Springer Climate

Lalit Kumar *Editor*

Climate Change and Impacts in the Pacific

Springer

Springer Climate

Series Editor

John Dodson, Chinese Academy of Sciences, Institute of Earth Environment, Xian, Shaanxi, China

Springer Climate is an interdisciplinary book series dedicated to climate research. This includes climatology, climate change impacts, climate change management, climate change policy, regional climate studies, climate monitoring and modeling, palaeoclimatology etc. The series publishes high quality research for scientists, researchers, students and policy makers. An author/editor questionnaire, instructions for authors and a book proposal form can be obtained from the Publishing Editor.
Now indexed in Scopus® !

More information about this series at http://www.springer.com/series/11741

Lalit Kumar
Editor

Climate Change and Impacts in the Pacific

Springer

Editor
Lalit Kumar
School of Environmental and Rural Science
University of New England
Armidale, NSW, Australia

ISSN 2352-0698 ISSN 2352-0701 (electronic)
Springer Climate
ISBN 978-3-030-32877-1 ISBN 978-3-030-32878-8 (eBook)
https://doi.org/10.1007/978-3-030-32878-8

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

Pacific island states are generally small in size with a limited and narrow range of natural resources. Due to their small sizes, generally low elevations and isolation, they are highly vulnerable to natural environmental events. Many of them fall directly in the paths of tropical cyclones. Floods, tropical cyclones, droughts and storm surges have become a part and parcel of these people. However, over many generations, these island people have adapted well to the natural events that are quite regular and over which they have no control. The people of the Pacific have become accustomed to these, and now, such events are inseparable from their lives. As if such challenges in life were not sufficient, we now have a new entrant that is causing havoc in many small islands and is destroying lives and livelihood. This is an event for which humankind is almost totally responsible and over which they have a large degree of control. Yet humankind still refuses to take responsibility for this, and any action to limit its damage is lethargic at best. What we are talking about is climate change.

Climate change and its related issues have become critical for the Pacific islands and its people. While many of the larger countries are modelling what will happen in their surroundings in 50–100 years' time, the people of the Pacific have to deal with it here and now. Communities are being relocated, land is being purchased in other countries to settle entire populations, salt water intrusion and salinity are leading to loss of limited arable land on many islands, crops that have been part of their diet can no longer be cultivated due to rising water tables, and extreme events such as more powerful tropical cyclones are ravaging villages. Yet many of us continue to deny that climate change is a reality and, unfortunately, the leadership of some of the most powerful nations on the planet are providing fuel to such groups. The real-world evidence seems to be having no impact on such thinking. We have pictures of graveyards that are now offshore; who in their right minds would select such locations to have graveyards? We have pictures of houses that have waves crashing into them at every high tide; we have pictures of houses that are almost permanently in the sea now; we have pictures of taro farms regularly inundated by sea water; and the list goes on.

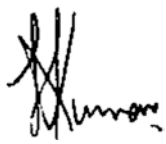
With the people of the Pacific becoming more vocal about this issue in recent years, the issue of climate change impacts in the region has garnered greater attention. Research on likely impacts and best adaptation practices are on the rise. More international support and funds are flowing into the region to support people to deal with the issue of climate change. However, the publicly available information on climate change, its impacts in the Pacific and means of adaptation are few and far in-between and spread over a wide range of scientific publications, web pages and grey literature. One of the objectives of this book is to provide a comprehensive overview of climate change issues in the Pacific, what the people are dealing with now, how susceptible are islands to climate change impacts and how many islanders are adapting to the changes brought about by climate change.

The book starts with a comprehensive overview of climate change and the Pacific, summarising what research has been undertaken and what are the projections for this part of the world over the next 50–100 years. Chapter 2 describes the islands in the Pacific, their settings, distribution and classification. Climate change scenarios and projections for the Pacific are discussed in detail in Chap. 3. This chapter looks at observed climate in the Pacific and compares it with future projections under various climate change scenarios. In Chap. 4, we propose an index that is a relative measure of susceptibility of individual islands in the Pacific to physical change under climate variables. This chapter describes both the physical attributes of islands and environmental variables such as tropical cyclones and significant wave height and how these could be combined to provide information on relative risks of islands. This idea is further refined to a more local (finer) resolution in Chap. 5 where methods are developed for downscaling from whole-island risk assessment to landform susceptibility. A selection of islands from the Pacific is used to demonstrate how this could be incorporated in more local landscape-level risk assessment. Chapter 6 reviews tropical cyclones, its natural variability and potential changes under future climate in the South Pacific. Chapter 7 reports on work undertaken to investigate the distribution of infrastructure in 12 Pacific island countries, with emphasis being on the proportion of built infrastructure in close proximity to the coast and so exposed to coastal climate change impacts. The chapter highlights the very high percentage of infrastructure located very close to the coast and how impacts on such infrastructure could impact on the whole country. Chapter 8 follows the same trend as Chap. 7 but looks at the population distribution across 12 countries in the Pacific. It uses locational data to report on percentage populations in very close proximity to the coastal fringe and how rising sea levels and storm surges related to climate change may impact them. Chapter 9 reports on agriculture under a changing climate in the Pacific. It discusses the significance of agriculture in the Pacific and how climate change and climate extremes may impact on agriculture and sustainability of some agricultural systems. Case studies are used to highlight some of the impacts. Chapter 10 changes from agriculture to marine resources in the Pacific, the importance of such resources to the people and the vulnerability of marine resources to climate change. In Chap. 11, freshwater resources and availability are discussed, including both current issues surrounding freshwater resources and impacts of climate change on water security. Climate change impacts on rainfall and evaporation are also presented. Chapter 12 looks at the impacts of climate change on biodiversity in the Pacific region. It uses the case of terrestrial vertebrate species to show the variety of vulnerable, endangered and critically endangered species that call the Pacific as home and how many of these species occur on one or a few islands only. Many of the species are endemic to the Pacific and so are at an increased risk of extinction due to climate change impacts on the islands they call home. The economic impacts of climate change in the Pacific are explored in Chap. 13. This chapter discusses the economic settings of Pacific islands and how climate change may impact on them. Chapter 14 rounds off the book, looking at the issue of adaptation to climate change. It uses a number of case studies to highlight how different people in different countries of the Pacific are adapting to climate change under different settings. The case studies showcase useful adaptation options and how adaptation could be improved to help people deal with the issues of climate change. So overall, the book covers a wide range of topics very relevant to the climate change debate and to the people of the Pacific and elsewhere.

