Climate Variability and Change and Sea-level Rise in the Pacific Islands Region

A Resource Book for Policy and Decision Makers, Educators and other Stakeholders

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Preface

Joint Statement by

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In recent years, global warming has come to the fore as one of the world's most serious environmental problems. Meanwhile, over the past ten years, international negotiations and the accumulation of scientific knowledge in this field have led to remarkable progress — such as the adoption and entry into force of the UN Framework Convention on Climate Change, the adoption of the Kyoto Protocol, and the release of the Third Assessment Report of the Intergovernmental Panel on Climate Change. With regard to the Kyoto Protocol, which sets forth the commitments of developed countries for reductions of greenhouse gas emissions, Japan completed its ratification procedures in June 2002, and is also working with other countries to make the Protocol's entry into force a reality.

Pacific Island Countries are in one of the most vulnerable regions of the world. Here, international assistance is especially needed in order to carry out the appropriate adaptation strategies for global warming. For this reason, the South Pacific Regional Environment Programme (SPREP) and Ministry of the Environment of Japan have implemented a variety of initiatives in cooperation with a number of the countries in this region, from the perspective of promoting implementation of adaptation measures by these countries. Vulnerability assessments of coastal zones and the feasibility of adaptation measures were the subject of studies conducted during 1992 to 1995 in a number of Pacific Island States (Tonga, Fiji, Western Samoa and Tuvalu), in collaboration with SPREP and the University of the South Pacific (USP).

This *Resource Book* was prepared based on the "Assessment of Possible Climate Change and Sea-level Rise Activities to be Undertaken in Pacific Island Countries in Cooperation with Japan" which was conducted in 1999 and 2000, through cooperation between SPREP and the Ministry of the Environment. The *Resource Book* is designed to be used widely as a tool for awareness-raising, being a summary of the latest knowledge about climate change as it relates to the Pacific Islands Region. A compilation of the latest literature, scientific knowledge and data, with frequent use of diagrams and tables, it is designed to be readily understood by readers with a variety of viewpoints and backgrounds, such as policy-makers, educators and research coordinators.

In preparation of this *Resource Book* we sought the cooperation of many leading experts in many fields. We would like to express heartfelt appreciation to Prof. John Hay from the International Global Change Institute (IGCI) of the University of Waikato, Prof. Nobuo Mimura of Ibaraki University, and others who were so generous in giving their assistance. It would give us great satisfaction if this *Resource Book* contributed further to the implementation of adaptation measures by Pacific Island States.

Summary for Policy and Decision Makers

This *Resource Book* has been prepared in order to meet the following objectives:

- To provide policy- and decision-makers in Pacific Island Countries with a coherent, authoritative and readily accessible body of knowledge and resource materials that characterise the region's resilience and vulnerability to climate and sea-level variability and change and identify a suite of proven and potential response options that are deserving of further consideration and implementation;
- To provide educators, outreach and related practitioners with an integrated and functional resource portfolio for use in formal education and professional development programmes and in support of efforts to enhance political and public awareness of the implications of global and regional variability and change for the Pacific Islands Region.

The *Book* comprises four main sections, reflecting the four principal dimensions of the climate issue – the changing climate, the observed and potential impacts, and the two broad categories of policy responses and actions, namely mitigation and adaptation

The key messages contained in this *Resource Book* are as follows:

- The Pacific Islands Region is noteworthy for its vibrant and dynamic nature – extreme events, variability and change are ubiquitous;
- Natural systems and human societies in the Pacific Islands Region had attributes that made them remarkably well attuned to the relatively large variations in environmental conditions that occurred in the recent and more distant past, with the associated high resilience fostering an ability to cope with natural environmental changes;
- The large uncertainties in specifying the future conditions that will stress both natural and human systems leads to a preference to use scenarios rather than attempt to make precise predictions;
- While climate change mitigation initiatives undertaken by Pacific Island Countries will have insignificant consequences climatologically, they should nevertheless be pursued because of their valuable contributions to sustainable development;
- Acting now to reduce the current vulnerability of Pacific Island Countries to natural climate extremes and variability, such as the El Niño-Southern Oscillation (ENSO), is one of the most effective ways to prepare for future changes in climate;
- Climate change will increase the likelihood of extreme events, and hence disaster risk; since, even today, extreme events are a major impediment to sustainable development, development planning must reflect both recurrent historical risks and new risks, including those associated with climate change, for effective risk management prevents precious resources from being squandered on disaster recovery and rehabilitation;
- Natural and human systems in the Pacific Islands Region will continue to face pressures that are not climate related, including those related to population growth, social change and economic transformation; responses to the climate and sea-level variability and change should be coordinated with the mainstream policies of

socioeconomic development and environmental protection, to facilitate sustainable development;

- Any plausible climate change scenario will require Pacific Island Countries to implement adaptation measures due to the unprecedented and potentially devastating nature of the resulting changes; and
- The most desirable adaptive responses are those that augment actions which would be taken even in the absence of climate change, due to their contributions to sustainable development.

Climate and Sea-Level Variability and Change: Processes and Projections

The Pacific Islands Region is noteworthy for its naturally vibrant and dynamic nature – extreme events, variability and change are ubiquitous. Despite the many uncertainties as to the nature and consequences of global warming, the climate of the Pacific Islands Region will continue to be dominated by the inter-annual variability associated with ENSO, by extreme events such as tropical cyclones, floods and drought and by persistent features such as the trade winds and convergence zones.

But in addition, due to the enhanced greenhouse effect the Region will likely warm, by between 0.6 and 3.5^{o}C in this century, a rate of warming which is much larger than the observed changes during the last century and very likely without precedent during at least the last 10,000 years. The projected temperature increase can be compared to the temperature difference, for the region, of around 3 to 4^{o}C between the middle of the last Ice Age and the present day.

During the present century the climate may become more "El Niño-like", with central and eastern equatorial Pacific sea surface temperatures projected to warm more than the western equatorial Pacific, and with a corresponding mean eastward shift of precipitation. Furthermore, during future El Niño-Southern Oscillation (ENSO) events anomalously wet areas could become even wetter, and unusually dry areas become even drier. While there is no evidence that tropical cyclone numbers will change with global warming, a general increase in tropical cyclone intensity (lower central pressures, stronger winds and higher peak and mean precipitation intensities) appears likely, as does an eastward extension in the area of formation.

Globally, rates of sea-level rise during the 20th century have been in the range of 1 to 2 mm/yr. Due to global warming this rate is expected to increase to between 1 and 7 mm/yr, with a central estimate of 4 mm/yr. While local sea levels change in response to many factors, including local uplift or sinking of the Earth's crust and variations in air pressure and wind velocity, it is expected that even those areas in the Pacific currently experiencing a relative fall in sea level will, by the end of this century, experience a rising relative sea level. However, interannual variations in sea level associated with ENSO, and storm surges associated with tropical cyclones, are likely to be of greater significance than sea-level rise in the coming decades.

Consequences of Climate and Sea-level Variability and Change

Pacific Island Countries may well be among the first to suffer the adverse impacts of climate change, and the first to be forced to adapt. Most countries are already experiencing disruptive changes consistent with many of the anticipated consequences of global climate change, including extensive coastal erosion, droughts, coral bleaching, more widespread and frequent occurrence of mosquito-borne diseases, and higher sea levels making some soils too saline for cultivation of traditional crops.

While much attention is focused on global warming causing gradual, long-term changes in average conditions, the most immediate and more significant impacts are likely to arise from changes in the nature of extreme events (e.g. flooding, tropical cyclones, storm surges) and climatic variability (e.g. drought, prevailing winds accelerating coastal erosion). Present problems resulting from increasing demand for water, from increasing pollution of water and from current patterns of extreme events and climate variability dwarf those which will result from climate change over the next few decades, in all but a few countries in the Pacific Islands Region. Examination of the impacts of climate extremes and variability, including those associated with seasonal and interannual phenomena, offers valuable insight into the likely potential effects of climate change on agriculture. Given that in the Pacific Islands Region most good quality land is already under intense cultivation, increasing population numbers combined with climate change impacts will threaten food security, as will the increasing reliance on imported food and the consequential vulnerability to short term breaks in supply and world food shortages due to climate events.

Even though terrestrial and freshwater ecosystems have been able to evolve and adapt over time to both climate extremes and variability, and to human pressures, there are indications that changes in climatic conditions coupled with unsustainable use will render terrestrial and freshwater ecosystems increasingly vulnerable in the longer term. Many of the likely impacts of climate change on coastal zones and marine ecosystems are already familiar to island populations, and some have experience in coping with them. However, in most countries and for most coastal and marine areas, coping with climate extremes and variability will be of more significance over the next few decades.

The impacts of climate variability and change on human health are most likely to be adverse in nature, and frequently will arise through initial impacts on ecosystems, infrastructure, the economy and social services. For example, economic hardship resulting from the diverse but collective impacts of climate variability and change may well become one of the key factors exacerbating and perpetuating impacts on human health. Poverty is likely to contribute to most if not all health impacts and to the reduced capacity and ability of individuals and communities to cope with them.

The growing "urbanness" and centralization of Pacific Island populations is increasing the likelihood of adverse impacts from climate variability and change, while repairs and rehabilitation for rural populations after an extreme event may well receive decreasing priority. The possibility of more extreme events such as tropical cyclones and storm surges, coupled with currently projected rates of sea-level rise and flooding, places critical infrastructure such as health and social services, airports, port facilities, roads, vital utilities such as power and water, coastal protection structures and tourism facilities at increased risk. A high island such as Viti Levu could experience average annual economic losses of $US23 to 52 million by 2050, equivalent to 2 to 4% of Fiji's GDP. A low group of islands, such as Tarawa atoll, could face average annual damages of $US8 to 16 million by 2050, as compared to a current gross domestic product (GDP) of $US47 million. These indicative costs could be considerably higher in individual years when extreme events such as cyclones, droughts or significant storm surges occur.

Regional, National and Community-based Responses to Climate and Sea-level Variability and Change - Mitigation

On average, individual Pacific Islanders are responsible for producing approximately one quarter of the CO_2 emissions attributable to the average person worldwide. In common with most other countries, the energy sector is the largest source of greenhouse gas emissions in Pacific Island Countries.

Most actions that slow the rate of climate change also contribute to sustainable development. National greenhouse gas emissions data can play a crucial role in national sustainable development planning, and in assessing the success of those strategies over time. For Pacific Island Countries mitigation options fall into three broad, interrelated categories – fuel substitution, energy efficiency and forestry. While more emphasis tends to be given to reducing greenhouse gas emissions, for some Pacific Island Countries there is also the opportunity to enhance the removal of carbon from the atmosphere, for example through new forest plantings.

Mitigation activities in Pacific Island Countries are normally best implemented through a collaborative partnerships involving at least some of the following key players: developed countries, government, the private sector, community-based organizations, investors, donors and the public at large. Despite the small quantities of greenhouse gases emitted by Pacific Island Countries, internationally agreed emissions reduction mechanisms such as the Clean Development Mechanism are still relevant, for the mechanisms are also designed to support sustainable development and, in some cases, adaptation.

Regional, National and Community-based Responses to Climate and Sea-level Variability and Change – Adaptation

Even in the near future climate variability and change (including extreme events) are likely to impose untenable social, environmental and economic costs on Pacific Island Countries. Importantly, such costs are inherently distributed inequitably, preferentially affecting the poor and other vulnerable groups. There is value in exploring and undertaking actions to adapt to current climate extremes and variability, both to deal with today's problems and as an essential step to building long term resilience to withstand the impending changes in climate. Communities and countries in the Pacific Islands Region have already identified and implemented a range of both indigenous and imported practices that enhance resilience and reduce vulnerability to climate variability. This capacity needs to be strengthened further, for it also forms part of a priority approach to preparing for longer term climatic change.

Failure to grasp the real and pervasive costs of climate-related disasters has made it difficult for policy and decision makers to gain support for diverting scarce resources from one part of the national, enterprise or community budget, in order to support disaster reduction programmes. Moreover, uncertainties in climate change impact estimates, and even more so in the likely success of adaptive responses, have often been judged too large for adaptation to be incorporated into national development planning in a meaningful way.

There is now hard evidence that climate extremes, variability and change are significant impediments to successful economic development – i.e. they represent risks to regional, national and local economies. This highlights the need to mainstream both disaster risk management and adaptation to climate variability and change, in a mutually consistent and supportive manner, by ensuring disaster reduction management and adaptation are integral components of the national risk management strategy and, in turn, of the national development planning process.

Many disaster and climate change response strategies are the same as those which contribute in a positive manner to sustainable development, sound environmental management, and wise resource use. They are also appropriate responses to climatic variability and other present-day and emerging stresses on social, cultural, economic and environmental systems. If adaptation is reactive, as opposed to anticipatory, the range of response options is likely to be fewer and adaptation may well prove more expensive, socially disruptive and environmentally unsustainable.

Many development plans and projects that are currently under consideration have a life expectancy that requires future climate conditions and sea levels to be given due consideration. In addition, Pacific Island Countries depend heavily on valuable and important ecosystems that are sensitive and hence vulnerable to climate change – it is easier to enhance the ability of ecosystems to cope with climate change if they are healthy and not already stressed and degraded. Adaptation also requires enhancement of institutional capacity, developing expertise and building knowledge – all these take time.

People will, as a result of their own resourcefulness or out of necessity, adapt to climate variability and change, based on their understanding and assessment of the anticipated or observed effects, and on the perceived options and benefits for response. In many cases such adaptations will be adequate, effective and satisfactory. However, under some circumstances such adaptation may not be satisfactory or successful. An external entity, such as central or local government, may need to facilitate the adaptation process to ensure that obstacles, barriers and inefficiencies are addressed in an appropriate manner.

International Responses to Climate and Sea-Level Variability and Change

The United Nations Framework Convention on Climate Change, and its related Protocol and procedures, provides important and effective means for ensuring a coordinated international response to climate change, through both mitigation and adaptation. The financial mechanism for the Convention, the Global Environment Facility, has been mandated to provide financial resources to developing country Parties, in particular to the Least Developed Countries and Small Island Developing States, for implementing adaptation planning and assessment activities and for establishing pilot or demonstration projects, amongst other responses. The Alliance of Small Island States has been effective in highlighting and promoting the interests of Pacific Island Countries at the international level. The Barbados Programme of Action was the first real opportunity for the international community to give practical effect to the agreements of the Rio Earth Summit, in that it acknowledged that Small Island Developing States have unique problems and special vulnerabilities, and need support to overcome them.

Monitoring networks and climate information systems (including seasonal and longer term forecasts) in the Pacific Islands Region are making an important contribution, not only to helping Pacific Island Countries address climate related issues, but also to international understanding of climate variability and change, including extreme events.

National, regional and international efforts to enhance the use of indigenous renewable energy technologies, and decrease reliance on imported petroleum and other energy products, are critical to the sustainable development of Pacific Island Countries, while also contributing to global efforts to slow the rate of climate change;

Retrospect and Prospects

The Small Island Developing States of the Pacific are sensitive microcosms of the Earth system. As such they can be considered a bell weather to the rest of the world. But more importantly, the people who inhabit these islands can be rightly portrayed as the "innocent victims" of global warming. But such facts are small comfort to those who are already experiencing disruptive changes consistent with many of the anticipated consequences of global climate change. The precursors of global climate change impacts now being experienced by Pacific Island Countries provide some of the more compelling and tangible indications of the seriousness of global warming, certainly more than the often quoted projections of increased global temperature and sea levels. The adverse consequences of climate variability and change are already an unfortunate reality for many small island inhabitants. They highlight the serious and wide-reaching consequences future climate changes will have on small island countries, likely exacerbating the existing adverse impacts of the high natural variability of the climate and related systems.

The combination of current and anticipated impacts of climate variability and change for Pacific Island Countries is thus of great and urgent concern, given the extensive, available and growing evidence of the vulnerability of these countries to climate variability and change and given the acknowledged limitations these countries have for adapting to climate change.

As noted above, variability and change are ubiquitous in the Pacific Islands Region. As a result, both natural systems and human societies in the Region are in some ways remarkably well attuned to relatively large variations in environmental conditions, and have in the past been able to cope with many of the repercussions of environmental change. However, the cumulative pressures on the closely integrated biophysical and human systems of the Pacific, many of which are resulting from rapid increases in total and urban population and in unsustainable production and consumption patterns, mean that these systems are less well placed to accommodate the unprecedented changes in climate and related environmental conditions that are anticipated to occur during the remainder of the current century.

Any plausible climate scenario will require Pacific Island Countries to implement adaptation measures due to the unparalleled and potentially devastating nature of the resulting changes. The most desirable adaptive responses are those that address the adverse impacts of present day climate variability (including extreme events) and augment actions which would be taken even in the absence of climate change, due to their contributions to sustainable development. Similarly, while climate change mitigation initiatives undertaken by Pacific Island Countries will have insignificant consequences climatologically, they should nevertheless be pursued because of their valuable contributions to sustainable development.

By making even greater efforts to implement these strategies, Pacific Island Countries will further enhance their international leadership in the integration of climate information into near term decision making and longer term planning, to the benefit of international, regional and local communities.

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Statement by Chair of the Editorial Board

John E. Hay
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The Pacific Islands Region is distinctive with respect to its exposure, resilience and vulnerability to climate and sea-level variability and change. This reflects the unique natural, social and economic conditions that characterise the islands and waters of the region. However, to date the nature of both the locally and regionally significant impacts, and appropriate responses to such global changes, have not been researched, synthesised and documented in a systematic and comprehensive manner. National and regional policy- and decision-makers are thus handicapped by the absence of a coherent and readily accessible body of knowledge and resource materials that can inform and empower them as they fulfil their responsibilities to prepare Pacific Island Countries to address the acknowledged serious consequences of climate and variability and change, including sea-level rise.

Financial resources made available by the Government of Japan have now allowed regional and national experts with diverse technical- and policy-related experience to develop and document a comprehensive understanding of how environmental, economic and social characteristics shape the overall characteristics of the impacts, resilience and vulnerability of Pacific Island Countries with respect to climate and sea-level variability and change, and to identify preferred adaptation policies and strategies. The findings are described in this *Resource Book*, and will also be made available in other formats, including CD-ROM and via the World Wide Web.

The necessary research, and the subsequent synthesis of the findings, was undertaken by the following team that constituted members of the Editorial Board for the *Resource Book*:

- John Campbell, Department of Geography, The University of Waikato;
- Solomone Fifita, Secretariat of the Pacific Community;
- John Hay, International Global Change Institute, The University of Waikato;
- Kanayathu Koshy, Pacific Centre for Environment and Sustainable Development, The University of the South Pacific;
- Roger McLean, School of Geography and Oceanography, University of New South Wales, Australian Defence Force Academy;
- Nobuo Mimura, Center for Water Environment Studies, Ibaraki University, Japan;
- Taito Nakalevu, South Pacific Regional Environment Programme;
- Patrick Nunn, Department of Geography, The University of the South Pacific; and
- Neil de Wet, International Global Change Institute, The University of Waikato.

One of the Pacific Islands Region's great strengths is the ability of individuals, institutions, organisations and countries to work together cooperatively. This *Resource Book* is a manifestation of such cooperation, not only in terms of the research and writing that culminated in the present volume, but also with respect to the assessments and other studies that provided the rich body of information on which the book is based.

July, 2002

Acknowledgements

The *Resource Book* reflects the collective but differentiated efforts of numerous individuals, institutions, organisations and agencies.

Financial support for the research, writing, design and publication of the *Book* was provided by the Government of Japan, through Pacific Consultants Ltd.

The South Pacific Regional Environment Programme implemented the *Resource Book* project, and was also responsible for design and publication.

The International Global Change Institute, University of Waikato, provided logistic, administrative and other in-kind support to the research and writing team.

Many regional organisations, notably the South Pacific Regional Environment Programme, the South Pacific Applied Geosciences Commission, the Secretariat of the Pacific Community and The University of the South Pacific, gave willingly of data and other information critical to documenting the significance of climate and sea-level variability and change to the countries of the Pacific Islands Region.

Similarly, individuals, government agencies and non-governmental organisations in individual Pacific Island countries have been forthcoming with relevant information. Of note is the significant body of knowledge compiled by countries that are Parties to the United Nations Framework Convention on Climate Change. In the absence of the technical and policy-relevant studies that these countries have undertaken in recent years, mostly under the auspices of the Pacific Islands Climate Change Assistance Programme (PICCAP), this *Resource Book* would have been very much the poorer in both quality and relevance.

Members of the Editorial Board wish to acknowledge the numerous national, regional and international climate assessment initiatives which provided many important resources that underpinned preparation of the *Resource Book*. These source documents are included in the References provided at the end of the *Resource Book*. Interested readers are encouraged to explore these more detailed reports.

Finally, members of the Editorial Board wish to acknowledge the constructive advice and guidance provided by the reviewers who commented on an early draft of the *Resource Book*.

Chapter 1. Introduction

1.1 Background and Objectives

For well over a decade, Pacific Island Countries, and the regional intergovernmental organizations that represent their collective interests, have highlighted the potentially disastrous consequences of the changes in atmospheric and oceanic conditions that are a consequence of global warming. While the serious threat of low lying island states being overwhelmed by the higher water levels associated with sea-level rise has captured the attention of the general public world wide, the reality may be much more subtle and multi-dimensional, but no less disastrous.

This book is a response to requests from Pacific Island Countries for an authoritative volume that presents the true nature of the threats and risks associated with climate change and sea-level rise, that documents these in the context of the natural variability in atmospheric and oceanic conditions which already stresses many of the natural and human systems of the island states, and offers meaningful commentary and guidance on the range of response options available to Pacific Island Countries and communities.

As recently as the Thirty-Second Meeting of the Pacific Islands Forum held in the Republic of Nauru in August 2001, and attended by Heads of State and representatives of the Governments of countries of the Pacific Islands Region, leaders recognised and endorsed the deep concern in the region about climate change and the need to seek international understanding of the unique circumstances of Pacific Island Countries, especially low lying islands. In response to this and other requests for international assistance, the Pacific-Japan Cooperation Project developed a portfolio of project-based responses. Among them, preparation of this *Resource Book* was given high priority, as a contribution to international understanding, a need recognized by the Pacific Islands Forum and other regional organizations.

Phenomenon consistent with the anticipated adverse consequences of climate change are already an unfortunate reality for Pacific Islanders - extensive coastal erosion, coral bleaching, persistent alternation of regional weather patterns, decreased productivity in fisheries and agriculture, coastal roads, bridges, foreshores and plantations suffering increased erosion, even on islands that have not experienced inappropriate coastal development, recent devastating droughts hitting export crops and causing serious water shortages, and more widespread and frequent occurrence of mosquito-borne diseases. These highlight the serious and wide-reaching consequences future climate changes will have on the small island countries of the Pacific, exacerbating the adverse impacts already being experienced due to the high natural variability of climate that characterizes the Pacific Islands Region.

The combination of current and anticipated impacts of climate variability and change for Pacific Island Countries are thus of great and urgent concern, given the extensive and growing evidence of the major and diverse impacts likely to occur as a result of climate change and given the acknowledged limitations these countries have for adapting to climate change.

The *Resource Book* has been prepared in order to meet the following objectives:

- To provide policy- and decision-makers in Pacific Island Countries with a coherent, authoritative and readily accessible body of knowledge and resource materials that characterise the region's resilience and vulnerability to climate and sea-level variability and change and identify a suite of proven and potential response options that are deserving of further consideration and implementation; and
- To provide educators, outreach and related practitioners with an integrated and functional resource portfolio for use in formal education and professional development programmes and in support of efforts to enhance political and public awareness of the implications of global and regional variability and change for the Pacific Islands Region.

The *Resource Book* is thus written and presented in a style that is consistent with the needs of a lay readership living and working in the Pacific Islands Region (Figure 1.1). Little or no prior knowledge of atmospheric and oceanic processes is assumed. The *Resource Book* progresses quickly from the fundamentals to their implications and desirable responses, recognizing that the latter will be of greatest interest and relevance to the target audiences. References within the main body of the *Resource Book* have been kept to a minimum, to enhance readability. Consolidated lists of references and relevant Web sites are provided towards the end of the volume.

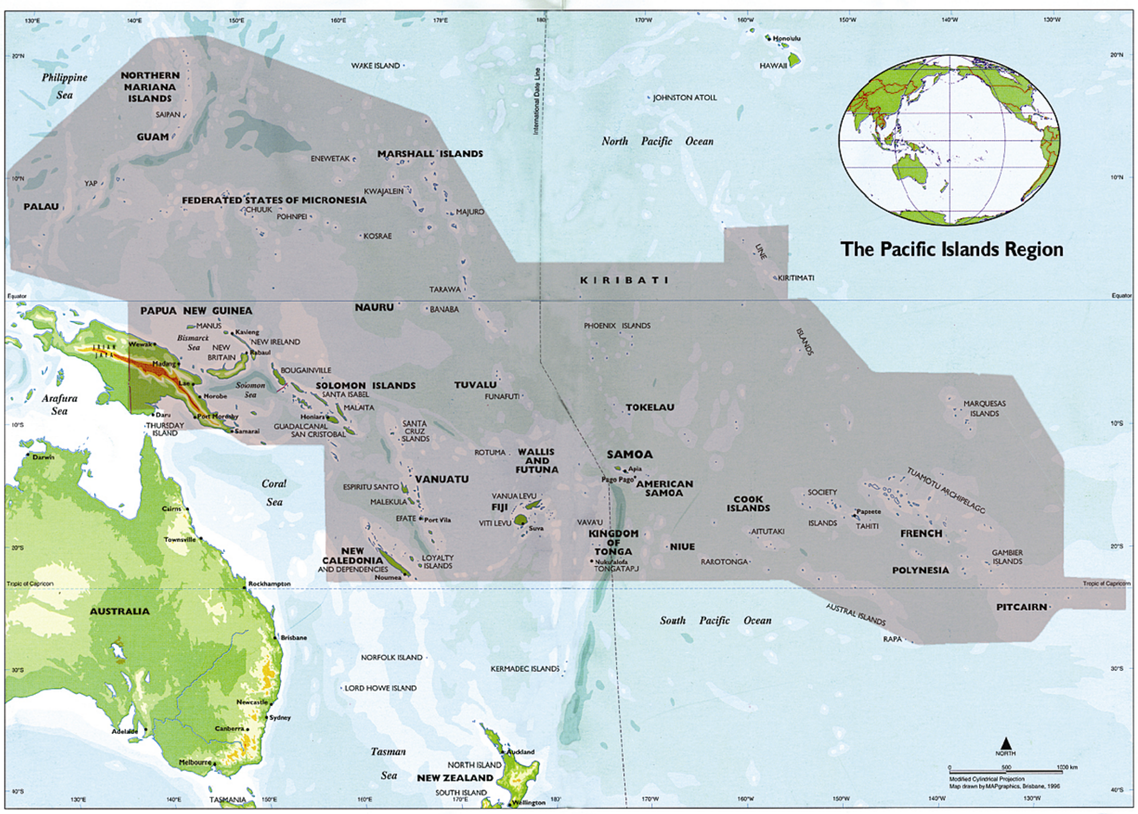


FIGURE.1. The Pacific Islands Region.

1.2 Structure and Contents of the *Resource Book*

The Book comprises four main sections, reflecting the four principal dimensions of the problem – the changing climate, the observed and potential impacts, and the two broad categories of policy responses and actions, namely mitigation and adaptation (Figure 1.2 and Box 1.1).

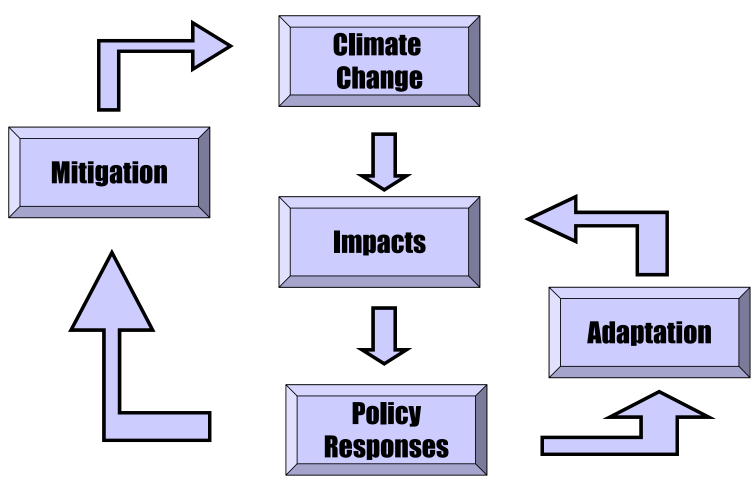


FIGURE 1.2. The key dimensions of the climate change issue, reflected in the areas of focus of the *Resource Book*.

A description of the physical and related processes associated with climate and sea-level variability and change leads into a characterisation of past, present and future climatic and sea-level regimes, both globally and for the Pacific Islands Region. The observed and anticipated consequences of these variations and changes are then described for various components of both natural (biophysical) and human (socioeconomic) systems, as well as on an integrated basis.

