noting that subsidence at the Apia tide gauge of up to -8.0mm/year has been observed since 2010.[28]

Figure 3.6: Sea Level Rise Projections to 2150 for Samoa Relative to 1995–2014 Mean Sea Level



Notes:
1. Shared Socioeconomic Pathway (SSP); H+ represents low confidence high consequence scenario.
2. Projections are given for the 50%ile of the CMIP6 model ensemble unless otherwise defined.

Table 3.4: Decadal Increments for Projections of Sea Level Rise in Meters for Samoa Relative to the 1995–2014 Mean Sea Level

Year	*Low* SSP1–2.6	*Intermediate* SSP2–4.5	*High* SSP3–7.0	*Very High* SSP5–8.5	*Very High – Low* SSP5–8.5 H+
1995–2014	0.00	0.00	0.00	0.00	0.00
2020	0.09 (0.05–0.13)	0.09 (0.05–0.13)	0.08 (0.05–0.11)	0.09 (0.06–0.13)	0.09 (0.06–0.14)
2030	0.16 (0.10–0.21)	0.16 (0.11–0.21)	0.15 (0.10–0.21)	0.16 (0.13–0.21)	0.17 (0.12–0.24)
2040	0.22 (0.17–0.29)	0.23 (0.17–0.30)	0.23 (0.17–0.31)	0.24 (0.19–0.31)	0.25 (0.18–0.37)
2050	0.30 (0.23–0.39)	0.32 (0.25–0.40)	0.33 (0.25–0.42)	0.35 (0.27–0.44)	0.35 (0.26–0.55)
2060	0.37 (0.28–0.48)	0.40 (0.32–0.51)	0.42 (0.33–0.53)	0.45 (0.35–0.57)	0.47 (0.35–0.76)
2070	0.45 (0.36–0.58)	0.49 (0.39–0.63)	0.53 (0.43–0.67)	0.57 (0.45–0.73)	0.60 (0.45–1.01)
2080	0.53 (0.42–0.69)	0.59 (0.47–0.77)	0.65 (0.52–0.83)	0.70 (0.56–0.91)	0.76 (0.56–1.31)
2090	0.61 (0.48–0.79)	0.70 (0.55–0.91)	0.78 (0.63–1.01)	0.86 (0.69–1.12)	0.95 (0.69–1.65)
2100	0.68 (0.50–0.91)	0.81 (0.63–1.08)	0.92 (0.71–1.22)	1.03 (0.81–1.36)	1.17 (0.81–2.02)
2110	0.77 (0.56–1.05)	0.92 (0.69–1.24)	1.03 (0.75–1.39)	1.16 (0.85–1.58)	1.38 (0.85–2.37)
2120	0.85 (0.61–1.16)	1.03 (0.76–1.39)	1.17 (0.85–1.58)	1.32 (0.97–1.80)	1.63 (0.97–2.71)
2130	0.92 (0.66–1.27)	1.13 (0.83–1.54)	1.31 (0.95–1.77)	1.47 (1.08–2.02)	1.90 (1.08–3.52)
2140	0.99 (0.71–1.37)	1.23 (0.91–1.69)	1.45 (1.04–1.96)	1.61 (1.18–2.22)	2.19 (1.18–4.63)
2150	1.06 (0.75-1.48)	1.33 (0.98-1.83)	1.57 (1.13-2.15)	1.75 (1.28-2.43)	2.52 (1.28-5.83)

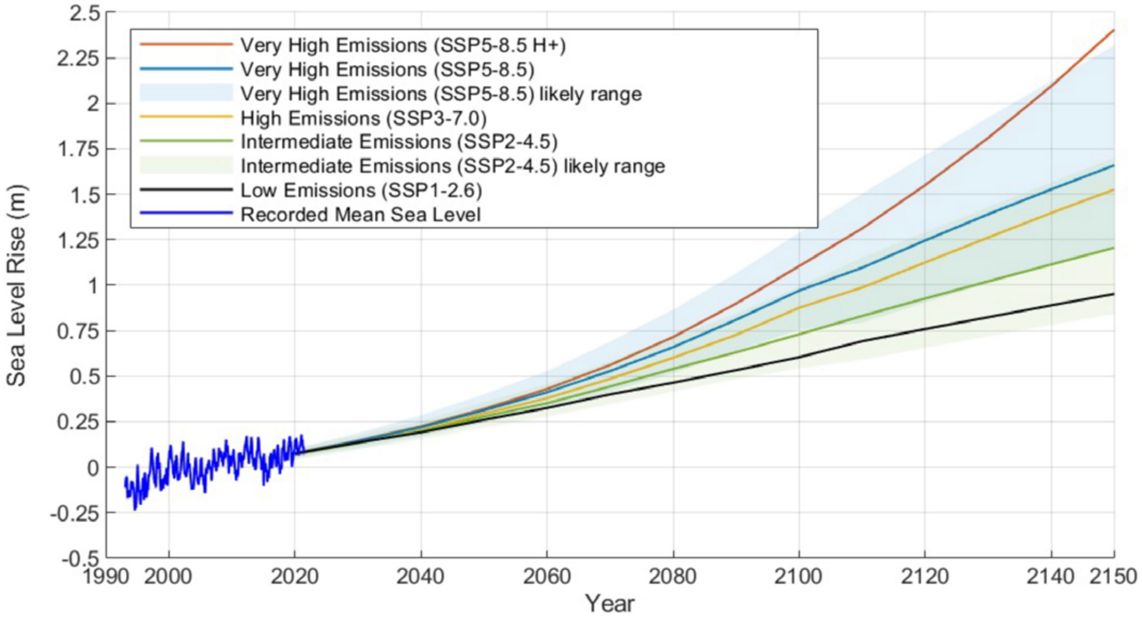
Notes:
1. Shared Socioeconomic Pathway (SSP); H+ represents low confidence high consequence scenario.
2. Projections based on IPCC (2021), sourced from AR6 and interpolated to nearest decade and adjusted for the upper bound of the *most likely* vertical land movement as defined by Fox-Kemper et al. (2021).
3. Projections are given for the 50%ile of the CMIP6 model ensemble and likely range shown in brackets.

[27] B. Fox-Kemper et al. 2021. Ocean, Cryosphere and Sea Level Change.
[28] N. J. Brown et al. 2020. Vertical Motion of Pacific Island Tide Gauges.

3.7 Tonga

Sea level rise projections applicable throughout Tonga are presented in Figure 3.7 and Table 3.5. The projections have been adjusted for the upper bound of the *most likely* long term vertical land movement with a constant subsidence rate of -1.4mm/year,[29] noting subsidence at the Nukuálofa tide gauge of up to -7.0mm/year has been observed since 2010.[30]

Figure 3.7: Sea Level Rise Projections to 2150 for Tonga Relative to 1995–2014 Mean Sea Level



Notes:
1. Shared Socioeconomic Pathway (SSP); H+ represents low confidence high consequence scenario.
2. Projections are given for the 50%ile of the CMIP6 model ensemble unless otherwise defined.

Table 3.5: Decadal Increments for Projections of Sea Level Rise in Meters for Tonga Relative to the 1995–2014 Mean Sea Level

Year	*Low* SSP1–2.6	*Intermediate* SSP2–4.5	*High* SSP3–7.0	*Very High* SSP5–8.5	*Very High – Low* SSP5–8.5 H+
1995–2014	0.00	0.00	0.00	0.00	0.00
2020	0.07 (0.05–0.10)	0.07 (0.04–0.10)	0.07 (0.04–0.10)	0.07 (0.05–0.10)	0.08 (0.05–0.11)
2030	0.14 (0.10–0.18)	0.13 (0.10–0.17)	0.13 (0.09–0.18)	0.14 (0.11–0.19)	0.15 (0.10–0.22)
2040	0.19 (0.14–0.25)	0.20 (0.15–0.25)	0.20 (0.15–0.27)	0.22 (0.17–0.28)	0.22 (0.16–0.35)
2050	0.26 (0.20–0.34)	0.28 (0.22–0.36)	0.29 (0.23–0.38)	0.31 (0.24–0.40)	0.32 (0.24–0.51)
2060	0.33 (0.25–0.43)	0.35 (0.28–0.46)	0.38 (0.30–0.49)	0.41 (0.33–0.53)	0.43 (0.32–0.71)
2070	0.40 (0.31–0.53)	0.44 (0.35–0.58)	0.49 (0.38–0.63)	0.53 (0.41–0.69)	0.56 (0.41–0.96)
2080	0.46 (0.35–0.62)	0.54 (0.42–0.71)	0.60 (0.47–0.79)	0.66 (0.52–0.87)	0.72 (0.52–1.25)
2090	0.53 (0.40–0.72)	0.63 (0.49–0.84)	0.73 (0.57–0.96)	0.81 (0.64–1.07)	0.90 (0.64–1.59)
2100	0.60 (0.44–0.83)	0.73 (0.54–0.99)	0.88 (0.66–1.17)	0.97 (0.76–1.29)	1.11 (0.76–1.93)
2110	0.69 (0.49–0.96)	0.83 (0.59–1.15)	0.99 (0.69–1.35)	1.10 (0.80–1.50)	1.31 (0.80–2.28)
2120	0.76 (0.53–1.06)	0.93 (0.66–1.29)	1.13 (0.79–1.54)	1.25 (0.91–1.71)	1.55 (0.91–2.60)
2130	0.82 (0.57–1.16)	1.02 (0.72–1.43)	1.26 (0.88–1.73)	1.39 (1.01–1.92)	1.81 (1.01–3.38)
2140	0.89 (0.61–1.26)	1.11 (0.78–1.57)	1.40 (0.97–1.92)	1.53 (1.11–2.12)	2.09 (1.11–4.46)
2150	0.95 (0.65–1.36)	1.21 (0.84–1.70)	1.53 (1.06–2.11)	1.66 (1.20–2.32)	2.41 (1.20–5.63)

Notes:
1. Shared Socioeconomic Pathway (SSP); H+ represents low confidence high consequence scenario.
2. Projections based on IPCC (2021), sourced from AR6 and interpolated to nearest decade and adjusted for the upper bound of the *most likely* vertical land movement as defined by Fox-Kemper et al. (2021).
3. Projections are given for the 50%ile of the CMIP6 model ensemble and likely range shown in brackets.

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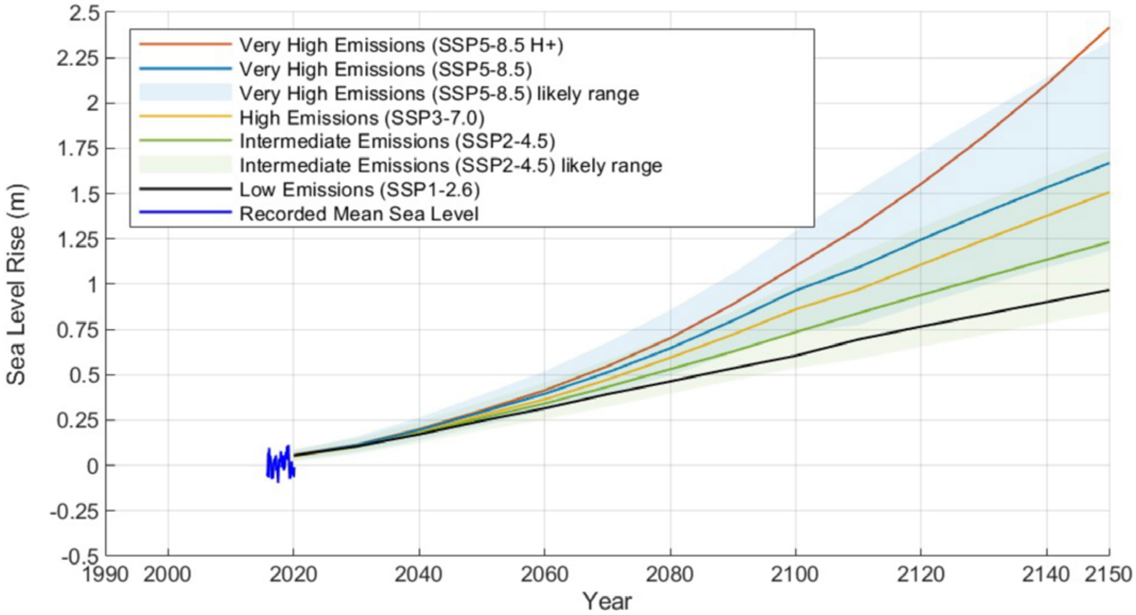
[29] B. Fox-Kemper et al. 2021. Ocean, Cryosphere and Sea Level Change.
[30] N. J. Brown et al. 2020. Vertical Motion of Pacific Island Tide Gauges.

3.8 Niue

Sea level rise projections applicable throughout Niue are presented in Figure 3.8 and Table 3.6. The projections have been adjusted for the upper bound of the *most likely* long term vertical land movement with a constant subsidence rate of -1.8mm/year,[31] noting subsidence at the Alofi tide gauge of up to -1.5mm/year has been observed since 2006.[32]

Figure 3.8: Sea Level Rise Projections to 2150 for Niue Relative to 1995–2014 Mean Sea Level



Notes:
1. Shared Socioeconomic Pathway (SSP); H+ represents low confidence high consequence scenario.
2. Projections are given for the 50%ile of the CMIP6 model ensemble unless otherwise defined.

Table 3.6: Decadal Increments for Projections of Sea Level Rise in Meters for Niue Relative to the 1995–2014 Mean Sea Level

Year	*Low* SSP1–2.6	*Intermediate* SSP2–4.5	*High* SSP3–7.0	*Very High* SSP5–8.5	*Very High – Low* SSP5–8.5 H+
1995–2014	0.00	0.00	0.00	0.00	0.00
2020	0.05 (0.03–0.08)	0.05 (0.02–0.09)	0.05 (0.02–0.08)	0.06 (0.03–0.08)	0.06 (0.03–0.09)
2030	0.11 (0.06–0.15)	0.10 (0.06–0.15)	0.10 (0.06–0.15)	0.11 (0.07–0.16)	0.11 (0.07–0.19)
2040	0.17 (0.11–0.24)	0.18 (0.13–0.24)	0.18 (0.13–0.25)	0.20 (0.14–0.26)	0.20 (0.14–0.32)
2050	0.25 (0.17–0.34)	0.26 (0.19–0.35)	0.28 (0.21–0.37)	0.29 (0.22–0.39)	0.30 (0.21–0.49)
2060	0.32 (0.23–0.42)	0.34 (0.25–0.46)	0.36 (0.27–0.48)	0.40 (0.30–0.52)	0.41 (0.30–0.70)
2070	0.39 (0.29–0.53)	0.43 (0.32–0.58)	0.47 (0.36–0.62)	0.51 (0.39–0.68)	0.55 (0.39–0.95)
2080	0.46 (0.34–0.63)	0.53 (0.40–0.71)	0.59 (0.45–0.78)	0.65 (0.50–0.86)	0.70 (0.50–1.25)
2090	0.54 (0.39–0.73)	0.63 (0.47–0.85)	0.72 (0.55–0.96)	0.80 (0.62–1.06)	0.89 (0.62–1.58)
2100	0.61 (0.43–0.84)	0.74 (0.54–1.01)	0.86 (0.64–1.16)	0.97 (0.73–1.29)	1.10 (0.73–1.94)
2110	0.70 (0.48–0.98)	0.84 (0.59–1.17)	0.97 (0.68–1.33)	1.09 (0.78–1.51)	1.31 (0.78–2.28)
2120	0.77 (0.52–1.08)	0.94 (0.66–1.31)	1.11 (0.77–1.52)	1.25 (0.89–1.73)	1.55 (0.89–2.61)
2130	0.83 (0.56–1.18)	1.04 (0.72–1.46)	1.24 (0.86–1.72)	1.39 (0.99–1.94)	1.82 (0.99–3.40)
2140	0.90 (0.60–1.28)	1.14 (0.79–1.60)	1.38 (0.96–1.91)	1.53 (1.09–2.14)	2.10 (1.09–4.48)
2150	0.97 (0.64–1.38)	1.23 (0.85–1.74)	1.51 (1.04–2.09)	1.67 (1.18–2.34)	2.42 (1.18–5.65)

Notes:
1. Shared Socioeconomic Pathway (SSP); H+ represents low confidence high consequence scenario.
2. Projections based on IPCC (2021), sourced from AR6 and interpolated to nearest decade and adjusted for the upper bound of the *most likely* vertical land movement as defined by Fox-Kemper et al. (2021).
3. Projections are given for the 50%ile of the CMIP6 model ensemble and likely range shown in brackets.

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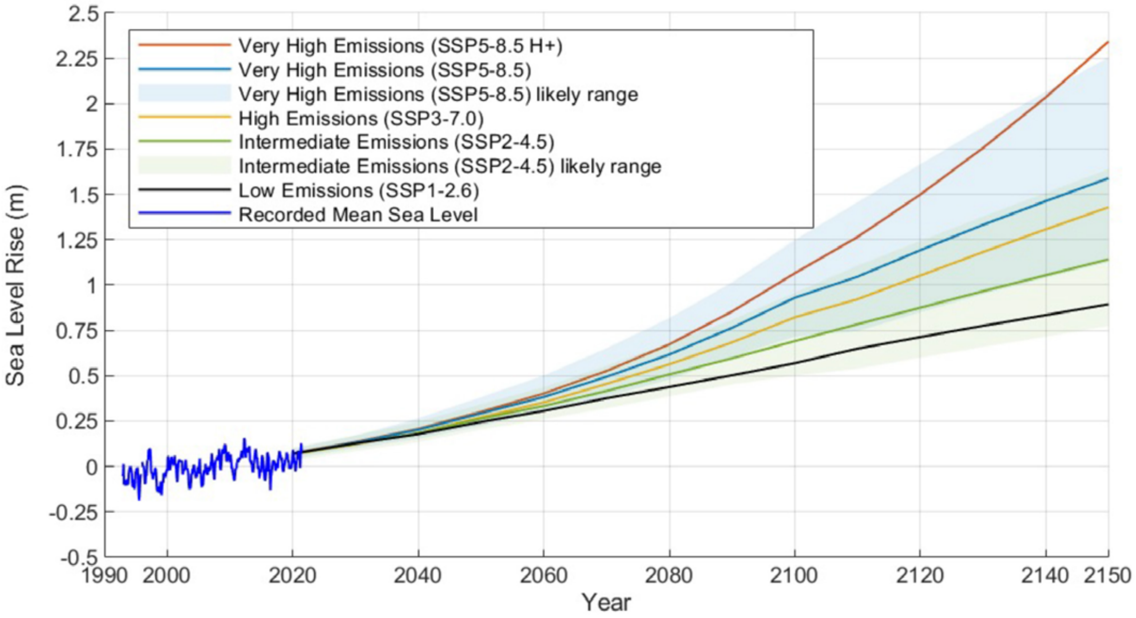
[31] B. Fox-Kemper et al. 2021. Ocean, Cryosphere and Sea Level Change.