The travesty is that, quite often, in discourse about climate change and its impacts, the Pacific is overlooked since it is home to only around 12 million people (0.16% of the world's population). What is discounted is that we are talking about 26 countries in this region (13.33% of the 195 countries in the world) having over 30,000 islands, 35 biodiversity hotspots, more than 3200 threatened species of flora and fauna and the world's widest linguistic diversity. The authors contributing to this book hope that it will go some way in highlighting the problems climate change is creating in this part of the world and bringing together a body of literature specifically dealing with the Pacific that will help practitioners make more informed decisions that support them in dealing with climate change.

Finally, I am extremely grateful to all the authors who have volunteered their precious time to share their knowledge with the broader community. I am positive that the knowledge and experience they have willingly shared will have a positive impact on the lives and livelihood of the people of the Pacific. Climate change is now an everyday reality for the Pacific, and their contributions will be appreciated by all.

My heartfelt thanks to the contributors and best wishes to the people of the Pacific in dealing with something they have not contributed to creating but are at the receiving end of probably the greatest impacts. I hope this book serves many researchers and practitioners in this exciting field of climate change.



Armidale, NSW, Australia Lalit Kumar

Contents

Abbreviations

ACIAR	Australian Centre for International Agricultural Research
AD	Anno Domini
ADB	Asian Development Bank
ANZ	Australia and New Zealand
AOGCMs	Atmosphere-Ocean General Circulation Models
APCC	APEC Climate Centre
APEC	Asia-Pacific Economic Cooperation
APSIM	Agricultural Production Systems Simulator
AR4	Fourth Assessment Report
AR5	Fifth Assessment Report
BISP	British Solomon Islands Protectorate
BMI	Body Mass Index
BOM	Bureau of Meteorology
$CaCO_3$	Calcium Carbonate
CBA	Community-Based Adaptation
CDF-t	Cumulative Distribution Function Transform
CePaCT	Centre for Pacific Crops and Trees
CH_4	Methane
CMIP3	Coupled Model Intercomparison Project Phase 3
CMIP5	Coupled Model Intercomparison Project Phase 5
CO_2	Carbon Dioxide
CO_3^{2-}	Carbonate Ions
CR	Critically Endangered
CSIRO	Commonwealth Scientific and Industrial Research Organisation
Cv	Coefficient of Variation
DACCRS	Development Assistance Committee Creditor Reporting System
DSAP	Development of Sustainable Agriculture in the Pacific
DSSAT	Decision Support System for Agrotechnology Transfer
EEZ	Exclusive Economic Zone
EN	Endangered
ENSO	El Niño-Southern Oscillation

ESMs	Earth System Models
ESRI	Environmental Systems Research Institute
EU	European Union
FADs	Fish Aggregation Devices
FAO	Food Agriculture Organizations
FRDP	Framework for Resilient Development in the Pacific
FSM	Federated States of Micronesia
GCCA	Global Climate Change Alliance
GCF	Green Climate Fund
GCMs	Global Climate Models
GDP	Gross Domestic Product
GEIC	Gilbert and Ellice Islands Colony
GERD	Gross Domestic Expenditure
GHGs	Greenhouse Gases
GIS	Geographical Information System
GIZ	German Agency for International Cooperation
GSHHG	Global Self-Consistent, Hierarchical, High-Resolution Geography Database
HIV/AIDS	Human Immunodeficiency Virus/Acquired Immunodeficiency Syndrome
H_s	Mean Significant Wave Height
ICM	Integrated Coastal Management
ICT	Information and Communication Technology
IFAD	International Fund for Agricultural Development
IPCC	Intergovernmental Panel on Climate Change
IPO	Interdecadal Pacific Oscillation
IUCN	International Union for Conservation of Nature
LAT to HAT	Lowest Astronomical Tide to Highest Astronomical Tide
LC	Least Concern
LEAP	Local Early Action Planning and Management Planning
LGM	Last Glacial Maximum
LiDAR	Light Detection and Ranging
LMI	Lifetime Maximum Intensity
MEIDECC	Ministry of Meteorology, Energy, Information, Disaster Management, Environment, Climate Change and Communications
MJO	Madden-Julian Oscillation
MORDI	Mainstreaming of Rural Development Innovation
MORDI TT	Mainstreaming of Rural Development and Innovation Tonga Trust
MPAs	Marine Protected Areas
MSL	Mean Sea Level
Mt	Metric Tonnes
N_2O	Nitrous Oxide
NASA	National Aeronautics and Space Administration
NDCs	Nationally Determined Contributions
NESP	National Environmental Science Programme

NGO	Non-government Organisations
NIWA	National Institute of Water and Atmospheric Research (New Zealand)
NT	Near-Threatened
OECD-DAC	Organisation for Economic Co-operation and Development's Development Assistance Committee
PACC	Pacific Adaptation to Climate Change
PACCSAP	Pacific-Australia Climate Change Science and Adaptation Planning Programme
PacRIS	Pacific Risk Information System
PCCSP	Pacific Climate Change Science Program
PCRAFI	Pacific Catastrophe Risk Assessment and Financing Initiative
PDO	Pacific Decadal Oscillation
PICs	Pacific Island Countries
PICTs	Pacific Island Countries and Territories
PLA	Participatory Learning and Action
PNA	Parties to the Nauru Agreement
PNG	Papua New Guinea
PPP	Purchasing Power Parity
PRRP	Pacific Risk Resilience Programme
PSIDS	Pacific Small Island Developing States
PWWA	Pacific Water and Wastes Association
RCMs	Regional Climate Models
RCPs	Representative Concentration Pathways
REDD+	Reducing Emissions from Deforestation and Forest Degradation
RMI	Republic of the Marshall Islands
RO	Reverse Osmosis
SAM	Southern Annular Mode
SEAPODYM	Spatial Ecosystem and Populations Dynamics Model
SLP	Sea-Level Pressure
SLR	Sea-Level Rise
SOI	Southern Oscillation Index
SOPAC	South Pacific Applied Geoscience Commission
SPC	Secretariat of the Pacific Community
SPCZ	South Pacific Convergence Zone
SPCZI	South Pacific Convergence Zone Index
SPEArTC	Southwest Pacific Enhanced Archive for Tropical Cyclones
SST	Sea Surface Temperature
t	Tonnes
TC	Tropical Cyclone
TPI	Tripole Index
UK	United Kingdom
UNDP	United Nations Development Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change