Appropriate regional, national and community-based responses to these consequences of climate and sea-level variability and change are identified and elaborated. Policies and actions that serve to limit future changes in climate and increases in sea level (i.e. "mitigation") are considered along with those that focus on reducing the adverse and exploiting the favourable consequences of present-day or anticipated extreme events, variations and changes in the atmospheric-ocean system (i.e. "adaptation").

Finally, to complement the review of regional, national and community-based responses, attention is directed to international efforts. These are considered from two perspectives: the contributions Pacific Island Countries are making to international understanding of climate change and related issues; and the implications of international agreements and activities for Pacific Island Countries.

BOX 1.1. Some Key Definitions

Climate change – trends or other systematic changes in either the average state of the climate, or in its variability (including extreme events), with these changes persisting for an extended period, typically decades or longer.

Climate variability – variations in climatic conditions (average, extreme events etc) on time and space scales beyond that of individual weather events, but not persisting for extended periods of, typically, decades or longer.

Sea-level rise (fall) - an increase (decrease) in the mean level of the ocean, persisting for an extended period, typically decades or longer.

Sea-level change – trends and other systematic changes in mean sea level, persisting for an extended period, typically decades or longer.

Sea-level variability - variations in mean sea-level conditions (including extreme events) that do not persist for extended periods of, typically, decades or longer.

Climate impacts – the changes that may occur in the integrated natural and human system, or its component parts, as a consequence of externally imposed forces associated with climate change and variability, including extreme events.

Vulnerability (to climate variability and change) – the extent to which a natural or human system is susceptible to sustaining damage resulting from climate variability and change, despite human actions to moderate or offset such damage

Resilience (to climate variability and change) – the ability of a natural or human system to withstand the adverse consequences of climate variability and change, including extreme events, and return to some degree of normalcy as a result of the capacity to cope or adapt.

Adaptation (to climate variability and change) – Policies, actions and other initiatives designed to limit the potential adverse impacts arising from climate variability and change (including extreme events), and exploit any positive consequences.

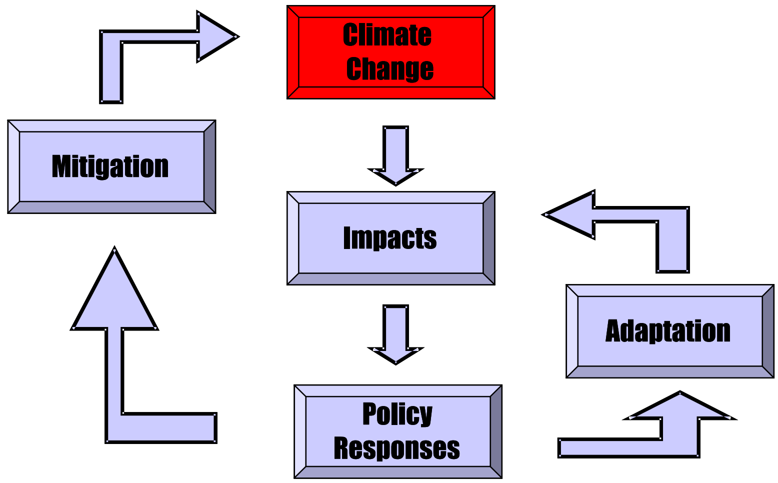
Adaptive capacity – the degree to which adjustments processes (both natural and human), practices or structures can moderate or offset the potential for damage, or take advantage of opportunities created by variations or changes in the climate.

Mitigation (of climate change) – Policies, actions and other initiatives that reduce the net emissions of "greenhouse gases", such as CO_2, CH_4, N_2O, that cause climate change through global warming.

Scenario – a plausible course of anticipated events or a probable future condition, constructed for explicit use in investigating the potential consequences of changes from current conditions.

In summary, the key messages the *Resource Book* aims to deliver are as follows:

- The Pacific Islands Region is noteworthy for its vibrant and dynamic nature – extreme events, variability and change are ubiquitous;
- Natural systems and human societies in the Pacific Islands Region had attributes that made them remarkably well attuned to the relatively large variations in environmental conditions that occurred in the recent and more distant past, with the associated high resilience fostering an ability to cope with natural environmental changes;
- The large uncertainties in specifying the future conditions that will stress both natural and human systems leads to a preference to use scenarios rather than attempt to make precise predictions;
- While climate change mitigation initiatives undertaken by Pacific Island Countries will have insignificant consequences climatologically, they should nevertheless be pursued because of their valuable contributions to sustainable development;
- Acting now to reduce the current vulnerability of Pacific Island Countries to natural climate extremes and variability, such as the El Niño-Southern Oscillation (ENSO) is one of the most effective ways to prepare for future changes in climate;
- Climate change will increase the likelihood of extreme events, and hence disaster risk; since, even today, extreme events are a major impediment to sustainable development, development planning must reflect both recurrent historical risks and new risks, including those associated with climate change, for effective risk management prevents precious resources from being squandered on disaster recovery and rehabilitation;
- Natural and human systems in the Pacific Islands Region will continue to face pressures that are not climate related, including those related to population growth, social change and economic transformation; responses to the climate and sea-level variability and change should be coordinated with the mainstream policies of socioeconomic development and environmental protection, to facilitate sustainable development;
- Any plausible climate change scenario will require Pacific Island Countries to implement adaptation measures due to the unprecedented and potentially devastating nature of the resulting changes; and
- The most desirable adaptive responses are those that augment actions which would be taken even in the absence of climate change, due to their contributions to sustainable development.



Chapter 2. Climate and Sea-Level Variability and Change: Processes and Projections

Key Findings:

- The Pacific Islands Region is noteworthy for its naturally vibrant and dynamic nature – extreme events, variability and change are ubiquitous;
- Despite the many uncertainties as to the nature and consequences of global warming, the climate of the Pacific Islands Region will continue to be dominated by the trade winds and convergence zones, and by the inter-annual variability associated with ENSO;
- However, the projected rate of warming for the Pacific Islands Region (by between 0.6 and 3.5^{o}C in this century) is much larger than the observed changes during the last century and is very likely to have been without precedent during at least the last 10,000 years;
- The projected increase should be compared to the temperature difference, for the region, of around 3 to 4^{o}C between the middle of the last Ice Age and the present day;
- During the present century the climate may become more "El Niño-like", with central and eastern equatorial Pacific sea surface temperatures projected to warm more than the western equatorial Pacific, and with a corresponding mean eastward shift of precipitation;
- During future ENSO events anomalously wet areas could become even wetter, and unusually dry areas become even drier;
- While there is no evidence that tropical cyclone numbers will change with global warming, a general increase in tropical cyclone intensity (lower central pressures, stronger winds and higher peak and mean precipitation intensities) appears likely, as does an eastward extension in the area of formation;

- Globally, rates of sea-level rise during the 20th century have been in the range of 1 to 2 mm/yr; due to global warming this rate is expected to increase to between 1 and 7 mm/yr, with a central estimate of 4 mm/yr;
- While local sea levels change in response to many factors, including local uplift or sinking of the Earth's crust and variations in air pressure and wind velocity, it is expected that even those areas in the Pacific currently experiencing a relative fall in sea level will, by the end of this century, experience a rising relative sea level;
- However, interannual variations in sea level associated with ENSO, and storm surges associated with tropical cyclones, are likely to be of greater significance in the coming decades.

2.1 The Global Climate System

To understand the climate of the Earth, and its variations and changes over time, we must have some understanding the *global climate system*. The system consists of the composition of, and changes in, the atmosphere, oceans, ice and snow masses, land surfaces, rivers, lakes and the biosphere (including humans), and the mutual interactions that are a consequence of the large variety of physical, chemical and biological processes taking place in and between these components (Figure 2.1). Another key feature of the system is the existence of various external forcing mechanisms, the most important being the Sun.

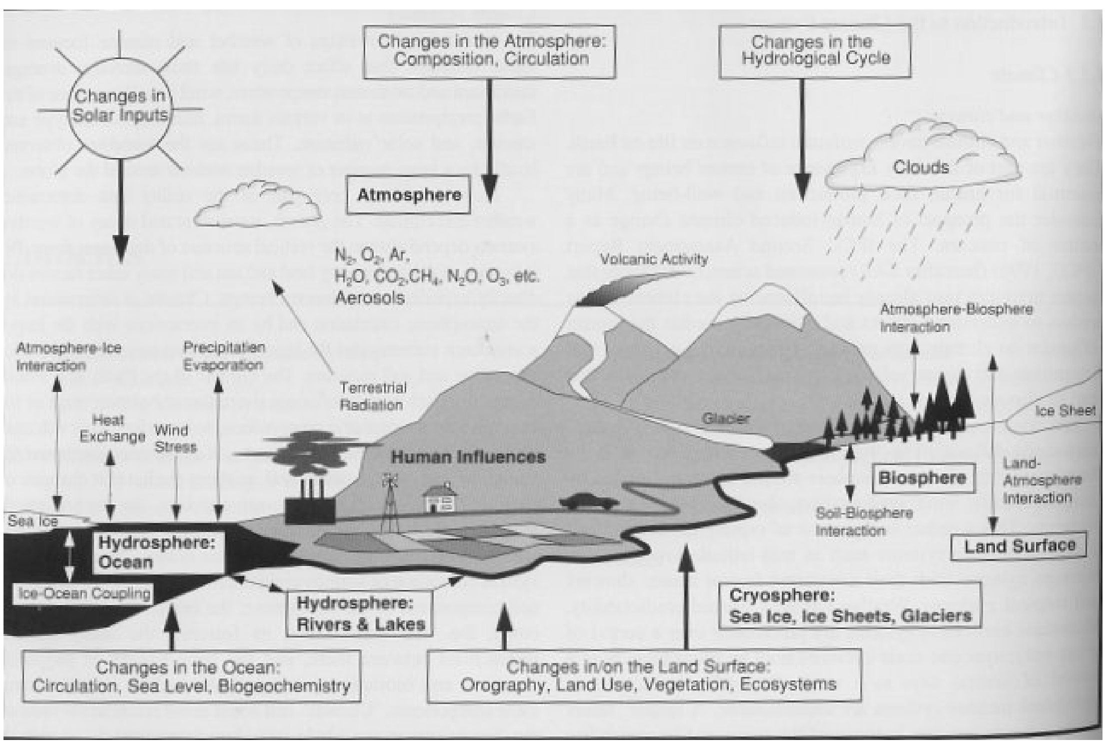


FIGURE 2.1. Schematic view of the components of the global climate system (bold), their processes and interactions (thin arrows) and some aspects of change (bold arrows). From IPCC, 2001.

The atmosphere is the most rapidly changing part of the climate system, its composition having changed as the Earth has evolved. Despite their low concentrations relative to gases such as nitrogen (N_2) and oxygen (O_2), a collection of atmospheric gases, notably carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ozone (O_3) and water vapour (H_2O), play a critical role in determining the temperature of the Earth. These so-called *greenhouse gases* absorb little or none of the short wavelength radiant heat energy reaching the Earth from the Sun, but are highly effective absorbers of the longer wavelength radiant heat energy emitted by the Earth. These gases, in turn, emit longer wavelength radiant heat energy both upward and downward (Figure 2.2). The resulting energy "trapping" process raises the temperature of the Earth's surface to an average of 14^{o}C, some 33^{o}C above what it would be if the Earth's atmosphere contained no greenhouse gases. This raised temperature is termed the *natural greenhouse effect.*

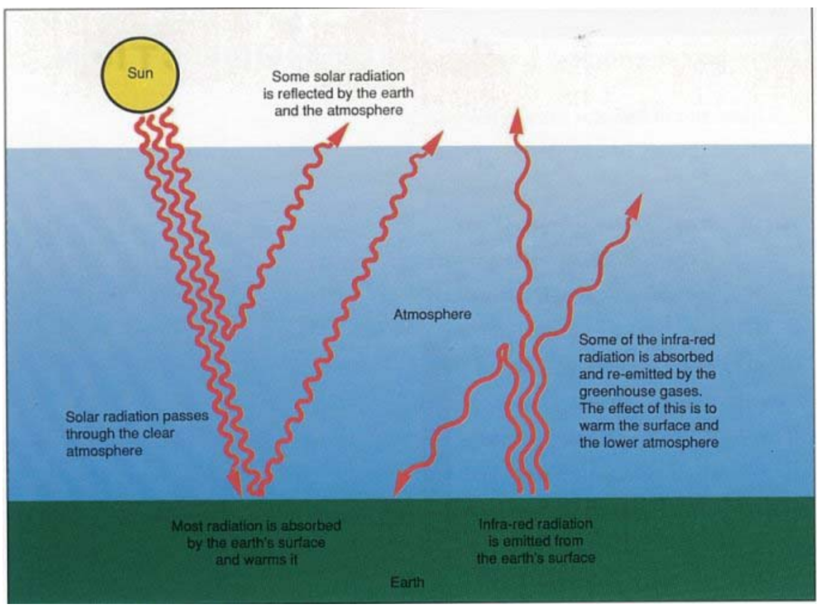


FIGURE 2.2. How greenhouse gases warm the Earth's surface and the lower atmosphere. From Commonwealth of Australia, 1995.

The atmosphere also contains solid and liquid particles (aerosols) and clouds. These interact with the incoming and outgoing radiant heat energy in complex ways that vary from place to place due to variations in the types and amounts of cloud and aerosols. However, the overall effect of clouds and aerosols is to cool the Earth.

Meanwhile, the overall warming effect of the absorbed radiant heat energy is greatest at the Earth's surface, and more so at low (i.e. tropical) latitudes than at high (i.e. polar) latitudes. Further, the snow and ice cover that persists at higher latitudes for some or all of the year presents a mirror-like surface that reflects sunlight back to the atmosphere and space, before it has the chance to be absorbed by (and warm) the Earth's surface. Scientists refer to the reflective property of a surface as *albedo*. But more importantly, at lower latitudes such as in the Pacific Islands Region, where the Sun is higher in the sky for longer periods of time, the Sun's energy is typically intense and the surface reflectivity (albedo) is relatively low. The potential thus exists for escalating surface temperatures. This contrasts with the atmosphere, where the potential is for continuous cooling since the atmosphere absorbs little energy from the Sun and is always losing longer wavelength energy, mostly to space.

But the Earth's surface does not become hotter and hotter; neither does the atmosphere continually cool. Vertical air currents (the extreme manifestations are tornados and convective thunderstorms) move warm air from the surface to higher levels in the atmosphere. Evaporation of water (at times preceded by melting) at the Earth's surface, and its subsequent condensation at higher levels in the atmosphere, is another way the surplus of radiant heat energy at the surface and the atmospheric energy deficit are offset. Similarly, warm air and ocean currents convey heat energy poleward; cold equatorward-moving currents achieve the same result, that is preventing the low latitudes from becoming hotter and hotter, and the high latitudes from cooling over time.

Thus the hydrologic cycle (precipitation, evaporation, melting), the large scale weather patterns (cyclones, anticyclones, tradewinds, convergence zones etc) and the ocean currents (Figure 2.3) are integral and important features of the global climate system.

The natural climate system is in *dynamic equilibrium* – that is, variations occur, but large systematic changes are suppressed. For example, if the heat content of the tropical ocean increases in a persistent manner, the resulting increases evaporation and convection (manifest as tropical cyclones and thunderstorms) will soon move the excess heat energy into the atmosphere, cooling the ocean, and hence suppressing the initial change. This is called a *negative feedback*.

Variations may result from alterations in the external forcing conditions - the influence of sunspot activity on weather and hence climate is an example. But variability is also intrinsic (i.e. due to internal natural causes), as a result of the complex interactions between the multiple components of the climate system itself. The El Niño-Southern Oscillation (ENSO), which results from the interaction between the atmosphere and ocean in the tropical Pacific, is an example of such natural variability. ENSO does not appear to have an external cause, but it does have significant and wide reaching effects (see Box 2.1 and Section 2.3.2).

Sometimes systematic changes do occur. For example, the long term changes in the Earth's orbit that occur over periods of tens of thousands of years change the distance between it and the Sun. The reduced radiant heat energy input when the Earth is distant from the Sun results in an Ice Age (see Section 2.3.1). Interactions between components of the global climate system can suppress or enhance the externally forced change. These are referred to as *negative* or *positive feedbacks*, respectively. For example, not all the cooling associated with an Ice Age will be due to the orbital changes. Some of the cooling will reflect the fact that the amount of water vapour in the atmosphere decreases as the Earth cools. Since water vapour is a very effective greenhouse gas, its reduced concentration will amplify the cooling – a positive feedback.

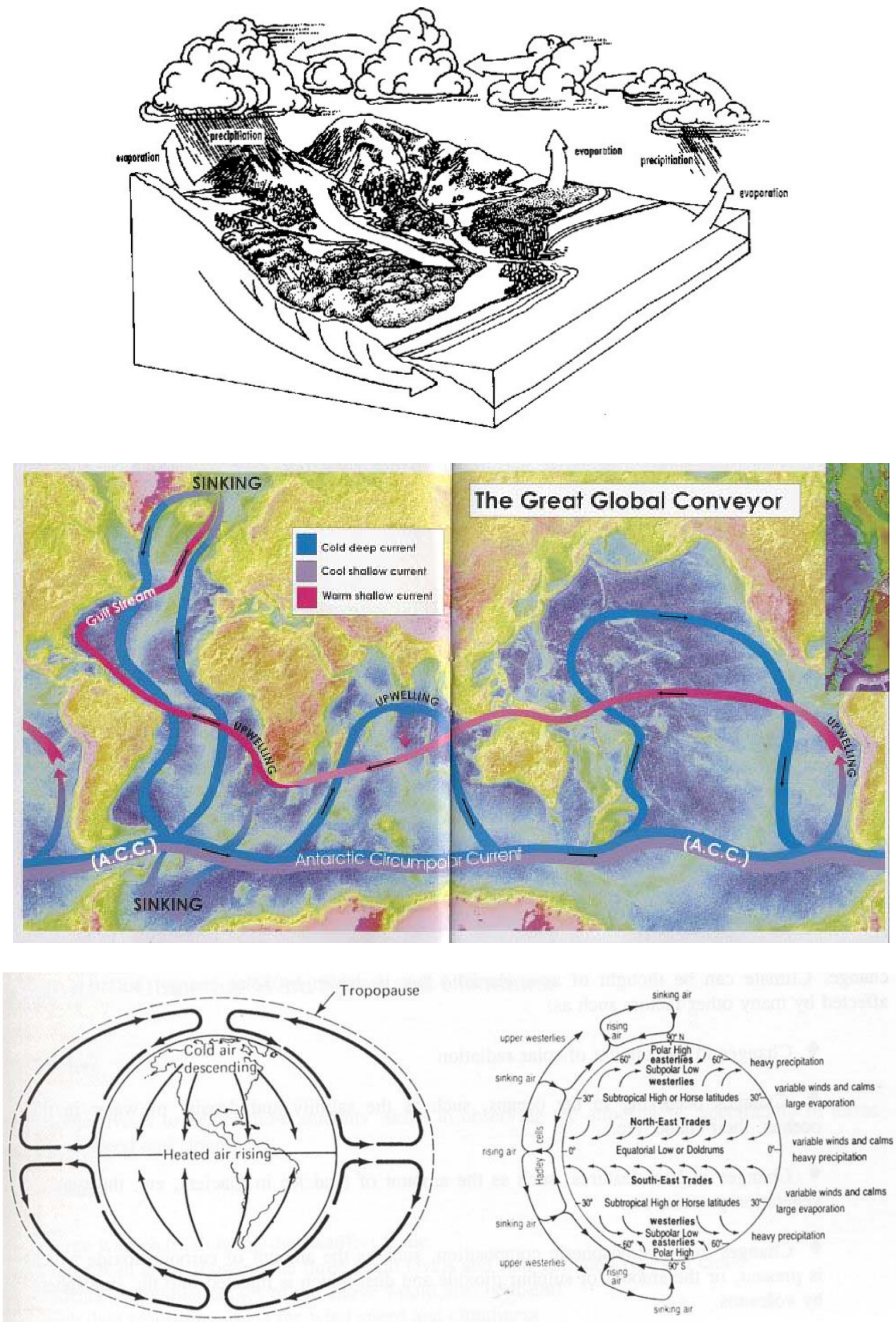


FIGURE 2.3 (a) The hydrologic cycle; (b) the role of the Earth's oceans as great global conveyor of heat (from NIWA, 2001); and (c) The idealised system of air movement for a non-rotating Earth (left) and for a rotating Earth (right).

Another systematic change in the Earth's climate results from human activity increasing the concentration of greenhouse gases in the atmosphere, enhancing the greenhouse effect and resulting in *global warming* (see Section 2.4).

2.2 Role of Oceans in the Global Climate System

The oceans cover 70% of the Earth's surface and form one of the major components of the global climate system (the others being the atmosphere, land surface, cryosphere and biosphere, see Section 2.1). The oceans regulate the Earth's climate and also modulate the global biogeochemical cycles, having significant capacity to store heat while also serving as the largest reservoir of the two most important greenhouse gases, water vapor and carbon dioxide. The oceans absorb carbon dioxide and other gases and exchange them with the atmosphere. From a climate system point of view the ocean and atmosphere are 'coupled'.

Globally, the oceanic circulation that is driven by changes in sea water temperature and salinity plays an important role in controlling the distribution of heat, water (through evaporation and precipitation) and greenhouse gases in the atmosphere, by redistributing heat and freshwater around the globe via the "conveyer belt" (see Section 2.1). Wind driven ocean currents are also of special importance in the tropical Pacific. Because of its huge mass and ability to absorb heat energy, the ocean slows climatic change and influences the time-scales of variability in the ocean-atmosphere system.

In both the atmosphere and the ocean the dominant gases are nitrogen, oxygen and carbon dioxide. Typically the ocean contains only a small percentage of the gases making up the atmosphere, the major exception being carbon dioxide. The oceans contain about 60 times more carbon than the atmosphere - some 40,000 Gt of carbon in dissolved, particulate and living forms, compared to about 2200 Gt of carbon on land. Ultimately it is the oceans that determine the level of CO_2 in the atmosphere, the ocean acting as a store for carbon through the carbon dioxide cycle which forms part of the larger carbon cycle.

Significantly, marine biota play a central role in shaping the Earth's climate. Marine biological processes, which occur principally in the uppermost few hundred metres of the ocean, are critical in the overall transfer of carbon from the atmosphere, through the ocean surface layers, to the deeper ocean. Carbon dioxide is taken up by photosynthesis, transformed into organic matter and exported towards the deep ocean either by sinking or by migrations of pelagic animals and plants (e.g. phytoplankton). Organic carbon burial in marine sediments removes atmospheric CO_2 for long periods of time. Calcium carbonate is also fixed during photosynthesis by those marine algae and animals that have 'hard' parts of $Ca\ CO_3$. There are two consequences. $Ca\ CO_3$ sinks out of the surface layer, thus exporting organic carbon; CO_2 is created in the surface ocean. The latter more than offsets the removal of organic carbon, resulting in the ocean being a source of carbon. Coral reefs, made up primarily of $CaCO_3$, are an example of this process.

This integrated process, called the *biological pump* (Figure 2.4), reduces the total carbon content of the atmosphere and the surface oceanic layers and increases it in the deeper layers. However, carbon dioxide can return to the ocean surface by upwelling, and then be exported into the atmosphere. While on average the ocean takes up CO_2 from the atmosphere, the flow of CO_2 is not always from atmosphere to ocean. Thus the ocean is both a 'sink' and a 'source' for atmospheric CO_2, depending on season and location

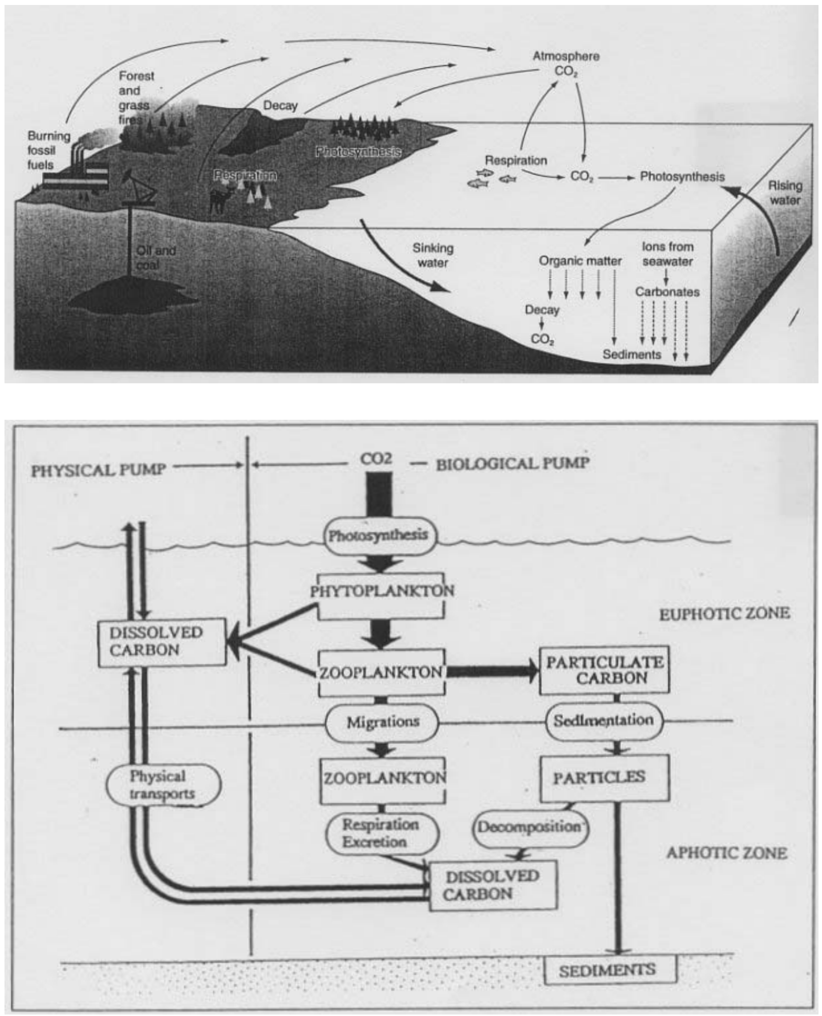


FIGURE 2.4: Pathways of the carbon and carbon dioxide cycles within the ocean, and exchanges with the atmosphere.

Nowhere in the world is this system of carbon sources and sinks better seen than in the tropical Pacific. Here carbon fluxes within the marine system, and between the ocean and the atmosphere, are closely linked to the westerly flowing ocean surface currents and the associated movement towards the surface of deep, cold waters that contain high carbon dioxide and nutrient (e.g. nitrate, phosphate, silicate) concentrations. The result in this case is the transport of CO_2 from the sea to the atmosphere and an increase in CO_2 uptake as a result of photosynthesis by phytoplankton which are in turn supported by nutrients in the upper layers. The area of the eastern tropical Pacific, where upwelling dominates, essentially covers the total *oceanic* 'source' area of CO_2 for the Earth, despite it also being an area of enhanced photosynthesis by phytoplankton. The extent of this oceanic CO_2 source area varies interannually with ENSO. During El Niño events upwelling and CO_2 export from the ocean to the atmosphere is at a minimum, while during La Niña events upwelling and CO_2 export are at a maximum (see Box 2.1).