[32] N. J. Brown et al. 2020. Vertical Motion of Pacific Island Tide Gauges.

3.9 Fiji

Sea level rise projections applicable throughout Fiji are presented in Figure 3.9 and Table 3.7. The projections have been adjusted for the upper bound of the *most likely* long term vertical land movement with a constant subsidence rate of -1.0mm/year,[33] noting subsidence at the Lautoka tide gauge of up to -1.1mm/year has been observed since 2002.[34]

Figure 3.9: Sea Level Rise Projections to 2150 for Fiji Relative to 1995–2014 Mean Sea Level



Notes:
1. Shared Socioeconomic Pathway (SSP); H+ represents low confidence high consequence scenario.
2. Projections are given for the 50%ile of the CMIP6 model ensemble unless otherwise defined.

Table 3.7: Decadal Increments for Projections of Sea Level Rise in Meters for Fiji Relative to the 1995–2014 Mean Sea Level

Year	*Low* SSP1–2.6	*Intermediate* SSP2–4.5	High SSP3–7.0	*Very High* SSP5–8.5	*Very High – Low* SSP5–8.5 H+
1995–2014	0.00	0.00	0.00	0.00	0.00
2020	0.07 (0.04–0.10)	0.07 (0.03–0.11)	0.07 (0.04–0.09)	0.07 (0.04–0.10)	0.07 (0.04–0.11)
2030	0.13 (0.09–0.17)	0.13 (0.08–0.17)	0.12 (0.09–0.16)	0.13 (0.10–0.17)	0.14 (0.10–0.20)
2040	0.18 (0.13–0.24)	0.18 (0.13–0.25)	0.19 (0.14–0.25)	0.20 (0.15–0.27)	0.21 (0.15–0.33)
2050	0.25 (0.18–0.33)	0.26 (0.20–0.34)	0.27 (0.20–0.36)	0.29 (0.22–0.38)	0.30 (0.22–0.49)
2060	0.31 (0.23–0.41)	0.33 (0.26–0.44)	0.35 (0.28–0.46)	0.38 (0.30–0.50)	0.40 (0.30–0.68)
2070	0.38 (0.29–0.50)	0.42 (0.32–0.56)	0.46 (0.36–0.59)	0.49 (0.39–0.65)	0.53 (0.39–0.93)
2080	0.44 (0.34–0.59)	0.51 (0.39–0.68)	0.56 (0.44–0.74)	0.62 (0.48–0.82)	0.67 (0.48–1.21)
2090	0.50 (0.38–0.69)	0.60 (0.45–0.81)	0.68 (0.54–0.91)	0.76 (0.60–1.02)	0.85 (0.60–1.54)
2100	0.57 (0.41–0.79)	0.69 (0.50–0.96)	0.82 (0.62–1.11)	0.93 (0.72–1.25)	1.07 (0.72–1.89)
2110	0.65 (0.45–0.92)	0.78 (0.54–1.11)	0.92 (0.65–1.28)	1.05 (0.75–1.46)	1.27 (0.75–2.23)
2120	0.71 (0.49–1.02)	0.88 (0.60–1.24)	1.05 (0.73–1.46)	1.19 (0.85–1.67)	1.50 (0.85–2.56)
2130	0.78 (0.53–1.11)	0.97 (0.66–1.38)	1.18 (0.82–1.65)	1.33 (0.95–1.87)	1.76 (0.95–3.34)
2140	0.83 (0.56–1.20)	1.05 (0.72–1.51)	1.31 (0.91–1.83)	1.46 (1.04–2.07)	2.04 (1.04–4.42)
2150	0.89 (0.60–1.30)	1.14 (0.77–1.64)	1.43 (0.99–2.01)	1.59 (1.13–2.26)	2.34 (1.13–5.60)

Notes:
1. Shared Socioeconomic Pathway (SSP); H+ represents low confidence high consequence scenario.
2. Projections based on IPCC (2021), sourced from AR6 and interpolated to nearest decade and adjusted for the upper bound of the *most likely* vertical land movement as defined by Fox-Kemper et al. (2021).
3. Projections are given for the 50%ile of the CMIP6 model ensemble and likely range shown in brackets.

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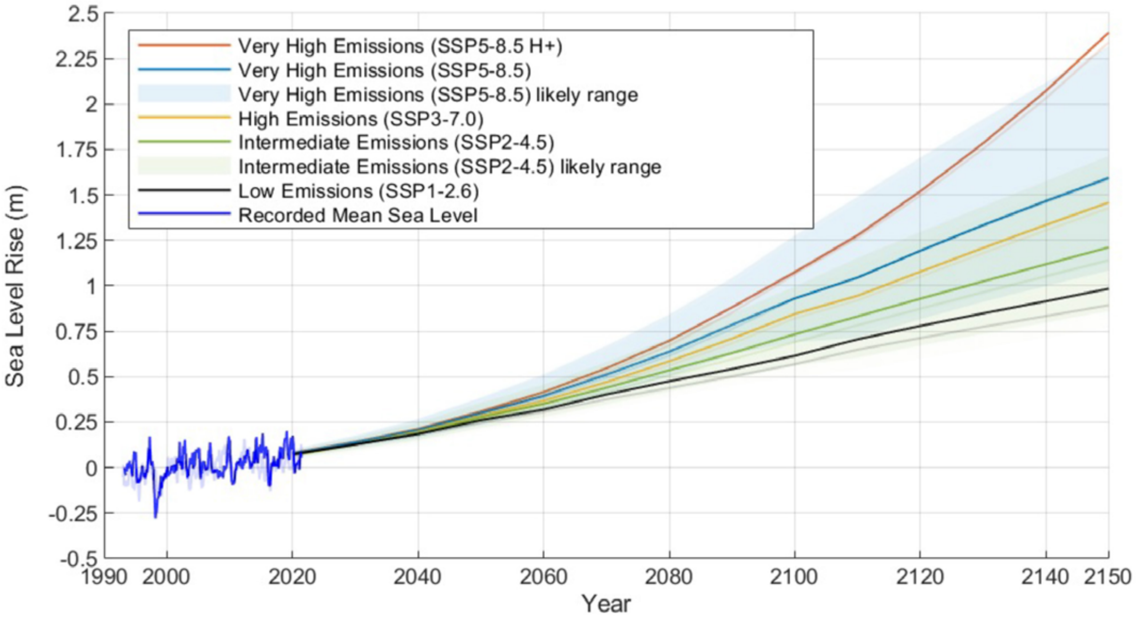
[33] B. Fox-Kemper et al. 2021. Ocean, Cryosphere and Sea Level Change.
[34] N. J. Brown et al. 2020. Vertical Motion of Pacific Island Tide Gauges.

3.10 Kiribati

Sea level rise projections applicable throughout Kiribati are presented in Figure 3.10 and Table 3.8. The projections have been adjusted for the upper bound of the *most likely* long term vertical land movement with a constant subsidence rate of -1.3mm/year.[35] Subsidence at the Betio tide gauge of up to -2.1mm/year has been observed since 2004.[36] It is noted that projected AR6 long term vertical land movement for other Kiribati islands is lower than assessed for Betio.

Figure 3.10: Sea Level Rise Projections to 2150 for Kiribati Relative to 1995–2014 Mean Sea Level



Notes:
1. Shared Socioeconomic Pathway (SSP); H+ represents low confidence high consequence scenario.
2. Projections are given for the 50%ile of the CMIP6 model ensemble unless otherwise defined.

Table 3.8: Decadal Increments for Projections of Sea Level Rise in Meters for Kiribati Relative to the 1995–2014 Mean Sea Level

Year	*Low* SSP1-2.6	*Intermediate* SSP2-4.5	*High* SSP3-7.0	*Very High* SSP5-8.5	*Very High – Low* SSP5-8.5 H+
1995–2014	0.00	0.00	0.00	0.00	0.00
2020	0.07 (0.05–0.10)	0.07 (0.05–0.09)	0.07 (0.05–0.09)	0.08 (0.06–0.10)	0.08 (0.06–0.11)
2030	0.13 (0.10–0.17)	0.13 (0.10–0.16)	0.13 (0.10–0.16)	0.14 (0.11–0.18)	0.14 (0.11–0.21)
2040	0.19 (0.14–0.24)	0.19 (0.15–0.25)	0.20 (0.15–0.26)	0.21 (0.16–0.27)	0.21 (0.16–0.34)
2050	0.26 (0.20–0.34)	0.28 (0.22–0.36)	0.29 (0.23–0.37)	0.30 (0.24–0.39)	0.31 (0.24–0.50)
2060	0.32 (0.25–0.42)	0.35 (0.28–0.46)	0.37 (0.29–0.48)	0.39 (0.32–0.51)	0.42 (0.31–0.71)
2070	0.40 (0.31–0.53)	0.44 (0.35–0.58)	0.47 (0.37–0.61)	0.51 (0.41–0.67)	0.55 (0.41–0.97)
2080	0.47 (0.36–0.64)	0.54 (0.42–0.71)	0.58 (0.46–0.77)	0.64 (0.50–0.84)	0.70 (0.50–1.27)
2090	0.54 (0.41–0.74)	0.63 (0.49–0.85)	0.71 (0.56–0.94)	0.79 (0.62–1.04)	0.88 (0.62–1.61)
2100	0.62 (0.43–0.86)	0.73 (0.56–1.00)	0.85 (0.64–1.14)	0.93 (0.69–1.28)	1.08 (0.69–1.96)
2110	0.71 (0.47–1.00)	0.83 (0.61–1.15)	0.95 (0.66–1.31)	1.05 (0.71–1.49)	1.28 (0.71–2.32)
2120	0.78 (0.51–1.11)	0.93 (0.67–1.30)	1.08 (0.75–1.50)	1.19 (0.82–1.71)	1.52 (0.82–2.65)
2130	0.85 (0.55–1.23)	1.02 (0.74–1.44)	1.21 (0.83–1.69)	1.33 (0.91–1.92)	1.78 (0.91–3.46)
2140	0.92 (0.58–1.33)	1.12 (0.80–1.58)	1.34 (0.92–1.87)	1.47 (1.00–2.12)	2.07 (1.00–4.58)
2150	0.98 (0.62–1.44)	1.21 (0.86–1.71)	1.46 (1.00–2.06)	1.59 (1.08–2.32)	2.39 (1.08–5.82)

Notes:
1. Shared Socioeconomic Pathway (SSP); H+ represents low confidence high consequence scenario.
2. Projections based on IPCC (2021), sourced from AR6 and interpolated to nearest decade and adjusted for the upper bound of the *most likely* vertical land movement as defined by Fox-Kemper et al. (2021).
3. Projections are given for the 50%ile of the CMIP6 model ensemble and likely range shown in brackets.

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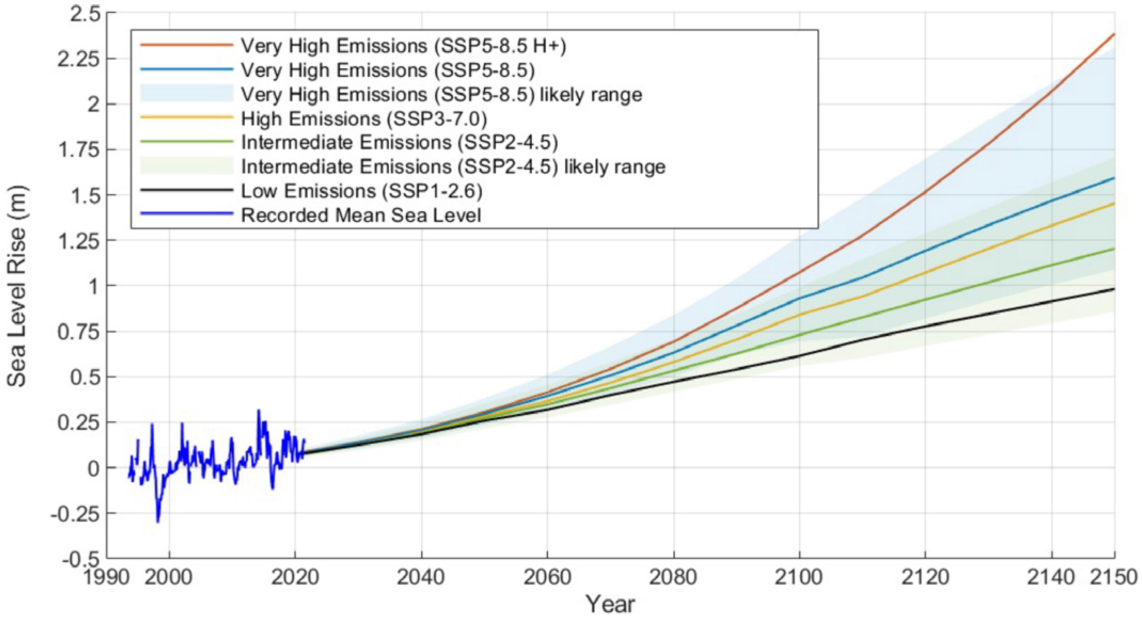
[35] B. Fox-Kemper et al. 2021. Ocean, Cryosphere and Sea Level Change.
[36] N. J. Brown et al. 2020. Vertical Motion of Pacific Island Tide Gauges.

3.11 Nauru

Sea level rise projections applicable throughout Nauru are presented in Figure 3.11 and Table 3.9. The projections have been adjusted for the upper bound of the *most likely* long term vertical land movement with a constant subsidence rate of -1.2mm/year,[37] noting subsidence at the Aiwo tide gauge of up to -1.2mm/year has been observed.[38]

Figure 3.11: Sea Level Rise Projections to 2150 for Nauru Relative to 1995–2014 Mean Sea Level



Notes:
1. Shared Socioeconomic Pathway (SSP); H+ represents low confidence high consequence scenario.
2. Projections are given for the 50%ile of the CMIP6 model ensemble unless otherwise defined.

Table 3.9: Decadal Increments for Projections of Sea Level Rise in Meters for Nauru Relative to the 1995–2014 Mean Sea Level

Year	*Low* SSP1–2.6	*Intermediate* SSP2–4.5	*High* SSP3–7.0	*Very High* SSP5–8.5	*Very High – Low* SSP5–8.5 H+
1995–2014	0.00	0.00	0.00	0.00	0.00
2020	0.07 (0.05–0.10)	0.07 (0.05–0.09)	0.07 (0.05–0.09)	0.08 (0.06–0.10)	0.08 (0.06–0.11)
2030	0.13 (0.09–0.16)	0.13 (0.10–0.16)	0.13 (0.10–0.16)	0.14 (0.11–0.18)	0.14 (0.11–0.21)
2040	0.18 (0.14–0.24)	0.19 (0.15–0.25)	0.02 (0.15–0.26)	0.21 (0.16–0.27)	0.21 (0.16–0.33)
2050	0.26 (0.20–0.34)	0.27 (0.22–0.35)	0.28 (0.22–0.36)	0.30 (0.24–0.38)	0.31 (0.23–0.50)
2060	0.32 (0.25–0.42)	0.35 (0.28–0.46)	0.37 (0.29–0.48)	0.39 (0.32–0.51)	0.41 (0.31–0.71)
2070	0.40 (0.31–0.53)	0.44 (0.35–0.58)	0.47 (0.37–0.61)	0.51 (0.40–0.67)	0.54 (0.40–0.97)
2080	0.47 (0.36–0.63)	0.53 (0.42–0.71)	0.58 (0.46–0.76)	0.63 (0.50–0.84)	0.69 (0.50–1.26)
2090	0.54 (0.41–0.74)	0.63 (0.49–0.85)	0.71 (0.56–0.94)	0.78 (0.62–1.04)	0.88 (0.62–1.60)
2100	0.61 (0.43–0.86)	0.73 (0.56–0.99)	0.84 (0.64–1.14)	0.93 (0.70–1.27)	1.07 (0.70–1.95)
2110	0.70 (0.47–1.00)	0.83 (0.60–1.15)	0.94 (0.66–1.30)	1.05 (0.72–1.49)	1.28 (0.72–2.31)
2120	0.78 (0.51–1.11)	0.92 (0.67–1.29)	1.07 (0.75–1.49)	1.19 (0.82–1.70)	1.52 (0.82–2.64)
2130	0.85 (0.55–1.22)	1.02 (0.73–1.43)	1.20 (0.83–1.68)	1.33 (0.92–1.91)	1.78 (0.92–3.44)
2140	0.91 (0.59–1.33)	1.11 (0.80–1.57)	1.33 (0.92–1.86)	1.47 (1.01–2.11)	2.07 (1.01–4.56)
2150	0.98 (0.62–1.43)	1.20 (0.86–1.71)	1.45 (1.00–2.04)	1.59 (1.09–2.31)	2.39 (1.09–5.79)

Notes:
1. Shared Socioeconomic Pathway (SSP); H+ represents low confidence high consequence scenario.
2. Projections based on IPCC (2021), sourced from AR6 and interpolated to nearest decade and adjusted for the upper bound of the *most likely* vertical land movement as defined by Fox-Kemper et al. (2021).
3. Projections are given for the 50%ile of the CMIP6 model ensemble and likely range shown in brackets.

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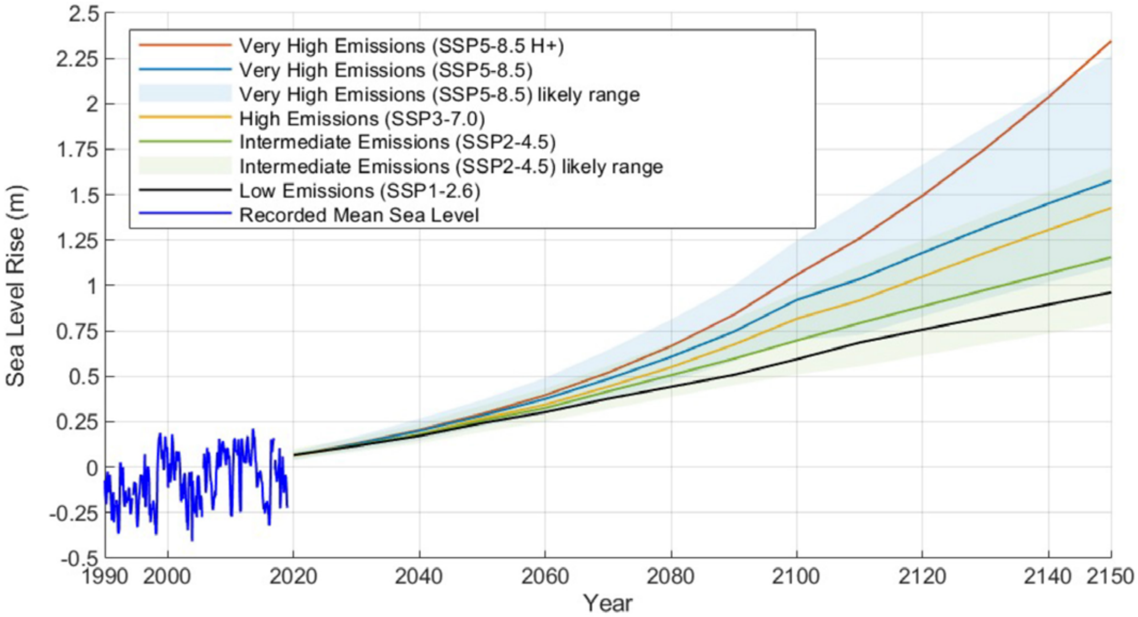
[37] B. Fox-Kemper et al. 2021. Ocean, Cryosphere and Sea Level Change.
[38] N. J. Brown et al. 2020. Vertical Motion of Pacific Island Tide Gauges.