US	United States
US$	US Dollars
USA	United States of America
USAID	United States Agency for International Development
USD	US Dollars
USGS	United States Geological Survey
USP	The University of the South Pacific
VDS	Vessel Day Scheme
VU	Vulnerable
WCPFC	Western and Central Pacific Fisheries Commission
WCPO	Western and Central Pacific Ocean
WDI	World Development Indicators Database
WGS84	World Geodetic System 1984
WHO	World Health Organization
WMO	World Meteorological Organization
WRI	World Resources Institute
WVS	World Vector Shorelines

About the Editor

Lalit Kumar is a Professor in Spatial Modelling, specialising in GIS and remote sensing applications in agriculture, environment and climate change-related impacts. He has an MSc in Environmental Physics from the University of the South Pacific in Fiji and a PhD in Remote Sensing from the University of New South Wales in Sydney, Australia. He worked as a Lecturer at the University of the South Pacific and the University of New South Wales for a number of years before moving to Europe and taking a position as an Associate Professor at the International Institute for Aerospace Survey and Earth Sciences (ITC) where he worked for 5 years. He then moved to the University of New England in Australia where he is currently a Full Professor in Environmental Science.

He has over 25 years' experience in the application of satellite and environmental data layers for broad-scale environmental monitoring, change detection, land-use change and its impacts, above-ground biomass estimation, pasture quality assessment and impacts of climate change on invasive species and biodiversity. He has research and consultancy experience in a number of countries, including Kenya, South Africa, Tanzania, Burkina Faso, Indonesia, India, Nepal, Bhutan, Sri Lanka, Bangladesh, Fiji and Australia, to name a few.

He has published extensively in international peer-reviewed journals, with over 220 journal articles and more than 150 conference papers and technical reports. His work has been cited over 6500 times. He is an Editor on a number of international journals, such as *Remote Sensing*; *ISPRS Journal of Photogrammetry and Remote Sensing*; *Geomatics, Natural Hazards and Risk*; *PLOS One*; *Sustainability*; and *Remote Sensing Applications: Society and Environment.* He has successfully supervised over 25 PhD students to completion and currently has 14 PhD students in his lab group. Some of his work is showcased at lalit-kumar.com, and he can be reached at lkumar@une.edu.au.

Contributors

Valerie Allain Pacific Community (SPC), Noumea, New Caledonia

Britt Basel C2O Pacific, California, USA

Ecothropic, San Cristóbal de las Casas, Chiapas, Mexico

Johann D. Bell Australian National Centre for Ocean Resources and Security, University of Wollongong, Wollongong, NSW, Australia

Conservation International, Arlington, VA, USA

Samuel Bell Center for Informatics and Applied Optimization, Federation University Australia, Mt Helen, VIC, Australia

Sairusi Bosenaqali Pacific Centre for Environment and Sustainable Development, University of the South Pacific, Suva, Fiji

Satish Chand School of Business, Australian Defence Force Academy, UNSW Canberra, Canberra, ACT, Australia

Savin S. Chand Center for Informatics and Applied Optimization, Federation University Australia, Mt Helen, VIC, Australia

Andrew Chin College of Science and Engineering, James Cook University, Townsville, QLD, Australia

Annika Dean University of New South Wales, Sydney, NSW, Australia

Andrew Dowdy Bureau of Meteorology, Melbourne, VIC, Australia

Leo X. C. Dutra CSIRO Oceans and Atmosphere Business Unit, Queensland BioSciences Precinct, St Lucia, Brisbane, QLD, Australia

School of Marine Studies, Faculty of Science, Technology and Environment, The University of the South Pacific, Suva, Fiji

Ian Eliot University of Western Australia and Damara WA Pty Ltd., Innaloo, WA, Australia

Matt Eliot Damara WA Pty Ltd., Innaloo, WA, Australia

Tony Falkland Island Hydrology Services, Canberra, ACT, Australia

Teddy Fong University of the South Pacific, Suva, Fiji

Tharani Gopalakrishnan School of Environmental and Rural Science, University of New England, Armidale, NSW, Australia

Siosiua Halavatau Land Resource Division—Pacific Community (SPC), Suva, Fiji

Robin Havea School of Computing, Information and Mathematical Sciences, The University of the South Pacific, Suva, Fiji

Elisabeth Holland Pacific Centre for Environment and Sustainable Development, University of the South Pacific, Suva, Fiji

Eryn Hooper C2O Pacific, Port Vila, Vanuatu

Viliamu Iese Pacific Centre for Environment and Sustainable Development, University of the South Pacific, Suva, Fiji

Sadeeka Jayasinghe Department of Export Agriculture, Faculty of Animal Science and Export Agriculture, Uva Wellassa University, Badulla, Sri Lanka

Johanna E. Johnson C2O Pacific, Port Vila, Vanuatu

College of Science and Engineering, James Cook University, Townsville, QLD, Australia

Manasa Katonivualiku United Nations Economic and Social Commission for Asia and the Pacific, Bangkok, Thailand

Carola Klöck SciencePo, Paris, France

Isoa Korovulavula University of the South Pacific, Suva, Fiji

Lalit Kumar School of Environmental and Rural Science, University of New England, Armidale, NSW, Australia

Roselyn Kumar University of the Sunshine Coast, Maroochydore, QLD, Australia

David Loubser Ecosystem Services Ltd, Wellington, New Zealand

Janice Lough Australian Institute of Marine Science (AIMS), Townsville, QLD, Australia

Roger McLean School of Physical, Environmental and Mathematical Sciences, University of New South Wales at the Australian Defence Force Academy, Canberra, ACT, Australia

Bradley R. Moore Institute for Marine and Antarctic Studies (IMAS), University of Tasmania, Hobart, TAS, Australia

National Institute of Water and Atmospheric Research (NIWA), Nelson, New Zealand

Otto Navunicagi Pacific Centre for Environment and Sustainable Development, University of the South Pacific, Suva, Fiji

Simon Nicol Pacific Community (SPC), Noumea, New Caledonia

Patrick D. Nunn University of the Sunshine Coast, Maroochydore, QLD, Australia

Antoine De Ramon N'Yeurt Pacific Centre for Environment and Sustainable Development, The University of the South Pacific, Suva, Fiji

Soane Patolo Mainstreaming of Rural Development Innovations, Tonga Trust (MORDI TT), Nuku'alofa, Tonga