BOX 2.1. The El Niño -Southern Oscillation (ENSO)

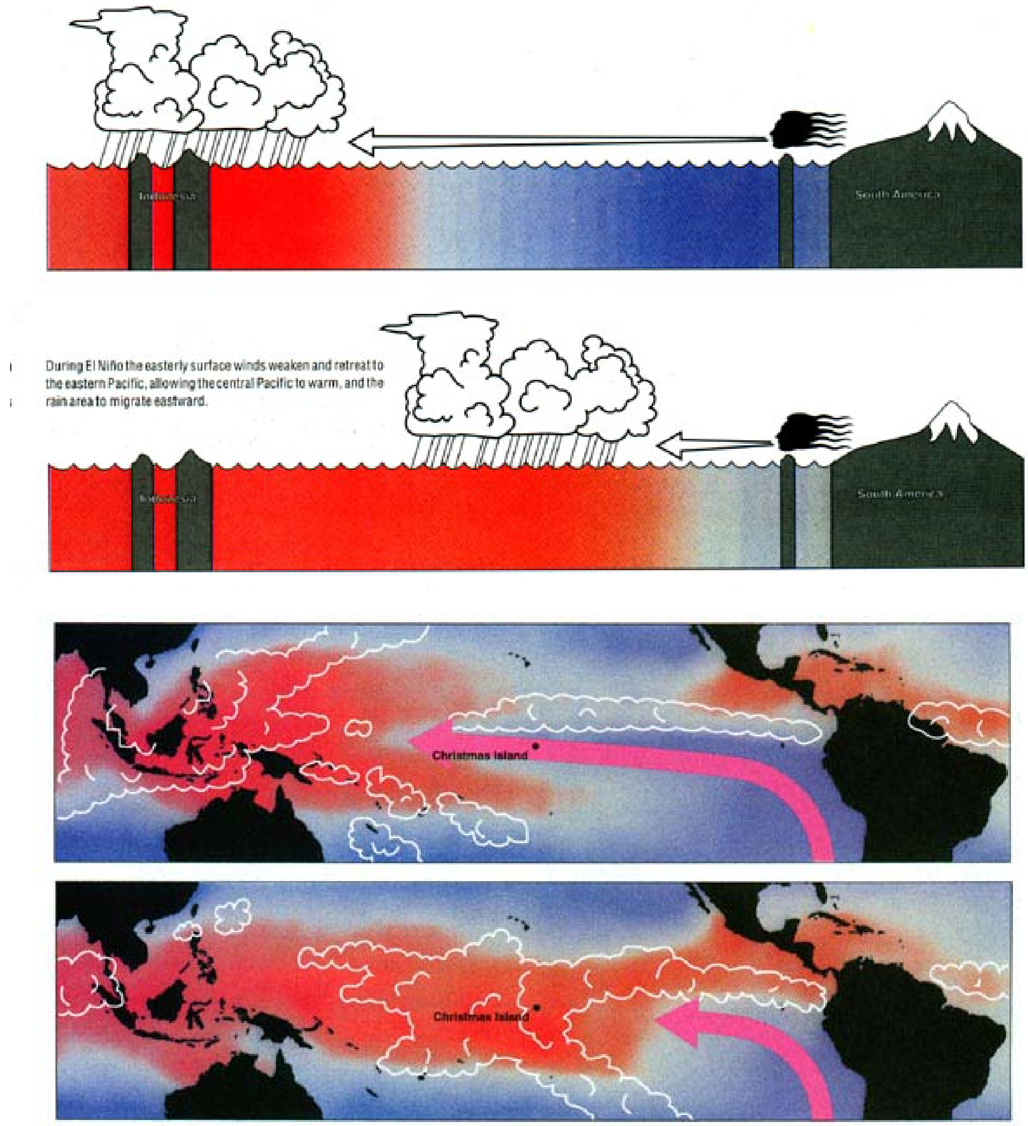
The El Niño-Southern Oscillation (ENSO) is a result of ocean-atmosphere interactions internal to the tropical Pacific Ocean and the overlying atmosphere. Unusually warm temperatures in the eastern equatorial Pacific (termed an "El Niño event) reduce the normally large sea surface temperature difference between the eastern and western sides of the tropical Pacific. As a consequence, the northeast and southeast trade winds weaken and sea level falls in the west and rises in the east, as warmer waters move eastward along the equator. At the same time, the weakened trade winds reduce the upwelling of cold water in the eastern equatorial Pacific, thereby strengthening the warm temperature anomaly.

The eastward shift in the location of organised convention and rainfall, and the associated release of energy into the atmosphere resulting from the associated condensation, alters the heating patterns of the atmosphere and thence wind patterns, including the mid-latitude jet stream and storm tracks. This has consequences for weather patterns and results in societal and economic impacts around the world.

The term "El Niño" originally applied to a weak warm current that runs southwards along the coast of Peru about Christmas time. It is recognized that this localized coastal warming is at times associated with the much more extensive and unusual ocean warming described above.

ENSO is a natural phenomenon which has occurred for thousands of years, at least. Ocean and atmospheric conditions in the Pacific tend to fluctuate between El Niño (warm) events and a cooling of the tropical Pacific, termed the "La Niña" (cool) phase. While the fluctuations are irregular, they tend to have a preferred period of about three to six years, with the most intense phase of each event lasting about a year.

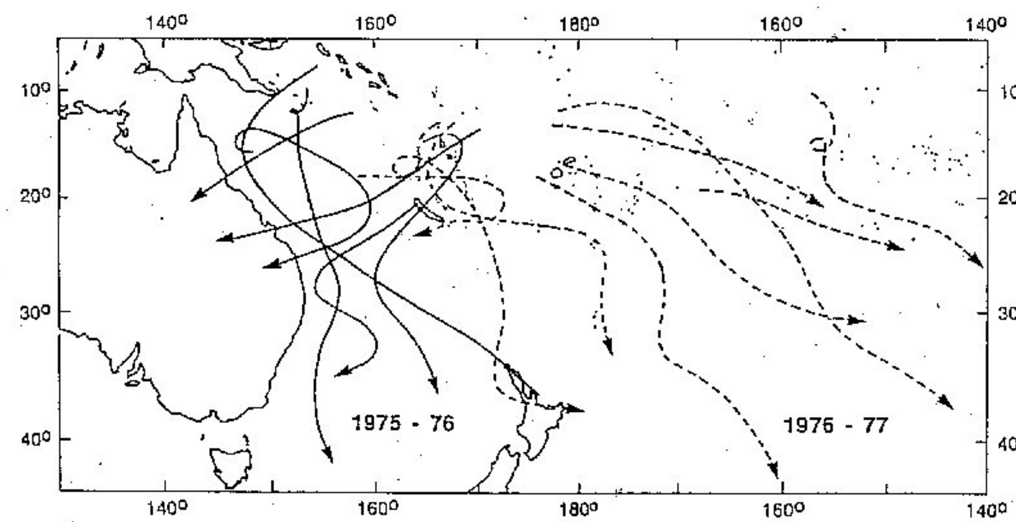
Key long-term features of the Pacific Ocean are the "warm pool" in the tropical western Pacific (where the warmest ocean waters in the world occur), much cooler waters in the eastern Pacific, and a cold tongue along the equator (see figure below). The easterly trade winds in the tropics pile up warm waters in the west, producing an upward slope of sea level along the equator, with an approximate 0.6 m rise from east to west. The winds also drive the surface currents, with cooler, nutrient-rich waters upwelling along both the equator and the western coasts of the Americas, favouring occurrence of phytoplankton, zooplankton, and hence fish (see Box 3.3).



(a - above) Cross-sectional views of the Pacific Ocean under La Niña (upper) and El Niño (lower) conditions; (b - below) As for (a), but plan view.

Because convection and thunderstorms preferentially occur over warmer waters, the pattern of sea surface temperatures influences the distribution of rainfall and tropical cyclones in the tropics and the associated warming of the atmosphere through the release of latent heat when changing the water phase from vapour to liquid. The heating drives the large-scale monsoonal type circulations in the tropics, and consequently influences the wind patterns. This strong coupling between the atmosphere and ocean in the tropics gives rise to the ENSO phenomenon.

During El Niño the trade winds weaken, allowing the warm waters from the western tropical Pacific to extend further eastward, shifting the pattern of tropical cyclones (see figure below) and rainstorms, and further weakening the trade winds and in turn the changes in sea temperatures. Sea level drops in the west, but in the east rises by as much as 0.25 m as warm waters surge eastward along the equator. Approximately reverse patterns occur in the Pacific during the La Niña phase of ENSO.



Tropical cyclone tracks for 1975-76, a non-El Niño year (solid lines) and 1976-77, an El Niño year (broken lines). From Zillman et al., 1989.

ENSO plays a prominent role in modulating exchanges of CO_2 between the ocean and atmosphere. The normal upwelling of cold, nutrient-rich and CO_2-rich waters in the tropical Pacific is suppressed during El Niño (see Box 3.3).

Studies based on a combination of observations and modelling suggest that the oceans have taken up about 30% of carbon dioxide produced as a result of fossil-fuel use and tropical deforestation during the 1980s. This oceanic uptake slows down the rate of global warming associated with the enhanced greenhouse effect.

In addition to their importance in global cycling of CO_2, marine organisms are also significant sources of climatically active tracer gases, especially dimethyl sulphide (DMS). The oceans also contribute about 20% of the total nitrous oxide (N_2O) (a potent greenhouse gas) being added to the atmosphere on an annual basis.

2.3 The Regional Climate – Past and Present

2.3.1 Past Climate

Most people are aware that over geological time the global climate has changed substantially, due to natural causes. In the last two million years, for example, there have been a number of ice ages (called *glacial periods*) separated by warmer periods (called *interglacials*). These changes in climate have largely resulted from fluctuations in solar radiation – a consequence of variations in the orbit and hence the distance of the Earth from the Sun. We are currently between glacial periods. The present interglacial, known as the Holocene, began about 10,000 years ago and has been characterised by relatively warmer conditions and higher sea levels than the preceding glacial period. At the last glacial maximum, about 20,000 years ago, temperatures across the Earth were at their coolest. The tropical Pacific was perhaps 3-4°C cooler than today. Coral reefs, along with other biomes intolerant of cool conditions, occupied a much smaller area than they do today. Sea level was also lower, by as much as 120 m below present levels, and it has subsequently risen with the general warming of the climate from 20,000 years ago to about 5,000 years ago.

From this information we learn that small changes in the global average temperature have many and profound local and regional consequences.

In the last few thousand years century-scale variations in global temperatures and sea levels have occurred, including a period of warming (known as the 'Little Climatic Optimum') from approximately 750 to1250 AD and a cooler period (known as the 'Little Ice Age') from about 1350 to 1800 AD. Since then there has been slow warming and gradual sea-level rise, both of which on average continue to this day.

2.3.2 Present Climate

Systematic weather measurements began at a few stations in the Pacific Islands Region during the second part of the nineteenth century, but a reasonable network of stations is available only since about 1950. However, adequate sea surface temperature records are available since the 1870s.

The climate, and also the shorter-term weather, of the Pacific Islands Region are strongly influenced by its oceanic character; with the ocean acting as a large mass that prevents air temperatures deviating very far from those of the ocean surface (Figure 2.5). The ocean is also a moisture source that helps maintain high humidity.

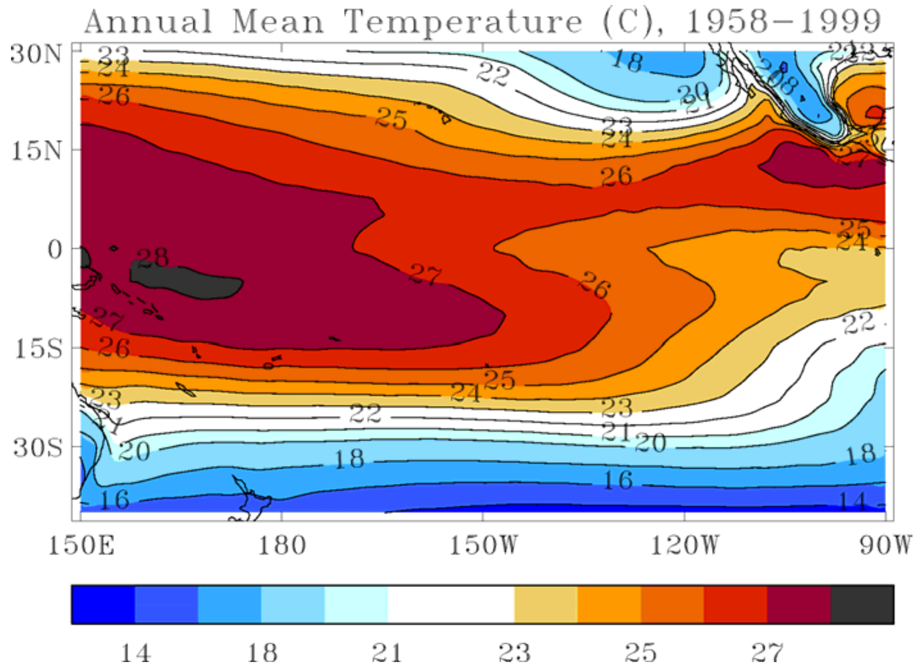


FIGURE 2.5. Mean annual near surface air temperature for the Pacific Islands region, for the period 1958 to 1999. Courtesy of B. Mullan.

The principal circulation features affecting the Pacific Islands Region are the easterly trade winds, the Intertropical Convergence Zone (ITCZ) and the South Pacific Convergence Zone (SPCZ) (Figure 2.6).

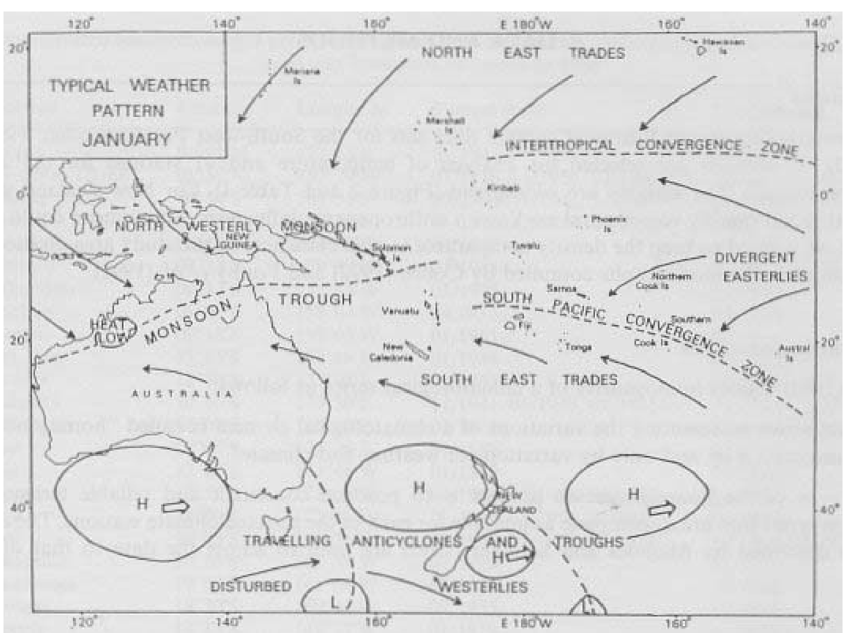


FIGURE 2.6 The South-west Pacific, showing the main climatological features of the area in a typical January. From Salinger et al., 1995.

The NE and SE trades have their source in the semi-permanent anticyclones that are found in the subtropics on the eastern side of the Pacific Ocean. The convergence of the NE and SE trades in the equatorial region (forming the ITCZ that typically lies from about 5°N to 10°N) and the resulting rising air are part of the Hadley circulation (Figure 2.3c). Another component is the subsiding air in the sub-tropical high pressure areas, these being associated with clearer skies and lower rainfall amounts (Figure 2.7). In the western South Pacific the easterly trades have a more southerly component, giving rise to the SPCZ. This zone of convergence runs diagonally from near the Solomon Islands to Samoa, and then south eastward.

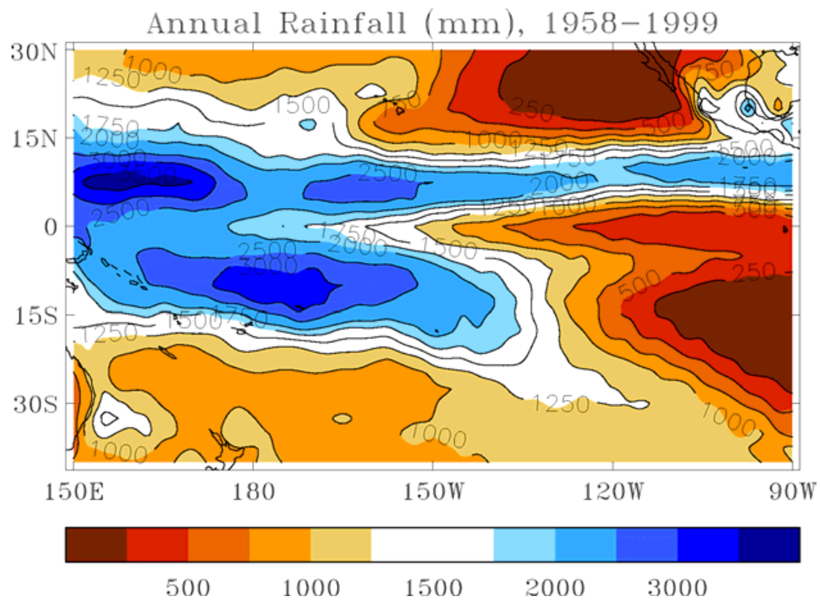


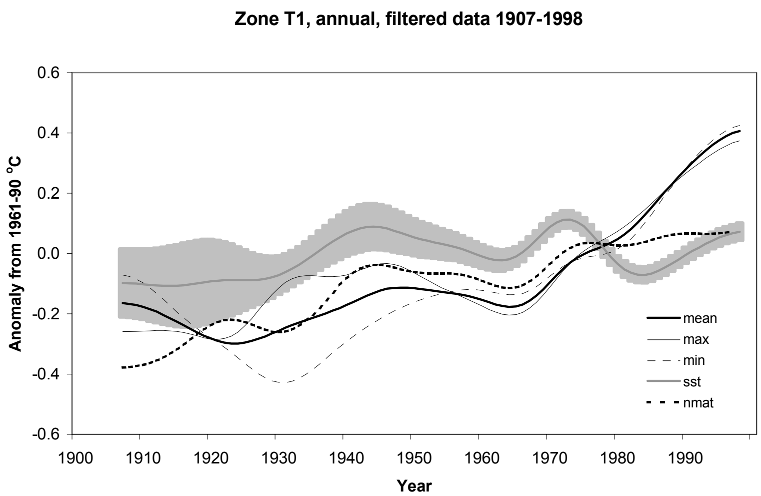
FIGURE 2.7 Mean annual precipitation for the Pacific Islands region, for the period 1958 to 1999. Courtesy of B. Mullan.

The ITCZ and SPCZ are generally associated with cloud and precipitation. The rainfall maximum just north of the equator (Figure 2.7) coincides with the ITCZ, while the precipitation maximum which extends eastward from the Solomons reflects the SPCZ. Annual rainfall in these regions exceeds 3000 mm. The two rainfall maxima are separated by a marked equatorial dry zone. Since all these zones move seasonally, locations that come under their influence experience seasonal rhythms in both weather and climate. Some islands may experience a distinct 'wet' season followed by a "dry" season for the remainder of the year, while others may have two wet periods as a convergence zone moves across them.

Tropical cyclones are also a major feature of the weather *and* climate of the region, particularly to the north of 10°N and south of about 10°S latitude. Cyclones form over the warm tropical oceans (water temperatures typically above about 28°C), and at least 5° from the equator.

Large year to year variability is also a dominant characteristic of the Pacific's tropical climate, and is mainly attributable to the ENSO phenomenon (See Box 2.2). ENSO gives rise to marked rainfall anomalies in many Pacific island groups through, among other things, a systematic shift in the position of the SPCZ between El Niño and La Niña events.

Despite the short period of observations and the large interannual variability described above, trends are evident in the climate record. For example, in the Southeast Trades region, which runs from New Caledonia northeastward to Fiji and Samoa and then southeastward to the southern Cook Islands and French Polynesia, mean air temperatures show little systematic change until the 1970s and then a steady upward trend, with the overall change between decades 1911-20 and 1981-90 amounting to 0.8°C (Figure 2.8a). Sea surface temperatures for the same period increased by only about 0.4°C. The decade 1981-90 is about 15 per cent drier than the 1951-80 average.



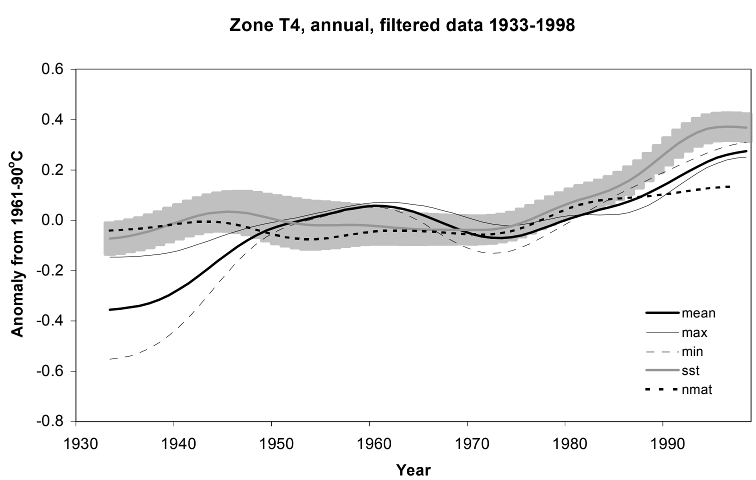


FIGURE 2.8 Composite marine and surface air temperatures smoothed to remove variations with a duration of less than a decade. a) for the Southeast Trades region (see text for description), 1907 – 1998; b) for Convergence Zone region (see text for description), 1933 – 1998. (From Folland et al., submitted).

In the Central Equatorial Pacific minimum air temperatures have increased at almost twice the rate of maximum air temperatures (0.8^{o}C and 0.4^{o}C, respectively). Sea surface temperatures have increased by about 0.4 C since 1951. Since the 1980s rainfall has increased by around 30 per cent relative to the 1951-80 average.

In the convergence zone that runs north of Fiji through Tuvalu to Tarawa in Kiribati mean air temperatures increased by around 0.6^{o}C between 1933 and 1998 (Figure 2.8b) with high temperatures in the 1950s and early 1960s and climbing even higher since the 1970s. In the same period sea surface temperature increased by 0.4^{o}C, with most of the increase occurring since the 1970s.

Many of the preceding patterns appear linked to systematic changes in ENSO. Since the mid 1970s there has been a tendency for more frequent El Niño episodes, without intervening La Niña events. The duration of the 1990-95 El Nino is unprecedented in the climate record of the past 124 years. Both mean annual air temperature and precipitation anomalies show marked interannual variability, and are closely associated with the ENSO cycle. In the Southeast Trades region conditions are cooler and drier during El Niño and warmer and wetter during La Niña. In the regions encompassing the central equatorial Pacific and the convergence zones the opposite relationships prevail – conditions are warmer and wetter during El Niño and cooler and drier during La Niña.

Consequently, since the mid 1970s wetter than average conditions have prevailed in western Kiribati, Tuvalu, Tokelau, the northern Cook Islands and northern French Polynesia, but it has been drier in New Caledonia, Fiji, Tonga and Samoa. These changes are coincident with the prevalence of El Niño conditions, including an eastward shift of the South Pacific Convergence Zone.

Despite the many uncertainties surrounding the nature and consequences of global warming, there is reasonable confidence that the climate of the Pacific Islands Region will continue to be dominated by the trade winds and convergence zones, by extreme events such as tropical cyclones and storm surges and by the inter-annual and longer variability associated with ENSO. A key question is the extent to which global warming will modify their significant characteristics, and hence the weather and climate of the region.

2.3.3 Recent Trends and Changes in the Global Marine System

During the past 100 years or so some of the physical characteristics of the oceans have changed. Global sea-level rise is one of the most obvious (see Section 2.6), but others include:

- increases in sea-surface temperature;
- decreases in sea-ice cover; and
- changes in wave climate

Globally, the heat content of the ocean has increased. Sea surface temperature (SST) has also increased along with air temperature, though probably not by as much or as rapidly. However, a few areas of the globe have not warmed in recent decades, notably some parts of the Southern Ocean and parts of Antarctica.

Increases in air temperature and SST have resulted in decreases in sea-ice. Sea-ice covers around 10% of the ocean, fluctuating with the seasons. It affects albedo, sea salinity and ocean-atmosphere heat energy exchange. In recent decades spring and summer sea-ice extent and thickness in the Arctic has decreased (the extent by 2.9% per decade). This systematic decrease is consistent with increases in temperature over most of the adjacent land and ocean. Evidence from the Antarctic is less clear, though whaling records since 1931 indicate that the southern limit of whaling, which is constrained by sea-ice, has shifted almost 3° further south, implying a significant decline in the area covered by Antarctic sea-ice between the mid-1950s and early 1970s. As discussed in Section 2.7.1, global warming may increase, at least temporarily, the amount of snow and ice in Antarctica and Greenland.

Decade to decade changes in wave climate (wave height and direction, for example) have not been well documented in the past though there is increasing interest in this topic, especially because of the potential impact on coastal erosion and sedimentation. For example, systematic changes in wave climate associated with ENSO have resulted in alternating periods of shoreline erosion and sand and gravel build-up along the lagoon shore of South Tarawa, Kiribati.

2.4 Global Warming – the Enhanced Greenhouse Effect

Human induced climate change is sometimes referred to as *global warming*, but the changes involve more than just an increase in temperature (see Section 2.5).

For centuries prior to the Industrial Revolution the concentrations of greenhouse gases in the atmosphere remained relatively constant. But since then the concentrations have increased, largely as a result of the combustion of fossil fuels (coal, oil, natural gas) for industrial and domestic purposes, and due to biomass burning and deforestation. For example, the carbon dioxide concentration has increased by more than 30%, and is still increasing at the unprecedented annual average rate of 0.4% (Figure 2.9). The concentrations of other greenhouse gases, such as methane and nitrous oxide, are also increasing, due in the main to agricultural and industrial activities. The concentrations of the nitrogen oxides (NO and NO_2) and of carbon monoxide (CO) are also increasing. While these are not greenhouse gases, they are involved in chemical reactions that result in higher ozone concentrations in the lower atmosphere. Ozone is a greenhouse gas, and its concentration has increased by 40% since pre-industrial times. This increasing concentration of greenhouse gases is exacerbated by chlorofluorocarbons (CFCs) and other chlorine and bromine compounds. These do not occur naturally, but are manufactured for industrial and domestic use. In addition to being strong greenhouse gases they destroy stratospheric ozone (see Box 2.2).

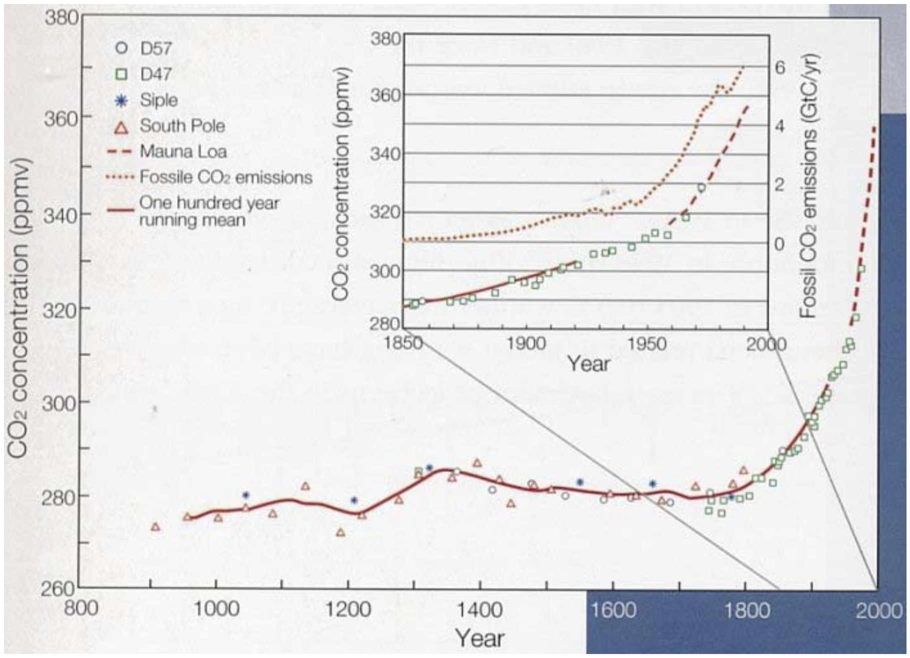


FIGURE 2.9. CO_2 concentrations over the past 1000 years, from ice core records, and since 1958 for the Mauna Loa, Hawaii, measurement site. The smooth curve is based on a 100 year moving average. The rapid increase in atmospheric CO_2 concentration has followed closely the increase in CO_2 emissions from fossil fuel burning (see inset). From IPCC, 1996.

The increased concentration of greenhouse gases in the atmosphere enhances the absorption and emission of long wavelength radiant heat energy. The overall effect is a reduction in the long wavelength energy lost to space. This must in turn be compensated for by an increase in the temperature of the Earth's surface and lower atmosphere. Computer models that simulate many of the complex interactions of the global climate system project a temperature increase to 1.4 to 5.8°C during this century. The range is large, reflecting in the main uncertainties in future emissions of greenhouse gases as well the poorly understood influences of clouds. To place it in context, this increase should be compared to the global mean temperature difference of around 5 to 6°C between the middle of the last Ice Age and the present.

In addition to changing the concentration of greenhouse gases, human activities also increase the amount of aerosols in the atmosphere. The direct effect of aerosols is to scatter some of the short wavelength radiant heat energy back to space, thereby partly, and locally perhaps even completely, offsetting the enhanced greenhouse effect. But some aerosols, such as soot, also absorb short wavelength radiant heat energy, leading to local heating of the atmosphere. Other aerosols absorb and emit long wavelength radiant heat energy, similar to greenhouse gases, thus adding to the enhanced greenhouse effect.

BOX 2.2. Human Activities and the Atmosphere

A. Greenhouse Gases
Greenhouse gases may be naturally occurring or entirely manufactured. They are distinguished from other atmospheric gases by their ability to absorb and emit radiant heat energy at wavelengths lying within the range of the longer wavelength radiant heat energy emitted by the Earth's surface, atmosphere and clouds. This property means that the gases trap radiant heat energy within the Earth-Atmosphere system, resulting in its overall warming. Global warming is an *entirely different* process to stratospheric ozone depletion.