3.12 Palau

Sea level rise projections applicable throughout Palau are presented in Figure 3.12 and Table 3.10. The projections have been adjusted for the upper bound of the *most likely* long-term vertical land movement with a constant subsidence rate of -1.0mm/year.[39]

Figure 3.12: Sea Level Rise Projections to 2150 for Palau Relative to 1995–2014 Mean Sea Level



Notes:
1. Shared Socioeconomic Pathway (SSP); H+ represents low confidence high consequence scenario.
2. Projections are given for the 50%ile of the CMIP6 model ensemble unless otherwise defined.

Table 3.10: Decadal Increments for Projections of Sea Level Rise in Meters for Palau Relative to the 1995–2014 Mean Sea Level

Year	*Low* SSP1–2.6	*Intermediate* SSP2–4.5	*High* SSP3–7.0	*Very High* SSP5–8.5	*Very High – Low* SSP5–8.5 H+
1995–2014	0.00	0.00	0.00	0.00	0.00
2020	0.07 (0.03–0.10)	0.07 (0.04–0.10)	0.06 (0.03–0.10)	0.06 (0.04–0.09)	0.07 (0.04–0.10)
2030	0.12 (0.07–0.18)	0.12 (0.09–0.16)	0.12 (0.08–0.16)	0.13 (0.09–0.17)	0.13 (0.09–0.20)
2040	0.17 (0.12–0.24)	0.18 (0.13–0.24)	0.18 (0.13–0.24)	0.20 (0.15–0.27)	0.21 (0.14–0.33)
2050	0.24 (0.18–0.32)	0.26 (0.19–0.34)	0.27 (0.20–0.35)	0.28 (0.22–0.37)	0.29 (0.22–0.49)
2060	0.30 (0.22–0.41)	0.33 (0.25–0.43)	0.34 (0.26–0.46)	0.38 (0.30–0.49)	0.40 (0.29–0.69)
2070	0.38 (0.28–0.51)	0.42 (0.32–0.56)	0.44 (0.34–0.59)	0.49 (0.38–0.65)	0.52 (0.38–0.94)
2080	0.44 (0.34–0.60)	0.51 (0.39–0.68)	0.55 (0.42–0.73)	0.61 (0.47–0.81)	0.67 (0.47–1.23)
2090	0.51 (0.38–0.70)	0.60 (0.45–0.82)	0.68 (0.52–0.91)	0.75 (0.58–1.00)	0.84 (0.58–1.55)
2100	0.59 (0.40–0.84)	0.70 (0.51–0.96)	0.82 (0.60–1.12)	0.92 (0.70–1.25)	1.06 (0.70–1.93)
2110	0.69 (0.45–0.98)	0.79 (0.56–1.11)	0.92 (0.63–1.28)	1.04 (0.73–1.46)	1.26 (0.73–2.28)
2120	0.76 (0.49–1.09)	0.89 (0.62–1.25)	1.05 (0.72–1.47)	1.18 (0.83–1.67)	1.50 (0.83–2.60)
2130	0.83 (0.53–1.20)	0.98 (0.68–1.38)	1.18 (0.80–1.65)	1.32 (0.93–1.88)	1.75 (0.93–3.37)
2140	0.90 (0.57–1.30)	1.07 (0.74–1.52)	1.31 (0.89–1.84)	1.45 (1.02–2.07)	2.04 (1.02–4.46)
2150	0.96 (0.60–1.41)	1.16 (0.79–1.65)	1.43 (0.97–2.02)	1.58 (1.10–2.27)	2.35 (1.10–5.65)

Notes:
1. Shared Socioeconomic Pathway (SSP); H+ represents low confidence high consequence scenario.
2. Projections based on IPCC (2021), sourced from AR6 and interpolated to nearest decade and adjusted for the upper bound of the *most likely* vertical land movement as defined by Fox-Kemper et al. (2021).
3. Projections are given for the 50%ile of the CMIP6 model ensemble and likely range shown in brackets.

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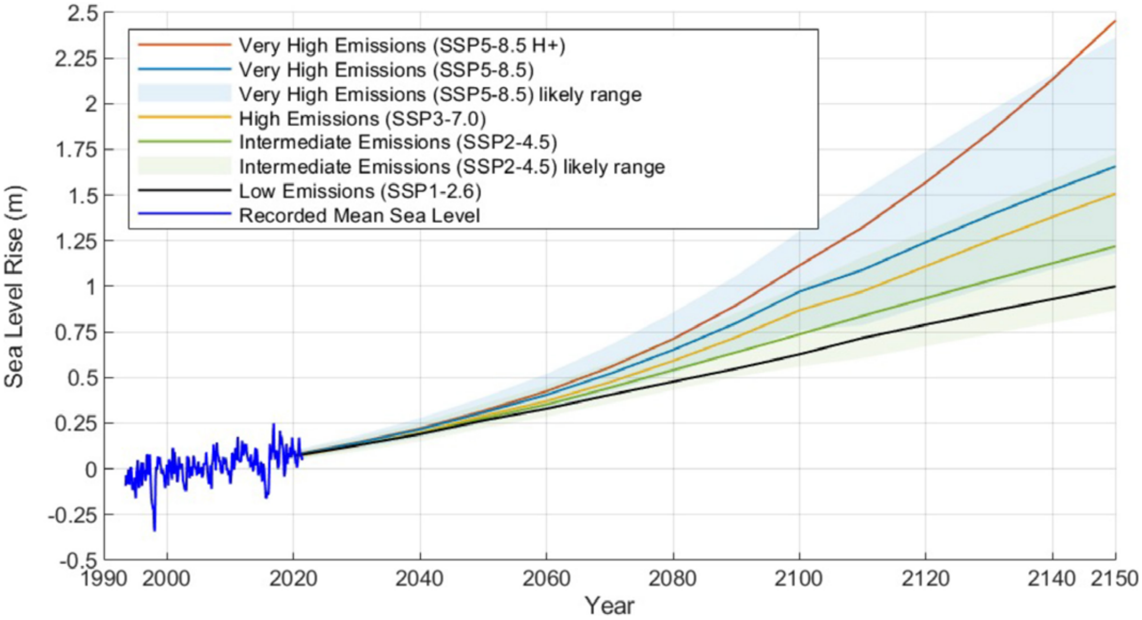
[39] Fox-Kemper et al. 2021. Ocean, Cryosphere and Sea Level Change.

3.13 Republic of the Marshall Islands (RMI)

Sea level rise projections applicable throughout RMI are presented in Figure 3.13 and Table 3.11. The projections have been adjusted for the upper bound of the *most likely* long-term vertical land movement with a constant subsidence rate of -1.3mm/year.[40] Subsidence at the Uliga tide gauge of up to -1.0mm/year has been observed since 2007.[41] It is noted that projected AR6 long term vertical land movement for other RMI islands is lower than assessed for Uliga.

Figure 3.13: Sea Level Rise Projections to 2150 for the Republic of the Marshall Islands Relative to 1995–2014 Mean Sea Level



Notes:
1. Shared Socioeconomic Pathway (SSP); H+ represents low confidence high consequence scenario.
2. Projections are given for the 50%ile of the CMIP6 model ensemble unless otherwise defined.

Table 3.11: Decadal Increments for Projections of Sea Level Rise in Meters for the Republic of the Marshall Islands Relative to the 1995–2014 Mean Sea Level

Year	*Low* SSP1–2.6	*Intermediate* SSP2–4.5	*High* SSP3–7.0	*Very High* SSP5–8.5	*Very High – Low* SSP5–8.5 H+
1995–2014	0.00	0.00	0.00	0.00	0.00
2020	0.07 (0.04–0.10)	0.07 (0.05–0.10)	0.07 (0.04–0.09)	0.07 (0.05–0.10)	0.08 (0.05–0.11)
2030	0.13 (0.09–0.17)	0.13 (0.09–0.17)	0.13 (0.09–0.17)	0.14 (0.11–0.18)	0.14 (0.11–0.21)
2040	0.19 (0.14–0.25)	0.19 (0.15–0.25)	0.20 (0.16–0.26)	0.22 (0.17–0.28)	0.22 (0.17–0.35)
2050	0.26 (0.21–0.34)	0.28 (0.22–0.36)	0.29 (0.24–0.37)	0.31 (0.25–0.39)	0.32 (0.25–0.51)
2060	0.33 (0.26–0.43)	0.35 (0.29–0.46)	0.37 (0.30–0.48)	0.41 (0.33–0.52)	0.43 (0.33–0.73)
2070	0.41 (0.32–0.53)	0.44 (0.36–0.58)	0.47 (0.38–0.62)	0.52 (0.42–0.68)	0.56 (0.42–0.99)
2080	0.48 (0.37–0.64)	0.54 (0.43–0.71)	0.59 (0.48–0.77)	0.65 (0.52–0.86)	0.71 (0.52–1.29)
2090	0.55 (0.43–0.74)	0.64 (0.50–0.85)	0.72 (0.58–0.95)	0.80 (0.64–1.06)	0.90 (0.64–1.64)
2100	0.63 (0.46–0.86)	0.74 (0.56–1.00)	0.87 (0.67–1.16)	0.97 (0.76–1.30)	1.11 (0.76–2.01)
2110	0.72 (0.51–1.00)	0.84 (0.61–1.16)	0.97 (0.70–1.33)	1.09 (0.79–1.52)	1.32 (0.79–2.37)
2120	0.79 (0.56–1.11)	0.94 (0.67–1.30)	1.11 (0.79–1.53)	1.24 (0.89–1.74)	1.57 (0.89–2.72)
2130	0.86 (0.60–1.22)	1.03 (0.74–1.45)	1.25 (0.89–1.72)	1.39 (1.00–1.96)	1.84 (1.00–3.52)
2140	0.93 (0.64–1.32)	1.13 (0.80–1.58)	1.38 (0.98–1.91)	1.53 (1.09–2.16)	2.13 (1.09–4.67)
2150	1.00 (0.69–1.43)	1.22 (0.87–1.72)	1.51 (1.06–2.10)	1.66 (1.18–2.36)	2.46 (1.18–5.91)

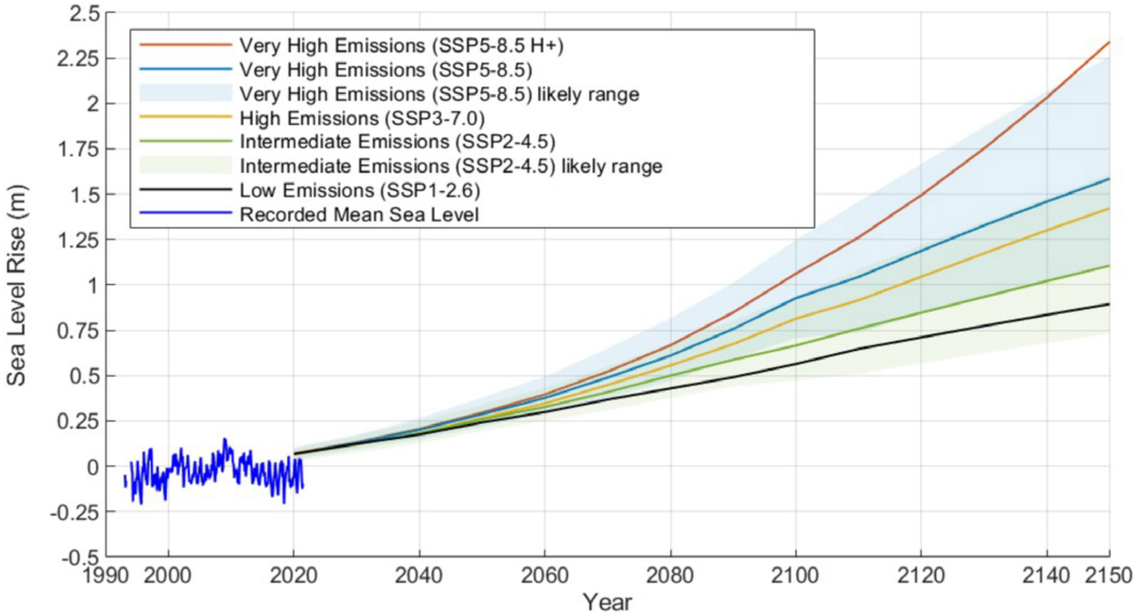
Notes:
1. Shared Socioeconomic Pathway (SSP); H+ represents low confidence high consequence scenario.
2. Projections based on IPCC (2021), sourced from AR6 and interpolated to nearest decade and adjusted for the upper bound of the *most likely* vertical land movement as defined by Fox-Kemper et al. (2021).
3. Projections are given for the 50%ile of the CMIP6 model ensemble and likely range shown in brackets.

[40] B. Fox-Kemper et al. 2021. Ocean, Cryosphere and Sea Level Change.
[41] N. J. Brown et al. 2020. Vertical Motion of Pacific Island Tide Gauges.

3.14 Vanuatu

Sea level rise projections applicable throughout Vanuatu are presented in Figure 3.14 and Table 3.12. The projections have been adjusted for the upper bound of the *most likely* long term vertical land movement with a constant subsidence rate of -0.8mm/year,[42] noting uplift at the Port Vila tide gauge of up to 3.0mm/year has been observed since 2013.[43]

Figure 3.14: Sea Level Rise Projections to 2150 for Vanuatu Relative to 1995–2014 Mean Sea Level



Notes:
1. Shared Socioeconomic Pathway (SSP); H+ represents low confidence high consequence scenario.
2. Projections are given for the 50%ile of the CMIP6 model ensemble unless otherwise defined.

Table 3.12: Decadal Increments for Projections of Sea Level Rise in Meters for Vanuatu Relative to the 1995–2014 Mean Sea Level

Year	*Low* SSP1–2.6	*Intermediate* SSP2–4.5	*High* SSP3–7.0	*Very High* SSP5–8.5	*Very High – Low* SSP5–8.5 H+
1995–2014	0.00	0.00	0.00	0.00	0.00
2020	0.07 (0.04–0.10)	0.07 (0.03–0.11)	0.07 (0.03–0.10)	0.07 (0.04–0.10)	0.07 (0.04–0.11)
2030	0.12 (0.08–0.17)	0.12 (0.08–0.17)	0.12 (0.08–0.17)	0.13 (0.10–0.17)	0.13 (0.10–0.20)
2040	0.18 (0.12–0.24)	0.18 (0.13–0.25)	0.18 (0.13–0.25)	0.20 (0.15–0.27)	0.21 (0.15–0.33)
2050	0.24 (0.18–0.32)	0.26 (0.20–0.34)	0.27 (0.20–0.35)	0.29 (0.22–0.38)	0.30 (0.21–0.48)
2060	0.30 (0.22–0.40)	0.33 (0.25–0.43)	0.35 (0.27–0.45)	0.38 (0.30–0.49)	0.40 (0.29–0.68)
2070	0.37 (0.28–0.49)	0.41 (0.31–0.55)	0.45 (0.35–0.59)	0.49 (0.38–0.65)	0.52 (0.38–0.92)
2080	0.43 (0.32–0.59)	0.50 (0.38–0.68)	0.56 (0.43–0.74)	0.61 (0.47–0.82)	0.67 (0.47–1.21)
2090	0.49 (0.37–0.68)	0.59 (0.44–0.80)	0.67 (0.52–0.90)	0.76 (0.59–1.01)	0.85 (0.59–1.53)
2100	0.56 (0.40–0.79)	0.67 (0.47–0.94)	0.81 (0.61–1.10)	0.93 (0.71–1.25)	1.06 (0.71–1.89)
2110	0.65 (0.44–0.92)	0.76 (0.51–1.09)	0.92 (0.64–1.27)	1.04 (0.74–1.46)	1.26 (0.74–2.23)
2120	0.71 (0.48–1.02)	0.85 (0.57–1.22)	1.05 (0.73–1.46)	1.19 (0.84–1.67)	1.50 (0.84–2.55)
2130	0.77 (0.51–1.12)	0.93 (0.62–1.35)	1.17 (0.81–1.64)	1.33 (0.94–1.87)	1.75 (0.94–3.34)
2140	0.84 (0.55–1.21)	1.02 (0.68–1.48)	1.30 (0.90–1.82)	1.46 (1.03–2.07)	2.03 (1.03–4.41)
2150	0.89 (0.59–1.30)	1.11 (0.73–1.61)	1.42 (0.98–2.00)	1.59 (1.11–2.26)	2.34 (1.11–5.59)

Notes:
1. Shared Socioeconomic Pathway (SSP); H+ represents low confidence high consequence scenario.
2. Projections based on IPCC (2021), sourced from AR6 and interpolated to nearest decade and adjusted for the upper bound of the *most likely* vertical land movement as defined by Fox-Kemper et al. (2021).
3. Projections are given for the 50%ile of the CMIP6 model ensemble and likely range shown in brackets.

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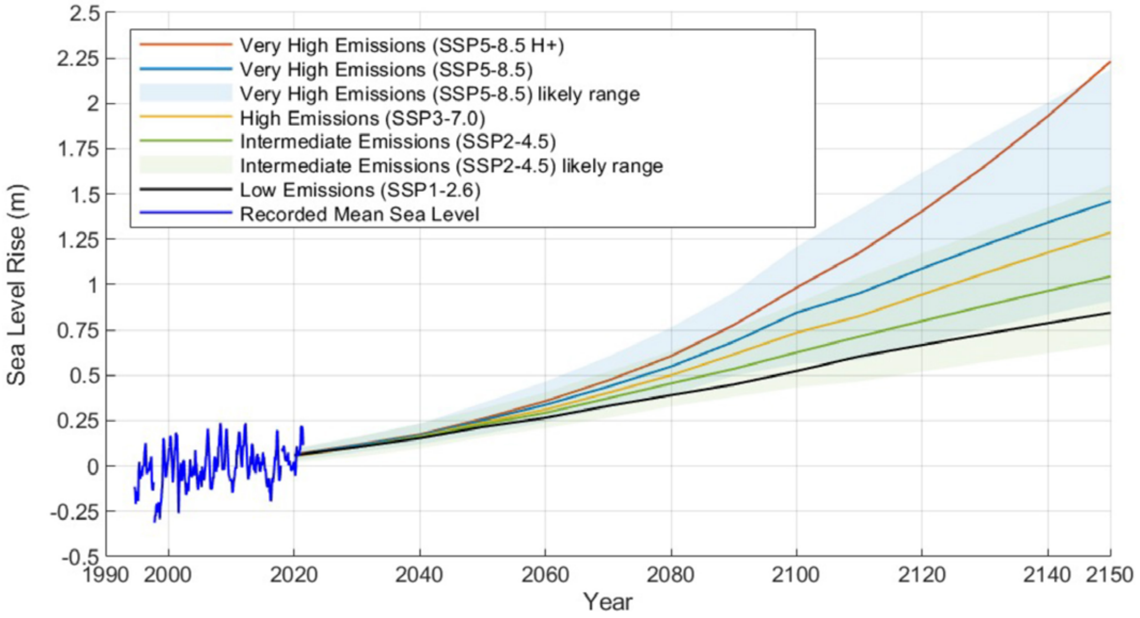
[42] B. Fox-Kemper et al. 2021. Ocean, Cryosphere and Sea Level Change.
[43] N. J. Brown et al. 2020. Vertical Motion of Pacific Island Tide Gauges.