Tanya Stul Damara WA Pty Ltd., Innaloo, WA, Australia

Tammy Tabe University of the South Pacific, Suva, Fiji

Kevin Tory Bureau of Meteorology, Melbourne, VIC, Australia

Filipe Veisa Pacific Centre for Environment and Sustainable Development, University of the South Pacific, Suva, Fiji

Morgan Wairiu Pacific Centre for Environment and Sustainable Development, University of the South Pacific, Suva, Fiji

Ian White Fenner School of Environment and Society, Australian National University, Canberra, ACT, Australia

Chapter 1
Climate Change and the Pacific Islands

Lalit Kumar, Sadeeka Jayasinghe, Tharani Gopalakrishnan, and Patrick D. Nunn

1.1 Introduction

Since the late twentieth century, climate change has undeniably been the world's most prominent environmental issue. When it first emerged, climate change was discussed exclusively by scientists. However, in recent years, the general public has become much more involved in the concept, with the subject also creating major political repercussions in several countries. The likely consequences of global climate change have reached an alarming state in view of environmental, physical, and socio-economic aspects and pose a critical threat on a global scale. Increased public involvement in climate change discourse, ensuring subsequent awareness of the potential threats and uncertainties associated with the issue, is crucial.

The term 'climate change' is used with different implications and perspectives. In its broadest sense, climate change refers to any significant change in the statistical properties of the climate system that persists for an extended period, typically 30 years (IPCC 2014). In order to understand climate change, one has to have an understanding of all of the system's components (i.e. atmosphere, ocean, land surface processes, cryosphere, and biosphere), climate variables (temperature and precipitation), and climate descriptors (such as the Earth's surface temperature, ocean

L. Kumar (✉) · T. Gopalakrishnan
School of Environmental and Rural Science, University of New England, Armidale, NSW, Australia
e-mail: lkumar@une.edu.au; tgopalak@myune.edu.au

S. Jayasinghe
Department of Export Agriculture, Faculty of Animal Science and Export Agriculture, Uva Wellassa University, Badulla, Sri Lanka
e-mail: ljayasi2@myune.edu.au

P. D. Nunn
University of the Sunshine Coast, Maroochydore, QLD, Australia
e-mail: pnunn@usc.edu.au

L. Kumar (ed.), *Climate Change and Impacts in the Pacific*, Springer Climate,
https://doi.org/10.1007/978-3-030-32878-8_1

temperatures, and snow cover) (IPCC 2001; Weber 2010). This global phenomenon has been created from a combination of natural (such as changes in the sun's radiation and volcanoes) and anthropogenic (such as burning fossil fuels and inappropriate land use changes) activities (Fröhlich and Lean 1998).

Palaeoclimatologists have been investigating how the climate system, including increasing atmospheric temperature trends, rising sea levels, and increasing atmospheric greenhouse gases, has changed on a global scale over many decades (Easterling et al. 2010). An overwhelming majority in the scientific community conclude that future human-induced climate change is inevitable and will have far-reaching environmental impacts that will affect the ways people live in many parts of the world. It is widely agreed that observed global warming is rooted in climate change. Global warming disturbs natural cycles and causes several irreversible changes over the long term. The main cause of the warming trend is the emission of greenhouse gases (GHGs) from human activity which enhances the 'greenhouse effect'. The consequences of a continued enhancement of the natural greenhouse effect is likely to result in warming greater than what has been experienced on average over the past century. Warmer conditions will result in more evaporation and precipitation, but different regions will experience these changes at different scales; some will be wetter and others drier (Van Aalst 2006). Moreover, a stronger greenhouse effect increases sea levels, increases ocean heat content, and promotes the loss of ice mass in Greenland, Antarctica, and the Arctic and mountain glaciers worldwide; it generates more intense and longer droughts in many regions, relatively lower mountain glaciers and snow cover in both hemispheres, higher atmospheric water vapour, ocean acidification, and changes in the historical pattern of extreme weather events (Meinshausen et al. 2009; Nerem et al. 2018).

Since the industrial revolution, the average temperature of the Earth has increased; average global surface temperature rose by 0.9 °C between 1880 and 2015 (Rahmstorf et al. 2017). Much of this heat has been absorbed by the oceans, with the top 700 meters of ocean warming over 0.2 °C since 1969 (Levitus et al. 2017). This warming has been driven mainly by increases in all the major GHGs, particularly carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Emissions of these GHGs continue to increase. For example, concentrations of atmospheric CO_2 rose from approximately 290 ppm to 430 ppm between 1880 and 2014 (IPCC 2014). The IPCC (2014) report states that CO_2 concentrations are likely to rise to around 450 ppm by 2030, and if they continue to increase and reach around 750 ppm to 1300 ppm, the Earth may experience global mean temperature rises of 3.7 °C to 7.8 °C (compared to the 1986–2005 average) by 2100 (Rahmstorf et al. 2017). Net greenhouse gas emissions from anthropogenic activities worldwide increased by 35% from 1990 to 2010. Burning of fossil fuels is still on the rise and is the primary cause of observed growth in GHGs, which accounts for 80% of the overall emissions. Greenhouse gas emissions from agriculture are in the range of 10–15% of the total emissions, and 5–10% of emissions are created from changes in land use patterns. Increased levels of GHGs cause radiative energy to rise and then increase the temperature on Earth's surface. Higher GHG concentrations increase the amount of heat that the atmosphere absorbs and redirects back to the surface. It has been reported that the Earth currently retains approximately 816 terawatts of excess heat per year, which further increases the surface temperature (Henderson et al. 2015).

Scientific evidence of global warming is unambiguous, and many research organizations have built a comprehensive basis of evidence to understand how our climate is already changing (IPCC 2014). Each of the last three decades has been warmer than any previous decade. Changes have been observed since 1950 in many extreme weather and climate events (Gutowski et al. 2008). Greenland and Antarctica's ice sheets have declined in volume and area. Data from NASA's Gravity Recovery and Climate Experiment (NASA 2019) show that, between 1993 and 2016, an average of 286 billion tonnes of ice per year was lost by Greenland, while Antarctica has lost about 127 billion tonnes of ice per year over the same period. Over the past decade, the Antarctic ice mass loss rate has tripled (NASA 2019). Greenland lost 150 km^3 to 250 km^3 of ice annually between 2002 and 2006, while Antarctica lost about 152 km^3 of ice between 2002 and 2005. Glaciers have retreated throughout the world, particularly in the Alps, the Himalayas, the Andes, the Rockies, and Alaska. Declining Arctic sea ice has also been observed over the past several decades (Church et al. 2013). Satellite images show that the extent of snow cover in spring in the northern hemisphere has fallen in the last five decades and that winter snow is now melting earlier than normal (Du Plessis 2018). Over the last century, global sea level rose about 20.3 cm, yet the rate over the past two decades is almost double that of the last century and is slightly accelerating each year (Nerem et al. 2018).