Water vapour, carbon dioxide, nitrous oxide, methane and ozone are the primary greenhouse gases in the Earth's atmosphere. The Kyoto Protocol seeks to limit emissions of these greenhouse gases (other than water vapour) by developed countries. It also covers the greenhouse gases sulphur hexafloride, hydrofluorocarbons and perfluorocarbons.

B. Stratospheric Ozone Depletion
In addition to the above mentioned greenhouse gases there are a number of entirely human-made greenhouse gases, including halocarbons and other chlorine and bromine containing substances. Limitations on their manufacture, export and use are dealt with under the Montreal Protocol.

The Montreal Protocol, including its subsequent amendments and adjustments, is a response to another global environmental issue, the destruction of stratospheric ozone by gases containing chlorine and bromine. While largely inert at the temperatures and pressures prevailing in the lower atmosphere, these gases become highly reactive in the Earth's stratosphere. At these great heights the atmosphere has not yet filtered out the very short wavelength energy emitted by the Sun. Stratospheric ozone is the principal filter of this energy. By decreasing the amounts of ozone more biologically damaging short wavelength (ultraviolet) sunlight is able to reach the Earth's surface. More of this ultraviolet sunlight means more melanoma and non-melanoma skin cancers, more eye cataracts, weakened immune systems in many animals and plants, reduced plant yields, damage to ocean ecosystems, reducing fishing catches and more damage to plastics.

Ironically, in high concentrations ozone is toxic to many life forms. Higher amounts of ozone are increasingly being observed in cities and other areas where photochemical smog is an issue. This ozone has adverse effects on crop production, forest growth and human health. It is clear that protecting stratospheric ozone levels is essential to a healthy planet. So too is preventing ozone formation near the Earth's surface.

Some land-use changes, such as those associated with agriculture, irrigation, deforestation, urbanisation and increased vehicle use, may also modify the climate system, locally, regionally and in some cases globally. Some changes, such as those that alter the reflectivity or roughness of the Earth's surface, or modify the exchange of water vapour and other greenhouse gases, may also contribute to global warming.

Global and regional climate change projections that reflect the ongoing enhancement of the greenhouse effect as a result of human activities are described in the following Section.

2.5 Projections of Future Climate

2.5.1 Global

As discussed in Section 2.1, the complex interactions between and within the various components of the global climate system make it difficult to predict the response of the global climate system to increased greenhouse gas concentrations in the Earth's atmosphere. Sophisticated computer-based *global climate models* are used to estimate winds and ocean currents, the exchange of heat and gases between land, air and ocean, the transport of heat and gases around the Earth, and cloud cover, sea ice and land cover. Such models are computationally expensive – it can take up to two months of computing to simulate one century! For this and associated reasons, complex models of this type are often substituted by simple models that use and estimate only global average values (Figure 2.10).

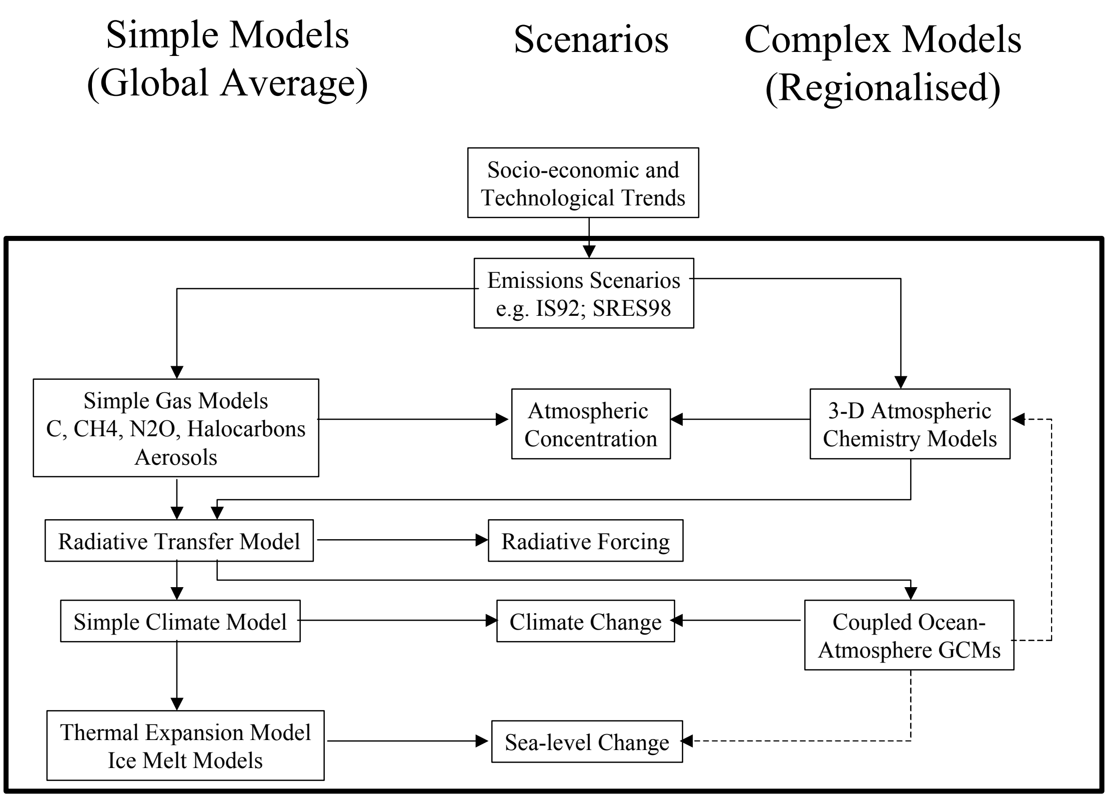


FIGURE 2.10. Alternative, complementary pathways for obtaining projections of atmospheric composition, radiative forcing, climate and sea level. From Carter et al., 2000.

Typically the complex models are started with estimates of gas concentrations for around 1850, and gas concentrations are increased at various rates in order to model selected greenhouse gas emission scenarios (see Box 2.3). Scenarios are used, in part, because no one can be certain about greenhouse gas emissions into the future. These depend on the rate of economic development and other factors that are difficult if not impossible to predict. Since scenarios are used to answer "what if?" questions, we speak of *climate projections* as apposed to climate predictions. Divergences between projected climates as a result of using different scenarios can also shed light on the uncertainties that are a consequence of modelling a complex system and where there is imprecise knowledge of greenhouse gas emissions and other future inputs. There are around 12 research centres worldwide that have each developed a global climate model, with its own set of assumptions and other distinguishing features.

BOX 2.3. Greenhouse Gas Emission Scenarios

The development of climate change scenarios, that serve as input to impact models, often require gas emission or atmospheric concentration scenarios as these are the key drivers of climate change. Emission scenarios attempt to represent the future development of emissions of substances that are potentially radiatively active (e.g. greenhouse gases, aerosols), based on a set of assumptions about future global demographic and socio-economic development and technological change. In 1992 the Intergovernmental Panel on Climate Change (IPCC) presented a set of emission scenarios that were used as a basis for the climate projections in its Second Assessment Report. These emission scenarios are referred to as IS92 scenarios.

In 2000 the IPCC produced a *Special Report on Emissions Scenarios* (SRES) that included a set of four emissions scenarios and their associated socio-economic driving forces. The SRES scenarios were constructed quite differently from those previously developed by the IPCC. They are reference scenarios that seek specifically to exclude the effects of climate change and climate policies on society and the economy. Rather, they are based on a set of narrative storylines which are subsequently quantified using different modelling approaches. The storylines combine two sets of divergent tendencies: one set covering the range between strong economic values and strong environmental values, the other set between increasing globalisation and increasing regionalisation. The storylines are summarised as follows (Carter et al., 2000):

A1: a future world of very rapid economic growth, cultural and economic convergence, low population growth, rapid introduction of new and more efficient technologies and pursuit of personal wealth rather than environmental quality.
A2: a differentiated world, with high population growth, less concern for rapid economic development and a strengthening of regional cultural identities.
B1: A convergent world with rapid change in economic structures, "dematerialization", introduction of clean technologies, and an emphasis on global solutions to environmental and social sustainability.
B2: A world in which the emphasis is on local solutions to economic, social and environmental sustainability and a heterogeneous world with less rapid, and more diverse technological change, but a strong emphasis on community initiative and social innovation to find local rather than global solutions.

Recently the IPCC released its *Third Assessment Report*, which summarises modelling results for a variety of scenarios and model outputs. Globally averaged surface temperatures are projected to increase by between 1.4 and 5.8°C during this century (Figure 2.11), and sea level is projected to rise by between 9 and 88cm (see Section 2.6.1). These projected rates are much larger than the observed changes during the 20th century, and are likely without precedent during at least the last 10,000 years.

FIGURE 2.11 ABOUT HERE

Caption: Historical, human-induced global mean temperature change, and future changes, illustrating both consensus and uncertainties in the temperature projections. From IPCC, 2001.

The consensus scientific opinion is that changes are more likely in the middle of the ranges given above, than at the extremes. For this reason, projections are often presented as the average of the estimates provided by several global climate models, with the results from individual models indicating the level of uncertainty (see Section 2.5.2).

On an aggregated basis the model-based projections suggest that, globally, temperatures will increase faster over land than over the oceans, and at higher latitudes relative to the lower latitudes (Figure 2.12). The Southern Hemisphere will warm more slowly than the globe as a whole because water sinking near the Antarctic carries heat away from the surface to the ocean depths. This also increases the temperature difference between the tropics and the Antarctic, causing an increase in westerly wind speeds. Global precipitation is projected to increase overall (Figure 2.13), with a larger percentage of the annual total occurring as intense rainfall events. Fewer frosts (including those in areas such as the Papua New Guinea highlands) and a smaller range of daily temperatures are likely, with higher risks of summer droughts in mid-latitude continents. Table 2.1 summarises these findings for the globe as a whole.

FIGURE 2.12 ABOUT HERE

Caption: Multi-model ensemble annual mean change of temperature (unit °C) for the B2 emissions scenario, over the period 2071 to 2100 relative to the period 1961 to 1990. From IPCC, 2001.

FIGURE 2.13 ABOUT HERE

Caption: Multi-model ensemble annual mean change of precipitation (unit %) for the B2 emissions scenario, over the period 2071 to 2100 relative to the period 1961 to 1990. From IPCC, 2001.

Table 2.1. Estimates of Changes in Climate and in Extreme Weather Events During the 21^{st} Century
From IPCC, 2001

Phenomenon	Confidence in Projected Changes During 21^{st} Century
Higher maximum temperatures and More hot days over nearly all land areas	Very Likely
Higher minimum temperatures, fewer cold days and fewer frost days over nearly all land areas	Very likely
Reduced diurnal temperature range over nearly all land areas	Very likely
Increase in heat index over land areas	Very likely, over most areas
More intense precipitation events	Very likely, over many areas
Increased summer continental drying And associated risk of drought elsewhere)	Likely over most mid-latitude continental interiors (lack of consistent projections
Increase in tropical cyclone peak wind intensities	Likely, over some areas
Increase in tropical cyclone mean and peak precipitation intensities	Likely, over some areas

2.5.2 Regional

The coupled atmosphere-ocean global climate models described and used above provide only limited regional-scale information because of their coarse spatial resolution – typically 500km horizontally. Three techniques are used to enhance regional detail:

- high, and variable resolution global atmospheric circulation models;
- regional climate models with boundary conditions specified by a global climate model, and
- statistical downscaling methods.

Simulations of present day climate have been used to assess the relative merits of these techniques. At the sub-continental scale the coupled models show seasonal temperature biases of up to 4°C, and precipitation biases mostly between –40 and +80% of observations. Generally the performance of high/variable resolution models improves as resolution increases. Regional climate models driven by observed boundary conditions show area-averaged temperature biases generally within 2°C and precipitation biases within 50% of observations. Statistical downscaling demonstrates similar performance, although results vary with the methods used, and the application.

The variety of approaches is reflected in the following three studies. The *Pacific Islands Regional Assessment of the Consequences of Climate Variability and Change* used two coupled atmosphere-ocean global climate models to project seasonal changes in climate for the Pacific Islands Region and an average of nine coupled global climate models to generate annual means and demonstrate uncertainty in the projections. As part of the Pacific Islands Climate Change Assistance Programme (PICCAP), CSIRO Australia prepared regional climate change scenarios for the Pacific Islands Region. Four regions, covering Micronesia, Melanesia, and north and south Polynesia, were studied. Six model simulations (five coupled ocean-atmosphere models plus a regional climate model nested in a coupled model) were used to generate the regional climate change scenarios. Lal et al. (2002) also used the outputs of five coupled atmosphere-ocean global climate models to estimate regional changes in climate for the remainder of this century. Key results from these studies are presented below.

Table 2.2 presents estimated changes in mean temperature and precipitation from the 1990s to the 2050s, on an annual or half-year basis, along with a measure of the uncertainty as derived from the variability between individual models.

Table 2.2. Changes in Climate from the 1990s to the 2050s Decades, and Associated Uncertainties, in the Pacific Islands Region
(from Lal et al., 2002)

	Projected Change	Range of Uncertainty
Annual Temperature (C)	+1.63	± 0.23
Summer Temperature (C)	+1.65	±0.20
Winter Temperature (C)	+1.61	± 0.27
Annual Precipitation (%)	+4.90	±0.80
Summer Precipitation (%)	+3.70	±1.20
Winter Precipitation (%)	+6.80	±3.30

Regional scenarios for temperature, as estimated by CSIRO, are shown in Table 2.3.

Table 2.3. Scenarios of Temperature Change (°C) for Selected Regions
(from Jones et al., 1999)

Region	Local warming per °C of global warming	Warming to 2050			Warming to 2100		
		Low	Median	High	Low	Median	High
Micronesia	0.7 to 1.0	0.4	0.8	1.3	0.6	1.6	3.5
Melanesia	0.7 to 0.9	0.4	0.8	1.2	0.6	1.6	3.2
Polynesia N	0.8 to 1.0	0.4	0.8	1.3	0.7	1.6	3.5
Polynesia S	0.7	0.4	0.7	0.9	0.6	1.4	2.5

Even more detail can be seen in Figure 2.14, which presents projected changes in surface air temperature for two time periods (2025-2035; 2090-2099) relative to 1961-1990. Outside the continental areas, warming is projected to be greater in a region along and slightly south of the equator, extending from the dateline in the west to the South American coast in the east, and in a region that extends east-northeast from the equatorial Central Pacific to the southwest coast of the North American continent. A similar, but smoother, pattern is shown for the nine model ensemble projection of air temperature change from 1960-1990 to 2071-2100 (Figure 2.15).

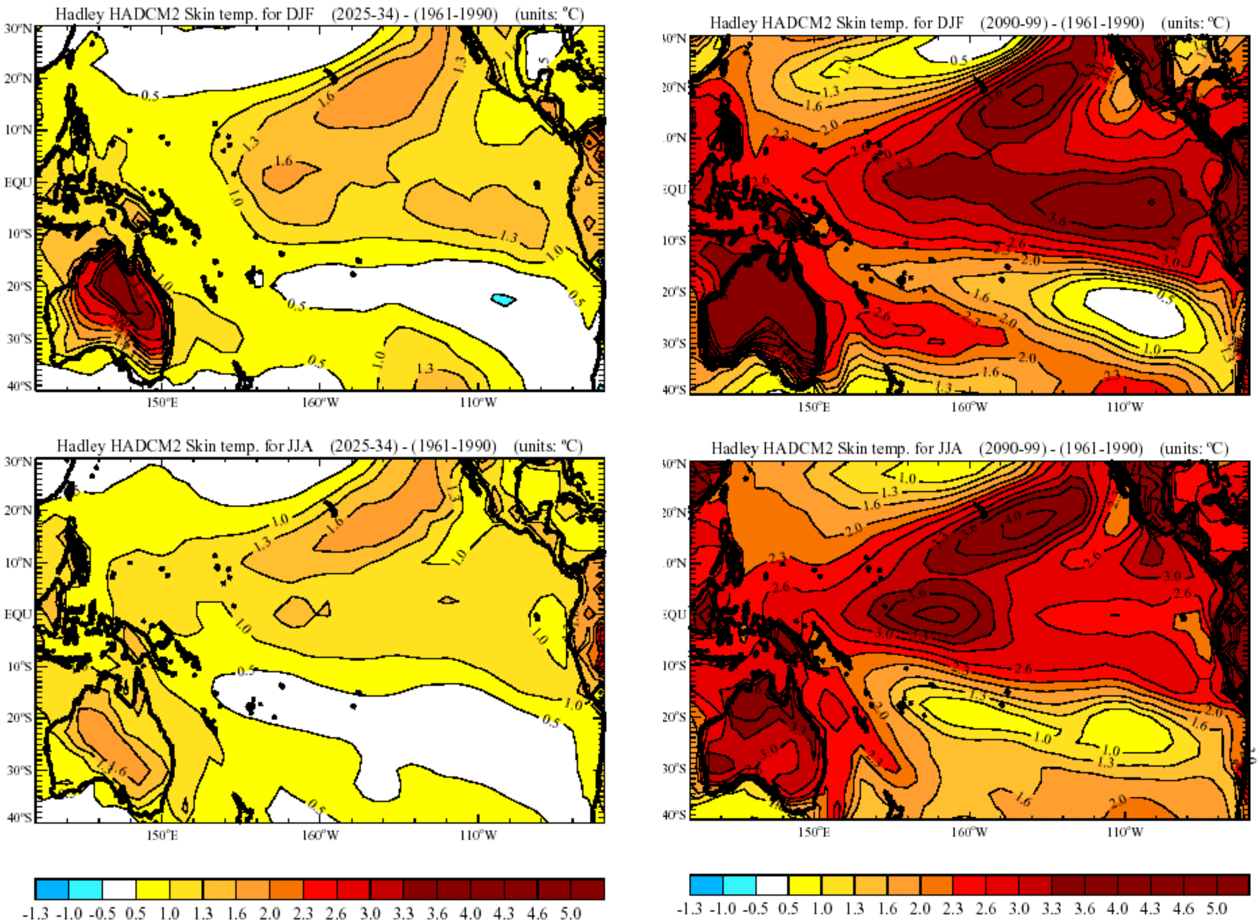


FIGURE 2.14. (a - left) Projected changes in surface air temperature (°C) for December through February (upper) and June through August (lower) 2025-2034, relative to 1961-1990; (b - right) as for (a), but for 2090-2099 relative to 1961-1990. From Shea et al., 2001.

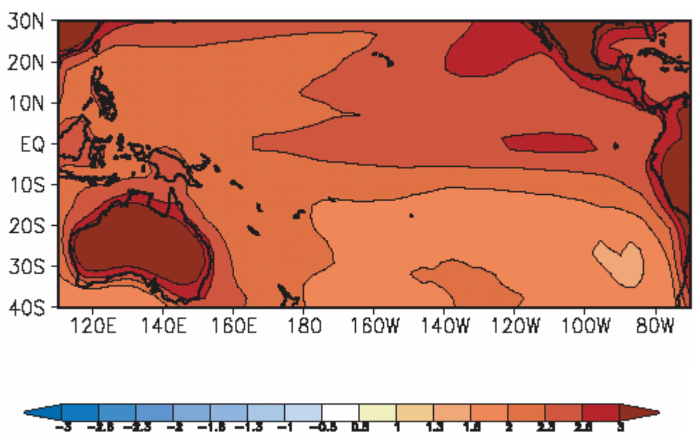


FIGURE 2.15. Projected changes in surface air temperature (°C) for 2071-2100, relative to 1961-1990, based on a nine model ensemble. From Shea et al., 2001.

The areas likely to experience the greatest increase in rainfall (Figure 2.16) are in general those where warming is projected to be greatest, for higher surface temperatures will typically favour more convection, cloud formation and often precipitation. This is especially the case in summer months (December through January), when surface temperatures are more likely to exceed the threshold for convection. While the projected changes in annual precipitation, using the nine model ensemble again show less detail, the consistent increase in precipitation along the equator east of the dateline is clearly evident (Figure 2.17). Increases in daily rainfall intensity are expected in many regions, including those where rainfall is projected to increase, remain the same or decrease slightly. Even with an appreciable decrease in average rainfall, reductions in daily rainfall intensity may well be negligible. The results concerning rainfall intensity come from a number of models and studies, so have a high confidence.

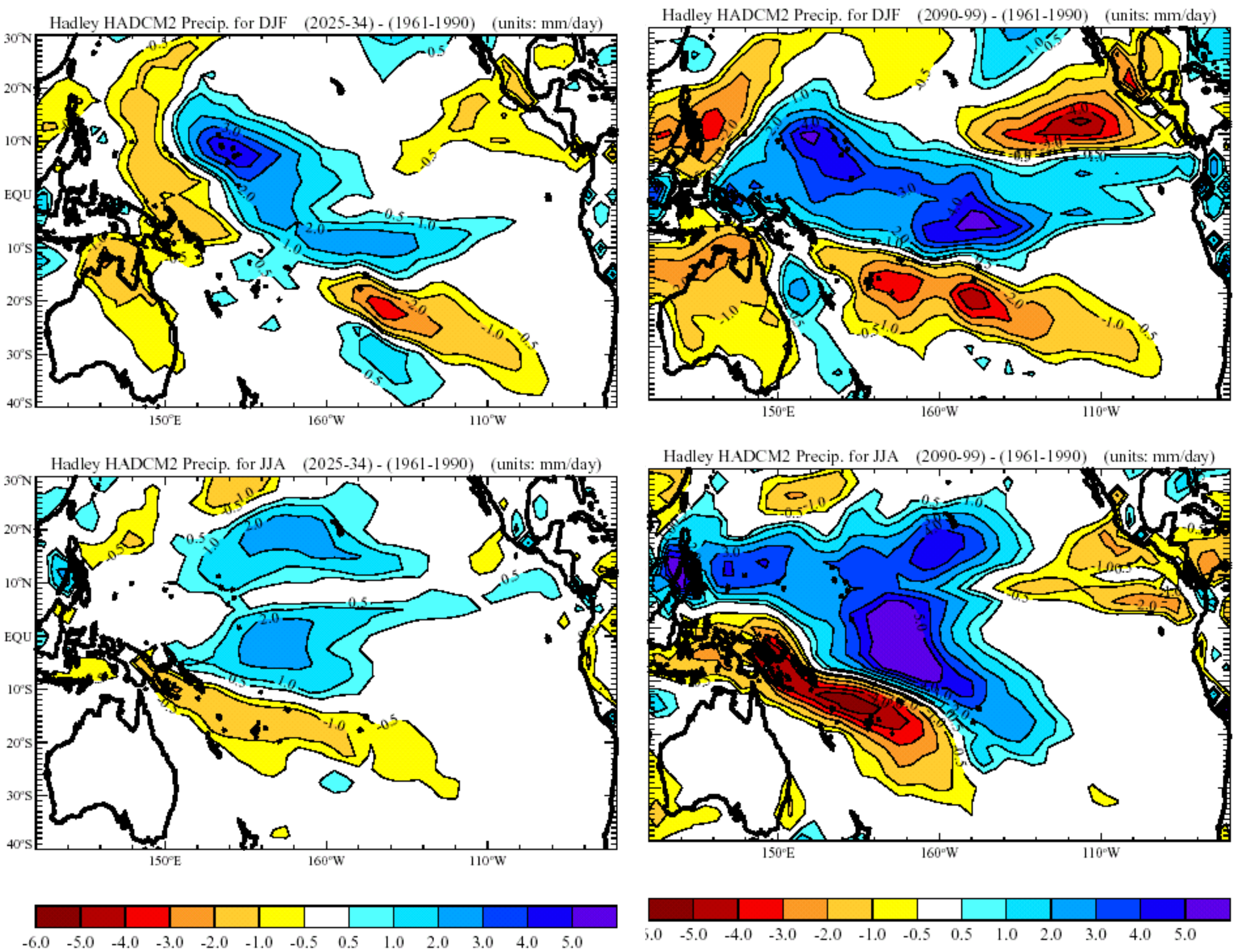


FIGURE 2.16. (a - left) Projected changes in precipitation (%) for December through February (upper) and June through August (lower) 2025-2034, relative to 1961-1990; (b - right) as for (a), but for 2090-2099 relative to 1961-1990. From Shea et al., 2001.

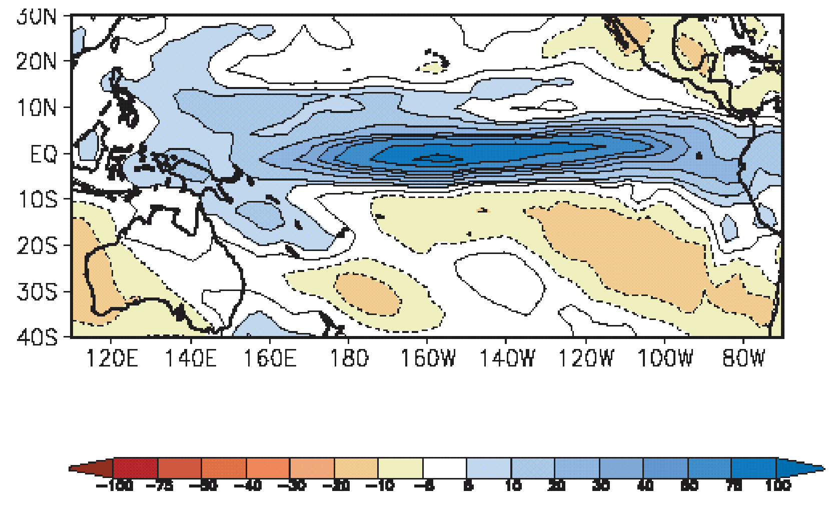


FIGURE 2.17. Projected changes in precipitation (%) for 2071-2100, relative to 1961-1990, based on a nine model ensemble. From Shea et al., 2001.

The increase in both temperature and precipitation in the eastern Pacific, along the equator, is termed an ‘El Niño-like response’ (see Box 2.1). Recently, CSIRO scientists have shown that global warming may initially be associated with a weakening of the strong equatorial upwelling in the eastern Pacific, resulting in a delay in warming and the appearance of a La Niña-like pattern. This is followed by an El Niño-like response, triggered by warm extratropical water from the northern Pacific penetrating through subsurface layers to the tropics. These findings provide an explanation for the appearance of an El Niño-like warming pattern in observational data only since the 1970s and its absence, despite global warming, prior to that time.

ENSO is likely to remain a key driver of climatic variability in the Pacific Islands Region, even with climate change. Recent modeling studies indicate more El Niño-like conditions with global warming, that is a greater warming of surface temperatures in the eastern tropical Pacific than in the west. This change can be expected to increase the frequency of El Niño conditions and reduce the frequency of La Niña conditions, relative to the current climate.

The causal relationship between sea surface temperature and the formation of tropical cyclones suggests that the intensity, frequency and distribution of tropical cyclones may change in the future. However, the evidence inferred from models based on this relationship is considered ambiguous (see Section 2.4). Similarly, with ENSO, though there is some evidence to suggest El Niño-like conditions may become more frequent with global warming.

But while there is no evidence that tropical cyclone numbers may change with global warming, a general increase in tropical cyclone intensity, expressed as possible increases in wind speed and decreased central pressures by 5 to 10%, and mean and peak precipitation intensities by 20 to 30% at the time of CO_2 doubling, now appears likely. No significant change in regions of formation have been noted in modelling studies, although it is possible that the area of cyclone formation may extend further eastward given the increasing sea surface temperatures. The regions of formation may also change in response to long-term changes to ENSO. There appear to be no major changes in regions of occurrence, except that tropical cyclones may track further poleward.

At higher latitudes of the Pacific Islands Region changes in the frequency of extratropical storms with global warming is of concern. An index that measures such changes in storminess is given by the variability of sea-level pressure over the time period of 2.5 to 8 days. This index is plotted in Figure 2.18, for two periods (2006-2036 and 2070-2100), compared to a baseline period of 1990-2020. In the near future, increased storminess is projected for a region extending north and east of the Hawaiian Islands to the area north of the Federated States of Micronesia and westward to the Commonwealth of the Northern Mariana Islands. Towards the end of this century the storminess in this region is likely to be further enhanced, and the area enlarged to encompass the entire Hawaiian Islands as well as most of the Federated States of Micronesia and the Republic of the Marshall Islands. The equatorial region between 100°W and the dateline, including Kiribati, is also expected to experience more storminess. On the other hand, the southern hemisphere between 10° and 30°S and 170°E and 90°W, is projected to experience decreased storminess, with precipitation decreases also likely. This would include Fiji and eastward to French Polynesia.