3.15 Solomon Islands

Sea level rise projections applicable throughout the Solomon Islands are presented in Figure 3.15 and Table 3.13. The projections have been adjusted for the upper bound of the *most likely* long term vertical land movement with a with a constant subsidence rate of -0.3mm/year,[44] noting subsidence at the Honiara tide gauge of up to -2.5mm/year has been observed since 2009.[45]

Figure 3.15: Sea Level Rise Projections to 2150 for the Solomon Islands Relative to 1995–2014 Mean Sea Level



Notes:
1. Shared Socioeconomic Pathway (SSP); H+ represents low confidence high consequence scenario.
2. Projections are given for the 50%ile of the CMIP6 model ensemble unless otherwise defined.

Table 3.13: Decadal Increments for Projections of Sea Level Rise in Meters for the Solomon Islands Relative to the 1995–2014 Mean Sea Level

Year	*Low* SSP1–2.6	*Intermediate* SSP2–4.5	*High* SSP3–7.0	*Very High* SSP5–8.5	*Very High – Low* SSP5–8.5 H+
1995–2014	0.00	0.00	0.00	0.00	0.00
2020	0.06 (0.02–0.10)	0.06 (0.02–0.10)	0.05 (0.02–0.09)	0.06 (0.03–0.09)	0.06 (0.03–0.10)
2030	0.10 (0.05–0.16)	0.10 (0.05–0.16)	0.10 (0.05–0.16)	0.11 (0.07–0.16)	0.12 (0.07–0.19)
2040	0.15 (0.10–0.22)	0.16 (0.10–0.24)	0.16 (0.10–0.24)	0.17 (0.12–0.23)	0.17 (0.12–0.30)
2050	0.22 (0.15–0.30)	0.23 (0.16–0.32)	0.24 (0.17–0.33)	0.25 (0.18–0.35)	0.26 (0.17–0.45)
2060	0.27 (0.18–0.38)	0.29 (0.21–0.41)	0.31 (0.21–0.44)	0.34 (0.24–0.47)	0.36 (0.24–0.65)
2070	0.33 (0.23–0.47)	0.37 (0.27–0.52)	0.40 (0.29–0.56)	0.44 (0.32–0.60)	0.47 (0.32–0.88)
2080	0.39 (0.27–0.56)	0.46 (0.33–0.63)	0.50 (0.36–0.70)	0.55 (0.39–0.76)	0.61 (0.39–1.16)
2090	0.45 (0.31–0.64)	0.54 (0.38–0.76)	0.62 (0.45–0.85)	0.69 (0.50–0.96)	0.78 (0.50–1.48)
2100	0.52 (0.30–0.79)	0.63 (0.43–0.90)	0.74 (0.50–1.04)	0.85 (0.56–1.21)	0.98 (0.56–1.84)
2110	0.60 (0.33–0.93)	0.71 (0.47–1.04)	0.83 (0.52–1.20)	0.95 (0.58–1.41)	1.18 (0.58–2.18)
2120	0.67 (0.35–1.04)	0.80 (0.52–1.17)	0.95 (0.60–1.38)	1.09 (0.67–1.62)	1.41 (0.67–2.49)
2130	0.73 (0.37–1.15)	0.88 (0.57–1.30)	1.06 (0.67–1.55)	1.22 (0.76–1.82)	1.65 (0.76–3.27)
2140	0.79 (0.39–1.25)	0.97 (0.62–1.43)	1.18 (0.74–1.72)	1.34 (0.84–2.01)	1.93 (0.84–4.33)
2150	0.85 (0.41–1.35)	1.05 (0.67–1.55)	1.29 (0.81–1.89)	1.46 (0.91–2.19)	2.23 (0.91–5.52)

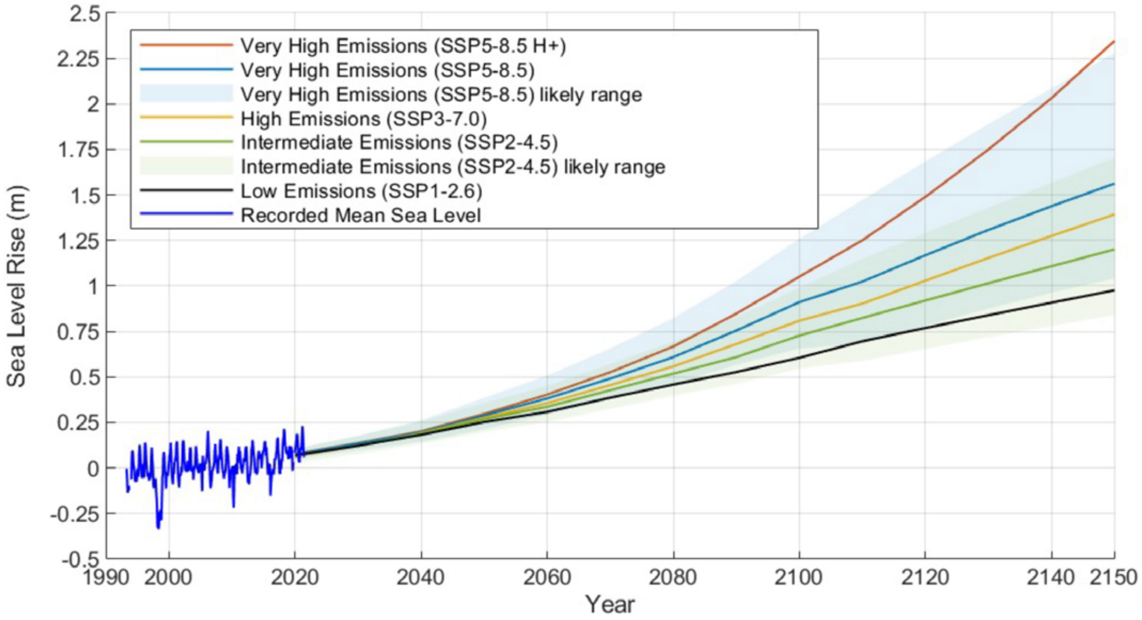
Notes:
1. Shared Socioeconomic Pathway (SSP); H+ represents low confidence high consequence scenario.
2. Projections based on IPCC (2021), sourced from AR6 and interpolated to nearest decade and adjusted for the upper bound of the *most likely* vertical land movement as defined by Fox-Kemper et al. (2021).
3. Projections are given for the 50%ile of the CMIP6 model ensemble and likely range shown in brackets.

[44] B. Fox-Kemper et al. 2021. Ocean, Cryosphere and Sea Level Change.
[45] N. J. Brown et al. 2020. Vertical Motion of Pacific Island Tide Gauges.

3.16 Tuvalu

Sea level rise projections applicable throughout Tuvalu are presented in Figure 3.16 and Table 3.14. The projections have been adjusted for the upper bound of the *most likely* long term vertical land movement with a constant subsidence rate of -1.1mm/year,[46] noting subsidence at the Fongafale tide gauge of up to -1.5mm/year has been observed since 2003.[47]

Figure 3.16: Sea Level Rise Projections to 2150 for Tuvalu Relative to 1995–2014 Mean Sea Level



Notes:
1. Shared Socioeconomic Pathway (SSP); H+ represents low confidence high consequence scenario.
2. Projections are given for the 50%ile of the CMIP6 model ensemble unless otherwise defined.

Table 3.14: Decadal Increments for Projections of Sea Level Rise in Meters for Tuvalu Relative to the 1995–2014 Mean Sea Level

Year	*Low* SSP1–2.6	*Intermediate* SSP2–4.5	*High* SSP3–7.0	*Very High* SSP5–8.5	*Very High – Low* SSP5–8.5 H+
1995–2014	0.00	0.00	0.00	0.00	0.00
2020	0.07 (0.03–0.11)	0.07 (0.03–0.11)	0.06 (0.03–0.10)	0.08 (0.05–0.10)	0.08 (0.05–0.12)
2030	0.12 (0.07–0.18)	0.12 (0.08–0.17)	0.12 (0.07–0.18)	0.13 (0.10–0.18)	0.14 (0.10–0.21)
2040	0.18 (0.13–0.25)	0.19 (0.13–0.25)	0.19 (0.14–0.26)	0.20 (0.14–0.26)	0.20 (0.14–0.33)
2050	0.25 (0.18–0.34)	0.27 (0.20–0.36)	0.28 (0.20–0.37)	0.29 (0.21–0.39)	0.30 (0.21–0.49)
2060	0.31 (0.23–0.42)	0.34 (0.25–0.45)	0.36 (0.26–0.48)	0.38 (0.29–0.51)	0.40 (0.29–0.70)
2070	0.39 (0.29–0.52)	0.43 (0.33–0.57)	0.46 (0.35–0.61)	0.49 (0.38–0.66)	0.53 (0.38–0.95)
2080	0.46 (0.34–0.62)	0.52 (0.40–0.70)	0.56 (0.42–0.75)	0.61 (0.46–0.82)	0.67 (0.46–1.23)
2090	0.53 (0.39–0.72)	0.61 (0.46–0.83)	0.68 (0.52–0.92)	0.76 (0.57–1.03)	0.85 (0.57–1.56)
2100	0.61 (0.39–0.87)	0.73 (0.55–0.99)	0.81 (0.59–1.11)	0.91 (0.66–1.26)	1.05 (0.66–1.92)
2110	0.70 (0.42–1.02)	0.82 (0.59–1.15)	0.90 (0.62–1.27)	1.02 (0.68–1.47)	1.25 (0.68–2.27)
2120	0.77 (0.46–1.14)	0.92 (0.66–1.29)	1.03 (0.70–1.45)	1.17 (0.78–1.68)	1.49 (0.78–2.60)
2130	0.84 (0.49–1.25)	1.02 (0.72–1.43)	1.15 (0.78–1.63)	1.31 (0.88–1.89)	1.75 (0.88–3.40)
2140	0.91 (0.52–1.37)	1.11 (0.78–1.57)	1.28 (0.86–1.80)	1.44 (0.96–2.09)	2.03 (0.96–4.50)
2150	0.98 (0.55–1.48)	1.20 (0.84–1.70)	1.39 (0.94–1.98)	1.56 (1.04–2.28)	2.35 (1.04–5.71)

Notes:
1. Shared Socioeconomic Pathway (SSP); H+ represents low confidence high consequence scenario.
2. Projections based on IPCC (2021), sourced from AR6 and interpolated to nearest decade and adjusted for the upper bound of the *most likely* vertical land movement as defined by Fox-Kemper et al. (2021).
3. Projections are given for the 50%ile of the CMIP6 model ensemble and likely range shown in brackets.

[46] B. Fox-Kemper et al. 2021. Ocean, Cryosphere and Sea Level Change.
[47] N. J. Brown et al. 2020. Vertical Motion of Pacific Island Tide Gauges.

4. Application of Sea Level Rise Projections

In lieu of finalized adaptation plans, transitional guidance is provided based on fixed levels of sea level rise and/or selected projections (Section 3) for various infrastructure types, planning horizons, and infrastructure importance. The guidance is intended to provide a balanced risk profile built around the *Intermediate emissions likley* range which captures the median estimates of projected sea level rise for *Low emission* (SSP1–2.6) to *Very high emission* (SSP5–8.5) projections of which there is overall medium confidence.

4.1 Infrastructure Planning

For infrastructure and land use planning, the suite of sea level rise projections described in Section 3 of this guidance should be considered to assess the range of plausible scenarios of sea level rise. Reflecting the large uncertainty at longer timeframes and the limited adaptative capacity of PICs, recommended minimum single sea level rise values or projections while in transition to developing adaptative pathways are presented in Table 4.1. Four infrastructure categories have been defined and sea level allowances are either expressed as a range of emission scenarios or recommended minimum values via defined timeframes.

Table 4.1: Recommended Transitional Guidance for Infrastructure Planning

Category	Description	Minimum Transitional Response
A	Coastal subdivision, greenfield developments, and major new infrastructure.	**Avoid** risk and apply median *Very High Emissions – Low Confidence* scenario (SSP5–8.5 H+) with a 100-year planning timeframe.
B	Changes in land use and redevelopment including intensification.	**Adapt** to hazards by conducting risk assessment using the range of median *Intermediate* to *Very High Emissions* scenarios (SSP2–4.5 to SSP5–8.5).
C	Land use planning controls for existing coastal development and infrastructure planning.	**Accommodate** risk and apply 83rd percentile of the *Intermediate Emissions* scenario (SSP2–4.5) with reference to the respective planning timeframe.
D	Non habitable short-lived assets with a function that needs to be in the coastal zone and is readily adaptable.	**Median** *Intermediate Emissions* (SSP2–4.5) projection with reference to respective planning timeframe.

SSP = Shared Socioeconomic Pathway.
Source: Adapted from MfE - New Zealand Ministry of Environment (2017): *Coastal Hazards and Climate change – Guidance for Local Government.*

For planning of critical or major greenfield infrastructure (Category A), a precautionary approach is recommended with the adoption of the median *Very High Emissions – Low confidence* (SSP5–8.5 H+) scenario, which is equivalent to the upper bound of the likely range for the Very high emissions (SSP5–8.5) scenario. This reflects the long lifetime of the infrastructure, which is typically greater than 100 years, and adopts an "avoid" risk profile that minimizes future hazard risks over long-term planning timeframes (commonly 100 years).

Informing where intensification of existing development is inadvisable (Category B), the range of sea level rise scenarios should be applied to develop suitable adaptive dynamic pathways for the scale of the intensification. Reflecting the current sea level rise trends, it is recommended that the *Intermediate to Very High Emission* projections (SSP2–4.5 to SSP5–8.5) be adopted.

For existing development (Category C), the application of a single value of sea level rise can lead to a rigid predetermination of the future if planning is solely based on this value. A range of risks exists for different scales of activity from sea level rise and a lower allowance may be appropriate for activities that have a functional need to be near the coast, or short-lived non-habitable assets, where low consequences and high capacity for adaption exists. To accommodate the potential range in planning timeframes, it is recommended that sea level rise projections from the *Intermediate Emissions* (SSP2–4.5) scenario 83rd percentile are adopted.

The 83rd percentile is the largest value presented in the bracketed *likely* projections presented in Sections 3.4 to 3.16 (e.g., 0.66–1.29). In the absence of a defined planning timeframe, it is recommended that a planning horizon of 100 years is adopted, which typically results in an estimated sea level rise of 1.2m for PICs. This magnitude of sea level rise is consistent with international planning guidelines.[48]

For non-habitable activities (Category D), the allowance of future sea level rise is recommended to be limited to the intended asset design life in accordance with the median *Intermediate emission* (SSP2–4.5) projection.

4.2 Engineering Design

When considering sea level rise in engineering design, there is large variability in advice throughout codes and standards due to the inability to define likelihood. As a result, the allowance for future sea level rise is often arbitrary, outdated, or not commonly defined.

Infrastructure codes and standards typically define minimum design requirements based on the consequence of failure, design life, and function. An example of the linkage between type and consequence is the concept of infrastructure Importance, which is common throughout Australian and New Zealand standards, such as NZS 1170.5 and AS 4997. Importance level is determined as a function of the potential consequence on human life, economics, society, and the environment. Following selection of Importance level, the likelihood to be considered for various design considerations is generally prescribed via the adopted standard.

To provide guidance, a further linkage between infrastructure design life, type, importance, and sea level rise projections is proposed. The linkage is based on a precautionary approach and errs to the higher sea level projections that are consistent with currently observed rates of change.

For engineering design where there is no prescribed magnitude of sea level rise in the applicable codes and standards, recommended minimum sea level rise projections (Section 3) as a function of infrastructure design life and Importance where a single value is required are presented in Table 4.2. The guidance is based on the application of likely median sea level rise with increased risk allowance for infrastructure importance.

Table 4.2: Recommended Transitional Guidance for Infrastructure Engineering Design

Consequence of Failure	Description	Importance Level	Minimum Transitional Response
Low	Low consequence for loss of human life, or small or moderate economic, social, or environmental consequence.	**1**	Minor structures (failure not likely to endanger human life. Adopt median *Intermediate Emissions* (SSP2–4.5) projection considering design life.
Ordinary	Medium consequence for loss of human life, or considerable economic, social, or environmental consequence.	**2**	Normal structures not falling into other levels. Adopt median *High Emissions* (SSP3–7.0) projection considering design life.
High	High consequence for loss of human life, or very great economic, social, or environmental consequence.	**3**	Major structures and critical infrastructure. Adopt median *Very High Emissions* (SSP5–8.5) projection considering design life.
		4	Post disaster structures. Adopt median *Very High Emissions* (SSP5–8.5 H+) projection considering a minimum design life of 100 years.

SSP = Shared Socioeconomic Pathway.
Source: Adapted from MfE - New Zealand Ministry of Environment (2017): *Coastal Hazards and Climate change – Guidance for Local Government.*

The level of risk and magnitude of sea level rise to consider for infrastructure planning and development is ultimately dependent on the individual PIC risk profile. This guidance does not intend to replace codes, standards, or guidance manuals that are in existence.

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[48] New Zealand Ministry of Environment (MfE). 2017. *Coastal Hazards and Climate Change – Guidance for Local Government.*

5. Sea Level Variability and Future Risk

Sea levels are highly variable and are already showing the effects from past emissions. The effects of sea level rise typically translate the current tidal variation vertically proportional to the amount of sea level rise. However, there are components of sea level that are individually affected by climate change, such as storm surge, that can be further amplified. Supporting Step 2 of the adaptative planning framework (Section 2.3.2), this section provides further background on sea level rise processes for PICs and provides additional data for consideration when assessing impacts at sites of interest.