The acidity of ocean waters, particularly surface ocean waters, has increased by about 30% since the beginning of the industrial revolution. This is due to more CO_2 being emitted into the atmosphere with concomitant increases in its absorption by the oceans. The amount of CO_2 absorbed by the upper ocean layer has been increasing by approximately 2 billion tonnes per year (Sabine et al. 2004; Schmutter et al. 2017). The scientific community generally agrees that global warming needs to be limited to 2 °C above pre-industrial levels by the end of the twenty-first century in order to avoid potentially dangerous impacts. This requires concentrations of atmospheric CO_2, estimated at around 430 ppm in 2016, to remain below 450 ppm. Therefore, keeping the Earth within the 2 °C limit requires urgent action. Climate change is a systemic transboundary problem with far-reaching health, security, and prosperity implications for the world. However, despite ongoing efforts to mitigate climate change, global emissions continue to rise. Appropriate approaches will require systematic global efforts to implement systemic changes, and many questions remain as to what form such an effort should take (First 2018).

Many scientists are concerned that the impacts of global warming have developed much more rapidly than expected. Hence the scientific community, the government bodies, and the media have paid considerable attention to climate change and related issues. Signatories to the UNFCCC, the Kyoto Protocol, and the Paris Agreement are discussing how best to tackle this problem, in particular by developing mitigation and adaptation strategies to prevent excessively negative impacts for future generations and to reduce the world's vulnerability to these changes (Saxena et al. 2018; Schelling 2002).

The world is addressing climate change in two ways: mitigation and adaptation. Mitigation involves a reduction in greenhouse gas emissions to alleviate the acceleration of climate change, whereas adaptation involves learning how to live with existing climate change and protecting ourselves against unavoidable future climate change effects (IPCC 2014). The growing body of scientific evidence has led to a clear global consensus on the need for action. UNFCCC commits parties to address climate change by 'preventing dangerous anthropogenic interference with the climate system' by stabilizing GHG levels. Yet the implementation of strategies to mitigate or survive under turbulent climatic conditions requires a broad acceptance/awareness of climate change. A broadened perspective on adaptation and mitigation strategies could help all nations understand the adjustments or actions that can ultimately increase resilience or reduce vulnerability to expected climate and weather changes (IPCC 2014, 2018).

1.2 Impacts of Climate Change

1.2.1 Global Warming of 1.5 °C

In 2018, the IPCC published a special report on the impacts of exceeding 1.5 °C global warming. The report prescribed that limiting global warming to 1.5 °C would need rapid, far-reaching, and unprecedented changes in all aspects of society (First 2018). By limiting global warming to 1.5 °C compared to 2 °C, for example, the negative impacts of climate change would be significantly reduced. While previous estimates focused on estimating the damage where average temperatures were to rise by 2 °C or more (New et al. 2011), this report shows that there will still be many adverse effects of climate change at 1.5 °C. For example, by 2100, global sea-level rise would be 10 cm lower with global warming of 1.5 °C compared to 2 °C. With global warming of 1.5 °C, coral reefs would decline by 70–90%, while almost all would be lost with a 2 °C increase (Hoegh-Guldberg 2014). Global net human-induced CO_2 emissions would have to fall by approximately 45% from 2010 levels by 2030, reaching 'net zero' by 2050, in order to limit global warming to 1.5 °C (First 2018).

1.2.2 Global Warming and Sea-Level Rise

Given the current concentrations and ongoing greenhouse gas emissions, the global mean temperature is likely to continue to rise above pre-industrial levels by the end of this century. This has resulted in extensive melting of ice sheets, both in the Arctic and Antarctic, resulting in rising sea levels regionally and globally. The Arctic Ocean is anticipated to become essentially devoid of summer ice before the middle of the twenty-first century as a result of the warming. Rates of sea-level rise have accelerated since 1870 and now average around 3.5 mm per year (Chen et al. 2017). The average sea-level rise is projected to be 24–30 cm by 2065 and 40–63 cm by 2100 under various scenarios compared to the reference period of 1986–2005 (Allen et al. 2014; Pachauri et al. 2014).

Accelerated sea-level rise will result in higher inundation levels, rising water tables, higher and more extreme flood frequency and levels, greater erosion, increased salt water intrusion, and ecological changes in coastal flora and fauna. These will lead to significant socio-economic impacts, such as loss of coastal resources, infrastructure, and agricultural land and associated declines in economic, ecological, and cultural values (Church et al. 2013). An important issue concerning rising sea levels is that it could submerge parts of low-lying coastal lands which are the habitat of an estimated 470–760 million people (Dasgupta et al. 2007). A number of islands are already submerged, including 11 in Solomon Islands and several in Pohnpei (Federated States of Micronesia (Albert et al. 2016; Nunn et al. 2017). It is predicted that between 665,000 and 1.7 million people in the Pacific will be forced to migrate owing to rising sea levels by 2050, including from atoll islands in the Marshall Islands, Tuvalu, and Kiribati (Church et al. 2013). Very large proportions of the population of Bangladesh (46%) and the Netherlands (70%) are likely to be forced to relocate. By 2100, coastal properties worth $238 billion to $507 billion in the United States alone are likely to be below sea level, with particular risk of inundation and flooding in major cities including Miami, Florida, and Norfolk, Virginia (United Nations 2017).

1.2.3 Changing Weather Patterns and Extreme Events

Climate change will also lead to more frequent and/or severe extreme weather events (Trenberth et al. 2007) and possibly even large-scale, abrupt climate change (Alley et al. 2003). Extreme weather events occur when an individual climate variable (such as temperature or rainfall) exceeds a specific threshold and forces significant divergence from mean climate conditions. The world has already witnessed direct and indirect impacts of climate forcing on extreme events such as storms, hurricanes, tornadoes, severe thunderstorms, floods, and hail, and this trend is expected to continue (Walsh et al. 2016).