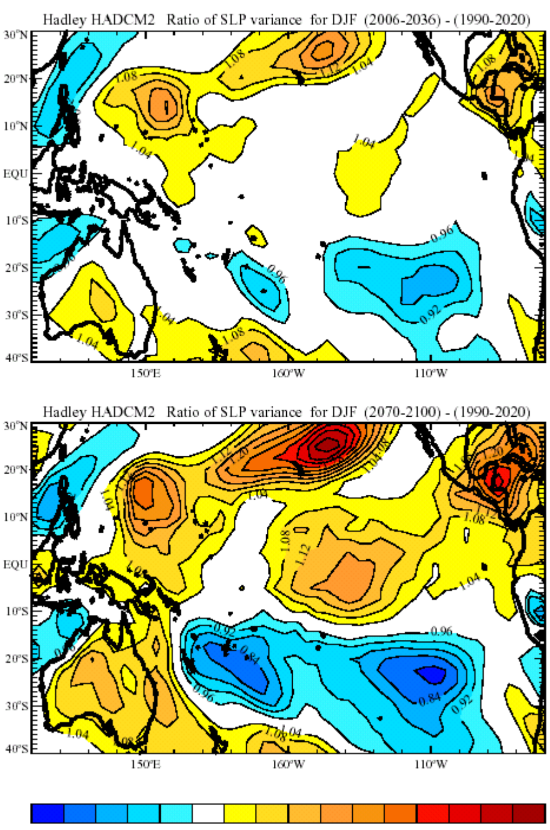


FIGURE 2.18. Caption: Index of storminess in December through February, as given by the variability of sea-level pressure over the time period of 2.5 to 8 days, for 2006-2036 (upper) and 2070-2100(lower), relative to 1990-2020. From Shea et al., 2001.

2.5.3 Impact of Global Warming on Marine Systems, and Feedback to Climate

It is evident from the preceding discussion, and Section 2.4, that future global warming will induce ocean temperature increases and changes in sea level, sea-ice coverage and ocean circulation, though it is not expected that weakening of the major ocean heat conveyer (Figure 2.3(b)) will be affected until the 22^{nd} Century.

Global warming will cause the oceans to warm and expand, thus increasing sea level. Thermal expansion is estimated to have contributed between 3 and 7 cm to sea-level rise during the last 100 years (see Section 2.6.1). The projected changes in climate should produce large reductions in the extent, thickness and duration of sea-ice. Because sea-ice insulates the sea from heat loss during winter, this will reinforce climate warming at high latitudes.

Global warming is also expected to have an impact on the processes controlling biogeochemical cycling of elements in the oceans, with potential feedback on the various components of the carbon cycle. These impacts include the uptake of, and storage capacity for CO_2, by both physico-chemical and biological processes. The net effect of marine biota storing CO_2 and releasing it to the atmosphere from carbon-enriched deep water carried to the surface is not expected to be large. There is, however, some evidence to suggest that a reduction of ocean circulation and vertical mixing will increase oceanic carbon storage slightly. Shifts in the structure of biological communities in the upper ocean could also alter the downward fluxes of organic carbon, and consequently the efficiency of the ocean's biological pump.

2.6 Sea Level Projections: Global and Regional

2.6.1 Global Sea-level Rise

Globally sea level has risen over the last one hundred years. But regional sea level has changed – in some places rising, some staying the same and some falling (relative to a fixed point on the land). Similarly, into the future, mean sea level averaged around the world will gradually rise, as a result of global warming, and primarily as a consequence of:

- the continued melting of mountain glaciers and small ice caps; and
- the expansion of sea water (thermal expansion) as a result of the increase in sea water temperature.

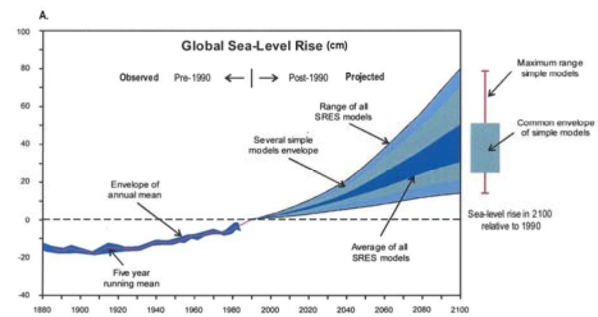
The latter is of greater importance. When water warms it expands. Since the oceans are confined in the horizontal the expansion must manifest as a rise in sea level.

This is believed to have been the main cause of the increase in global sea level over the last hundred years. Paradoxically, immediate reductions of the largest bodies of ice in the world (Antarctica and Greenland) are less likely. Global warming may in fact increase the amount of snow and ice in both places, with the stored water thus reducing the rate in rise of sea level. Less well known is the role of the amount of water stored on land in constructed reservoirs and in aquifers.

Based on tide gauge data, the rate of global average sea level rise during the 20th C has been in the range of 1 to 2 mm/yr, with a central value of 1.5 mm/yr. Due to global warming, this rate is expected to increase from 1 to 7 mm/yr, with a central estimate of 4 mm/yr. The difference between past and projected sea-level rise, and the relative importance of the several factors contributing factors to that rise, is shown in Box 2.4.

Box 2.4. Characterising and Projecting Sea-level Rise

Figure right. Global sea-level rise, and its components, pre-1990 and post-1990. The left hand side of the upper diagram shows a composite sea level curve from 1880 to 1990, based on observations from tide gauge stations, Data are shown relative to 1990 and with a five-year moving average represented by the red line. The blue envelope represents the range of annual mean sea levels (based on Figure 1b from Gornitz, 1995).



B.

Global Sea-Level Rise Components (mm/yr)

Component	Pre-1990 Low	Pre-1990 Middle	Pre-1990 High	Post-1990 Low	Post-1990 Middle	Post-1990 High
Thermal expansion	0.3	0.5	0.7	1.0	2.45	3.90
Glaciers + ice sheet adjustment	0.2	0.55	0.9	0.09	1.09	2.09
Greenland	0	0.06	0.1	-0.18	0.36	0.81
Antarctica	-0.2	-0.1	0	-1.54	-0.72	0.18
Permafrost + sed. deposition	0	0.05	0.1			
Terrestrial storage	-1.1	-0.35	0.4			
Total	-0.8	0.7	2.2	1.0	4.0	7.0
Observed (1910-90)	1.0	1.5	2.0			

The right hand side of the upper diagram shows the projected global average sea level rise from 1990 to 2100 for the SRES scenarios (see Box 2.3). Thermal expansion and land ice changes were calculated using a 'simple' (global average) climate model calibrated separately for each of seven coupled general circulation models. Contributions from changes in permafrost, the effect of sediment deposition and the long-term adjustment of the ice sheets to past climate change were incorporated in the calculations. The dark blue shading shows the range of the average of all 35 SRES scenarios. The green shading shows the range of sea-level rise for the simple model when it is tuned to a number of complex models with a range of climate sensitivities. The region delimited by the outermost lines shows the full range of all coupled general circulation models and SRES scenarios, including uncertainty in land-ice changes, permafrost changes and sediment deposition.

On the extreme right of the upper diagram the range of sea level projections at 2100 is shown. The green block is the common envelope covered by the 'simple' model for the six illustrative SRES scenarios and the red bar the maximum range covered by those models (modified from IPCC 2001).

The table quantifies the components of sea-level rise, pre-1990 and post-1990, and in mm/yr. The pre-1990 values are based on observations and models over the period 1910 to 1990. In the table 20thC melting from glaciers and ice sheet adjustments since the Last Glacial Maximum have been combined, as have permafrost melt and sediment deposition in the ocean. Terrestrial storage is not directly related to climate change (data from IPCC, 2001). The post-1990 values are based on IPCC 2001, and have been converted from metres for the 110 year period (1990-2100) to mm/yr to enable comparison with the pre-1990 values. The values relate to sea-level rise due to climate change derived from experiments using coupled general circulation models and the IS92a scenario, including the direct effect of sulphate aerosols.

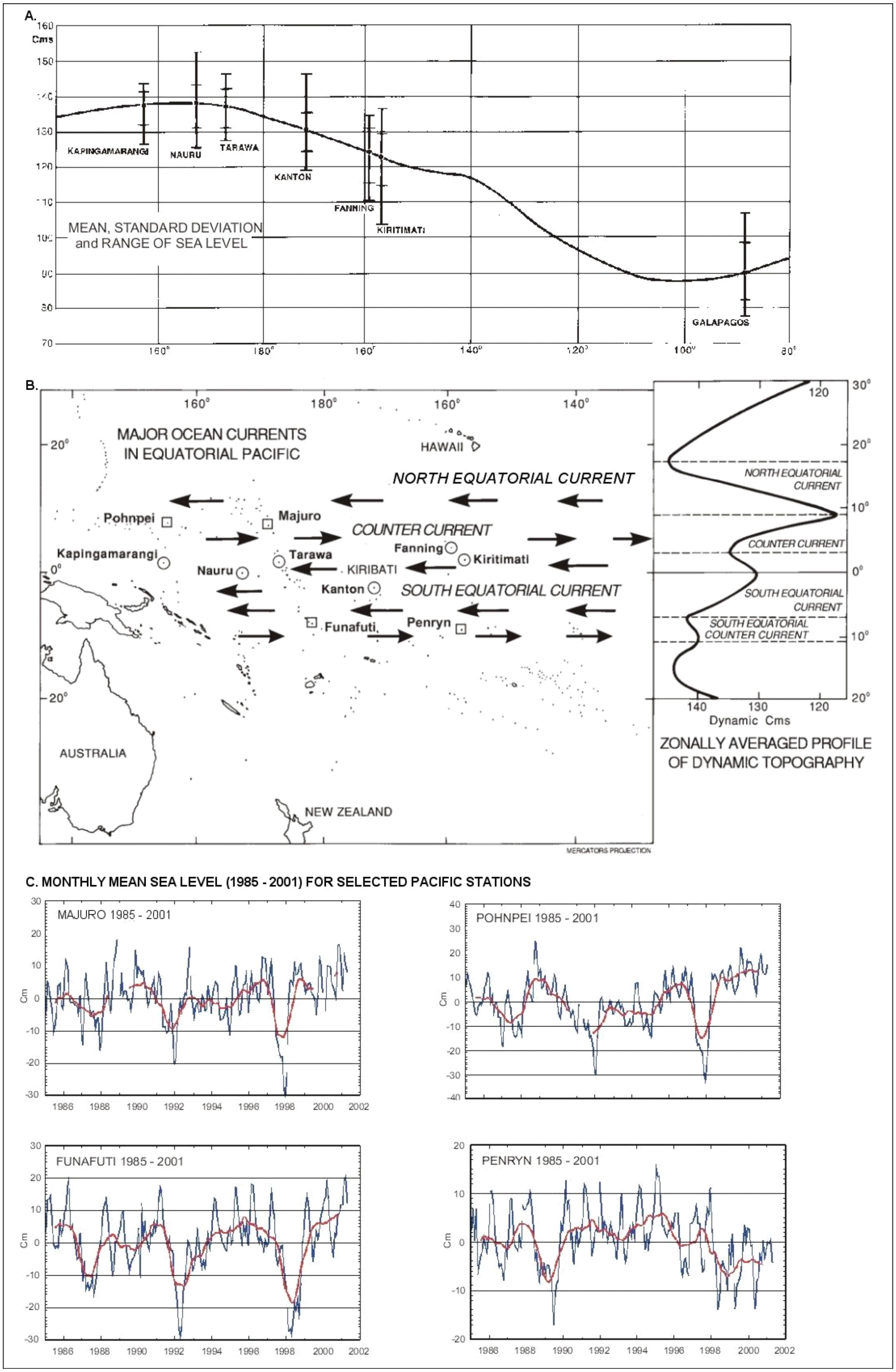
2.6.2. Regional Sea-level Change

Accompanying the global rise in ocean level are additional changes that contribute to regional and local variations in relative sea-level trends, which may exacerbate or reduce any global effect. These include uplift or sinking of the land as a result of crustal movements, and loading or unloading of the Earth's surface due to changes in the overlying mass of water or ice. Other variations are associated with local climatic and meteorological conditions (e.g. variations in air pressure, wind strength and direction), hydrological regimes (e.g. river discharge of freshwater) and with oceanographic conditions (e.g. strength and direction of ocean currents, sea waves and swell). Such changes may be permanent or short term, the latter resulting in variations in sea level rather than persistent changes. Thus the level of the sea in relation to the land at a particular place results from a combination of both global and local factors, with the significance of the latter varying in time and space.

These local and regional factors will continue to influence sea level in the 21st C, and at rates which are unaffected by climate change. They should be added to, or subtracted from, global sea-level rise. However, on account of a future increases in the rate of rise as a consequence of global warming, it is expected that by 2100 many regions currently experiencing relative sea level fall, due to occasional or ongoing uplift of the land, will instead experience a rising relative sea level. An example is Rabaul, in Papua New Guinea (see Section 2.6.3).

While the islands of the Pacific have been subject to long term sea-level changes of the same order of magnitude as other coastal regions in the world, in the last several decades variability in sea level rather than persistent rise has been of greater significance in the region. The interannual variability associated with ENSO is of particular importance (see Figure 2.19). During the 1982-83 El Niño event the variability in monthly mean sea level ranged from 32 cm at Penryn to 54 cm at Pohnpei.

FIGURE 2.19. (see next page for figure) Sea-level variability in the Pacific. (a) Sea level near the equator during the 1982-83 El Niño event. Vertical bars show the standard deviations of monthly mean sea level at each station as well as the highest and lowest monthly mean relative to the long-term mean at each station prior to 1982 (after Wyrtki, 1984, Figure 1). (b) Ocean currents in the equatorial zone and the dynamic topography in a north to south cross-section on right. Stations shown in circles are those in (a), above. Stations shown in squares are those in (c), below. (c) Four recent sea level records from Pacific Island stations 1985 – 2001, illustrating the high inter-annual variability resulting from variations in ENSO (data from University of Hawaii Sea level Center).


A.
MEAN, STANDARD DEVIATION and RANGE OF SEA LEVEL
KAPINGAMARANGI
NAURU
TARAWA
KANTON
FANNING
KIRITIMATI
GALAPAGOS
B.
MAJOR OCEAN CURRENTS IN EQUATORIAL PACIFIC
HAWAII
NORTH EQUATORIAL CURRENT
Pohnpei
Majuro
COUNTER CURRENT
Kapingamarangi
Tarawa
Fanning
Kiritimati
Nauru
KIRIBATI
Kanton
SOUTH EQUATORIAL CURRENT
Funafuti
Penryn
AUSTRALIA
NEW ZEALAND
NORTH EQUATORIAL CURRENT
COUNTER CURRENT
SOUTH EQUATORIAL CURRENT
SOUTH EQUATORIAL COUNTER CURRENT
Dynamic Cms
ZONALLY AVERAGED PROFILE OF DYNAMIC TOPOGRAPHY
MERCATORS PROJECTION
C. MONTHLY MEAN SEA LEVEL (1985 - 2001) FOR SELECTED PACIFIC STATIONS
MAJURO 1985 - 2001
POHNPEI 1985 - 2001
FUNAFUTI 1985 - 2001
PENRYN 1985 - 2001
Cm

2.6.3 Future Sea Levels in the Pacific Islands Region

To determine the practical implications of projections of global sea level rise in particular islands and coastal regions, it is necessary to include both global and local components in order to provide estimates of relative sea level change. Figure 2.20 shows projected changes in sea level (m) for 2020-2040 (upper) and 2080-2099 (lower), relative to 1961-1990.

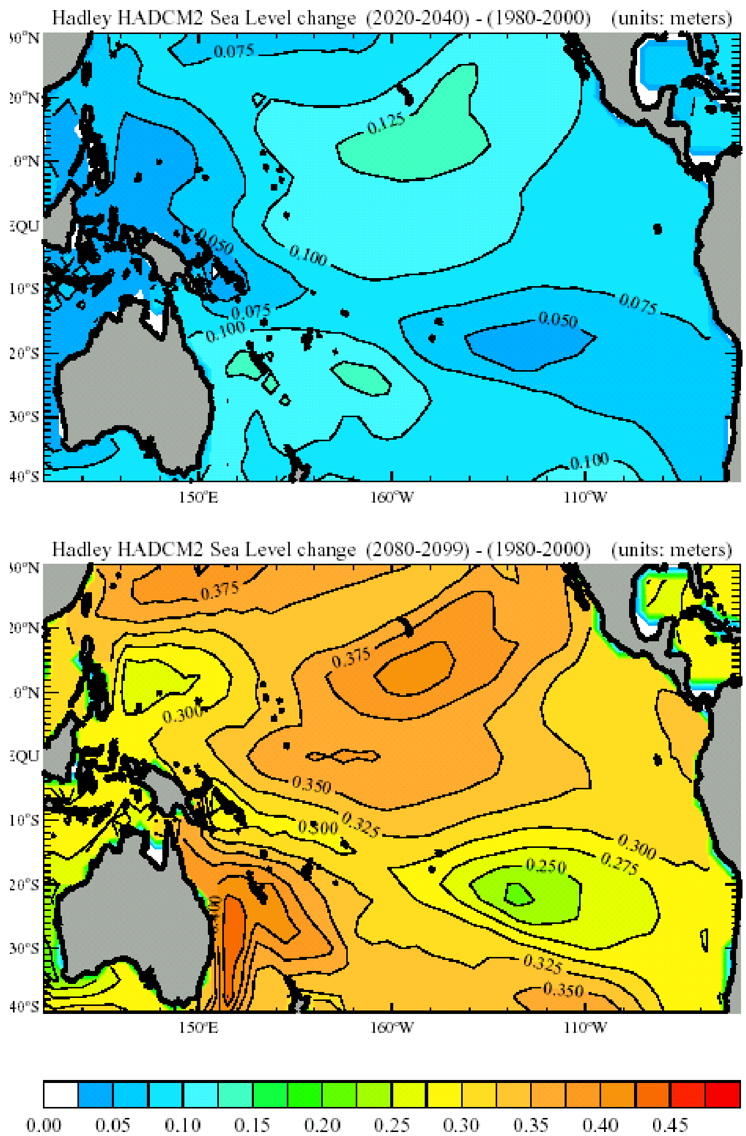


FIGURE 2.20. Projected changes in sea level (m) for 2020-2040 (upper) and 2080-2099 (lower), relative to 1961-1990. From Shea et al., 2001.

A simple method for computing local projections of mean sea-level rise uses historical observations at a site and projections of global average sea level. To allow for local land movements, and our current inability to model sea level change accurately, the historical record is extrapolated linearly, to which a globally averaged projection is added. To avoid double counting, it is necessary to correct the global projection for the corresponding modelled trend of sea level rise during the period of the historical observations.

Figure 2.21 shows the result of using this method (see Box 2.5 for details) to estimate sea level changes for six tide gauge stations in the Pacific. The sea-level monitoring stations presented in the figure include Rabaul in Papua New Guinea where sea level has been falling at a rate of over – 2 mm/year (as a result of land uplift); Kiritimati (Christmas Island) in Kiribati where mean sea level has remained stable (0.0 mm/yr) and four other stations where sea level has been rising at rates ranging from 0.07 mm/yr to 2.9 mm/yr.

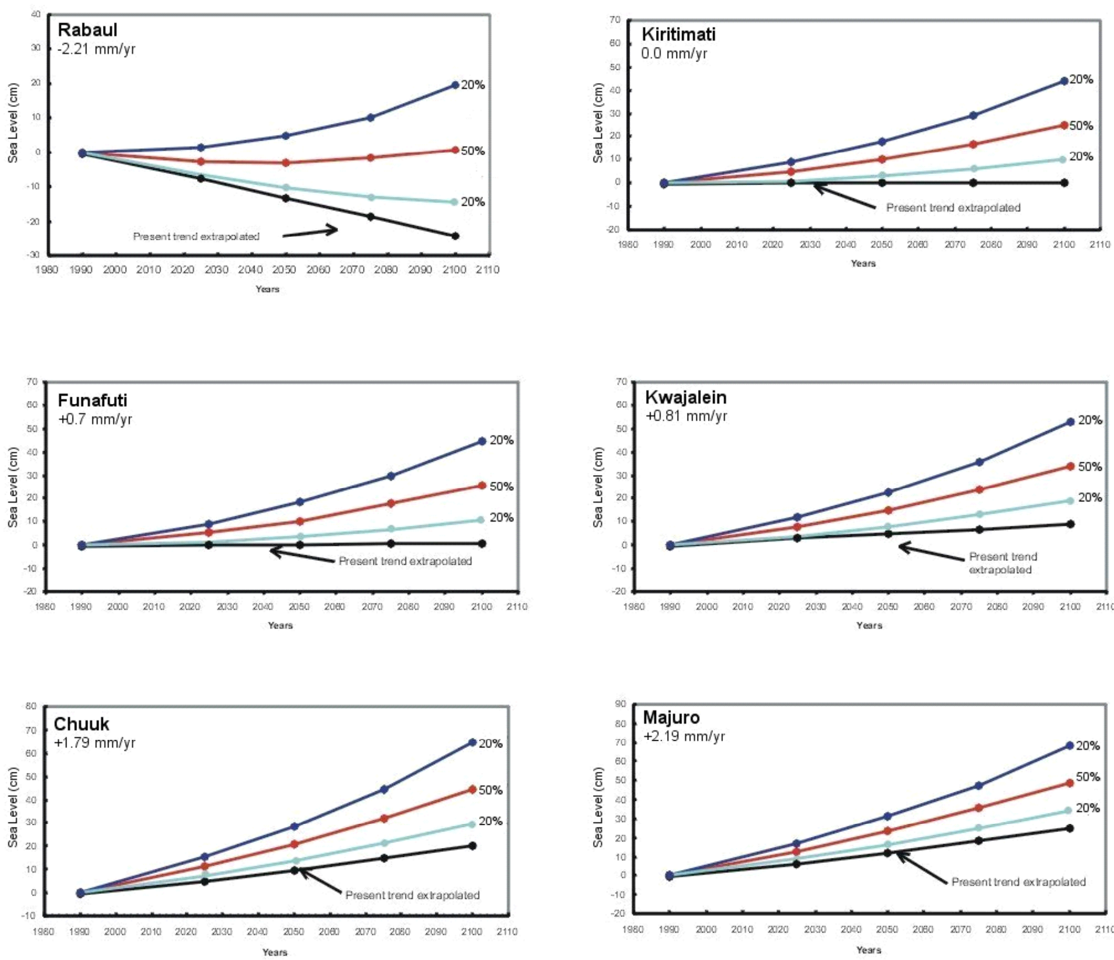
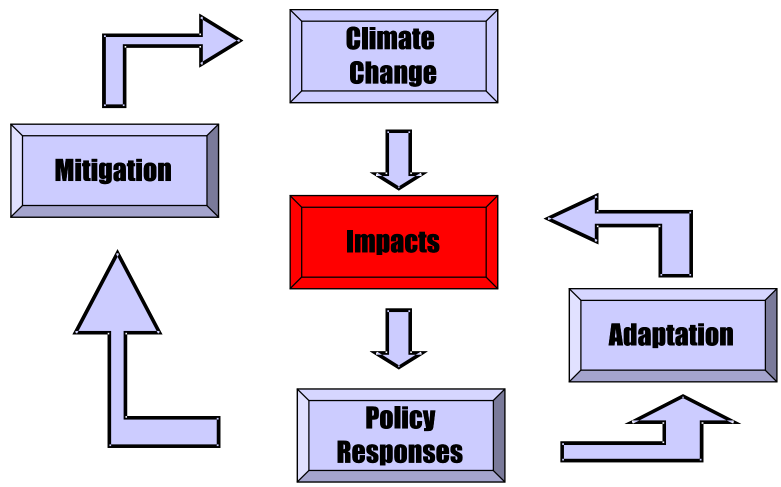


FIGURE 2.21. Sea level projections for selected Pacific Island locations.

Box 2.5. A Simple Method for Computing Local Projections of Mean Sea-level Rise

Historic trends of sea level for Pacific stations were taken from the University of Hawaii archive which has at least 25 years of hourly data. The overall average relative sea level trend for a number of Pacific stations cited by Mitchell et al (2000) is +0.77 mm/yr. The graphs in the figure have been calculated following the approach recommended in Titus and Narayanan (1996) using the normalised values contained in their Table V (page 204). For example, if sea level is currently rising at 2.19 mm/year at Majuro, then under current trends sea level will rise 13.1 cm between 1990 and 2050. Adding 13.1 cm to the normalised values, the median estimate for Majuro in 2050 is 23.1 (i.e. 13.1 + 10 cm), with a 20 % chance (80 % cumulative probability on Table 9.1) of a rise greater than 31.1 cm (i.e. 13.1 + 18 cm) and a similar 20 % chance (20 % cumulative probability) of a rise of less than 16.1 cm (ie 13.1 + 3 cm). Because even current trends would result in a rise of 13.1 cm, the total rise in Majuro is most likely to be 23.1 cm; but there is also has a 20% chance of exceeding 31.1 cm and a 20% chance of being less than 16.1 cm. The normalised projections estimate the extent to which future sea level rise will exceed what would have happened if current trends simply continued. Implicit in the calculations is that sea level has risen by about 0.5 mm/yr over the last century as a result of global warming.

The foregoing procedures have been advocated in the IPCC WG1 chapter *Changes in Sea Level* (IPCC, 2001). It should be noted that the science of predicting sea-level change is still evolving and there is need for more critical and quantitative assessments of model uncertainties than is possible at present.



Chapter 3. Consequences of Climate and Sea-level Variability and Change

Key Findings:

- Countries of the Pacific Islands Region may well be among the first to suffer the adverse impacts of climate change, and the first to be forced to adapt;
- Most of these countries are already experiencing disruptive changes consistent with many of the anticipated consequences of global climate change, including extensive coastal erosion, droughts, coral bleaching, more widespread and frequent occurrence of mosquito-borne diseases and higher sea levels making some soils too saline for cultivation of traditional crops;
- While much attention is focused on global warming causing gradual, long-term changes in average conditions, the most immediate and more significant impacts are likely to arise from changes in the nature of extreme events (e.g. flooding, tropical cyclones, storm surges) and climate variability (e.g. drought, prevailing winds accelerating coastal erosion);
- Present problems resulting from increasing demand for water, from increasing pollution of water and from current patterns of extreme events and climate variability dwarf those which will result from climate change over the next few decades, in all but a few countries in the Pacific Islands Region;
- Examination of the impacts of climate extremes and variability, including those associated with seasonal and interannual phenomena, offers valuable insight into the likely potential effects of climate change on agriculture;
- Given that in the Pacific Islands Region most good quality land is already under intense cultivation, increasing population numbers combined with climate change impacts will threaten food security, as will the increasing reliance on imported food and the consequential vulnerability to short term breaks in supply and world food shortages due to climate events;

- Even though terrestrial and freshwater ecosystems have been able to evolve and adapt over time to both climate extremes and variability and to human pressures, there are indications that changes in climatic conditions coupled with unsustainable use will render terrestrial and freshwater ecosystems increasingly vulnerable in the longer term;
- Many of the likely impacts of climate change on coastal zones and marine ecosystems are already familiar to island populations, and some have experience in coping with them; however, in most countries and for most coastal and marine areas, coping with climate extremes and variability will be even more demanding over the next few decades;
- The impacts of climate variability and change on human health are most likely to be adverse in nature, and frequently will arise through initial impacts on ecosystems, infrastructure, the economy and social services;
- For example, economic hardship resulting from the diverse but collective impacts of climate variability and change may well become one of the key factors exacerbating and perpetuating impacts on human health; poverty is likely to contribute to most if not all health impacts and to the reduced capacity and ability of individuals and communities to cope with them;
- The increasing "urbanness" and centralization of Pacific Island populations is increasing the likelihood of adverse impacts from climate variability and change, while repairs and rehabilitation for rural populations after an extreme event may well receive decreasing priority;
- The possibility of more extreme events, such as tropical cyclones and storm surges, coupled with currently projected rates of sea-level rise and flooding, places critical infrastructure such as health and social services, airports, port facilities, roads, vital utilities such as power and water, coastal protection structures and tourism facilities at increased risk;
- A high island such as Viti Levu could experience average annual economic losses of $US23 to 52 million by 2050, equivalent to 2 to 4% of Fiji's GDP;
- A low group of islands, such as Tarawa atoll, could face average annual damages of $US8 to 16 million by 2050, as compared to a current gross domestic product (GDP) of $US47 million; and
- These indicative costs could be considerably higher in individual years when extreme events such as cyclones, droughts or significant storm surges occur.

3.1 Framework and Methods for Assessing Impacts

3.1.1 The Wider Context of Impact Assessment

Two fundamental questions arise when developing and assessing policy and planning responses to climate change. These are:

- What are the potential impacts on the natural and human systems of Pacific Islands; and
- How vulnerable will these systems be, even after adaptation strategies have been invoked?

In order to answer these and related questions a systematic framework for vulnerability assessment is needed (see Figure 3.1). The wider context is illustrated in Figure 1.2 (see also figure heading this chapter). In practice, a methodology, or series of methodologies, is required for each of the components of the framework. As an example, Figure 3.2 shows the steps to be followed when assessing potential impacts.