5.1 Components of Sea Level

Sea level changes occur from the combination of natural phenomena that individually may not be extreme.[49] These natural phenomena occur over a range of time and space scales in any given PIC location, meaning their contribution to average and extreme sea levels varies. Box 5.1 describes the individual components that contribute to sea level variability and inundation throughout PICs.

For infrastructure planning and development, the following scenarios are important to consider:

- the likely change in risk from normal tidal cycles, including the effects of sea level rise; and
- the likely change in risk from extreme water levels, including the effects of sea level rise.

Normal tidal cycles are predominantly a function of astronomical tide and typically represent the zone that is permanently affected by coastal processes. Extreme water levels, which are dominated by the additional effects of storm surge and wave setup, occur rarely but, in association with other climate variables, present a hazard to infrastructure, particularly for low lying PICs.

Of all the sea level components, the effect of wave setup is the most sensitive to local geomorphology, bathymetry, and shoreline exposure to extreme wave conditions and, hence, is highly variable around the periphery of PIC islands. Furthermore, the magnitude of wave setup can be a significant component of local extreme sea levels (Box 5.1).

To provide baseline information for individual components of sea level, analysis of hourly sea level data recorded for each PIC has been completed. Most of the data are sourced from the Pacific Sea Level and Geodetic Monitoring Project that is being completed by the Australian Bureau of Meteorology and Geoscience Australia,[50] except for Palau, which was sourced from the Permanent Service for Mean Sea Level.[51] Details of the datasets are presented in Tables 5.1 and 5.2.

The sea level datasets are limited in both geographic coverage and length. It is important to note that the analysis provided herein is a function of dataset length and the methods used; alternative methods may provide different results particularly for extreme analysis. However, the available data do provide sufficient baseline information to define water level variability and trends of local change. As tide gauges are typically located in protected harbors, they tend to not capture the effects of wave setup.

There are a variety of vertical datums throughout the Pacific and locally for each PIC. The data and analysis presented herein is to the respective tide datum that has been established for each tide gauge, termed Chart Datum (CD). Prior to comparison to other datasets, it is important to check that the datums are consistent. Full information on the datums is regularly updated and maintained on the Australian Bureau of Meteorology and Permanent Service for Mean Sea Level websites.

AR6 has adopted a new baseline period extending between 1995 to 2014 for which future projections are referenced. This period coincides with the recorded datasets and reference mean sea levels, equivalent to the 50% tidal exceedance for each PIC over the baseline period, is presented in Table 5.2. It is noted that

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[49] K.L. McInnes, et al. 2016. Natural Hazards in Australia: Sea Level and Coastal Extremes. *Climatic Change*. 139(1). pp. 69–83.
[50] http://www.bom.gov.au/pacific/projects/pslm. Data accessed 20 May 2021.
[51] https://www.psmsl.org/. Data accessed 20 May 2021.

present-day mean sea level will be slightly higher than the values in Table 5.2 due to ongoing sea level rise since 2014 and ENSO variability. Table 5.2 also presents the standard deviation of tide levels, which is a proxy for tidal range that captures 68% of the tidal levels around mean sea level and minimum and maximum recorded levels. Tidal ranges for PICs are typically narrow, with standard deviation ranges of less than 0.50m (range 0.22m to 0.50m), which makes PICs particularly susceptible to sea level rise impacts and associated hazards.

Box 5.1: Sea Level Components

Mean Sea Level (MSL) is the average (mean) level of the sea relative to a set vertical datum over a defined period, usually several years. For this guidance, MSL is assessed as the 50% exceedance water level for the period of 1995 to 2014.

Mean Sea Level Anomaly (MSLA) is the variation of the nontidal sea level about the longer-term MSL on time scales from months to decades, due to climate variability. Sources of MSLA in the Pacific include the influence of the El Niño Southern Oscillation (ENSO) and the Interdecadal Pacific Oscillation (IPO) patterns on sea level, winds, sea temperature, and seasonal effects. ENSO and IPO have large impacts on sea level variability throughout PICs.

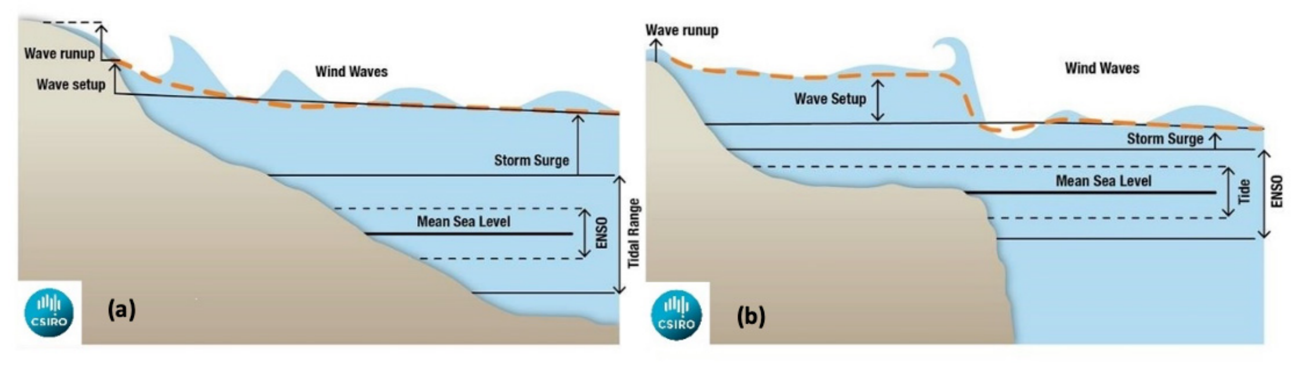
Astronomical tide is the rise and fall of the tide due to the gravitational effects of the sun and moon. Tidal cycles range from diurnal (one high tide a day) to semi-diurnal (twice a day) and are predictable and vary throughout the months and years depending on the earth's orbit. Astronomical tide is the main component of sea level variability throughout PICs.

Storm Surge is the super elevation of tide levels induced by wind and barometric pressure during weather events. The effects of storm surge are typically more pronounced during tropical cyclone events and extend from hours to days in duration.

Wave setup is the nearshore increase in sea level from wave breaking processes in the surf zone that pile water against the coast. Wave setup is typically more pronounced in environs with relatively flat and shallow bathymetries such as coral reef atolls and is a significant component of extreme water levels for PICs. As wave setup is a function of the bathymetry and geomorphology the magnitude of setup is variable, localized, and tends to be limited to hours in duration.

Wave runup and overtopping is the sporadic uprush of greenwater on the beach or coastal structure. The effects are short lived and tend to not contribute to inundation unless overtopped water is trapped in the lee of a dune or coastal structure.

Contributions to Extreme Sea Levels from Tides, El Niño Southern Oscillation, Storm Surges and Wind Waves on Continental Shelf Areas (a) and Reef Atolls (b).



Source: CSIRO, Causes of extreme sea levels – Sea Level, Waves and Coastal Extremes (csiro.au)

Table 5.1: Tide Gauge Location

Country	Island/Atoll	Town/District	Latitude	Longitude
Cook Islands	Rarotonga	Avatiu	21° 11' 58" S	159° 47' 10" W
Federated States of Micronesia	Pohnpei	Dekehtik	06° 58' 42" N	158° 11' 50" E
Samoa	Upolu	Apia	13° 49'09" S	171° 45' 21" W
Tonga	Tongatapu	Nuku'alofa	21° 08' 25" S	175° 10' 45" W
Niue	Niue	Alofi	19° 03' 10" S	169° 55' 15" W
Fiji	Viti Levu	Lautoka	17° 36' 19" S	177° 26' 17" E
Kiribati	Tarawa	Betio	01° 21' 45" N	172° 55' 48" E
Nauru	Nauru	Aiwo	00° 31' 55" S	166° 54' 33" E
Palau	Palau	Malakal	07° 20' 00" N	134° 28' 00" E
Marshall Islands	Majuro	Uliga	07° 06' 27" N	171° 22' 15" E
Vanuatu	Efate	Port Vila	17° 45' 41" S	168° 17' 35" E
Solomon Islands	Guadalcanal	Honiara	09° 25' 18" S	159° 57' 19" E
Tuvalu	Funafuti	Fongafale	08° 30' 10" S	179° 12' 33" E

Source: http://www.bom.gov.au/pacific/projects/pslm/; https://www.psmsl.org/.

Table 5.2: Recorded Tide Gauge Data and Reference Levels

Country [a]	Record start [b]	Record complete [c]	MSL (m CD) [d g]	Tide SD (m) [e]	Min/Max Level (m CD) [f g]
Cook Islands	02/1993	97.5%	0.59	0.22	-0.11/1.62
Federated States of Micronesia	12/2001	95.2%	0.75	0.30	-0.09/1.80
Samoa	02/1993	95.9%	0.79	0.32	-0.38/1.84
Tonga	01/1993	98.8%	1.01	0.39	-0.07/2.45
Niue	08/2015	73.3%	0.82	0.31	0.06/1.94
Fiji	10/1992	99.5%	1.27	0.49	-0.05/2.78
Kiribati	12/1992	97.0%	1.65	0.50	0.17/3.15
Nauru	07/1993	94.0%	1.40	0.48	-0.08/3.07
Palau	05/1969	98.7%	1.62	0.47	0.00/2.79
Marshall Islands	05/1993	99.2%	1.06	0.45	n/a/2.41
Vanuatu	01/1993	99.3%	0.91	0.32	-0.24/1.79
Solomon Islands	0.7/1994	98.6%	0.70	0.22	-0.07/1.37
Tuvalu	03/1993	97.2%	2.01	0.48	0.53/3.44

Notes:
a. Tide gauge location (Table 5.1).
b. Record start date (mm/yyyy).
c. Percentage of complete data over the timeframe (record start to May 2021).
d. Mean Sea Level (MSL) based on the 50% exceedance of water levels for the 1995–2014 baseline.
e. Standard Deviation (SD) of the tide with ~68% of tide levels values around MSL.
f. Minimum (Min) and Maximum (Max) recorded water levels during the timeframe (record start to May 2021).
g. CD = Chart Datum equivalent to tide gauge zero

5.2 Short-Term Mean Sea Level Variability

The South Pacific Convergence Zone (SPCZ) is a diagonal band of intense rainfall and deep atmospheric convection extending from the equator to the subtropical South (Figure 1.1). Displacement of the SPCZ causes variability in rainfall, tropical cyclone activity and sea level that affects South Pacific Island populations and surrounding ecosystems.

The SPCZ is strongly affected by ENSO and longer-term IPO. ENSO events have a strong modulating effect on the interannual sea level variability of the western tropical Pacific, with lower/higher than average sea level during El Niño/La Niña events, of the order of ± 20–30 cm. During La Niña events, strengthened easterly winds and displacement of the Pacific Warm Pool towards the west results in sea levels that are up to 20–30 cm higher than normal. Conversely, during El Niño, the Pacific Warm Pool is displaced to the east, resulting in sea levels that are up to 20–30 cm lower than normal in the western Pacific.[52]

To assess short-term variability of mean sea level, monthly mean sea level for each PIC was compiled from the PIC tide datasets (Table 5.1). Monthly mean sea levels were selected over annual levels to provide a wider sensitivity of trends. The data were adjusted to remove the effects of past sea level rise and vertical land movement via a linear relationship (Section 5.3) and an exceedance analysis was conducted on the variance. The resulting variance exceedances are an estimate of the likely frequency of mean sea level variation from both normal and seasonal fluctuations and wider climate processes such as ENSO. Maximum and minimum range observed for each PIC, 1%/99% and 17%/83% exceedance variances, are presented in Table 5.3. The durations of the analyzed datasets, apart from Niue, have captured a range of normal seasonal cycles, ENSO variations, and interdecadal oscillations and are representative of the expected variability.

The variances in Table 5.3 are consistent with the range of interannual water levels presented in Australian Bureau of Meteorology and CSIRO (2014) and, while not directly comparable, suggests similar trends to that of Becker et al. (2012). Of note is the high variability of mean sea level in the North Pacific reducing towards the South Pacific, which is also consistent with projected distribution of future sea level rise across the Pacific (Sections 3.2 and 3.3). This is particularly important as the magnitude of mean sea level variability is similar to magnitudes of projected near-term sea-level rise (i.e., in 2050), which in some cases will double the potential sea level rise exposure.

Table 5.3: Mean Sea Level Variance Exceedance Based on Recorded Data

Country [a]	Maximum/Minimum	1%/99% [b]	17%/83% [c]
Cook Islands	0.17/-0.15	0.13/-0.13	0.06/-0.06
Federated States of Micronesia	0.17/-0.26	0.16/-0.23	0.08/-0.08
Samoa	0.15/-0.29	0.13/-0.24	0.05/-0.04
Tonga	0.17/-0.16	0.15/-0.15	0.06/-0.06
Niue[d]	0.11/-0.10	0.11/-0.10	0.05/-0.05
Fiji	0.14/-0.16	0.13/-0.12	0.05/-0.05
Kiribati	0.20/-0.26	0.15/-0.20	0.06/-0.05
Nauru	0.27/-0.28	0.22/-0.22	0.06/-0.06
Palau	0.30/-0.35	0.24/-0.28	0.14/-0.13
Marshall Islands	0.19/-0.31	0.15/-0.22	0.06/-0.06
Vanuatu	0.19/-0.18	0.15/-0.16	0.06/-0.06
Solomon Islands	0.24/-0.26	0.22/-0.23	0.10/-0.09
Tuvalu	0.19/-0.31	0.17/-0.27	0.07/-0.07

Notes:
a. Tide gauge location (Table 5.1).
b. 1%/99% presents the likely highest 1% variance and 99% represents the lowest 1% level.
c. 17%/83% present the likely 17% highest mean level variance and 83% the lowest 17%.
d. Niue included for completeness, noting variances are not reliable due to short dataset.

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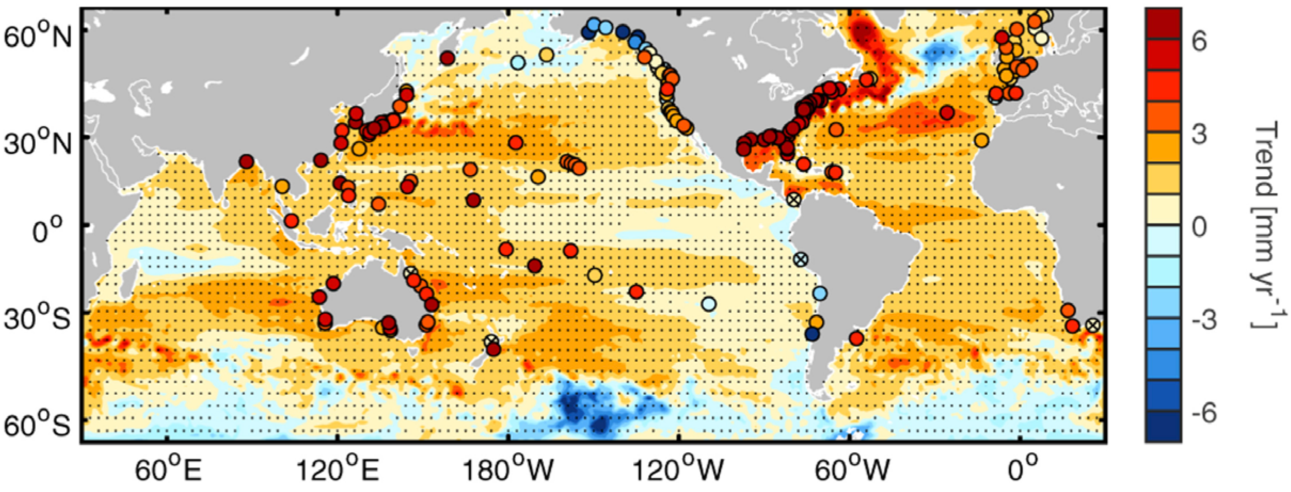
[52] M. Becker, B. Meyssignac, C. Letetrel, W. Llovel, A. Cazenave, and T. Delcroix. 2012. Sea Level Variations at Tropical Pacific Islands since 1950. Global and Planetary Change. 80-81. pp. 85–98.

5.3 Long-Term Mean Sea Level Variability

Relative long-term mean sea level variability considers the rate of change relative to the adjacent land mass. Components of long-term variability include a combination of predictable changes from astronomical tidal cycles, short term variability (Section 5.2), vertical land movement and the ongoing effects of global warming that result in sea level rise. Tidal measurements as recorded by tide gauges are useful as they capture these components and provide a full measure of change.

Global sea level rise is not spatially uniform due to large-scale climate drivers such as ENSO.[53] Figure 5.1 shows the observed sea level rise linear trend for the period 1970–2018 based on tide gauge data centered on the Pacific where the effects of ENSO can be seen with higher rates in the western and north Pacific and lower rates to the east.

Figure 5.1: Linear Trend of Sea Level Rise from Tide Gauge Data, 1970–2018



Source: J. Wang, J.A. Church, X. Zhang, and X. Chen. 2021. Reconciling Global Mean and Regional Sea Level Change in Projections and Observations. *Nature Communications*. 12(1). pp. 990.

To provide further insight on long-term variability for each PIC, the respective tide data were analyzed to assess monthly mean sea levels and linear rates of change. Rates of change are tabulated in Table 5.4 and are presented in Figure 5.2.

Table 5.4: Relative Sea Level Change Observed at Pacific Tide Gauges in mm/year

Country	Rate of Sea Level Rise (mm/year)
Cook Islands	3.94
Federated States of Micronesia	5.74
Samoa	10.24
Tonga	6.81
Niue	0.05
Fiji	3.54
Kiribati	3.97
Nauru	5.42
Palau	2.15
Marshall Islands	4.88
Vanuatu	0.28
Solomon Islands	4.55
Tuvalu	4.84

The observed sea level rise rates in Figure 5.2 show similar trends to those of Wang et al. (2021) and, on average, PICs are experiencing change well in excess of global rates (Section 3.2), particularly for locations such as Samoa and Tonga, which are subject to seismic events. The only location showing net zero change is Vanuatu, where the effects of sea level rise are currently being offset by land uplift. The effects of vertical land movement and periodic climate cycles can be observed in the sea level signal (Figure 5.2). Considering the relative difference in sea level rise rates between PICs, vertical land movement is clearly an important parameter to consider when considering long planning timeframes as it can amplify or negate sea level rise.

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[53] J. Wang, J.A. Church, X. Zhang, and X. Chen. 2021. Reconciling Global Mean and Regional Sea Level Change in Projections and Observations. Nature Communications. 12(1). pp. 990.

Vertical land movement is commonly a result of subsidence and uplift associated with long-term Glacial Isostatic Adjustment and tectonic movement due to seismic or volcanic events. Human activities such as groundwater extraction, urbanization, and sediment consolidation can contribute to subsidence.[54]

Despite its importance, there remain little information globally; within the Pacific, data are sparse and generally confined to tide gauge locations. Best estimates of long-term change for PICs have been utilized in AR6 based on analysis of historical tide gauge data trends and are presented in Table 5.5.[55] Rates are presented as medians (50%ile) and most likely rates (5th and 95th percentiles) and are representative of the geography of each PIC. It is noted that the global vertical land movements are spatially averaged and there is low to medium confidence in the estimates.