Climate change is an urgent threat to the entire human population, contributing to a range of increases in natural disasters. Global rainfall patterns are shifting with rising temperatures. Since the late 1990s, Somalia, Kenya, and other East African countries have experienced lower than average rainfall, contributing to a 30% drop in crop yields and famines in 2010, 2011, and 2016 (Henderson et al. 2015). Hurricanes and other destructive weather events have also increased in prevalence. For instance, the worst typhoons (tropical cyclones) recorded in the Philippines occurred in 2013, resulting in more than 6000 deaths and a displacement of almost four million people (Acosta et al. 2016). Since the early 1980s, the intensity, frequency, and duration of North Atlantic hurricanes and the frequency of the most severe hurricanes have increased (Kossin et al. 2013). Hurricane-related storm intensity and rainfall rates are projected to rise as the climate keeps warming. Storm surges, flooding, and coastal erosion threaten coastal settlements and associated infrastructure, transportation, water, and sanitation (IPCC 2007).

1.2.4 Pressure on Water and Food

Food production is closely related to water availability. In 2014, 16% of the Earth's croplands were irrigated as opposed to rain-fed farming, yet the irrigated land accounted for 36% of global harvest (Pimentel 2012). It is estimated that by 2020, approximately 75–250 million people could be affected by increased water stress in Africa, while rain-fed agriculture-related yields could decrease by up to 50% in some regions (Moriondo et al. 2006). In Pakistan and India, the warming Earth combined with water shortages has been blamed for threatening the viability of the region's agriculture (Henderson et al. 2015). Without significant GHG emission reductions, the proportion of the world's land surface in extreme drought could rise by 2090 to 30%, compared to the current 1–3%.

Warmer temperatures, increased CO_2 levels, and extreme weather events also affect global food production. Agriculture and fisheries depend on specific climatic configurations. Increased CO_2 or warmer weather has the potential to accelerate crop growth or increase yields in some crops; however, crop yield starts to decrease above an optimal temperature that varies from crop to crop (Pimentel 2012). On the other hand, some plant species can respond favourably to increased atmospheric CO_2 and grow more vigorously and more efficiently using less water (Bowes 1993). Higher temperatures and changing climate trends can affect the composition of natural plant cover and change the areas where crops grow best (Rahmstorf et al. 2017). Warmer weather facilitates for the spread of pests, weeds, and parasites, while extreme weather has the potential to harm farmlands, crops, and livestock. Climate change could have a direct and indirect impact on livestock production (Thornton 2010). The warmer climate, particularly heatwaves, has a negative impact on livestock. Drought will impact pasture and feed supplies, posing a risk to livestock retention, while increased prevalence of pests and diseases will affect livestock negatively. Temperature changes could affect fisheries by changing the natural habitat and migration ranges of many aquatic creatures (Brierley and Kingsford 2009).

1.2.5 Human Health Risks

Higher temperatures increase the possibility of injury and death related to heat. In the 2003 European heatwave, as many as 70,000 people died, and in 2010, more than 50,000 died in a heatwave in Russia (Parry 2011). Thousands more have been affected by severe heatwaves in India in 2015, in Europe in 2006, and in other regions around the world (Parry 2011). Water and vector-borne diseases are also projected to increase in a warmer world as insects and other carriers move into higher latitudes and altitudes (Benitez 2009; Conn 2014). Mosquito-breeding regions will also change, leading to potentially greater threats from mosquito-borne diseases (Khormi and Kumar 2014, 2016). A warmer climate also tends to increase lung-related health risk, while fossil fuel burning can lead to premature deaths. The World Health Organization found that, in 2012, seven million people died from air pollution worldwide (Lee and Dong 2012).

1.2.6 Impact on Wildlife and Ecosystems

Climate change also harms many natural habitats and increases many species' risk of extinction (IPCC 2014; Van Aalst 2006). The current extinction rate is 100 times the normal rate, and some scientists predict that the Earth is heading for the sixth mass extinction event in its history (Barnosky et al. 2011). By 2100, 30–50% of the world's terrestrial and marine species may be extinct. Climate change also has significant ocean-related effects (IPCC 2014). Oceans absorb about 25% of CO_2 emitted from the atmosphere, leading to the acidification of seawater. Over the past 100 years, warming has raised near-surface ocean temperatures by about 0.74 °C and has made the sea considerably more acidic, likely affecting marine animal reproduction and survival. As a result of various factors, coral coverage is only half of what it was in the 1960s in some places, and scientists predict that the world's coral reefs could become completely extinct by 2050 (Henderson et al. 2015). Projected future increases in sea surface temperatures of around 1–3 °C are very likely to result in more frequent coral bleaching events and widespread coral mortality if corals are unable to acclimatize or adapt (First 2018).

Ecosystems will continue to change with climate, with some species moving further poleward or becoming more successful at adapting to changes, while some species may be unable to adapt and could become extinct (Parmesan 2006). Changes in temperature and rainfall and extreme events may affect the timing of reproduction in animals and plants, animal migration, length of cropping season, distribution of species and population sizes, and availability of food species. Increased acidification and catastrophic flooding could reduce marine biodiversity and mangrove wealth (Hoegh-Guldberg 2014; Pearson et al. 2019; Schmutter et al. 2017).

1.3 The Pacific Ocean: Location, Size, and Distribution

The Pacific Ocean is the world's largest ocean, with an areal extent of 165 million km^2 and average depth of 4000 m, covering more than 30% of the Earth and bordering 50 countries or territories' coastlines (NOAA 2018). The equator divides the

Pacific Ocean into the North Pacific Ocean and the South Pacific Ocean. The South Pacific Ocean is generally taken to be located between 0° and 60°S latitude and 130°E and 120°W longitude. The Pacific Ocean plays host to a wide range of habitats, such as coral reefs, mangroves, seagrass, and seamounts, and accounts for much of the world's marine biodiversity (Cheung et al. 2010) while also playing a key role in regulating global climate and biogeochemical cycles (Cheung and Sumaila 2013).