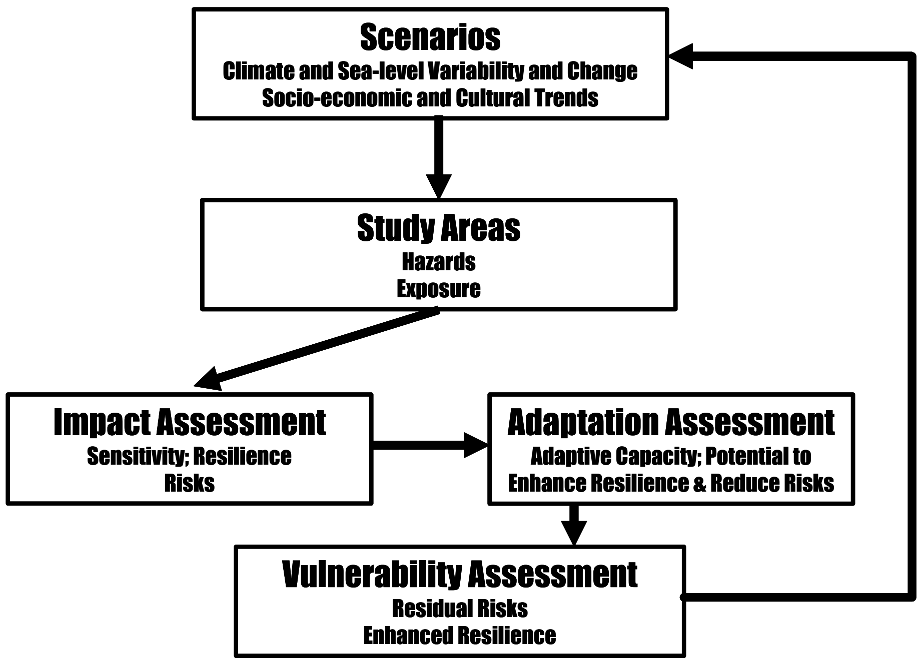


FIGURE 3.1. Framework for studies culminating in an assessment of vulnerability and adaptations to climate variability and change, including sea-level rise.

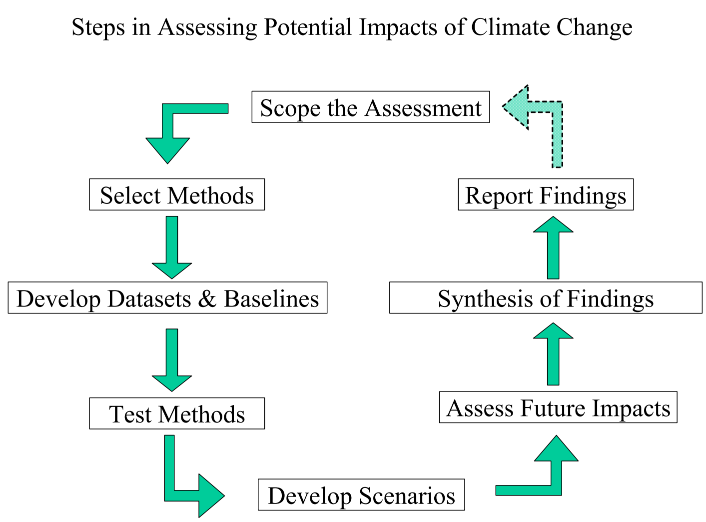


FIGURE 3.2. Steps in assessing the potential impacts of climate variability and change, including extreme events.

Impact assessment characterizes the *potential* effects of climate and sea level variability and change on both natural and human systems. Adaptation assessment builds on the findings of the impact assessment and identifies actions that will reduce adverse impacts and exploit those that have beneficial consequences. Vulnerability assessment characterizes any residual adverse impacts, i.e. negative impacts that will likely occur, despite efforts to adapt.

Since the early 1990s various methods and approaches to impact assessment have been developed and applied. Generally these have used a step-wise framework similar to that in Figure 3.2, with refinement dependent on whether the prime purpose is to identify adaptation options or consider the vulnerability of a natural system, economic sector, a particular area, region or island, or a country as a whole. An example of an approach developed for specific application to the coastal zone is shown in Box 3.1. Key to the assessment is defining and placing manageable boundaries on the problem, identifying and applying methods that are appropriate to the local circumstances, developing scenarios of both environmental and socioeconomic changes, identifying how the systems will adapt without direct intervention (termed autonomous adaptation) and select and evaluate deliberate interventions that will reduce the adverse impacts.

The present chapter focuses on the identification and characterization of the potential impacts related to climate change. This requires application of a variety of methods designed to assess impacts, including development of scenarios.

BOX 3.1. Methods for Climate Variability and Change Impact Assessment and for Identification of Adaptation Strategies in Coastal Areas. From UNEP, 1998.

Nature and scope of the problem
- Delineation of the study area
- Absolute and relative sea-level change
- Biogeophysical effects and socio-economic impacts

An array of methods
- Acquisition and management of data
    - Global sea-level changes
    - Coastal topography and land use
    - Socio-economic data
    - Management of data
- Index-based approaches
- Methods for assessing biogeophysical effects
    - Increasing flood-frequency probabilities
    - Erosion and inundation
    - Rising water tables
    - Saltwater intrusion
    - Summary
- Methods for assessing potential socio-economic impacts
    - Population
    - Marketed goods and services
    - Non-marketed goods and services

Scenarios
- Relative sea-level rise
- Other scenarios

Autonomous adaptation

Planned adaptation
- Identification of adaptation options
- Evaluation of adaptation options

Summary and implications

3.1.2 Methodologies for Impact Assessment

Climate impact assessment is the practice of identifying and evaluating both the detrimental and beneficial affects of climate change on natural and human systems. Methodologies for impact assessment vary greatly between the different systems and sectors that are being assessed. However, five general analytical methods for climate impact assessment can be identified, namely:
- Experimentation;
- Modelling;
- Use of empirical analogues;
- Expert judgement; and
- Use of anecdotal information

Experimentation

Experimental approaches are difficult to apply given that the system being studied is typically large and involves human subjects. Only when the scale of impact is within manageable bounds, the impacts measurable and the environment conditions controllable, can experiments be usefully conducted. Most experimentation has involved growing plants under controlled environmental conditions that are thought to be representative of future climatic regimes. Usually experiments of this type are both expensive and time consuming. Another area where experimentation will yield useful information is in studying the effects of water quality and soil quality, including nutrient availability as a result of leaching and erosion resulting from climate extremes or change. Yet another area is testing new building materials for their resilience under changed climatic conditions. Such experimental information is also very useful in calibrating, testing and validating impact models.

Modelling

Several categories of models are used in impact studies. In addition to the models used to estimate and characterize future climatic conditions at given time and space scales, and for a range of climatic variables, separate or coupled models can be used to estimate how natural and human systems, or selected components, respond to both current and projected climatic conditions. The models may be based on statistical relationships, derived using observed data, process-based models founded on theoretical relationships or, more commonly, a combination of the two. Economic models may, in turn, be used to evaluate the implications of climate change for local and regional economies. Integrated assessment models take into account climate change induced impacts, and incorporate feedbacks and policy interventions. Initiatives undertaken on behalf of Pacific Island Countries have resulted in the region being a pioneer in integrated assessment modelling for climate variability and change studies (see Box 3.2).

Empirical analogue studies

Observations of the current and past interactions between climatic conditions and biophysical and socioeconomic systems, or their components, are often of value for identifying future impacts, especially in an information poor region such as the Pacific. Three general types of analogue can be identified: i) the temporal analogue where an event or conditions at another time can be used as an indicator of future conditions under global warming (e.g. an El Niño event, drought, floods or hot spells); ii) the spatial analogue where the conditions occurring at another location are used to characterise future conditions in the study area (e.g. locations closer to the equator, at lower elevations or under the influence of an atmospheric circulation feature such as the South Pacific Convergence Zone, may be experiencing conditions analogous to those anticipated for the study area under global warming); and iii) the historical trend analogue which uses past trends or events unrelated to climate change as a surrogate for global warming induced changes (e.g. land subsidence is an analogue of future sea level rise). In practical applications combinations of the three analogue types are often used.

BOX 3.2. Tools for Integrated Assessments of Impacts

The numerous and well-developed interactions between the natural and managed systems of island countries means that integrated assessment tools are of particular relevance. One such tool that has proved particularly beneficial is VandaClim, an integrated assessment model based on the imaginary island country of Vanda. The model has evolved into a number of real world variants, including those used in integrated assessments for Kiribati and Fiji (see Section 3.4).

VandaClim, and its derivatives, were developed by the International Global Change Institute (University of Waikato, New Zealand), in collaboration with the South Pacific Regional Environment Programme (SPREP) and United Nations Institute for Training and Research (UNITAR), initially as a tool to support training and other capacity enhancement activities. Development of VandaClim involved linking a regional climate change scenario generator with selected impact models for four key sectors. The main components of VandaClim are: i) Time-dependent (1990-2100) projections of global-mean temperature and sea-level change for given greenhouse gas emission scenarios; ii) A regional climate change scenario generator that is driven by the preceding global projections; and iii) Sectoral impact models, including impact models for agriculture, coastal zone, human health and water resources. A user has considerable flexibility in generating scenarios, being able to choose among a large range of projections from greenhouse gas emission scenarios; the low, mid or high cases from each projection (which encompasses the range of uncertainty in model parameter values); several global climate model patterns; and the year of interest (in 5-year increments from 1990-2100).

A wide range of models is available for use in vulnerability and adaptation assessments of agriculture. These range from relatively simple biophysical indices to complex process-based models. Two methods for assessing impacts of climate change and sea-level rise on the Vanda coast have been incorporated into VandaClim: (1) a variant of the 'Bruun Rule', suitable for assessing time-dependent erosion of beach and dune systems; and (2) a simple inundation model ('drowning' concept) suitable for flat, low-lying deltaic coastal plains. Health impacts can be examined using a biophysical index which estimates potential incidence of malaria as influenced by temperature and rainfall and a simple threshold index for estimating change in risk of cholera outbreaks as a result of extreme flooding. For water resources three models are included: an atmospheric-land surface water balance model for assessing the water resource situation for the country as a whole; a water balance-river discharge model that is used for estimating monthly mean discharge for evaluation of wet and dry season river flow, and a discharge-flood area model that is used for the areal extent of flooding.

Expert Judgement

Expert judgement is an expedient way to obtain useful information concerning the effect of climate change on a study area, or its component systems or parts. The method may involve consensus opinion (e.g. provided by a committee of experts), surveys of experts or a review of published studies that are relevant to the task in hand, or some combination of these approaches.

Use of Anecdotal Information

The dearth of long-term and spatially-detailed climatic data in the Pacific also leads to greater emphasis being placed on anecdotal sources of information – material gleaned from oral and written records. Despite its typically more qualitative and subjective nature, such information often helps fill a data void and hence contributes to understanding. An example is provided by Nunn (1990) who undertook a study designed to demonstrate changes in sea level since 1900, to record and analyse important environmental changes associated with recent sea level changes and to summarize likely future impacts of global warming on coastal areas in the South Pacific. The basic data for the study were obtained by students who questioned elderly inhabitants of coastal settlements in the Cook Islands, Fiji, Kiribati, the Solomon Islands, Tonga, Tuvalu, Vanuatu and Western Samoa in order to obtain information about recent changes in sea level and other indicators of environmental quality and variability. Part of the interview encouraged elderly interviewees to indicate the approximate location of low tide in their youth. The researchers then measured the horizontal and vertical distances between the old and present low tide marks. Results for 48 tectonically-stable coastal settlements from the Solomon Islands to the Cook Islands show that shoreline inundation has been at the rate of around 10 cm/year.

Nunn acknowledges the imprecision of the information obtained through such procedures. He argues that discussion of the results on the basis of national and regional averages will minimize the effects of any errors while still providing a generalized picture of recent shoreline changes in the Pacific. But when using anecdotal information attention must be given to the fact that there are often differences between perceptions of reality, and reality itself. Much of this has to do with factors such as the time-scales over which the observations (technical and anecdotal) have been made.

The Second and Third Assessment Reports for Working Group II of the IPCC provide comprehensive reviews of impact assessment methodologies, many of which have been applied in impact studies in the Pacific Islands Region and are referred to in Section 3.3.

3.1.3 Methodologies for Scenario Generation

Scenarios are plausible and often simplified descriptions of how the future may develop, based on a coherent and internally consistent set of assumptions about the key driving forces and key relationships. At least four categories of scenario are important for vulnerability assessment:

- Climate change and sea-level rise scenarios;
- Land-use and land-cover scenarios;
- Environmental scenarios; and
- Socioeconomic scenarios.

The first, at both global and regional scales, has been discussed in Sections 2.4 and 2.6. As noted there, global socioeconomic scenarios characterise the demographic, socioeconomic and technological driving forces that establish the greenhouse gas emission scenarios. Net emissions are determined by also taking into account land-use and land-cover changes which result in removal or additional emissions of greenhouse gases to the atmosphere. The net emissions, in turn, are input to the global and regional climate models used to develop the climate change and sea-level rise scenarios.

But in order to determine the potential impacts of future changes in climate and sea level it is also necessary to develop regional, national or sub-national socioeconomic and environmental scenarios, as appropriate. The former are used to establish socioeconomic vulnerability prior to climate change (the *socioeconomic baseline*), to determine climate change impacts on the socioeconomic system, and to assess post-adaptation vulnerability. Similarly, the environmental scenarios characterise the non-climatic changes in the natural environment that are likely to occur in the future, in the absence of climate change. Such changes could influence the ways in which future climatic changes impact both natural and human systems. An example is the vulnerability of a reef ecosystem to climate change being enhanced as a result of excessive harvesting of living marine resources. Another example is the erosion and transport of sediment from steep slopes that have been converted to farmland.

3.2 The Special Circumstances of Pacific Island Countries

While the Pacific Islands Region is diverse in terms of the size and features of the island countries, there are many shared characteristics that have a substantial influence on the potential impacts of climate change. Of particular relevance in the present context are:

- Geographical isolation – the large expanses of water and small areas of land create numerous challenges, including difficulties of travel both within and between countries;
- Fragility of the environment – geographical and ecological isolation have lead to the evolution of unique species and communities of plants and animals, many of which are indigenous to only one island or island group within the region; global and other changes make the Pacific Island habitats particularly vulnerable to destruction or damage;
- Rapid population growth, and high population densities in some areas – the rapid growth in population that many Pacific Island Countries have experienced in the past decades, along with other changes such as increasing commercialization of traditional, subsistence-based economies, has been associated with rapid increases in rates of natural resource exploitation, especially of land, forests and living marine resources;
- Limited land resources – many Pacific Island Countries are characterized by extremely limited land resources, such as soil and forest; this makes many terrestrial and near-shore resources very vulnerable to overexploitation and to pollution from poorly planned waste disposal;

- Dependence on marine resources – there is a traditional dependence on marine resources for daily needs, foods, tools, transport and waste disposal, a dependency that remains despite new technologies and lifestyles; the region's ocean resources contain the highest marine biodiversity in the world and represent almost the sole opportunity for substantial economic development for many of the small island nations;
- Vulnerability and resilience – Pacific Island Countries often experience extremely damaging extreme events (e.g. tropical cyclones, drought, floods) and external and global pressures and shocks (e.g. fluctuations in demand for export commodities, prices of life-sustaining imports, tourism and flow of capital) and have a heavy reliance on the productivity of one or two economic sectors; Pacific Island Countries often have a priority to respond to more immediate environmental and resource management issues, and to adopt no regrets approaches; significantly, the natural ecosystems and the people of the Pacific also have many attributes which make them inherently resilient, having developed mechanisms to cope with the past changes in natural, social and economic conditions; and
- Small, highly integrated environmental and economic systems – the small size of island systems results in the interactions between components of natural systems and the sectors of economic activity being rapid and strong; environmental assessments and management need to take an integrated approach rather than being more sector based, and holistic and balanced approaches to environmental protection and economic development are required (i.e. a sustainable development approach).

As a consequence of these characteristics, and with respect to regional and national responses to global warming, countries of the Pacific Islands Region may well be among the first to suffer the adverse impacts of climate change and the first to be forced to adapt.

3.3 Impacts on, and Vulnerability of, Natural and Human Systems

3.3.1 Water Resources

Many Pacific Islands are extremely vulnerable to water shortages, even under present conditions. Periodic droughts, often associated with ENSO events, cause havoc in many tropical Pacific Island societies and ecosystems. During the 1982-1983 ENSO event, rainfall in many parts of the western Pacific was just 10-30% of the long term mean average. On January 1, 1983 the reservoir in Majuro, Marshall Islands, held 23 million litres, but by May 1983 the total storage had declined to 3 million litres, most of which was reserved for hospital use. At the height of the drought associated with the 1997-1998 ENSO event municipal water on Majuro was available for only seven hours every fourteen days.

In countries such as the Federated States of Micronesia and the Marshall Islands, where rainfall is the main source for the public water supply, the possibility of more frequent and intense ENSO events in the future (refer to Section 2.4.2) will stress even further the already limited water resources in many islands. Meanwhile, islands in the eastern tropical Pacific will likely see an increase in heavy rains. Large amounts of rain tend to be associated with the passage of tropical cyclones, often causing massive and enduring disruptions to life and infrastructure.

Some islands, despite receiving more than adequate rainfall under normal circumstances, may also suffer from periodic water shortages that may be exacerbated by inadequate rainwater catchment facilities, or the sandy nature of the soil allowing the limited rain that falls to infiltrate rapidly and become difficult to access. The problem on these islands is largely one of water management.

With growing populations, increasing fresh and ocean water pollution, and growing demands for drinkable water, it is clear that the water sector is highly vulnerable in many Pacific Island communities. Population growth rates vary from a low 0.4% in Samoa, where there is significant out-migration, through a more typical 1.7% for Fiji, to a high 3.1% for Solomon Islands[1]. Such rapid population growth rates strain resources in many sectors, not just water. Consumption patterns also vary between communities. On the island of Tahiti (French Polynesia), for example, a person uses an average of 1900 litres of water per day while the equivalent figures for Nouméa (New Caledonia) and Kosrae (Federated States of Micronesia) are 420 and 40 litres, respectively. Future increases in demand for water will not be met by simply increasing the supply. Integrated approaches, including demand management and improved maintenance of infrastructure, will be required.

There are many other factors which need to be considered in our understanding of the vulnerability of Pacific Islands hydrology and water resources, and the impacts of climate variability and change on this sector. One is the vegetation. Potential evapotranspiration rates are as high as 1700-1800 mm/year of equivalent precipitation in the tropical Pacific (Nullet, 1987). Furthermore, land use changes can increase the erosive power of the rainfall, increasing vulnerability. For example, deforestation in the tropical Pacific Islands Region allows the precipitation to impact the denuded land surface, causing increased surface runoff, increased soil erosion and more frequent, significant flooding.

Pollution is a serious problem for freshwater resources in many island nations, at a local scale, and sometimes for the entire island. Groundwater resources are the most vulnerable at the island scale, often being polluted by domestic wastes, particularly human wastes through improper sewage collection (e.g. pit latrine and inadequate septic tanks), drainage and sewage disposal. The increased use of chemical fertilisers and pesticides and the improper disposal of residual waste from fossil fuel use often pollute the groundwater. Groundwater quality is also reduced on some low islands by overwash during storms, when salt water is dumped on the land surface and percolates to the surface of the freshwater lens. The dispersal of saltwater layers of this kind can take several months to years and, in the interim, the supply of fresh groundwater is disrupted. Local sources of water pollution are more variable, ranging from domestic waste affecting local water supplies, typically from wells or a nearby stream, to industrial

[1] Developing countries have an average 2% population growth rate. With a 2% growth rate the population will double in 35 years. With a 3% growth rate the population will double in 24 years.

pollution and discharges from ships and other sources. All such sources of pollution are generally increasing in the most densely populated areas of the Pacific Islands Region.

In a recent detailed study (*Pacific Islands: Adapting to Climate Change*) of the potential impact of climate change on the water resources of South Tarawa, Kiribati, a 10% reduction in average rainfall by 2050 projected by one regional climate model translated into a 20% reduction in freshwater lens thickness. A 30% reduction in rainfall projected for 2100 could result in a 50% reduction in freshwater lens thickness. Plausible increases in potential evapotranspiration were found to cause relatively small decreases in groundwater recharge. Moreover, minor increases in sea level are unlikely to have a significant effect on the freshwater lens, and might even increase its volume slightly. However, where rising sea levels result in a reduction in island area, the volume of the freshwater lens would be reduced.

The study also showed that the effects of extreme events on the water supply in South Tarawa may also be significant. Drought events impact upon both groundwater and rainwater supplies, with the latter tending to be more liable to depletion. Rains following drought can also be disruptive, given evidence of an increase in diarrhoeal diseases when such conditions have occurred in the past. Projected increases in the frequency of island overtopping events, and the magnitude of inundation, increase the risk and severity of temporary saline contamination of the groundwater lens.

In a parallel study for Vitu Levu it was found that the potential effects of climate change on water resources depended on the global climate model being used. One model indicated an increase in maximum streamflows and a decrease in minimum streamflows; that is, low stream flows will become even lower, while high flows will increase in peak and volume. However, another model suggested the converse. Despite a potential combination of a drier future for Fiji and increased demand for water resources, a study of the Nadi Lautoka Regional Water Supply scheme indicated that shortfalls in water supply are unlikely to become significant until later in the 21st century. Under the worst case climate scenario (SRES A2, see Box 2.3) and a mid range population projection, a deficit of 32 per cent of the total demand is indicated.

In summary, present problems resulting from increasing demand for water, from increasing pollution of water and from current patterns of extreme events and climate variability, dwarf those which will result from climate change over the next few decades, in all but a few countries in the Pacific Islands Region.

3.3.2 Agriculture and Food Security

Agriculture is very important to the subsistence economies of Pacific Island Countries. On many islands, agricultural production systems are already stressed as a consequence of high population densities and growth rates. Examination of the agricultural impacts of climate variability associated with seasonal to interannual climate phenomena offers valuable insight into the potential effects of climate change on Pacific agriculture.

How climate change will affect the agricultural sector and the general food security in the Pacific will depend on the adaptability of local agricultural and social systems. These will also be influenced by globalisation, national policies and the socio-cultural changes.

Climate change related agricultural impact has a socioeconomic component as well. For example, in Fiji where the climate change impacts will vary spatially, the consequences will be socially uneven. Small islands and low-lying coastal areas will be in greater danger than other areas. Because of the traditional land tenure systems, losses are likely to affect some kin groups more than others. Since Pacific Islanders are very committed to agriculture, such land and crop losses will be very detrimental.

CO_2 rise and agricultural productivity in the Pacific

It is estimated that the global crop yield will increase by almost a third for a doubling of the current atmospheric CO_2 concentration. However, crop yield is a product of many interrelated physiological processes. Usually C_3 plants (see Table 3.1) benefit much more than C_4 plants, as the former have higher internal CO_2 concentrations than the latter, typically 200 ppm CO_2 in C_3 and 100 ppm CO_2 in C_4 plants.

Table 3.1. Classification of some tropical crop species by photosynthetic pathway

Photosynthetic pathway	Crop	Example
C_3*	Root crops	Cassava, sweet potato, taro, yam
	Cereals	Rice, temperate cereals
	Vegetable	Tomato, onions, beans, cabbage, squash, cucumber,
	Fruit	Mango, melons, banana, papaya, citrus
	Plantation crops	Coconut, cocoa, coffee, rubber, tea
C_4*	Cereals	Maize, sorghum, pearl millet
	Grass	Sugarcane
CAM*	Fruit	Pineapple

* C_3 plants produce a three-carbon compound during photosynthesis; such plants include most trees and agricultural crops such as rice, wheat, soybeans, potatoes and vegetables; C_4 plants produce a four-carbon compound during photosynthesis; such plants are mainly of tropical origin and include grasses and the agriculturally important crops such as maize, sugar cane, millet and sorghum; C_3 plants generally show a larger response to CO_2 than do C_4 plants.

** CAM (Crassulacean Acid Metabolism) plants have a better capacity to adapt to hot dry environments

Factors that affect agricultural productivity in the Pacific

Although crop yield may be positively influenced by elevated CO_2 concentrations, the response is by no means uniform across the range of species. There are a number of other factors that affect crop yield in the Pacific Islands Region.

Solar radiation: Although solar radiation is not usually a limiting factor in crop production in the tropics, under a changing climate with increasing temperature and cloud cover, reduced solar radiation inputs may indeed limit crop yield.

Temperature: The effects of higher temperatures on crop yield and other productivity measures is a focus of intense research. While for the high and mid latitudes increased temperatures may lengthen the growing season, in the Pacific Islands Region the smaller temperature increase relative to higher latitude locations (see Section 2.5.2) is unlikely to place a severe limitation on crop production. However, the physiology of crops may be influenced in ways not yet identified. But it is already known the rate of photosynthesis of C_3 plants decreases with increasing temperature more rapidly than for C_4 plants.

Sea-level rise: This may affect agriculture in three different ways:

- Coastal land may be permanently inundated, making it unsuitable for agriculture production;
- Land may be subjected to periodic inundation from extreme events, including high tides and storm waves, contaminating the fresh water lens, with devastating effects for atoll agriculture; and
- Seepage of saline water through rivers during dry seasons, thereby increasing the salt level in neighbouring soils.

Plants respond to salinity, including salt spray, by reducing leaf expansion and shoot growth. Prolonged exposure to salty water poisons the leaves with sodium and chlorine ions, resulting in leaf damage. This is particularly an issue for taro, a staple food that also has high cultural importance in many parts of the Pacific. Pit and swamp cultivation of taro is particularly susceptible to changes in water quality.

Nutrient availability: An increase in plant size under CO_2 enrichment will probably result in an increased demand for soil nutrients. In soils which are deprived of nutrients through increased rainfall and wind erosion, the decreased nutrient availability may result in growth limiting conditions, especially due to a lack of micronutrients.

Drought frequency: This may indeed increase in low and mid latitudes owing to increased uptake of water by the atmosphere (evapotranspiration) relative to the supply (precipitation), especially given the projected increase of dry spells in some areas. An extension of the dry season by 45 days has been estimated to decrease maize yields by 30 to 50%, and sugar cane and taro by 10 to 35% and 35 to 75%, respectively. In contrast, significant (>50%) increases in rainfall on the windward side of high islands during the wet season may increase taro yields by 5 to 15%, but would reduce rice and maize yields by around 10 to 20% and 30 to 100%, respectively.

Weed invasion: With increasing CO_2 concentration the relative importance of various weed species in agro-ecosystems may increase. Weedy species with broad ecological ranges are likely to prosper at the expense of endemic species, or those already in marginal habitats. In the tropics important C_4 crops such as maize and sugarcane, which are adapted to hot dry conditions, may experience yield reductions because of the improved performance of competing C_3 weeds.

Pest interactions: Recent reviews reveal that insect growth and abundance are expected to increase as a result of a possible lengthening in breeding seasons.

Climate change may thus have very serious consequences, especially on atoll agriculture. Sea level rise itself will result in inundation of a sizable portion of farm land, and further contaminate the fresh water lens through salt water intrusion. In most atolls the size of the fresh water lens is directly proportional to the size of the island. Thus small atolls in particular are faced with a very serious problem.

Impediments to food security in the Pacific

Pacific Islands farmers lack the financial resources, fertile land, irrigation facilities, access to drought tolerant species, alternate employment options or reasonable prices for inputs and products. This situation is compounded by inequitable social structures, land tenure and farming skills. In our changing world there will also be multiple stresses such as elevated biologically active radiation due to stratospheric ozone depletion (see Box 2.2). Global climate change will affect soils primarily through changes in soil moisture, soil temperature and soil organic matter. Higher air temperatures will be reflected in increased potential evapotranspiration and higher soil temperatures. This should in turn increase the cycling of nutrients in the soil, with more rapid decline of soil fertility and other desirable properties.. In the Pacific Islands Region most good quality land is already under intense cultivation. Increasing population numbers, coupled with climate change impacts, means that food security issues will be a major concern. In addition, Pacific communities are becoming increasingly dependent on imported food, thus becoming vulnerable to short term breaks in supply, and to any future world food shortages.

3.3.3 Terrestrial and Freshwater Ecosystems

Pacific Island Countries have a varied range of terrestrial and freshwater ecosystems because of their geography and geological complexity. These ecosystems range from mountain glaciers in parts of Papua New Guinea to humid tropical forests, grasslands, freshwater lakes, herbaceous swamps, swamp savanna to woodlands in most high islands of the Pacific, and mostly coconut and arboreal agroforestry in the atolls such as Tuvalu, parts of Marshall and Kiribati. In terms of both flora and fauna, the high islands in the Pacific, particularly Fiji, Papua New Guinea and the Solomon Islands, have some of the richest forests remaining in the world today.