Local direct measurement of vertical land movement is completed by Geoscience Australia in support of the Pacific Sea Level and Geodetic Monitoring Project. Results are presented in Table 5.5 and show that most locations, except for Vanuatu, are subsiding with rates of 1–2 mm/year, noting that the rates of change are within the documented uncertainties of the measurements.[56] Consistent with the AR6 assessment, rates for Samoa, Tonga, and Vanuatu are high, dominated by rapid short-term changes during seismic events followed by a period of readjustment.

It is noted that there are ongoing efforts to monitor vertical land movement throughout the Pacific that employ various analysis methods to establish vertical levels and not all methods provide similar rates. Accordingly, the rates provided in Table 5.5 are indicative of the likely long-term trend in the Pacific (AR6) and recent local changes, but caution is required when applying the rates to longer timeframes. Nevertheless, the long- and short-term rates demonstrate that net subsidence is amplifying the impacts of sea level rise throughout the Pacific.

Table 5.5: Regional Vertical Land Movement Based on AR6 and at the Pacific Tide Gauges

Country	AR6 Vertical Movement (mm/year) [b]	Gauge Vertical Movement (mm/year) [c]
Cook Islands	0.1 (-1.0/1.2)	-1.2±1.5 (2002)
Federated States of Micronesia	-0.5 (-1.3/0.2)	-1.4±1.7 (2006)
Samoa	-1.4 (-2.1/-0.7)	-8.0±2.8 (2010)
Tonga	-0.3 (-1.4/0.8)	-7.0±2.7 (2010)
Niue	-0.2 (-1.8/1.5)	~-1.5 (2006)
Fiji	0.0 (-1.0/0.9)	-1.1±1.3 (2002)
Kiribati	-0.1 (-1.3/0.9)	-2.1±1.5 (2004)
Nauru	-0.1 (-1.2/1.0)	-1.2±1.5 (2003)
Palau	0.0 (-1.0/1.0)	-
Marshall Islands	-0.6 (-1.3/0.1)	-1.0±1.6 (2007)
Vanuatu	0.3 (-0.8/1.4)	~3.0 (2013)
Solomon Islands	0.5 (-0.3/1.4)	-2.5±1.9 (2009)
Tuvalu	-0.3 (-1.1/0.5)	-1.5±1.3 (2003)

AR6 = Intergovernmental Panel on Climate Change 6th Assessment Report, GNSS = global navigation satellite system.
Notes:
a. Negative values imply subsidence and positive values uplift.
b. Absolute vertical rate of land movement based on AR6 long term trends as presented in Fox-Kemper et al. (2021). Rates defined as 50%ile and *most likely* range (5%/95%) shown in brackets.
c. Local vertical land movement at the Pacific tide gauges with start of dataset shown in brackets. Rates are averages based on GNSS measurements at the tide gauge from Brown et al. (2020). Estimates (~) are based on movement of GNSS base station.
Sources:
B. Fox-Kemper et al. 2021. Ocean, Cryosphere and Sea Level Change.
N. J. Brown et al. 2020. Vertical Motion of Pacific Island Tide Gauges.

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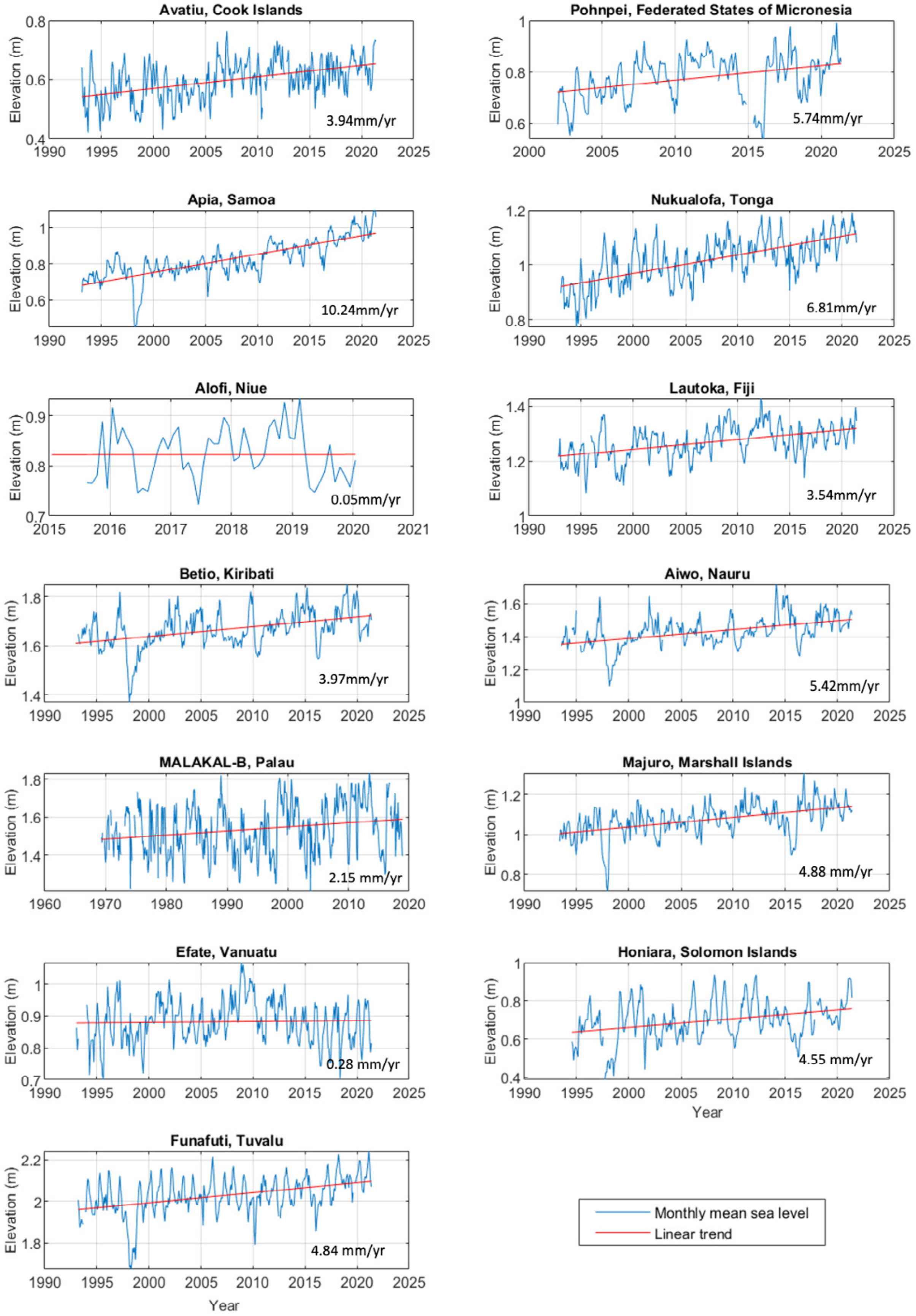
[54] K.L. McInnes, et al. 2016. Natural Hazards in Australia.

[55] Kopp et al. 2014. Probabilistic 21st and 22nd century sea-level projections at a global network of tide gauge sites. Earth's Future, 2, 383–406, doi:10.1002/2014ef000239

[56] N. J. Brown et al. 2020. Vertical Motion of Pacific Island Tide Gauges.

Recognizing the potential influence and uncertainty of vertical land movement on long-term sea-level rise trends, it is recommended that the upper bound of the *most likely* AR6 estimates are utilized in future infrastructure planning. The long-term estimates have been incorporated into the various sea level rise projections for each PIC presented in Sections 3.4 to 3.16.

Figure 5.2: Monthly Mean Sea Level for Each Pacific Island Country (PIC) Based on Recorded Data (Blue Line) and Resulting Linear Sea Level Rise Trend (Red Line)



5.4 Future Sea Level Exposure

For infrastructure planning and development, it is important to consider the potential change in permanent and intermittent exposure of infrastructure and land from the effects of sea level rise. The following section provides reference sea level information for ambient and extreme conditions and assesses the change in exposure from sea level rise for the years 2050 and 2100.

5.4.1 Permanent Change

Tides throughout PICs are dominated by astronomical forces (Box 5.1), which have a full cycle of approximately 18.6 years. To understand the current and future occurrence of high tides with respect to the existing mean sea level, exceedance analysis was completed for the PIC tide gauge datasets for the years 2000 to 2020. To assess the potential change in high tide occurrence due to future sea level rise, the *Very high emissions* (SSP5–8.5) projections as presented in Section 3 for the years 2050 and 2100 were applied. The results of the assessment in the form of exceedance curves are presented in Figure 5.3.

Tabulated high tide exceedance for each PIC is presented in Table 5.6 where mean sea level has been assessed from determining the 50% exceedance level over the baseline period (1995–2014) and the 10% high tide is equivalent to the pragmatic mean high water spring level. The 50% high tide is equivalent to the average high tide level.

Table 5.6: Mean Sea Level (1995–2014 Baseline) and High Tide Exceedance for PICs Tide Gauges

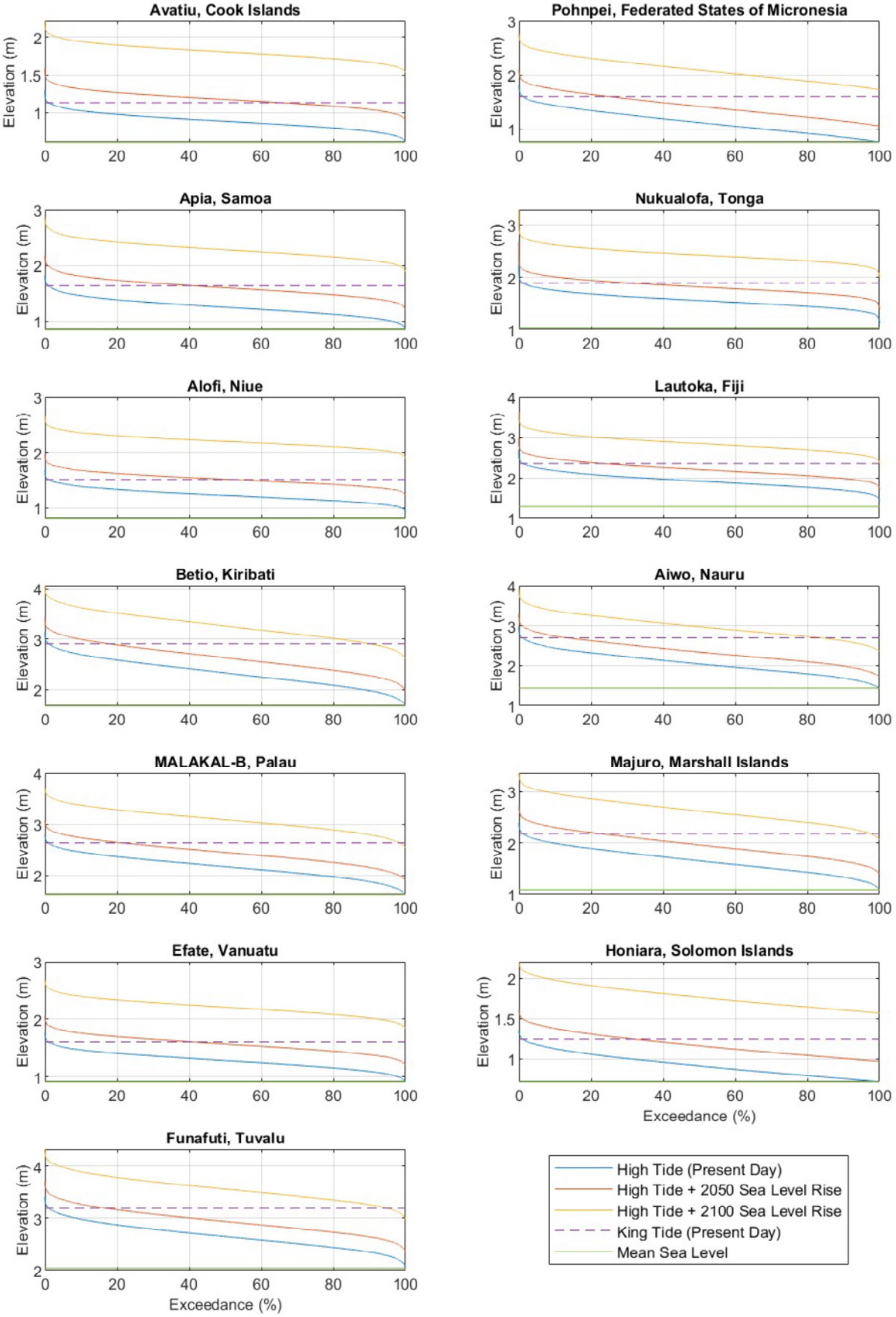
Country	Mean Sea Level (m CD)	10% High Tide (m CD)	50% High Tide (m CD)
Cook Islands	0.59	1.02	0.88
Federated States of Micronesia	0.75	1.43	1.12
Samoa	0.79	1.46	1.25
Tonga	1.01	1.75	1.56
Niue	0.82	1.39	1.23
Fiji	1.27	2.18	1.92
Kiribati	1.65	2.69	2.33
Nauru	1.40	2.44	2.04
Palau	1.62	2.45	2.16
Marshall Islands	1.06	1.99	1.65
Vanuatu	0.91	1.47	1.28
Solomon Islands	0.70	1.13	0.92
Tuvalu	2.01	2.98	2.65

PIC = Pacific Island Country.
CD = Chart Datum equivalent to tide gauge zero.

King Tides, which typically occurs a few times a year, are generally considered a proxy for the extent of permanent exposure to sea level variation. To assess potential change in exposure, the King Tide level, assumed to be equivalent to the 1% occurrence high tide level, is presented in Table 5.7 relative to local gauge and mean sea level datums.

Table 5.7 shows that, for a nominal sea level rise (0.25 to 0.35m), the present day 1% tide occurrence (approximately 4 days a year) will be exceeded on average 31% of the time (approximately 114 days a year) by 2050. For locations with a narrow tidal range, such as the Cook Islands, tides exceeding the present-day King Tide level will occur 66% of the time by 2050 and 100% of the time by 2100. Other locations show variability in exposure by 2050; by 2100 the existing King Tide level will typically be exceeded daily. The analysis shows that land and infrastructure near the coastal margin in the Cook Islands, Tonga, Niue, Vanuatu, and the Solomon Islands are highly susceptible to the impacts of sea level rise and will feel its impacts earlier compared to other PICs.

Figure 5.3: PIC High Tide Exceedance for Present Day, 2050, and 2100 under SSP5–8.5. Dotted Line Shows 1% Exceedance Level Equivalent to Defined King Tide Level



PIC = Pacific Island Country, SSP = Shared Socioeconomic Pathway.

Table 5.7: King Tide Levels (1% High Tide Frequency) with Respect to Local Gauge Datum (CD), Mean Sea Level (MSL) 1995–2014 Baseline and Change to King Tide Frequency at the years 2050 and 2100 with Sea Level Rise Under a *Very High Emissions* Scenario (SSP5–8.5).

Country	King Tide Level (m CD)	King Tide Level above MSL (m)	2050 Frequency	2100 Frequency
Cook Islands	1.13	0.54	66%	100%
Federated States of Micronesia	1.60	0.85	25%	100%
Samoa	1.64	0.85	40%	100%
Tonga	1.89	0.88	31%	100%
Niue	1.51	0.69	54%	100%
Fiji	2.35	1.08	23%	100%
Kiribati	2.91	1.26	17%	90%
Nauru	2.69	1.29	14%	84%
Palau	2.63	1.01	21%	98%
Marshall Islands	2.18	1.12	23%	98%
Vanuatu	1.60	0.69	42%	100%
Solomon Islands	1.25	0.55	32%	100%
Tuvalu	3.19	1.18	17%	95%

5.4.2 Rare Events

The potential increase in extreme sea levels is widely recognized as a critical risk for coastal infrastructure. Extreme sea levels include the contributions from tides, mean sea level anomaly, storm surges, and wave setup (Box 5.1). Even a small increase in mean sea level can significantly change the frequency and intensity of flooding.[57]

To assess the sensitivity of the average return period of extreme sea level events, a peak over threshold method was applied to the PIC recorded datasets using a declustering time duration of 6 hours. Using a maximum likelihood estimator, a Generalized Pareto Distribution was fitted to the peaks, allowing for extrapolation to return periods beyond the period of observations. Extreme sea levels assessed out to a 1 in 100-year event (1% Annual Exceedance Probability) are presented in Figure 5.4.

The estimates of extreme sea level are subject to limitations of each dataset and limited to the measurement location and do not include the effects of wave setup. The extreme analysis is only intended to demonstrate changes to exposure and is not intended to be used for engineering design. Alternative methods that synthetically extend the datasets or use alternative extreme analysis methods are likely to provide estimates above the values derived from the recorded datasets. Nevertheless, the assessed estimates are considered suitable to demonstrate PIC sensitivity to extreme sea levels.

The change in extreme sea level events is commonly expressed in terms of an amplification factor and the allowance. The amplification factor denotes the average recurrence frequency of a certain extreme event, often referenced to the water level with a 100-year return period. The allowance denotes the increased height of the water level with given return period. For this assessment the projected increases from *Very high emissions* scenario (SSP5–8.5) to 2050 (0.25m to 0.35m) and 2100 (0.85m to 1.03m) has been adopted.

Amplification factors are strongly dependent on the local variability of extreme sea level events and the method used for the extreme analysis. As shown in Figure 5.4, PICs have a low variability in extreme sea levels and hence experience large amplifications, even for moderate magnitudes of sea level rise.

Table 5.8 shows that for most of the PICs the current 1 in 100-year extreme level (1% Annual Exceedance Probability) will have a future occurrence of less than an annual event with a modest sea level rise of 0.25m to 0.35m.