The islands in this region cover nearly 528,090 km^2 of land (0.39%) spread throughout the ocean, with a combined exclusive economic zone (EEZ) of approximately 30 million km^2 (Carlos et al. 2008) and a total coastline of 135,663 km. Islands are distributed unevenly across the Pacific basin, most being located in the western, especially in the south and western tropical regions, and the fewest in the northeastern quadrant (Fig. 1.1) (Nunn et al. 2016b). The islands belong to a mixture of independent states, semi-independent states, parts of non-Pacific Island countries, and dependent states. The massive realm of islands of the tropical Pacific Ocean includes approximately 30,000 islands of various sizes and topography. In general, the size of the islands in the Pacific decreases from west to east. New Guinea, the largest island, accounts for 83% of the total land area, while Nauru, Tuvalu, and Tokelau have an area less than 30 km^2. Most Pacific Island nations are comparatively small with total areas less than 1000 km^2.

The ocean and its resources play a significant role in the livelihoods of the people of the Pacific Islands. Oceania's terrestrial diversity and endemism per unit area are

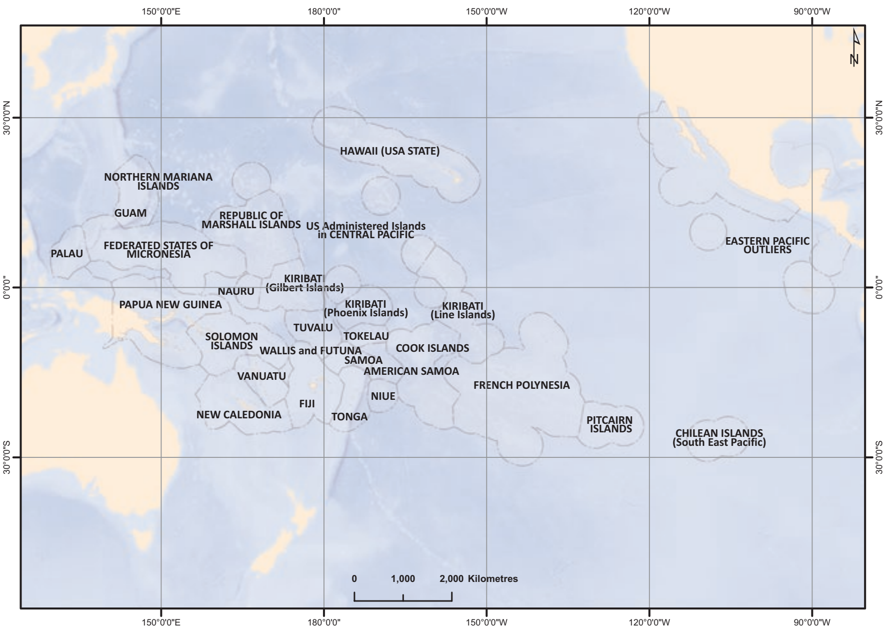


Fig. 1.1 The Pacific region with distribution of the main countries and territories

among the highest on the planet (Keppel et al. 2012; Kier et al. 2009). The region encompasses three global biodiversity hotspots with more than 30,000 plants and 3000 vertebrate species.

Pacific Island countries have been traditionally grouped along the lines of ethnogeographic and cultural lines as Melanesia, Micronesia, and Polynesia. This grouping excludes the adjoining continent of Australia, the Asian-linked Indonesian, Philippine, and Japanese archipelagos as well as those comprising the Ryukyu, Bonin, Volcano, and Kuril arcs which project seaward from Japan.

Melanesia is a subregion of Oceania located in the southwestern region of the Pacific basin, north of Australia, and bordering Indonesia to its east. The region includes the four independent countries of Fiji, Vanuatu, Solomon Islands, and Papua New Guinea and New Caledonia which is a French overseas territory. The dominant feature of Melanesia is relatively large high islands; it includes 98% of the total land area of the Pacific Islands and approximately 82% of the total population. Papua New Guinea is the largest among Melanesian countries as well as the largest country in the Pacific realm with total land area of 67,754 km^2 followed by Solomon Islands (29,675 km^2), New Caledonia (21,613 km^2), Fiji (20,857 km^2), and Vanuatu (13,526 km^2).

Micronesia consists of some 2500 islands spanning more than seven million square kilometres of the Pacific Ocean north of the equator. Micronesia comprises only 0.3% of the total land area of the Pacific Islands and about 5% of the Pacific population. It includes Kiribati, Guam, Nauru, Marshall Islands, Northern Mariana Islands, Palau, and the Federated States of Micronesia (FSM). Kiribati is the largest country in Micronesia with an area of 995 km^2, followed by the Federated States of Micronesia (799 km^2), Guam (588 km^2), Northern Mariana Islands (537 km^2), Palau (495 km^2), Marshall Islands (286 km^2), and Nauru, the smallest single island country of Micronesia with 23 km^2.

Polynesia is the largest region of the Pacific, made up of around 1000 islands scattered over 8000 km^2 in the Pacific Ocean. It is defined as the islands enclosed within a huge triangle connecting Hawaii to the north, New Zealand to the southwest, and Easter Island to the east. It encompasses more than a dozen of the main island groups of central and southern Pacific groups with large distances between them. Polynesia includes Tuvalu, Tokelau, Wallis and Futuna, Samoa (formerly Western Samoa), American Samoa, Tonga, Niue, the Cook Islands, French Polynesia, Easter Islands, and Pitcairn Islands. Polynesia comprises only about 1% of the total Pacific land area but more than 13% of the total population, excluding Hawaii. French Polynesia is the largest country with 3939 km^2 followed by Samoa (3046 km^2), Tonga (847 km^2), Cook Islands (297 km^2), Niue (298 km^2), American Samoa (222 km^2), Easter Island (164 km^2), Tuvalu (44 km^2), Pitcairn Island (54 km^2), and Tokelau with 16 km^2 area.

In terms of geological origin, the islands can be divided into reef islands, volcanic islands, limestone islands, and islands of mixed geological type. The reef islands are generally composed of unconsolidated sediments and commonly form linear groups where a reef has grown above a line of submerged volcanic islands. Examples include most islands in Kiribati, Marshall Islands and Tuvalu, and reef-island groups in the Federated States of Micronesia, French Polynesia, and the western islands of the Hawaii group. They are commonly characterized by their tendency to develop on wide reef surfaces in lower latitudes of the Pacific Ocean (Nunn et al. 2016a).

Volcanic islands are formed when volcanoes erupt (Nunn 1994) and produce islands often with high altitudes in the centre and extremely rugged inner cores. The high island terrain of volcanic islands is characterized by often abrupt changes in elevation (mountains, sheer cliffs, steep ridges, and valleys), with these characteristics varying in altitude and size depending on the island's age (Keener 2013). High islands receive more rainfall than the surrounding ocean from orographic precipitation. This occurs because of the height of the interior of the island, with the warm ocean air being forced up to the higher altitudes, cooling down and falling as rain. The high island landscape is favourable to the formation and persistence of freshwater streams and soil development capable of supporting large and diverse populations of plants and animals (Keener 2013).