There is little specific information on the possible impacts of climate change on the terrestrial and freshwater ecosystems of the Pacific Islands Region. Even though terrestrial ecosystems have been able to evolve and adapt to climate variability and human interventions over time, there are indications that changes in climatic conditions coupled with increases in unsustainable use will render terrestrial and freshwater ecosystems vulnerable in the longer term. Given the pressures the ecosystems are currently facing, including land-use changes, erosion and land-slides, siltation, eutrophication, acidification, deposition of nutrients and pollution, overgrazing by livestock, intensive mono-cultivation, introduction of exotic species and natural climate variability, any additional pressure could further endanger these ecosystems.

Terrestrial and freshwater ecosystems and changing climate

Forests, savanna, grassland ecosystems, freshwater lakes and wetlands have long been life-supporting systems for Pacific Islanders. They provide people with very important sources of dietary diversity (e.g. wild yams, ferns, nuts, grubs, insects, fruitbats, birds, fish, eels, freshwater mussels, water, wild pigs, fruits and greens), housing materials (e.g. sago fronds, bamboo, grass thatching, timber, grass for mat weaving) and other important products such as folk medicines and firewood. Retaining ongoing access to these resources is important. However, in intensively commercially planted areas in Fiji, for example, some of the previously mentioned ecosystem services might no longer be available. Fuelwood shortages, in particular, are a serious problem as large tracts of forests have been cleared to make way for agriculture. As a result, aggressive weeds such as African Tulip (*Spathodea campanulata*) are now populating fallowed lands in Fiji.

The climate change scenarios described in Section 2.5 suggest changes of particular importance to Pacific Island Countries, due to the terrestrial and freshwater ecosystems being small in size and vulnerable to short term climate variability and long term changes. Populations of many species already threatened are expected to be placed at a greater risk by the synergy between the stresses of changing climate and human interventions (Figure 3.3).

Higher temperatures may also mean greater evaporation and a greater chance of droughts. This would impact largely on water availability. Thus biodiversity loss due to die-backs of plants will be more prevalent. As a consequence of die-backs, food sources of birds, and animals will be scarce, leading to migration or possible extinction. Grasslands and savannas will suffer increased risk of fires. During the 1997-1998 El Niño extensive wildfires occurred in many Pacific Island Countries, including Samoa and Fiji. Forest composition may also change as a result of global warming, although the nature and extent of such changes are still very uncertain.

Loss of terrestrial and freshwater ecosystems and implications for climate change

Loss of the Pacific's extensive forest and grassland biomes through land-use change and incidental fires contribute to global warming, albeit in a minor way. On a global scale, forest burning and the decay of dead wood in the aftermath of logging is estimated to be responsible for 22 percent of the emitted greenhouse gases. In the Pacific, the intermittent burning of grasslands during the dry season, and the burning of savannah areas, as is occurring widely in Papua New Guinea and Fiji, are contributing in a minor way to the enhanced greenhouse effect. It is estimated that more than 80 percent of all grasslands in Papua New Guinea are burnt annually in order to chase away snakes, capture small marsupials and other bush game and release potash as fertilizer to the soil.

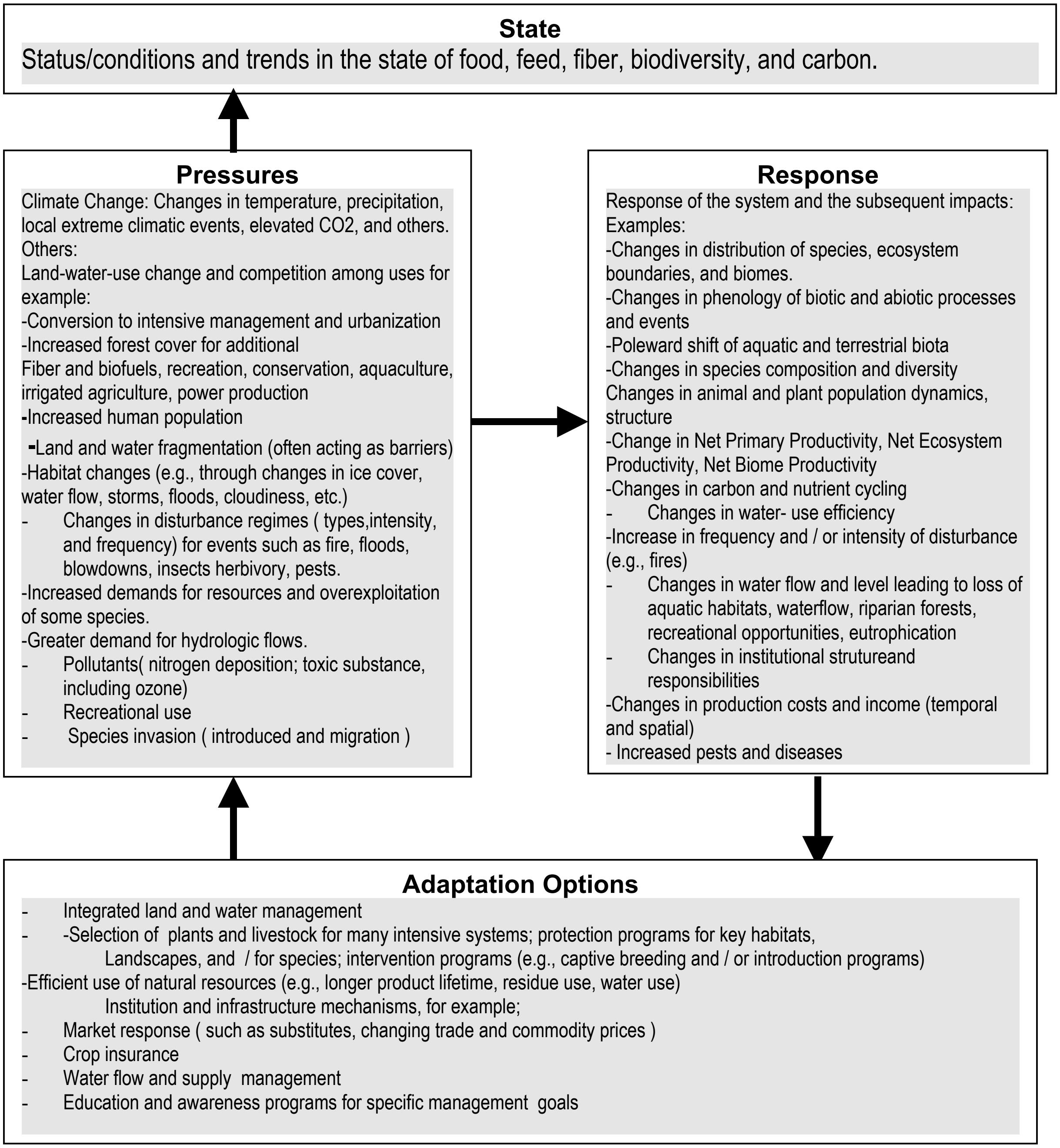


FIGURE 3.3. Generalized diagram of the state of specific goods and services that ecosystems provide, how these goods and services are affected by the multiple pressures of climate change and human activities, and how the system responds, thus affecting the provisions of goods and services. Adaptation options reduce the impacts and also enhance the resilience of the system. From IPCC, 2001.

Such changes affect global temperature in two ways; (i) the exposure of dark coloured soil as a result of deforestation or agrodeforestation decreases the reflective properties of the Earth's surface (i.e. the albedo) leading to more of the Sun's heat energy being absorbed, resulting in warmer temperatures; and (ii) growing forest removes carbon from the atmosphere, by taking in carbon dioxide and releasing oxygen to the atmosphere. With more forest lost to agriculture, burning, and uncontrolled logging, more carbon dioxide is released into the atmosphere and less is taken up. The direct (*first order*) effects are likely to be compounded due to increased atmospheric carbon dioxide levels causing plants to release less water vapour to the atmosphere, due to enhanced growth rates. When evapotranspiration is suppressed surface temperatures rise, the compensation being necessary to maintain the surface energy balance.

3.3.4 Coastal Zones and Marine Ecosystems

Potential impacts on coastal and marine systems

World-wide effects of global warming on the oceans will include:

- Increases in sea level;
- Increases in sea surface temperature;
- Decreases in sea-ice cover; and
- Changes in wave climate and ocean circulation.

All will, in turn, have profound impacts on coastal zones and marine ecosystems around the world, with the first two being of special importance in the Pacific. As a result, many coastal zones in the Pacific Islands Region will experience:

- New or accelerated coastal erosion;
- More extensive coastal inundation and higher levels of sea flooding;
- Increases in the landward reach of sea waves and storm-surges;
- Seawater intrusion into surface waters and fresh groundwater lenses;
- Further encroachment of tidal waters into estuaries and coastal river systems;
- Higher nearshore, lagoonal and groundwater temperatures; and,
- Increases in the presence of pathogenic micro-organisms in the coastal zone.

On the larger islands in the Pacific such impacts will be limited to the coastal fringe, with the low-lying coastal plains and sandy beaches, deltas, estuaries, lagoons, and river mouths being especially susceptible. But for atolls and smaller islands, the entire island will be vulnerable.

When considering the likely consequences of accelerated sea-level rise, and increases in sea-surface temperature, there are four important perspectives that Pacific Island communities and officials need to acknowledge:

- Globally sea-level has been rising over the last 100 years or so and many parts of the Pacific have already experienced relative sea-level rise;

- 'King-tides' that occur predictably though episodically throughout the region (e.g. in December-February in Kiribati) provide a present day analogue of sea-level conditions that may occur most of the time in the future;
- Most Pacific Island communities are mindful of the impacts of ENSO and the scale of inter-annual variability in climate and weather, including changes in the frequency of tropical cyclones and storms between El Niño and La Niña events; and
- Many small islands and coastal zones in the Pacific are already degraded and under stress from human activities, increasing their vulnerability to the consequences of global warming described above.

These consequences flow through to affect the livelihood of Pacific Island communities. Such direct and indirect impacts on socio-economic and cultural sectors include:

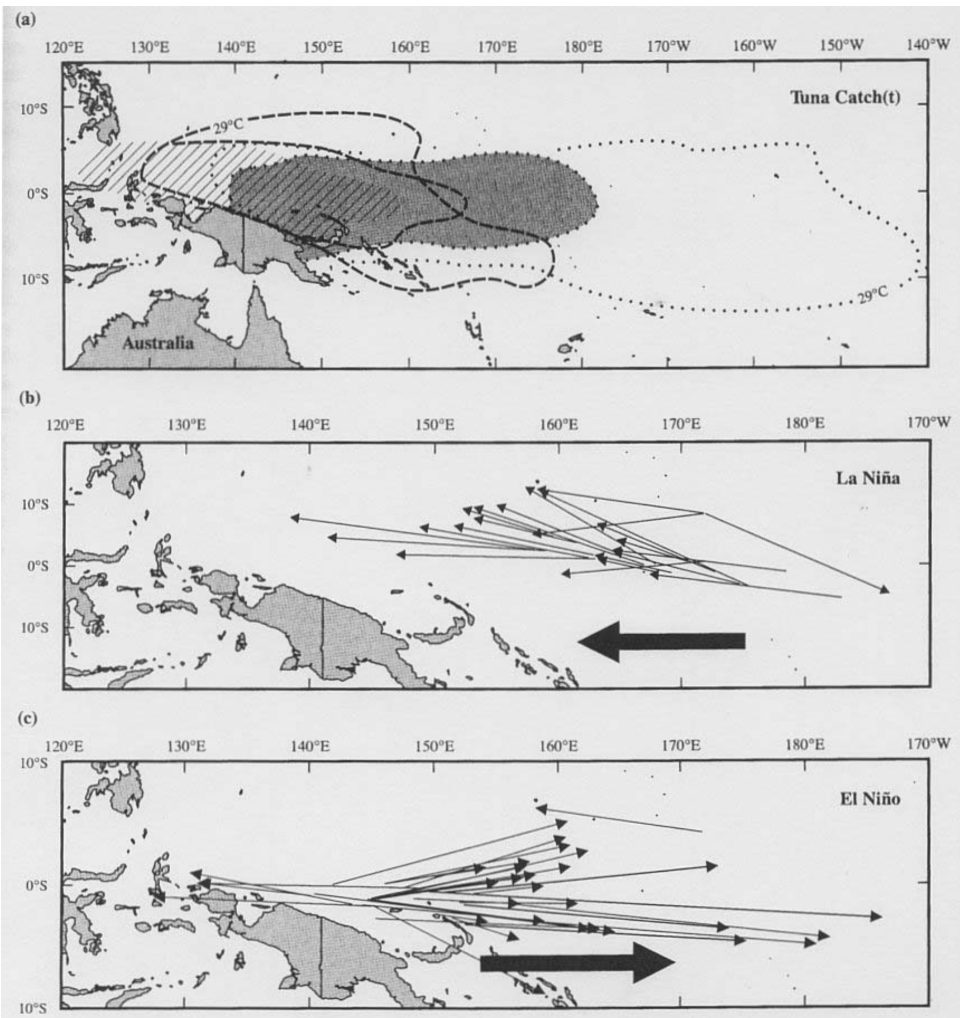
- Damage to coastal protection works, causeways, roads and other coastal infrastructure;
- Destruction or degradation of crops in babai and pulaka pits as a result of sea-water intrusion;
- Contamination of fresh groundwater supplies;
- Increased disease risk;
- Storm damage and incidence of storms in areas that currently experience few such storms, such as French Polynesia and Tokelau;
- Erosion of beaches and coasts undermining important facilities e.g. hospitals, airfields, storage facilities and graveyards;
- Loss of tourism, recreation and cultural resources; and
- Habitat degradation and harvest restrictions.

Many of these impacts are already familiar to island populations, and some have experience in coping with them. While there is scientific and political interest in distinguishing between the impacts from climate change and climate variability, the reality for Pacific Island Countries and communities is that they will have to face both. In most countries, and for most activities, coping with climate variability will be of more significance over the next few decades. Nowhere is the impact of variability better illustrated than in the Pacific tuna industry (see Box 3.3). In Kiribati a one unit decline in the Southern Oscillation Index (indicating a move towards El Niño conditions) has, on average, resulted in an increase in the annual average tuna catch of between 200 to 800 metric tons.

BOX 3.3 . Tuna Migration and Climate Variability

The largest tuna fishery occurs in the Pacific Islands Region, with nearly 70% of the world's annual tuna harvest. Annual production during the 1990s averaged nearly 1 million tonnes, with a landed value close to $US2 billion. Several countries in the equatorial Pacific gain significant income from licence fees for the right to fish in their Exclusive Economic Zone. Skipjack tuna *(Katsuwonus pelamis)* dominate the catch and catches are highest in the western equatorial Pacific warm pool where sea temperatures are at least 29°C.

The figure shows that major spatial shifts in the skipjack population can be linked to large zonal displacements of the warm pool that occur during ENSO events (see Box 2.2).
The close association between skipjack tuna catch and ENSO is evidence that climate variability profoundly affects the distribution of tuna and resulting fishing opportunities. It is not known how changes in climate may affect the size and location of the warm pool in the western and central Pacific, but if more El Niño-like conditions occur as is projected (see Box 2.2) an easterly shift of the centre of tuna abundance may become more persistent.
This example of the role of climate-ocean system variability and changes in influencing the distribution of fish populations suggests that the sustainability of the fishing industries of some countries in the Pacific will depend on the increasing use, and flexibility, of bilateral and multilateral fishing agreements, coupled with international stock assessments and management plans.



Links between the migration of tuna and ENSO. From Lehody et al., 1997 and 1998.
The location of the warm pool is linked to the El Niño Southern Oscillation (ENSO) and changes between El Niño and La Niña events. The catch area in early 1989 (a La Niña event) was centred around Palau and the Federated States of Micronesia, while in the first half of 1992 (an El Niño event) it shifted to the east, to the Marshall Islands and Kiribati. The scale of tuna migration is indicated by the displacement of tagged skipjack tuna compiled from records of a large scale tagging programme carried out by the Secretariat of the Pacific Community

Recreational, commercial and subsistence coastal fisheries

Fishing is an extremely important activity on most islands. It is important to the cultures and economies of many Pacific Island Countries and makes a significant contribution to the protein intake of Pacific Island peoples. As with other sectors, an assessment of climate change impacts on fisheries is complicated by human and other non-climate-related stresses, including habitat loss and over exploitation. But on islands where subsistence fishing is important, climate-induced changes in the productivity of marine and coastal ecosystems could alter carrying capacities. Food shortages could become particularly acute if declines in marine resources used for subsistence coincided with reduced agricultural productivity. Moreover, the economic viability of related industries such as mariculture could be affected adversely by climate related alterations in marine and coastal environments.

Many breeding grounds for commercially or artisanally important fish and shellfish species are located in shallow waters near coasts. These areas include mangroves, coral reefs and seagrass beds. All are affected by climate variability and change, including temperature, salinity and high sediment concentrations resulting from storms, floods and enhanced inland and coastal erosion. Generally, fisheries are not expected to be adversely affected by sea-level rise, at least in a direct manner. Higher sea level would be a serious factor for fisheries only if the rate of rise exceeded the natural adaptive ability of coastal ecosystems on which some fish species depend. These include mangroves, seagrasses and corals. The unfavourable effects of elevated CO_2 concentrations, and of widespread coral bleaching, may be significant in this regard.

There is some evidence that clams and sea turtles could be sensitive to sea temperature changes. Clams, like corals, are known to suffer from bleaching due to the expulsion of symbiotic algae, as a result of excess temperature or sunlight. Bleaching would cause loss of productivity or devastation in clams on reef-flats. Most species of sea turtles nest during the summer, when temperatures are close to their upper thermal limit. It is uncertain whether turtles will be able to adapt to warmer temperatures by nesting in the cooler months. If this is not possible, increased temperatures are likely to result in a higher ratio of females to males because the sex ratio of hatched sea turtles is directly determined by temperature.

A recent study of the consequences of climate variability and change for Pacific Island economies (*Pacific Islands: Adapting to Climate Change*) estimated the losses to subsistence and commercial fisheries if a hectare of mangrove habitat was removed due to coastal erosion. For Fiji the values ranged between $F464 and $702 per hectare per year for subsistence fishing and between $F179 and $272 per hectare per year for commercial fishing. The impact on fishing of the likely decreased productivity of coral reef ecosystems as a result of climate change was also evaluated. The losses for subsistence fishing in Viti Levu could vary between $F0.3 and $4.0 million per year. Comparable values for commercial fishing could be $F0.1 to $1.5 million per year.

These losses are a significant portion of the estimated total cost of climate change induced erosion of coastal land and infrastructure in Viti Levu by 2050 ($US3 to 6 million per year) and of loss of loss of coral reefs and associated ecosystem services ($US5 to 14 million per year).

Coral reefs and mangroves

In the Pacific Islands Region coastal areas are often dominated by complex ecosystems, including coral reefs and mangrove forests. But unlike skipjack tuna, which can migrate across the ocean and move to locations with more favourable feeding and environmental conditions, coral reefs and mangrove forests, for example, are fixed in location, and therefore must adapt to changing environmental conditions *in situ*.

Coral reefs, which occur in a variety of fringing, barrier, and atoll settings, provide a significant source of food for many coastal communities, as well as serving important functions as atoll island foundations, coastal protection structures, sources of beach sand and gravel and sites for tourism and recreational activities. Because of these multiple functions and attractions, many reefs are presently degraded or are under stress from excessive exploitation, pollution, overfishing and coral mining. In such circumstances the natural resilience of reefs is greatly reduced and the potential for rising sea levels and higher sea temperatures to cause adverse impacts is thereby increased. Degraded reefs, particularly those close to urban population centres and large villages, are especially vulnerable.

Recent IPCC assessments have concluded that for *healthy* reefs the threat of sea-level rise will not be as serious as that associated with increases in sea surface temperature. The latter is projected to rise by 1-2°C by 2100 (refer to Section 2.5.3). With many coral reefs occurring at or close to their upper temperature tolerance thresholds even today, steadily increasing sea surface temperatures will create progressively more hostile conditions for many reefs. Increased coral bleaching is seen as one likely outcome.

Corals bleach (i.e. pale in colour) as a result of physiological shock resulting from abrupt changes in temperature or in salinity and turbidity. The paling represents a loss of symbiotic algae which make essential contributions to coral nutrition and growth. Often bleaching may be temporary, with corals regaining colour once stressful environmental conditions ameliorate. However, more frequent and extensive bleaching decreases live coral cover, leading to reduced species and habitat diversity and greater susceptibility to other threats such as pathogens and emergent disease.

During the El Niño event of 1998-1999 near surface temperatures in the coastal water of Palau were over 30°C from June through November, 1998, causing a massive coral bleaching event that killed one third of Palau's reefs. High water temperatures capable of inducing coral bleaching occurred to depths as great as 90 m during September, 1998. While no species became locally extinct, some populations fell as much as 99% below pre-bleaching levels. The associated economic loss was estimated at $US91 million, based on a value of $6,000/ha/yr. There was a 9% drop in annual tourism revenues.

Mangrove forests, as with coral reefs, provide a measure of protection to island shorelines and often act to absorb wind and wave energy, thereby inducing sedimentation. Mangroves are sensitive to the rate of sedimentation from adjacent land areas, to the rate of accumulation of mangrove peat and to sea level. The impact on mangroves of accelerated sea-level rise resulting from global warming will depend on the vertical accretion rate of sediments and on adequate space for horizontal migration inland by the mangrove communities. The latter will often be limited by such features as infrastructure, roads, property boundaries and buildings. The degradation of mangrove forests, and total destruction in the case of reclamation, together with the limitations to horizontal migration, mean that many mangrove forest communities are unlikely to survive into the next century.

In Papua New Guinea alone, it is estimated that the permanent or periodic inundation of deltaic flood plains, swamps, and other low-lying areas could affect up to 50 percent of the Papuan coastline, and 10 percent of the northern shoreline (for a worst case scenario of a one metre sea-level rise), causing damage to mangrove and swamp forest ecosystems, as well as human productive systems. Warmer temperatures may create favorable conditions for intensive cropping at higher altitude. This can exacerbate problems of erosion and landslides currently occurring in some Pacific Island Countries, due largely to erosion resulting from inappropriate land use and land management practices in the watershed. The lack of forest conservation, and the declining dependence on trees in favor of monoculture, has progressively lead to the siltation of rivers resulting in drainage problems on floodplains, frequent inundation and the formation of shallow bars across river mouths. River dredging has become a very costly necessity with severe downstream impacts that are far reaching and damaging, particularly to freshwater and marine ecosystems. River dredging at present is costing the government of Fiji an average of $F4,000,000 per annum.

3.3.5 Human Health

Environmental conditions, including the ecological integrity and the health and productivity of the natural environment, are increasingly recognised as important underlying determinants of human health – particularly in the settings typical of Pacific Island Countries. Of growing concern in the Pacific Islands is the possibility that global climate change and sea-level rise are likely to impact human health in many ways - most of which will be adverse.

Frequently human health impacts are likely to result from ‘downstream’ and ‘flow-on’ effects from impacts in other areas, such as reduced quality and quantity of water supplies, loss of coastal resources, reduction in ecosystem productivity and decline of agricultural productivity. At least from a human point of view, human health could be seen as an endpoint of primary impacts in these other areas. For instance, in several Pacific Island Countries drought is a serious problem, with clear consequences for human health. These are illustrated in Figure 3.4. It shows how drought may directly and indirectly impact on human health through changes in the natural and socio-economic environment. The impact pathways are influenced by the prevailing environmental, social and economic conditions that determine the ability of communities to adapt to, and cope with, change.

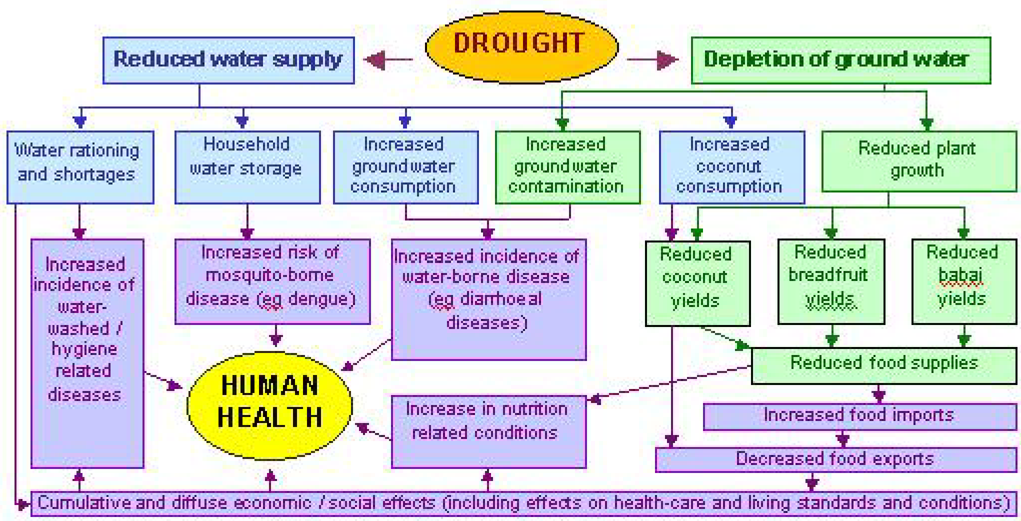


FIGURE 3.4. From drought to human health.

This broad understanding of the determinants of health is useful in comprehending the pathways that may lead to climate-related health impacts. It also provides a sound basis for identifying and developing possible adaptation strategies. However, it does make it difficult to define the full extent of potential adverse effects on human health and well-being that may be attributable to climate change and variability. One approach that aids understanding when defining the scope of health impacts is to consider the impacts in terms of: (i) first order (or direct) effects; (ii) second order (or indirect) effects; and (iii) higher order (or downstream and cumulative) effects.

Potential first order or direct health effects include deaths, injuries, illness and discomfort caused by change in average temperature and thermal extremes; and, deaths and injuries caused by more frequent and more intense cyclones, storms and floods. Second order or indirect effects are those mediated through ecological and environmental factors and include increased incidence rates of vector-borne diseases (such as dengue fever and malaria), waterborne diseases (such as viral and bacterial diarrhoea) and diseases related to toxic algae (such as ciguatera fish poisoning). Nutrition-related illnesses may be considered as second order effects but also fall into the category of higher order and cumulative effects. More diffuse and less well defined higher order health impacts would also include those arising from climate change impacts that lead to increases in poverty, homelessness, unemployment, economic instability and other forms of social disruption, such as forced migration.

Direct, and some indirect, effects are usually easier to define, describe and link to climate variability and change. However, while the higher order effects are more diffuse and difficult to research and document, they could be more important in terms of the overall public health impact of climate change and the burden of disease caused by climate impacts. Despite this possible limitation, only those potential health impacts of climate variability and change that have been more clearly described in the Pacific are discussed below.

Injury and drowning. An increase in intensity, and possibly frequency, of extreme climatic events such as tropical cyclones and other storm events is likely to result in an increase in the number of casualties due to injury and drowning. On atoll islands and coastal plains these effects may be exacerbated by sea-level rise and the consequential increase in the effective height of storm surges.

Heat stress. Even though some acclimatisation will occur with gradual climate change, increases in temperature and increases in humidity are likely to result in an increase in the frequency, duration and intensity of periods that can cause heat stress. This is likely to increase the incidence of heat-related conditions such as dehydration, heat exhaustion and heat stroke. The elderly and very young, as well as outdoor workers, are likely to be the most vulnerable.

Diarrhoeal diseases. Water shortages and poor water quality during times of drought, as well as disruption of sanitation services and contamination of water supplies during flooding, can lead to an increased diarrhoeal disease risk. A recent study in Fiji suggested that if future changes in climate were to include a trend towards more extremes in rainfall, an increase in the incidence of diarrhoeal diseases may occur. There is also evidence that increasing temperatures alone will result in an increase in the incidence of diarrhoeal diseases in Pacific Island Countries. An increase in the incidence of food poisoning is thought to be one of the mechanisms that would contribute to this risk, as higher temperatures promote bacterial growth and more rapid food spoilage.

Ciguatera fish poisoning. Ciguatera fish poisoning is common in warm tropical waters. Ciguatera is caused by eating reef fish containing ciguatoxin – a marine toxin that is produced by a type of plankton found in coral reefs, and concentrates up the food chain. In Pacific Islands, particularly atoll islands, where fish are a major protein source and subsistence food, ciguatera outbreaks not only cause significant morbidity (and occasionally mortality), but also result in a range of other adverse effects on diet, nutrition and household economies. It is thought that multiple factors contribute to ciguatera outbreaks, with these including pollution, reef damage and other forms of degradation and disturbance of coral reef systems. Warmer sea surface temperatures during El Niño events have also been linked to ciguatera outbreaks. This suggests that ciguatera, and its related socio-economic and health impacts, may become more common with climate change. Additional climate change related stresses on coral reef systems, such as coral bleaching, are also likely to contribute further to this risk.