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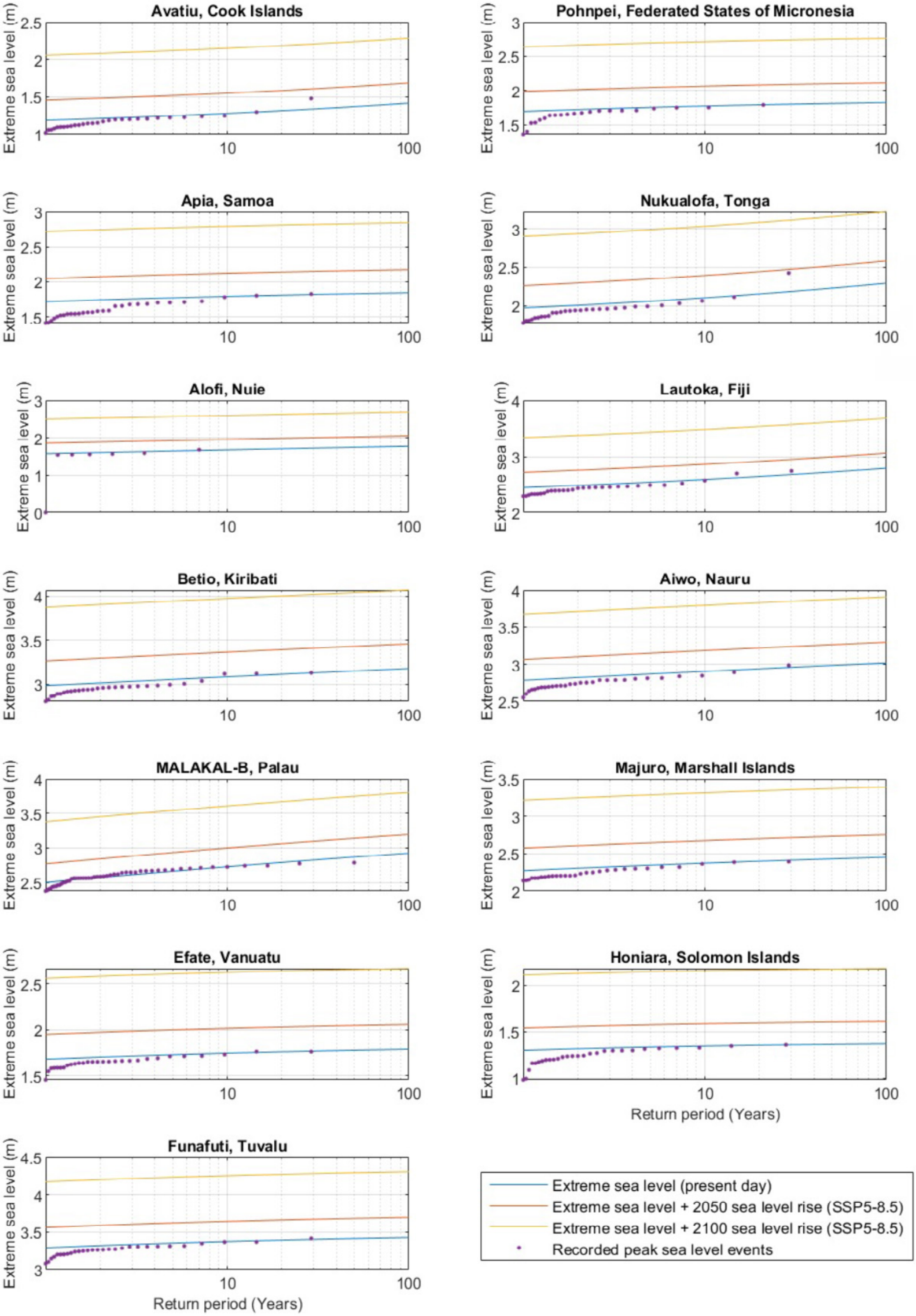
[57] IPCC. 2019. *IPCC Special Report on the Ocean and Cryosphere.*

Figure 5.4: PIC Extreme Sea Levels and Potential Change from Sea Level Rise at the Year 2050 and 2100 (SSP5–8.5)



PIC = Pacific Island Country, SSP = Shared Socioeconomic Pathway.

Considering sea level rise to 2100, the 1 in 100-year extreme sea level for most PICs will be exceeded frequently every year.

Table 5.8: 1 in 100-year Sea Level for Each PIC and the Projected Return Period Following Sea Level Rise to 2050 under Very High Emissions Scenario (SSP5–8.5) and Corresponding Amplification Factor

Country	1 in 100-year Sea Level (m CD)[a d]	1 in 100-year Sea Level (m MSL)[d]	Return Period in 2050	Amplification Factor[b]
Cook Islands	1.42	0.83	<1 year	100+
Federated States of Micronesia	1.83	1.08	<1 year	100+
Samoa	1.85	1.06	<1 year	100+
Tonga	2.29	1.28	<2 years	50+
Niue[c]	1.78	0.96	<1 year	100+
Fiji	2.79	1.52	<3 years	33+
Kiribati	3.18	1.53	<1 year	100+
Nauru	3.02	1.62	<1 year	100+
Palau	2.92	1.30	4 years	25
Marshall Islands	2.45	1.39	<1 year	100+
Vanuatu	1.79	0.88	<1 year	100+
Solomon Islands	1.37	0.67	<1 year	100+
Tuvalu	3.43	1.42	<1 year	100+

CD = Chart Datum, MSL = 1995–2014 Mean Sea Level, PIC = Pacific Island Country, SSP = Shared Socioeconomic Pathway.
Notes:
a. 1 in 100-year event based on 1% Annual Exceedance Probability
b. An amplification factor of 50 means that the current 1 in 100-year event will happen every 2 years due to the rise in mean sea level.
c. Niue included for completeness, noting extreme values are not reliable due to short dataset.
d. ESTIMATES NOT TO BE USED FOR DESIGN.

The results presented in Table 5.8 clearly show the increased exposure from near-term sea-level rise on extreme water levels, which has the potential to significantly affect existing and future coastal infrastructure. Changes in extreme water levels are likely to result in higher wave energy near the shore, more frequent coastal erosion, and inundation and exacerbate catchment flooding during high rainfall events.

It is noted that the magnitude of the sea level change in 2050 is similar regardless of the future climate scenario and the change of exposure is considered likely regardless of future emissions. Furthermore, an alternative methodology to assess global amplification factors was employed in AR6 and the results are generally much higher, suggesting the estimates in Table 5.8 are not conservative.[58]

5.5 Wave Climate

PICs are susceptible to the effects of the wave climate, particularly during extreme events such as tropical cyclones.[59] In addition to directly affecting the land-sea interface from wave processes, the wave climate also affects nearshore water level levels via wave setup.

Wave climate is directly affected by variability of winds; thus, future changes in wind intensity, frequency, and duration will affect the magnitude of the wave climate. Despite research, there remains large uncertainty in the future behavior of the SPCZ and Intertropical Convergence Zone (Figure 1.1) under future climate projections, which affects the prediction of future ambient and extreme wave climates.

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[58] IPCC. 2021. Climate Change 2021.

[59] T. Knutson, et al. 2019. Tropical Cyclones and Climate Change Assessment: Part I: Detection and Attribution. *Bulletin of the American Meteorological Society.* 100(10). pp. 1987–2007.

5.5.1 Ambient Wave Climate

A comprehensive assessment of the ambient wave climate and potential change to climate projections for each PIC was completed under the Pacific-Australia Climate Change Science and Adaptation Programme (PACCSAP).[60] The PACCSAP assessment presented potential change to significant wave height, wave period, and wave direction for two 20-year periods (2026–2045 and 2081–2100), relative to a 1986–2005 historical period. Overall, the magnitude of potential future change was found to be relatively small, albeit the confidence of the projections is *low* due to uncertainties associated with ENSO and hindcast model sensitivities.

Building on the PACCSAP assessment, a detailed assessment of the ambient wave climate for the PICs was completed by Bureau of Meteorology (Australia) via wave hindcast modelling for the period 1979 to present.[61] Statistics for ambient and extreme wave climates for each PIC have been assessed via the Changing Waves and Coasts in the Pacific (WACOP) program (http://wacop.gsd.spc.int/index.html), administered by the Pacific Community (SPC) and is currently the most comprehensive dataset for the Pacific (refer to Appendix 1).

5.5.2 Extreme Wave Climate

Tropical cyclones affect PICs with damage to infrastructure and livelihoods from the extreme effects of wind and rainfall coupled with waves, storm surge, and coastal flooding. There is a growing level of consistency between models that show on a global basis, the frequency of tropical cyclones is likely to decrease by the end of the 21st century with climate change. However, there remains large uncertainty in local and regional projections of future tropical cyclone activity and behavior, noting that the effects of anthropogenic emissions are not clearly detectable in observations of tropical cyclone metrics.

A recent study based on an ensemble of tropical cyclone studies assessed the impact of a 2°C global warming on activity.[62] Based on the study, there is general consensus that sea level rise over the coming century will lead to higher storm surge levels on average for the tropical cyclones that do occur, primary due to an expected increase in intensity. Tropical cyclone intensity is expected to increase globally by 1% to 10%, with a median increase of 5%. Intensity within the Southwest Pacific is more uncertain, with projected changes varying from -6% to 12% and a median of 1%.

Tropical cyclone frequency is expected to vary throughout the Pacific basin, with a net decrease of 10% (range -30% to 17%) within the Northwest Pacific, 4% (range -32% to 37%) within the Northeast Pacific and 18% (range -40% to 5%) within the Southwest Pacific.[63] There is *low confidence* in changes to frequency of Category 4 and 5 cyclones. However, there is consensus that the frequency will increase.[64] There is also a general agreement that there will be an increase in the mean maximum wind speed of cyclones of between 1% and 10% globally with a median increase of 5%.[65]

5.6 Assessing Vulnerability

As demonstrated in the preceding sections, sea levels are highly variable under both normal and extreme conditions. It is common that water level and land local datum relationships are unknown outside the region of the local tide gauge and local short-term measurements at the site of interest and/or hydrodynamic numerical modelling is required to assist quantification. Following establishment of the datum, trends and magnitudes observed at the tide gauge locations can be used to inform local tidal assessments or be transferred if appropriate.

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[60] Australian Bureau of Meteorology and Commonwealth Scientific Industrial Research Organization (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 Commonwealth Scientific and Industrial Research Organization, Melbourne, Australia.

[61] G.A. Smith, M. Hemer, D. Greenslade, C. Trenham, S. Zieger, T. Durrant. 2021. Global Wave Hindcast with Australian and Pacific Island Focus: From Past to Present. Geosci. Data J. 8. pp. 24–33.

[62] T. Knutson, et al. 2020. Tropical Cyclones and Climate Change Assessment: Part II: Projected Response to Anthropogenic Warming. Bulletin of the American Meteorological Society. 101(3). pp. E303–E322. doi:10.1175/bams-d-18-0194.1.

[63] Ibid.

[64] IPCC. 2021. Climate Change 2021.

[65] T. Knutson, et al. 2020. Tropical Cyclones and Climate Change Assessment.

To assist delineation of future inundation risk (Step 2 of the adaptation planning process), the current King Tide level and the assessed 1 in 100-year extreme sea level, caveated by the limitations outlined in Section 5.4.2, adjusted for the mean sea anomaly relative to the 1995–2014 mean sea level baseline, are presented in Tables 5.9 and 5.10. For the King Tide levels, the upper band of the *likely* mean sea level anomaly has been adopted (83%) and, following a precautionary approach, the 1% anomaly has been assumed for the 1 in 100-year extreme event. Due to the relatively small size of the PIC islands and geographic distance to adjacent neighboring islands, the estimates are likely to be applicable to most areas, noting that this assumption requires validation before application.

Table 5.9: King Tide Level with Respect to 1995–2014 Mean Sea Level (MSL) Baseline

Country	King Tide (m MSL) [b]	MSL Variance (m) [a]	Total Sea Level (m) [b]
Cook Islands	0.54	0.06	0.60
Federated States of Micronesia	0.85	0.08	0.93
Samoa	0.85	0.05	0.90
Tonga	0.88	0.06	0.94
Niue	0.69	0.05	0.74
Fiji	1.08	0.05	1.13
Kiribati	1.26	0.06	1.32
Nauru	1.29	0.06	1.35
Palau	1.01	0.14	1.15
Marshall Islands	1.12	0.06	1.18
Vanuatu	0.69	0.06	0.75
Solomon Islands	0.55	0.10	0.65
Tuvalu	1.18	0.07	1.25

Notes:
a. MSL variance based on upper band of the likely mean sea level anomaly (83%) as assessed for PIC tide gauge.
b. Sea levels exclude wave setup and are subject to dataset length limitations.

Table 5.10: 1 in 100-Year Sea Level with Respect to 1995–2014 Mean Sea Level (MSL) Baseline

Country	1 in 100-year Sea Level (m) [c]	MSL Variance (m) [a]	Total Sea Level (m) [c]
Cook Islands	0.83	0.13	0.96
Federated States of Micronesia	1.08	0.16	1.24
Samoa	1.06	0.13	1.19
Tonga	1.28	0.15	1.43
Niue [b]	0.96	0.13b	1.09
Fiji	1.52	0.13	1.65
Kiribati	1.53	0.15	1.68
Nauru	1.62	0.22	1.84
Palau	1.30	0.24	1.54
Marshall Islands	1.39	0.15	1.54
Vanuatu	0.88	0.15	1.03
Solomon Islands	0.67	0.22	0.89
Tuvalu	1.42	0.17	1.59

Notes:
MSL variance based on upper band of the 1% mean sea level anomaly as assessed for PIC tide gauge.
Niue MSL variance adjusted upwards (0.02m) to match neighboring countries due to short dataset.
Sea levels exclude wave setup and are subject to dataset length limitations.

The effects of wave setup that are additive to sea levels in Tables 5.9 and 5.10 are highly variable throughout PICs and are dependent on local bathymetry and shoreline exposure. As wave setup is proportional to the offshore wave height, its effects are relatively low during normal conditions and more pronounced during extreme conditions. To assess wave setup, mean and extreme wave parameters are required for the site of interest. Generally, site-specific numerical studies are required to simulate tropical cyclones or storm events to develop extreme offshore wave data, and further specialist numerical modelling is required to quantify wave setup. Generic sources of wave climate information to support such analysis are provided in Section 5.5.1 and Appendix 1.

For initial assessments empirical methods,[66] or first order estimates based on 15%–20% of the breaking wave height can be used.[67] It is not uncommon for wave setup during extreme events to be in excess of 1m and hence be a significant component of the overall inundation level leading to increased infrastructure risk. To demonstrate a high-level inundation assessment, Section 5.6.1 presents a case study for Nauru that assesses future inundation levels and resulting infrastructure risk.

5.6.1 Case Study – Initial Sea Level Rise Risk Assessment for Nauru

A conceptual sea level rise assessment has been completed for Nauru to assess potential infrastructure risk and vulnerability. This case study quantifies sea level inundation for future King Tide and 1 in 100-year sea level events in 2050 and 2100. Examples of the application of the assessed water levels to critical infrastructure (Importance Level 3) are assessed with reference to the National Institute of Water and Atmospheric Research - New Zealand static sea level assessment for Nauru. The intent of the case study is to demonstrate the method of applying sea level projections to identify future infrastructure risk and inform adaptation planning.

1) Source Site Data: Sources of data used in the assessment are provided in Table 5.11.

Table 5.11: Data Sources

Derived information	Source
Infrastructure location	• GIS polygon data for buildings, roads, airport, population, land, tanks, and poles sourced from SPC and presented in National Institute of Water and Atmospheric Research - New Zealand (2020).
Tidal elevations	• Astronomical tide levels sourced from ADB (2017) • Tidal levels sourced from Tables 5.2 and 5.6 • King Tide Level: sourced from Table 5.9
Mean sea level anomaly	• Mean sea level variance: sourced from Table 5.3
Mean sea level (MSL)	• Mean sea level sourced from Table 5.2 (1995–2014 baseline) http://oceanportal.spc.int/portal/library/assets/2021.Nauru.pdf
Sea level maxima	• 1 in 100-year extreme water level sourced from Table 5.8 and 5.10. • 1 in 100-year extreme water level estimate ADB (2017)
Land and seabed levels	• LIDAR survey flown in 2014 at 1m grid • SPC bathymetric survey (SOPAC, 2008) • Local survey data
Maps	• Infrastructure location and inundation maps as defined in National Institute of Water and Atmospheric Research - New Zealand (2020).
Wave height period and direction	• WACOP summary for Nauru (Ambient the Extreme Waves) https://wacop.gsd.spc.int/Atlas/Regional/Pdf/NA/Nauru.pdf
Meteorology	• PACCSAP Climate summary for Nauru • Climate Change in the Pacific | Volume 2: Country Reports | Chapter 8: Nauru

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[66] M.R. Gourlay, 1996. Wave Setup on Coral Reefs, Part 2: Set-up on Reefs with Various Profiles. *Coastal Engineering.* 28. pp. 17– 55; M.R. Gourlay. 1997. Wave Set-up on Coral Reefs: Some Practical Applications. Combined Australasian Coastal Engineering and Ports Conference, Christchurch, New Zealand.

[67] R.K. Hoeke, K.L. McInnes, J.C. Kruger, R.J. McNaught, J.R. Hunter, and S.G. Smithers. 2013. Widespread Inundation of Pacific Islands Triggered by Distant-Source Wind Waves. Global and Planetary Change 108 (2013), pp. 128–138.

2) Define Datums: All water levels and site data are relative to Nauru local datum (NID), which is referenced to the zero datum at the tide gauge. The 1995–2014 mean sea level is 1.40m with respect to NID (Table 5.2).

3) Determine Local Reference Sea Levels: Due to the low regional variation in sea levels around Nauru, the analysis for the tide gauge presented in Section 5 is considered applicable for the Nauru coastal margin. Reference tidal levels are presented in Table 5.12.

Table 5.12: Reference Tidal Levels in Meters Relative to Nauru Local Datum (NID)

Reference water level	Level (m NID)	Source
Mean Sea Level (MSL) 1995–2014	1.40	Table 5.2
King Tide Level [b]	2.75 (MSL 1.40m + 1.35m)	Table 5.2 and 5.9
1 in 100 Year Sea Level [a b]	3.24 (MSL 1.40m + 1.84m)	Table 5.2 and 5.10
Highest Astronomical Tide (HAT)	2.63	ADB (2017)
Lowest Astronomical Tide (LAT)	0.23	ADB (2017)

Notes:

a. For this assessment the 1 in 100-year sea level as defined in this guidance has been adopted noting that higher values have been estimated in ADB (2017) of 3.30m due to dataset uncertainties.

b. Includes mean sea level anomaly allowance.

4) Apply sea level rise projections: Local sea level rise projections for Nauru are presented in Section 3.11. Following the transitional guidance (Section 4), future sea level rise projections for the Very high emission scenario (SSP5-8.5) has been adopted for the Importance level 3 infrastructure. From Table 3.9, projected sea level rise to 2050 and 2100 is 0.30m and 0.93m, respectively.

5) Assess wave setup: For this assessment, the extreme wave heights were obtained from the WACOP assessment with the offshore 1 in 100-year significant wave height of 4.87m and the associated mean wave period of 8 seconds.[68] Based on local survey data, the reef crest elevation is variable with an average crest level of approximately 0.5m NID. Using the 1997 method of Gourlay, wave setup for the 1 in 100-year event is calculated to be 0.85m, 0.78m, and 0.65m for present day, sea level rise to 2050, and sea level rise to 2100, respectively.[69] It is noted that the magnitude of wave setup is expected to decrease in the future due to increased water depth over the reef crest. Wave setup during ambient conditions is negligible and hence not considered when assessing permanent change/effects.