The mixed geology-type islands are formed in various ways, principally as a combination of volcanic and coral reef formation. This commonly occurs when the volcanic island forms a high island and a coral reef forms a doughnut-shaped island around it above the water, serving as a barrier from erosion (these are the makatea island types described by Nunn (1994)). Table 1.1 gives some pertinent details, such as population, land area, political status, colonial connections, and dominant lithology of the main Pacific Island countries.

Sea-level rise will directly impact people living in coastal areas of Pacific Island countries. Population distribution is increasingly skewed and concentrated along or near coasts. This is a worldwide phenomenon that is much more pronounced in the Pacific. Kumar et al. (see Chap. 12) analysed the distribution of populations for 12 countries (Cook Islands, Kiribati, Marshall Islands, Nauru, Niue, Palau, Samoa, Solomon Islands, Tonga, Tuvalu, and Vanuatu) in the Pacific and found that around 55% of the population in these countries live within 500 m of the coast, with 20% residing within 100 m. For some of Pacific Island countries, almost the entire population resides in very close proximity to the shoreline. For example, in Kiribati, Marshall Islands, and Tuvalu, the percentage of people living within 500 m of the coast are 98%, 98%, and 99%, respectively.

1.4 Emissions by Pacific Island Countries

Greenhouse gas emissions are spread very unevenly across the world, with the top ten countries generating more than 73.01% of total GHG emissions, and three countries, China (26.83%), the United States (14.36%), and European Union (9.66%), are by far the largest contributors (IPCC 2014). The world's poorest countries have made the least per capita contribution to carbon emissions in the world. These countries burn trivial amounts of fossil fuel compared to countries like China, the United States, Russia, and Australia, and yet they have to bear the greatest impact of climate change (Padilla and Serrano 2006).

Table 1.1 Some key characteristics of the main Pacific Island countries

Country or territory	Population (2014)	Land area (km^2)	Political status	Colonial connections[a]	Dominant lithology
Melanesia					
Fiji	903,207	20,857	Independent	UK	Volcanic
New Caledonia	267,840	21,613	Territory	France	Limestone
Papua New Guinea	6,552,730	67,754	Independent	Australia	Volcanic
Solomon Islands	547,540	29,675	Independent	UK	Volcanic
Vanuatu	245,860	13,526	Independent	UK/France	Volcanic
Micronesia					
Fed. States of Micronesia	111,560	799	Free Association	USA	Reef
Guam	161,001	588	Territory	USA	Composite
Kiribati	104,488	995	Independent	UK	Reef
Marshall Islands	54,820	286	Free Association	USA	Reef
Nauru	10,800	23	Independent	UK	Limestone
Northern Mariana Islands	51,483	537	Territory	USA	Volcanic
Palau	20,500	495	Free Association	USA	Limestone
Polynesia					
American Samoa	54,517	222	Territory	USA	Volcanic
Cook Islands	19,800	297	Free Association	New Zealand	Reef
French Polynesia	280,026	3939	Territory	France	Reef
Niue	1480	298	Free Association	New Zealand	Limestone
Samoa	182,900	3046	Independent	New Zealand	Volcanic
Tokelau	1337	16	Territory	New Zealand	Reef
Tonga	103,350	847	Independent	UK	Limestone
Tuvalu	9561	44	Independent	UK	Reef
Wallis and Futuna	15,561	190	Territory	France	Reef/volcanic

[a]The current colonial government or prior to attaining independence status
Based on information from Campbell and Barnett (2010), Kumar and Taylor (2015), and Nunn et al. (2016a)

The Pacific Island region accounts for only 0.03% of the world's total greenhouse gas emissions but is one of the regions that is facing the greatest impacts of climate change from rising sea levels, warming oceans, drought, coral ecosystem destruction, ocean acidification, and extreme weather (Rogers and Evans 2011). For example, CO_2 emissions from Kiribati and Tuvalu are among the lowest of all nations, both in total and per capita terms, yet these are the two countries currently suffering the most from rising sea levels. From Table 1.2, large differences between

Table 1.2 Total CO_2 emissions per country per year and emissions per capita per year measured in 2017 for representative countries in the Pacific, together with selected larger emitters for comparison

Country	Total CO_2 emissions (Mt CO_2/year)	CO_2 emissions per capita (t CO_2/person/year)
Cook Islands	0.07	3.70
Federated States of Micronesia	0.20	1.70
Fiji	1.37	1.55
Kiribati	0.07	0.45
Marshall Islands	0.10	2.30
Nauru	0.10	4.90
New Caledonia	5.76	20.70
Palau	0.86	12.34
Papua New Guinea	5.88	0.70
Samoa	0.17	0.95
Solomon Islands	0.17	0.30
Tonga	0.12	1.30
Tuvalu	0.01	1.10
Vanuatu	0.15	0.50
USA	5188.69	15.85
China	10358.10	7.35
Australia	407.62	16.75
New Zealand	36.39	7.75
India	2460.88	1.80

Notes: (1) Values are fossil fuel-related emissions. They do not consider land use changes or forestry. (2) Presented numbers are averages taken from various sources, including https://en.wikipedia.org/wiki/List_of_countries_by_carbon_dioxide_emissions and http://www.globalcarbonatlas.org/en/CO2-emissions

emissions by the Pacific Island countries and some of the industrialized nations are evident. For comparison, it is more logical to look at CO_2 emissions on a per capita basis. For most of the Pacific Island countries, the per capita emissions are below 2.0 t CO_2 per year, yet for countries such as Australia and the United States, these figures are 16.75 and 15.85 t CO_2 per year, respectively. Australia is one of the world's highest polluters on a per capita basis.

1.5 Projected Climate Change and Impacts

The IPCC report on the impact of global warming states that, if warming continues to increase at the current rate, it is likely to reach 1.5 °C between 2030 and 2052 (high confidence) and small islands are projected to experience higher risks as a consequence (IPCC 2018). In the Pacific, under the RCP4.5 scenario, sea level is likely to increase 0.5 to 0.6 m by 2100 compared to 1986 to 2005 (Church et al. 2013).