6) Finalize Inundation Levels: Following the steps 1 to 5, the individual inundation components resulting from a King Tide, representative of the permanent coastal zone, and for a 1 in 100-year event representative of rare events, are presented in Tables 5.13 and 5.14, respectively.

Table 5.13: King Tide Inundation Level Including Sea Level Rise to 2050 and 2100 (NID datum)

Reference water level	2050	2100
King tide level (m)	2.75	2.75
Sea level rise (m)	0.30	0.93
Total (m)	3.05	3.68

NID = Nauru Local Datum.

Table 5.14: 1 in 100-year Inundation Level Including Sea Level Rise to 2050 and 2100 (NID datum)

Reference water level	2050	2100
1 in 100-year sea level (m)	3.24	3.24
Sea level rise (m)	0.30	0.93
Wave setup (m)	0.78	0.65
Total (m)	4.32	4.82

NID = Nauru Local Datum.

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[68] Asian Development Bank (ADB). 2017. *Climate Risk and Vulnerability Assessment. Nauru: Sustainable and Climate-Resilient Connectivity Project* (RRP NAU 48480-003). Manila: ADB.

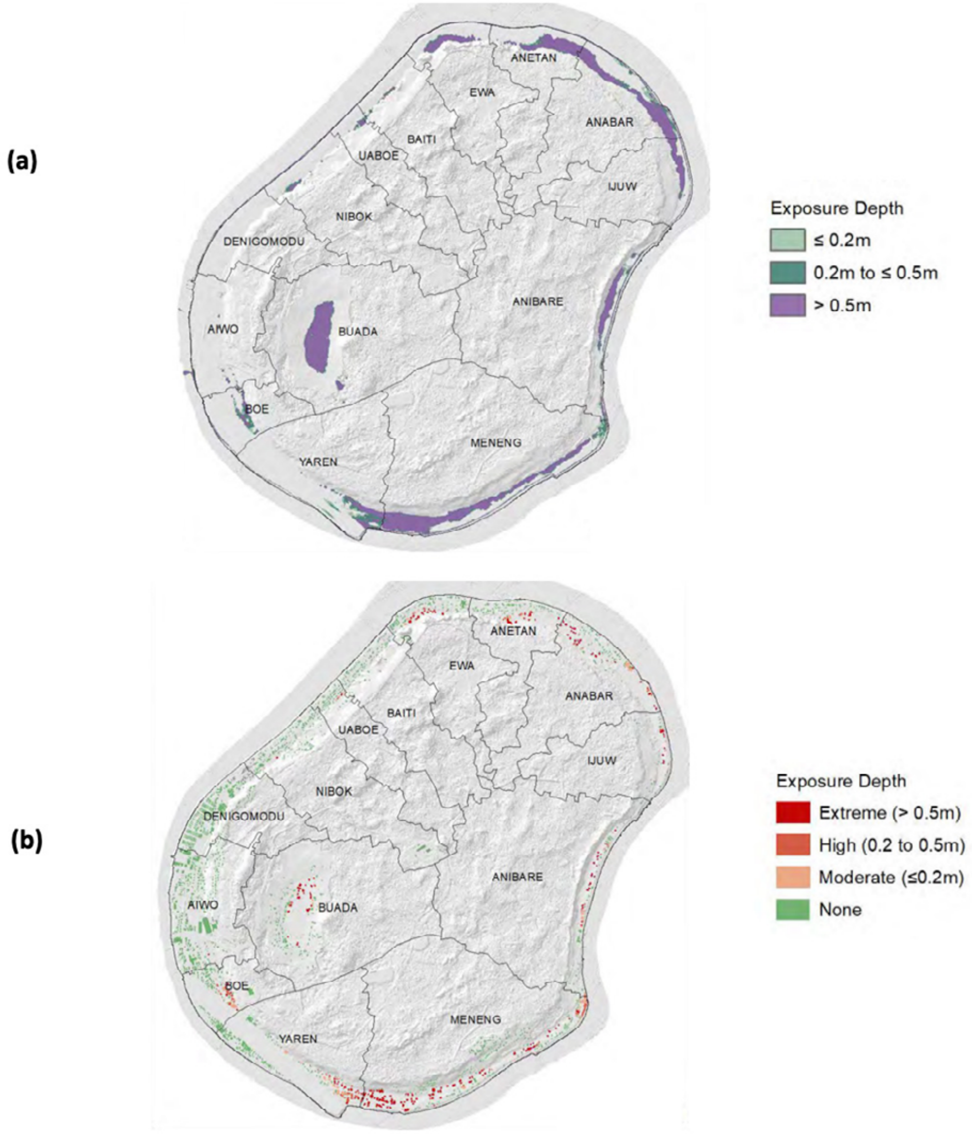
[69] M. Gourlay. 1997. Wave Set-up on Coral Reefs: Some Practical Applications.

7) **Map inundation extent:** utilizing the derived inundation levels in Tables 5.13 and 5.14, various scenarios of sea level can be mapped using topographic LIDAR data to provide spatial extent of inundation and infrastructure exposure. An example of spatial mapping is provided in Figure 5.5a that shows inundation depth for the 1 in 100-year event in 2100.

8) **Assess infrastructure risk:** via mapping of scenarios to critical infrastructure such as roads, electricity, utilities, and buildings, risk can be quantified to inform future decisions. An example is presented in Figure 5.5b that shows building exposure for a 1 in 100-year event at 2100 with ~22% of buildings subject to inundation. Additional at-risk infrastructure includes 5.6% of land, 8.5% of roads, 19.6% of water infrastructure, and 8.7% of energy infrastructure. Mapping King Tide as a measure of permanent change from sea level rise to 2050 shows low infrastructure exposure with only 1.7% of land, 2.4% of buildings, 1.3% of roads, and 0.3% of power transmission is at risk.[70]

Utilizing the defined inundation extents, infrastructure risk exposure in association with future coastal erosion and natural hazards assessments can be used to inform adaptative infrastructure plans to manage future risk.

Figure 5.5: (a) 1 in 100-year Inundation Depth; and (b) Inundation Depth at Individual Buildings for Sea Level Rise to 2100



Source: NIWA. 2021: Coastal flooding from sea-level rise in Nauru: Stage 1 - static inundation mapping. (Used with permission)

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[70] National Institute of Water and Atmospheric Research - New Zealand (NIWA). 2021: Coastal Flooding from Sea-Level Rise in Nauru: Stage 1 - Static Inundation Mapping.

6. Recommendations to Assist Future Sea Level Risk Assessment

To assist the further quantification of climate change effects, infrastructure risk, and development of future planning responses, a range of recommendations are provided to inform regional and PIC programs.

6.1 Data Consolidation and Update

Accessing data held by PICs is difficult and it is recommended that consideration should be given by each PIC and funders of programs to make the data open access. Priority data includes LIDAR topography and bathymetry, aerial photography, climate data and location of critical infrastructure. Recommended host portals include the SPC Pacific Data Hub (https://pacificdata.org) or the Secretariat of the Pacific Regional Environment Programme (SPREP) Pacific Environment Data Portal (https://pacific-data.sprep.org). Open access will enable better decisions by potential users of the data and contribute to regional research to manage climate change.

With the completion of AR6, it would be beneficial for the full suite of climate variables to be downscaled to each PIC, similar to the 2014 PACCSAP assessment. In the interim, it is recommended that summaries be compiled based on the AR6 regional assessments for the following IPCC regions:

a. Northwest tropics

b. Equatorial Pacific

c. Southwest South Pacific Convergence Zone

d. Northwest South Pacific Convergence Zone

e. Southern subtropics

It is recommended that summaries include the latest climate data for each PIC and the summaries are developed in association with the respective PIC Meteorological service.

6.2 Investigations

1) Fundamental to sea level rise risk assessment is spatial topographic and bathymetric data to decimeter accuracy. LIDAR survey coverage is variable throughout PICs, and it is recommended that a prioritized program to map high population areas with elevations less that 10m above mean sea level be developed. LIDAR survey is preferable as it can capture bathymetric information, albeit at a high cost. Alternative techniques include a high-resolution Digital Elevation Model from orthophotography captured by unmanned aircraft.

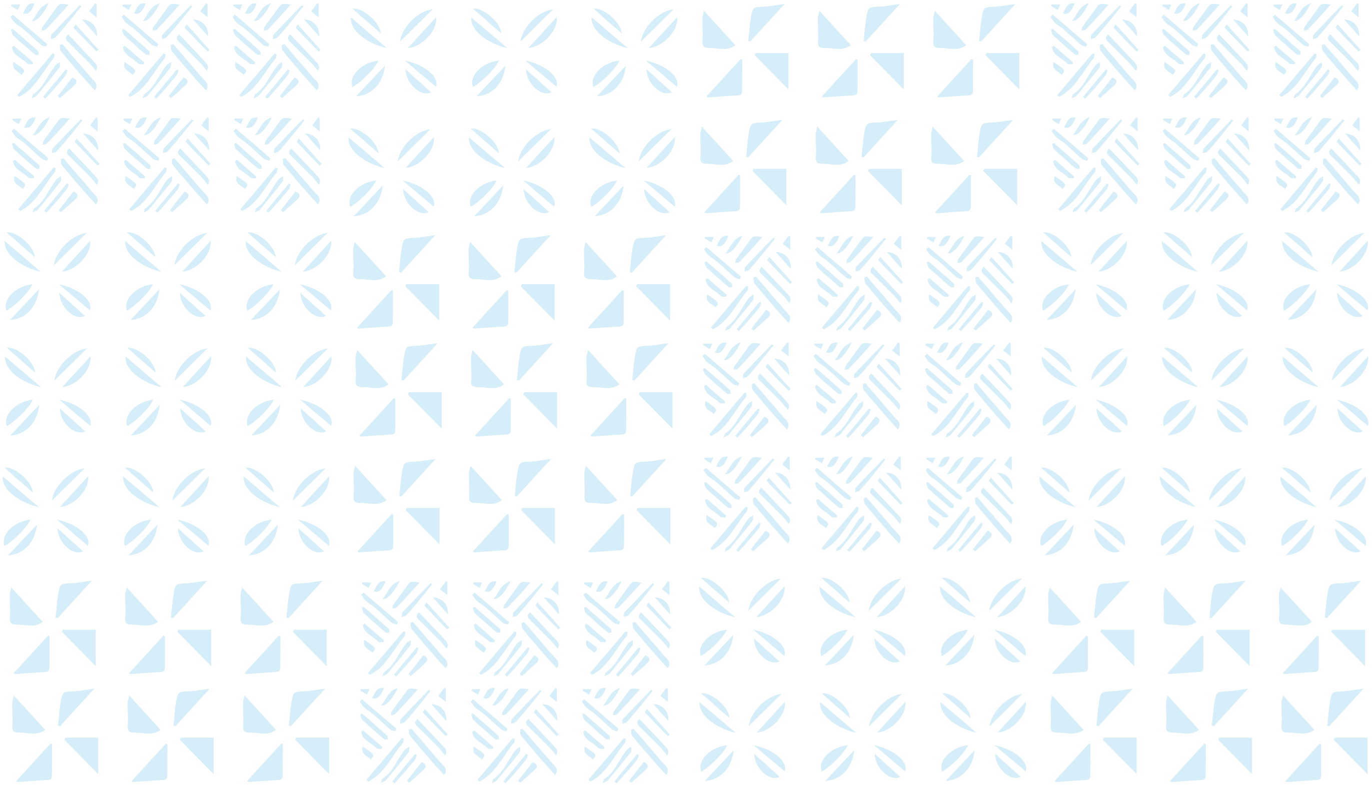
2) There is limited information on the spatial variability of extreme wave events across the Pacific. To assist each PIC, a regional synthetic cyclone database, as well as numerical modelling to define extreme wave parameters, would assist each PIC in defining spatial inundation variability.

3) There is limited information regarding vertical land movements across PICs. A targeted regional program leveraging the existing Pacific Sea Level and Geodetic Monitoring Project to capture the main low-lying PIC communities would improve future assessment of sea level rise impacts and delineation of risk.

6.3 PIC Risk Assessment

1) At the national level, the NAP programs are the primary vehicle for implementing climate change policies and strategies. While sea level rise is a critical threat to PICs, it would be beneficial for each PIC to develop an integrated climate change and disaster risk assessment that forms the basis of future land use and infrastructure plans to control development and manage risk.
2) Current PIC infrastructure risk assessments are at a high level and/or are limited in coverage and require further downscaling to regional or community level.
3) In support of the overarching NAP process, it is recommended that prioritized cascading adaptative land use plans be developed at a regional and community level. Prioritization should be based on known qualitative inundation risk, critical infrastructure value and population size.
4) Specifically, it is recommended that future iterations of the of PIC National Infrastructure Plans be developed in recognition of future climate change and utilize the adaptative planning approach when developing future work programs.
5) It can take time to develop adaptative plans. Accordingly, transitional guidance based on fixed values of sea level rise and/or projections has been developed (Section 4). It is recommended that the transitional guidance be operationalized as a priority to manage infrastructure risk in the interim.
6) The scientific basis of coastal hazards and climate change will continue to evolve over time and therefore it is important to ensure that PIC guidance is regularly updated to ensure it is current.

It is acknowledged that there is a significant amount of research occurring throughout the Pacific by PIC governments with support from PRIF multi-development partners. To minimize overlap in programs, it is recommended that a governance group across the PRIF development partners be established to ensure alignment of individual programs and investment.



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Appendix 1: Key Resources

A myriad of data and guidance is available for PICs at global, regional, and national levels. The following sections provide key sources of information to support assessment of potential climate change.

A.1 Global Assessments

Global assessments are coordinated by the Intergovernmental Panel on Climate Change, with the current revision being the 6th Assessment Report (AR6) and supported by special reports that include *Global Warming of 1.5°C* (IPCC, 2018) and *Ocean and Cryosphere in a Changing Climate* (IPCC 2019). AR6 is scheduled to be progressively released through 2021 and 2022. Core global guidance is provided in Box A.1.

Box A.1: Global Assessment Report links

IPCC Web Portal: IPCC — Intergovernmental Panel on Climate Change

AR6 Assessment Report: https://www.ipcc.ch/assessment-report/ar6

Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC): https://www.ipcc.ch/srocc

Special Report on Global Warming of 1.5 °C: https://www.ipcc.ch/sr15

A.2 Regional Assessments

Assessments to downscale global climate change variables are often completed by regional research organizations. These assessments typically follow the completion of the latest IPCC revision but are dependent on funding from development agencies and governments. Foundation programs for the Pacific that currently inform Pacific Island Countries (PICs) include the Pacific Adaptation to Climate Change (PACC), Pacific Climate Change Science Program, Pacific Australia Climate Change Science Adaptation Planning (PACCSAP) and more recently the Australia Pacific Climate Partnership. These programs are underpinned on input from research organizations such as Secretariat of the Pacific Regional Environment Programme, Secretariat for the Pacific Community, Commonwealth Scientific and Industrial Research Organization, and Pacific Region Infrastructure Facility partners.

The current regional assessment was completed under PACCSAP in 2014 based on the AR5 global assessment and Coupled Model Intercomparison Project Phase 5 models. As part of the assessment future climate projections were developed for each PIC and are used as the basis of existing climate change planning. Sources of regional climate change projections and variables are provided in Box A.2. While the projection information has been superseded by AR6, the base climate information and trends remain relevant.

There is a large body of data and information for the Pacific that is managed by SPREP, SPC and others via many portals. In the context of climate change-induced sea level rise, relevant portals are provided in Box A.3.

Box A.2: Regional Assessment Portal links

Pacific Climate Change Science: https://www.pacificclimatechangescience.org

Climate Variability, Extremes and Change in the Western Tropical Pacific: New Science and Updated Country Reports: https://www.pacificclimatechangescience.org/publications/reports

Regional Climate Consortium for Asia and the Pacific: https://www.rccap.org

Box A.3: Regional Data Portal Links

Secretariat of the Pacific Regional Environment Programme (SPREP) https://www.sprep.org

Secretariat for the Pacific Community (SPC): https://www.spc.int

SPC Geoscience, Energy and Maritime Division: https://gem.spc.int

Pacific Climate Change Portal: https://www.pacificclimatechange.net

Changing Waves and Coasts in the Pacific (WACOP): http://wacop.gsd.spc.int/index.html

Pacific Geodetic Monitoring: http://www.ga.gov.au/scientific-topics/positioning-navigation/geodesy/pacificsealevel

Pacific Sea Level Monitoring: http://www.bom.gov.au/pacific/projects/pslm/index.shtml

A.3 National Assessments

National and local assessments are focused on delineating risk and development of mitigation, resilience, and adaptation strategies. These studies are completed by numerous agencies, ranging from local government through to development banks and organizations. The national assessments leverage the global and regional assessments and are generally broad in scope. While these assessments address climate change at a high level they frequently do not extend to infrastructure risk and planning. This is primarily due to infrastructure risk and responses need to be defined at a local/catchment level. Ultimately, sea level rise risk is a function of the physical environment and the interaction with complex metocean variables and processes.

The potential effects of climate change as assessed via PACCSAP for each PIC remains the most comprehensive assessment for the region. AR6 has superseded the projections, albeit the trends and uncertainties for each PIC as defined by PACCSAP remain relevant. National climate summaries are presented in Box A.4.

Box A.4: National Climate and Projection Summaries

Cook Islands: Climate Change in the Pacific | Volume 2: Country Reports | Chapter 2: Cook Islands

Federated States of Micronesia: Climate Change in the Pacific | Volume 2: Country Reports | Chapter 4: FSM

Fiji: Climate Change in the Pacific | Volume 2: Country Reports | Chapter 5: Fiji Islands

Kiribati: Climate Change in the Pacific | Volume 2: Country Reports | Chapter 6: Kiribati

Marshall Islands: Climate Change in the Pacific | Volume 2: Country Reports | Chapter 7: Marshall Islands

Nauru: Climate Change in the Pacific | Volume 2: Country Reports | Chapter 8: Nauru

Niue: Climate Change in the Pacific | Volume 2: Country Reports | Chapter 9: Niue

Palau: Climate Change in the Pacific | Volume 2: Country Reports | Chapter 10: Palau

Samoa: Climate Change in the Pacific | Volume 2: Country Reports | Chapter 12: Samoa

Solomon Islands: Climate Change in the Pacific | Volume 2: Country Reports | Chapter 13: Solomon Islands

Tonga: Climate Change in the Pacific | Volume 2: Country Reports | Chapter 14: Tonga

Tuvalu: Climate Change in the Pacific | Volume 2: Country Reports | Chapter 15: Tuvalu

Vanuatu: Climate Change in the Pacific | Volume 2: Country Reports | Chapter 16: Vanuatu

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FOREIGN AFFAIRS & TRADE

European Union

European Investment Bank
The EU bank

JICA

WORLD BANK GROUP