Vector-borne disease. Climate change is likely to result in an increase in the incidence of vector-borne diseases such as malaria and dengue fever. The various mosquitoes that transmit these diseases, as well as other factors in the disease transmission cycle, are influenced by climate (Figure 3.5). In Pacific Island countries rainfall typically helps create suitable breeding sites for the vector mosquitoes, but it is not always a pre-requisite. *Aedes aegypti*, the main vector of dengue fever, has a preference for breeding in artificial containers and during the drought in Fiji in 1997/1998 it proliferated in water storage drums used in and near people's homes and so contributed to a subsequent dengue fever epidemic.

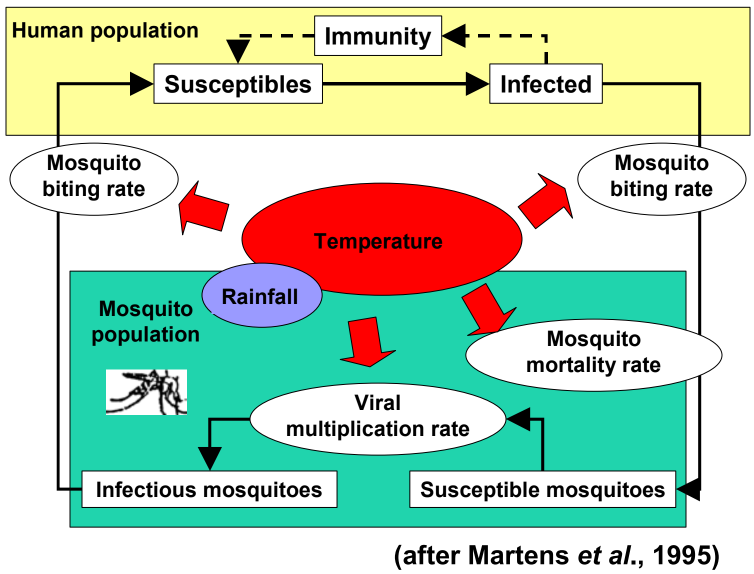


FIGURE 3.5. The influence of climate on the transmission of dengue fever and malaria. Adapted from Martens et al., 1995.

Warmer temperatures are a risk factor for dengue fever and affect the transmission of dengue fever from human to human via the vector population. Temperature affects two key factors in the transmission cycle. As temperature increases the mosquito biting rates increase. The viral replication rate in the mosquito host increases, making it capable of passing the virus on to the next human sooner. Together these factors may contribute to an increasing epidemic potential (or transmission efficiency), as temperatures warm.

Climate scenarios and model-based analyses show increasing temperatures and epidemic potentials for dengue fever in Pacific Island Countries. While many other factors (such as immunity, human behaviour and housing conditions) influence dengue fever transmission, the increased epidemic potentials suggest that under conditions of global climate change, epidemics are likely to occur more readily, grow faster, involve more people and be supported by smaller vector populations (Figure 3.6). So, with all else equal, increased epidemic potentials would most likely result in an increase in the incidence of dengue fever, and its more severe forms, making it more difficult to prevent and control epidemics.

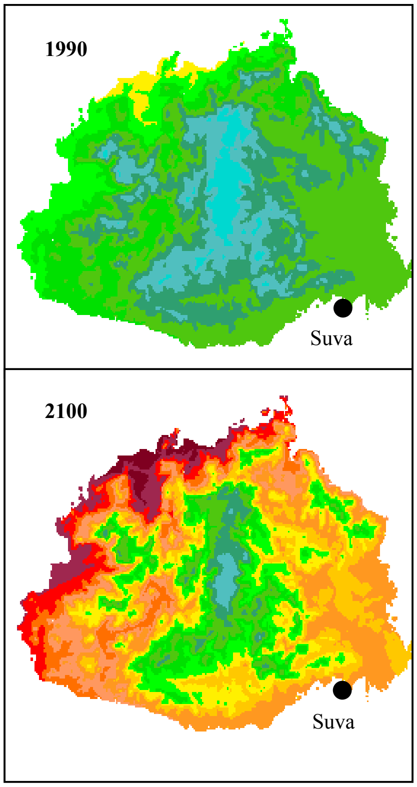


FIGURE 3.6. Dengue fever epidemic potential for Viti Levu, Fiji, for current conditions (upper figure) and for a high climate sensitivity scenario for 2100 (lower figure), based on results from FIJICLIM, an integrated assessment model developed for Fiji. Green and blue colours indicate low epidemic potential; red shades indicate high potential.

While dengue fever currently occurs throughout the Pacific Islands Region, malaria is limited to the Solomon Islands, Vanuatu and Papua New Guinea. Although caused by a parasite and not a virus, and transmitted by *Anopheles* species of mosquitoes, the transmission cycle of malaria is similar to that described for dengue in Figure 3.5 and it is likely to be affected by temperature in a similar way. Consequently, through the same mechanisms as described for dengue fever, climate change is likely to increase the overall risk of malaria, including risk of the severe forms of malaria caused by *Plasmodium falciparum*. One of the concerns in Papua New Guinea, for example, is that climate change will result in a spread of malaria from coastal areas to densely populated highland areas that are currently protected by the lower temperatures experienced above an altitude of about 1500 metres.

Nutrition. As illustrated in Figure 3.4, nutrition is likely to be affected by impacts in other sectors such as water resources and agriculture. Droughts currently have significant adverse effects on nutrition and any increase in the frequency and severity of droughts due to climate change would result in adverse health impacts. As was the experience in Fiji in 1987, and again in 1998, crop failures, economic hardship, unemployment, increased food prices and relatively high prices of imported foods all contribute to household food shortages during times of drought. Children, particularly in the under 5 age group, are the most vulnerable to malnutrition, as well as being the group most at risk of iron-deficiency anaemia and Vitamin A deficiency. In these age groups, severe or prolonged malnutrition may have adverse long-term impacts on health and normal development. Agricultural losses and more widespread economic losses caused by tropical cyclones may also impact food availability at the household level and so any increase in the frequency or severity of cyclones could also have significant impacts on nutritional status, especially if ‘recovery periods’ between successive extreme climatic events is decreased.

Economic hardship. National and household economic indicators are often closely linked with health status. Economic hardship resulting from a range of impacts of climate change may become one of the key factors exacerbating and perpetuating climate change impacts on human health. Poverty is likely to contribute to many, if not all, of the health impacts described above, thereby decreasing the capacity and ability of communities to cope with these impacts.

In summary, the possible impacts of climate variability and change on human health in Pacific Island Countries are most likely to be adverse in nature, and frequently will be mediated through primary impacts on ecosystems, infrastructure and economic sectors. Diffuse and cumulative impacts are the most difficult to analyse and describe, but may become the most important as climate change starts to affect the wider social, economic and ecological determinants of individual and public health.

3.3.6 Human Settlements, Infrastructure and Communities

Human settlements and communities take on a wide variety of forms in the Pacific Islands Region. Figure 3.7 shows the distribution of urban populations. Slightly fewer than a quarter of the region's population lives in urban areas although, as the figure suggests, there is great variation. Moreover, the "urbanness" of the various settlements is also highly variable. The number of large cities is relatively small and some urban locations are in many ways large villages. Nevertheless, in nearly all Pacific Island Countries urban populations are growing faster than rural ones. Just as there is considerable variation in urban settlements, so too is there great variation in rural settlements. These range from villages with several thousand inhabitants to small hamlets comprising a few households.

With the exception of some of the larger Melanesian islands, most settlements, urban and rural, are in coastal locations. Most Pacific Island Countries have one main urban centre, the capital, based on the original colonial headquarters. In almost all cases this urban area is a port town. Furthermore, in many instances the main infrastructure and government buildings are located close to the shore. Changes in sea level, and any changes in the frequency or magnitude of storm events, are likely to have serious implications for these urban areas.

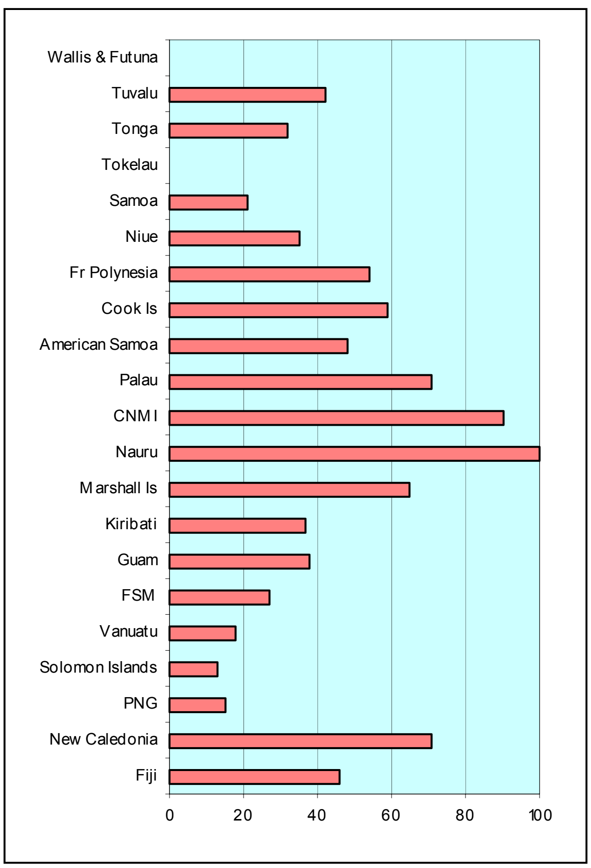


FIGURE 3.7. Urban population (percent) for Pacific Island Countries

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An assessment of the impact of sea-level rise on port facilities in Suva, Fiji, indicated the wharves themselves would be overtopped if, for example, the sea level rose by slightly more than 0.5 m and the harbour experienced winds and waves associated with a 50 year return period cyclone. But before this occurred there would be flooding of the hinterland. Decreased clearance between the wharf superstructure and water level would also increase the uplift force and might lead to critical stress on the wharf structure. At Lautoka Port, Fiji, the wharf would not be overtopped in a similar scenario, though use of an adjacent breakwater might be restricted due to overtopping waves. Port facilities at Apia were found to have a similar vulnerability to those in Suva, including both overtopping and flooding of the hinterland.

The propensity for infrastructure to be located in areas vulnerable to climate variability and change, including extreme events and sea-level rise, can be seen in Table 3.2. While only 6% of the land area of Upolo Island, Samoa, is classed as "coastal lowland", some 70% of the churches and 60% of the school are located in this zone. Similar values were found for Savai'i Island in Samoa. A preliminary estimate for Viti Levu suggests that more than 70% of the population lives at less than approximately 30 m above sea level.

Table 3.2. Spatial Clustering of Selected Infrastructure
(Data from Nunn et al. 1994a, 1994b)

Island	Category	All Island	Coastal Lowland*	% In Coastal Lowland*
Upolu, W. Samoa	Area (km^2)	1132	72	6
	Roads (km)	706	158	22
	Churches (no.)	302	211	70
	Schools	126	77	61
Savai'i, W. Samoa	Area (km^2)	1704	124	7
	Roads (km)	890	147	17
	Churches (no.)	144	105	73
	Schools	52	31	60
Viti Levu, Fiji	Area (km^2)	10830	1280	11
	Roads (km)	2360	840	36

* Operationally defined as below 10 m for Upolu Island, below approximately 17 m for Savai'i Island and below approximately 30 m for Viti Levu.

Table 3.3 lists the likely exposure to climate change effects for large urban areas (cities), smaller urban areas and rural settlements, respectively. As the table shows, the likelihood of serious losses as a result of climate change varies according to the characteristics of each settlement type. Thus, while urban areas may have a much greater exposure of infrastructure and likelihood of significant monetary losses in the event of damage from an extreme event such as a tropical cyclone, rural locations are in many ways more robust, with relatively little in the way of critical infrastructure to lose. On the other hand, rural communities often have only one telecommunications receiver/transmitter, one electricity generator and one road, all of which they are heavily dependent upon. While the magnitude of losses may not be great in such instances, the consequences of those losses may be severe. For the most isolated and the smaller communities, repair and rehabilitation of such infrastructure often lags behind the more urbanized areas that are given higher priority.

TABLE 3.3 Some implications of climate change for urban and rural settlements in Pacific Island Countries

	Large urban settlements	Small urban settlements	Rural settlements
Location	Most large cities are port towns and have much of the government property located close to the shore.	Capitals of small countries are port towns with similar characteristics to the larger cities. The atoll urban areas are all very much coastal locations.	The majority of Pacific island settlements with the exception of the larger Melanesian islands are coastal. Many are exposed to storm surge damage during tropical cyclones.
Areal expansion	Expansion of settlement onto marginal lands such as low-lying coastal areas or steeply sloped land.	On atolls the options for expansion are limted and instead	Most villages take up relatively little land. Expansion not a mjor issue in relation to climate change.
Squatter settlements	Growth in number of dwellings that are less likely to be stable in storm events, do not have adequate provision for roof catchments, are overcrowded and likely to experience greater exposure to any health problems associated with climate change.	May experience similar problems to large urban areas but to a lesser degree.	Less of a problem than in urban areas.
Housing	Urban areas tend to have a range of housing options from a variety of apartments and flats through to informal structures in squatter settlements.	A mix of traditional and "modern" housing types. Tendency for less investment in homes on land that is not owned.	Transitional and formal dwellings becoming more common but still traditional homes in many areas. Several studies have shown that traditional houses and materials in some parts of the Pacific are highly resistant to tropical cyclones.
Investment in infrastructure Roading	Heavy investment. Costs of storms and coastal erosion can be very high.	Moderate investment although in microstates this is still proportionately high.	Limited investment though a single road may play a critical role in a village economy.
Telecommunications	Heavy investment.	Moderate investment.	Low investment although village may be dependent on a single transmitter or receiver.
Water supply	Heavy investment in pumping, storage and reticulation. May be	Limited reticulation investment and more use of household	Some small scale reticulation schemes and heavy use of roof

	damaged by storm events or coastal erosion or inundation. May be impacted by drought.	systems such as roof catchments. Prone to storms and drought.	catchments. Prone to storms and drought.
Electricity	Heavy investment in generation and supply. Most prone to wind damage during cyclones.	Moderate investment in generation and supply. Similarly prone to wind damage.	Variable. Many villages do not have electricity. A wide range of sources are used all of which can be subject to storm damage.
Sewage and waste water	Heavy investment in infrastructure. Storm water outfalls might be affected by sea level rise.	Moderate investment though proportionately high in the smaller countries. Similar exposure to sea level rise.	Most villages have small scale household systems. Low level of exposure to climate change effects.
Solid waste management	Growing problem. A number of urban areas are reclaiming land using solid waste. Often coastal disposal sites are severely damaged during storms or high wave events.	Also a growing problem but of a smaller scale than the large urban areas. Similar problems in coastal disposal areas.	While solid waste is increasing the small populations of most villages and lower exposure to material consumerism renders this problem as less pressing
Under-employment/ Unemploy-ment	Major problem in these areas and likely to increase as urbanisation continues. Where CC effects industry and commerce it may increase unemployment levels.	Major problem in these areas and likely to increase as urbanisation continues. Where CC effects industry and commerce it may increase unemployment levels.	In rural areas subsistence economic activities are still very important. Cash employment plays a less important role.
Poverty	Increasing in urban areas. People suffering from poverty are less likely to have the resilience to cope with CC effects.	Increasing in urban areas. People suffering from poverty are less likely to have the resilience to cope with CC effects.	Increasing in some rural areas but in most cases kinship and subsistence agriculture reduce poverty.
Nutrition	Increasing dependence upon imported foods. Disaster related food price increases may have an impact.	Increasing dependence upon imported foods therefore less direct link to domestic food production. Disaster related food price increases may have an impact.	Much more direct link to food production. If agricultural output is lowered or climatic disasters cause more frequent devastation the impacts on nutrition may be serious.

Rural settlements and communities are more likely to be adversely affected by negative impacts upon agriculture, given that they are often directly dependent upon crop production for their nutritional inputs. While urban dwellers purchase domestically grown crops, they are also becoming increasingly dependent upon foreign food imports.

Local food shortages may increase prices, with greater adverse impacts on the poorer sections of the urban populations. On the other hand, rural communities are directly dependent upon their own production and any losses, particularly catastrophic ones as a result of climatic extremes, can have very serious nutritional and health implications (refer to Section 3.3.5).

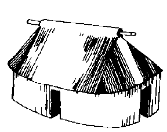
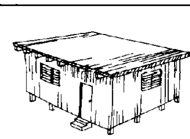
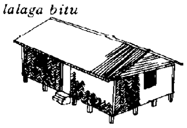
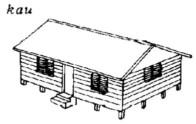
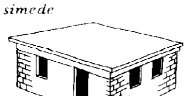
An important consideration in relation to human settlements is housing. In many parts of the Pacific Islands Region traditional housing styles, techniques and materials ensured that they were highly resistant to damage from extreme winds, or could be repaired quickly, using local materials and other resources. Similarly, many architecturally designed and professionally constructed buildings also incorporate designs to limit wind damage. However, in many parts of the region traditional dwellings have become less common, as skills are lost, new materials are incorporated and new shapes and designs are adopted. Moves away from traditional forms of housing has increased vulnerability to thermal stress and, in some countries, increased the use of air conditioning. For example, in Pohnpei the dominant form of modern construction is solid, concrete structures, built at ground level. Such buildings are designed to be cooled by air conditioning and often have little provision for natural ventilation.

Table 3.4 lists some of the characteristics of houses that reduce their likelihood of damage from severe winds, while Figure 3.8 illustrates how "transitional" housing, in particular, is highly susceptible to wind damage. A very large proportion of homes in both rural and urban areas, especially squatter settlements, will be increasingly at risk of serious damage and destruction under scenarios indicating at least an increase in tropical cyclone intensity, if not an increase in frequency.

Table 3.4. Some characteristics of Houses that Influence their Vulnerability to Damage from High Winds

	Features that *REDUCE* vulnerability	Features that INCREASE vulnerability
Configuration of roof	Hipped (4-sided) Small eaves 30˚ - 45˚slope	Gabled Overhanging eaves Flat or slightly pitched
State of structural connections	Binding -- Sennit -- Wire Bolts Metal Straps	Nails
State of connection between wall and ground	Treated timber posts Deeply sunk posts "Anchors"	Stilts Concrete piers Untreated posts Shallow posts or foundations
Airtightness	Window shutters Closed space between wall and roof	Louvres Open spaces between wall and roof Gaps in walls
Masonry Features	Adequate reinforcing and use of rebars	Poor quality blocks Insufficient mortar between blocks Insufficient reinforcement in poured columns Insufficient rebars in side block walls Poor concrete mix

TABLE 2.10 Vulnerable Characteristics of Common House Types in Fiji

Type of House: *Fijian Terminology*	Type of House: *Technical Terminology*	*Example*	*Materials*	Common Characteristics of Houses in Fiji: Features that REDUCE Vulnerability	Common Characteristics of Houses in Fiji: Features that INCREASE Vulnerability
BURE	TRADITIONAL	 	Posts: indigenous hardwood Walls: woven bamboo reeds Roof: thatched pandanus, reeds, palm leaves	Strong hardwood corner posts Deeply sunk posts Steeply angled roofs Hipped roofs Small or no eaves Secure sennit bindings	Lack of rigidity in walls (with increasing distance from corners) Excessive spaces for air to enter Weakness in connections between corner posts and roof
			Modifications to Traditional Bure		
			Posts: downgrading of timber used (reduced availability of some hardwoods) Roof: corrugated iron	Wire bindings	Nails Increased size of eaves Iron sheets poorly fastened to roof trusses
VALE VAKAKENANI	TRANSITIONAL		Frame: local woods, sawn timber Walls: corrugated iron, masonite Roof: corrugated iron	Strong corner posts deeply sunk into ground (occasionally only)	Flat roof Short insufficiently anchored concrete or wooden piers Louvred windows Iron sheets poorly fastened to roof trusses Overhanging eaves Space between roof and walls
VALE TUDEI	FORMAL	*Vale lalaga bitu* 	*Wood Frame with Bamboo Walls* Frame: local woods, sawn timber Walls: Bamboo (*bitu*) mats (also other types) Roof: corrugated iron	Posts anchored into ground Shutters Bolts, metal straps	Short piers (concrete and wood) Louvred windows Nails Iron sheets poorly fastened to roof trusses
		Vale kau 	*Wood Frame with Wooden Walls* Frame: local woods, sawn timber Walls: sawn timber Roof: corrugated iron	Walls securely attached to frame Can be made relatively airtight	Gabled roof Space between roof and walls Walls poorly fastened at corners
		Vale simede 	*Concrete Block* Frame: reinforced corner columns (not always) Walls: concrete blocks Roof: corrugated iron	Corners well fastened Use of reinforcing and rebars (not always)	Poor connection of wooden roof frame to walls Unreinforced or poorly reinforced walls Louvred windows Large overhanging eaves

Source: Extracted from Intertect (1982)

FIGURE 3.8. Housing type and wind damage.

In the past, migration has been one response to the variety of pressures which can take island peoples and habitats beyond their adaptive capacities. For some Pacific Island communities, especially those that are in low lying areas and hence are highly vulnerable to rising sea levels, storm surges, coastal erosion and saltwater intrusion, migration is a potential response to global climate change, at least under the most adverse scenarios prepared by the international scientific community. But past migrations induced by climate and other dominant "push" factors have had limited success. These include Southwest Islanders to Palau (principally due to tropical cyclone damage); Kapingamarangi to Pohnpei (drought); Nukuoro to Pohnpei (social/interpersonal conflicts); Cateret Islanders to Bougainville, Southern Gilbertese to the Phoenix and Solomon Islands and I-Kiribati from the Gilbert Group to Fanning and Washington Islands in the Line Group (land and food shortages); and the relocation of Bikini Marshallese (Political Coercion). The limited successes of most migrations in the past makes this an inappropriate and likely unacceptable response option to future global climate changes. Because of these past failures, and the likely inability to redress these in the future, migration should *not* be viewed as a viable response to global warming.

3.3.7 Energy, Industry, Commerce and Transport

Climate and sea-level variability and change will have both direct and indirect impacts on the energy, industry, commerce and transport sectors of Pacific Island Countries.

Energy

The major impacts in the energy sector resulting from climate and sea-level variability and change will likely be the direct effects on energy facilities, infrastructure and resources from phenomena such as flooding, more intense cyclones, droughts and rising temperatures. The actual impacts will very much depend on the magnitude of the phenomena and the ability of the available energy facilities to absorb the impacts of these phenomena. But since energy has strong influences on all aspects of the economy, there could also be indirect impacts on the supply chain and flow-on impacts on the other socio-economic sectors in the economy. The examples provided below are not intended to cover all the potential direct and flow-on impacts.

The direct impacts on the energy sector of Pacific Island Countries can be grouped under three major categories:

- Disruptions to the supply of electricity;
- Disruptions to the supply of fossil fuels; and
- Disruptions to the supply of fuelwood.

<u>Disruptions to the supply of electricity</u>

Many of the powerhouses in the region are more than 20 years old, situated within 100 metres of the ocean and only a few metres above sea level, as in Kiribati, Marshall Islands, Tonga and Tuvalu. Such installations are vulnerable to storm surges, erosion and, in the longer term, to sea-level rise. In many places power is still distributed by overhead cables, these being especially vulnerable to strong winds and salt spray. Some countries rely on hydropower for a significant portion of their generation capacity (e.g. Fiji, Papua New Guinea and Samoa). In places such as New Caledonia, where wind power is an increasingly important source of electricity, winds of hurricane force can be destructive to the power generating and distribution infrastructure. There is also a growing number of solar installations in the rural and remote areas of most Pacific Island Countries, with these being prone to wind and salt damage. Independent regulatory control over the installation of a power facility, whether it be a powerhouse, distribution lines or solar panels, is lacking in many Pacific Island Countries. This means that the costs of proofing infrastructure against longer-term hazards may not be a priority.

The characteristics of the power sector, as described above, reveal how vulnerable the supply of electricity is to events such as a tropical cyclone, high tides, droughts, flooding or storm surges.

Disruptions to the electricity supply would potentially result in the following negative flow-on impacts:

- Decline in exports due to effects on refrigeration systems;
- Increase in night-time crimes;
- Delay in health services such as immunisation, radiography and surgery;
- Water supply problems where power is needed for water pumping;
- Closure of schools, particularly boarding schools;
- Food shortages because of disruption and deterioration of frozen and fresh food supplies;
- Decline in tourist numbers and foreign earnings;
- Disruption in domestic and international telecommunication services;
- Increased costs of services due to the need for more capital to replace the damaged power infrastructure;
- infrastructure development stalled;
- creation of a negative business climate due to persistent electricity supply disruptions; and
- general decline in economic growth.

In the longer term, disruptions to the power supply (depending upon their frequency and duration) may well lead to an improvement in the resilience of the power facilities through, for example, the adoption of the appropriate construction and installation standards.

<u>Disruptions to the supply of fossil fuel</u>

The supply of petroleum products into Pacific Island Countries is based on a supply chain originating from Singapore through entreport such as Fiji, Guam and Papua New Guinea, and extending from there to the most remote settlements in each country. The transport of the fuel from the refinery, and between each country's group of islands, is by sea. This is very much dependent on the marine weather conditions. The supply within the larger islands is mostly by road transport, which is also vulnerable to disruptions. Most roads are around the coastal areas, particularly in the low lying atoll countries, and through rugged mountain terrain in the higher islands. At certain places, the offloading facilities between the oil tankers to the bulk storage tanks are through pipes exposed at ground level. The storage and distribution of fuel by the oil companies are under industry-adopted guidelines and standards. These are often not strictly observed, including in the more upstream operations. The problem is also acute downstream – at the retail and individual user levels. Especially outside cities and towns, fuel storage and use practices often create health hazards which, in some cases, are life threatening.

The characteristics of the fossil fuel supply chain described above reveal how vulnerable fossil fuel supply is to marine weather conditions and to events such as tropical cyclones, high tides, storm surges and flooding. Since power generation in most Pacific Island Countries is very much reliant on fossil fuel, impacts of disruptions to the fossil fuel supplies would be the same as those described previously. There are also additional rural/remote area-related impacts such as:

- Disruption to electricity supply

- Poor lighting at night;
- Reversion to inconvenient and inefficient cooking techniques due to kerosene shortage;
- Shorter and less frequent fishing trips with less catch and less income due to gasoline shortages;
- Inability to transport emergency cases to hospitals as well as inability to respond to calls for urgent law and order assistance;
- Inability to transport handicrafts and agricultural produce to the markets;
- Inability to use farming machinery such as tractors and trucks; and
- Loss of earnings.

On the other hand, disruptions to the fossil fuel supply (depending upon their frequency and duration) would in some instances encourage a shift to the use of renewable energy for electricity generation and transport. In other cases such disruptions might foster a return to traditional fuels – e.g. fuelwood for cooking and the sun for drying.

<u>Disruptions to the supply of fuelwood</u>

Fuelwood is still a major source of energy in most Pacific Island Countries. Frequent cyclone events may result in a short term over supply of fuelwood, but a shortage in the longer term. On the other hand, prolonged wet weather conditions reduce the combustibility of fuelwood. Such conditions may also accelerate the growth of trees, but vegetation grown during wetter periods tends to have reduced solid wood content. Flooding as well as cyclones can decrease the land available for fuelwood collection. In lowlying atolls this problem can be more acute due to the erosion of coastal areas where fuelwood is grown.

A shortage of fuelwood would have the following impacts:

- Abandonment of traditional cooking methods;
- More time spent on fuelwood collection;
- Switch to more convenient but costly energy sources (more use of fossil fuels); and
- Increased expenditure on commercial energy in the family budget – a burden on subsistence lifestyles, even though access to modern fuels is often linked to social and economic development.

Any short term oversupply of fuelwood would have the following potential impacts:

- Increase in income due to sale of excess supply; and
- Continued inefficient use of fuelwood.

The flow-on impacts of the disrupted energy supplies to the other socio-economic sectors may eventually influence the choice of energy source and appliances. For instance, the impacts of the disruptions in fuelwood supplies on the income generating capacity of the government, or the individual, could result in a shift of demand from traditional energy sources (e.g. fuelwood) to more secure energy sources, such as liquid petroleum gas.

Industry

Manufacturing activities in Pacific Island Countries are predominantly in the food and garment sectors, and are very much labour and energy intensive. While the food industry generally uses local produce, garment factories rely mostly on imported raw materials.

The potential consequences of climate and sea-level variability and change on the manufacturing sector include impacts related to disruption of the energy supplies as well as the impacts affecting transportation, such as the following:

- Interruptions in production due to disruptions in the energy supply;
- Delays in the receipt of raw materials due to impacts on transport;
- Inability to meet the required quantity and quality of agricultural produce;
- Delays in meeting market demand; and
- Loss of competitiveness and loss of markets, leading in turn to loss of business, redundancies and social disruption.

Mining, while undertaken in only a few Pacific Island Countries, is an energy intensive operation and therefore vulnerable to climate and sea-level variability and change in the following ways:

- Disruptions in energy supplies can lead to temporary closures and reduced outputs;
- Frequent rains can lead to landslides causing temporary closures and loss of lives; and
- Flooding and any prolonged adverse weather conditions can lead to increased production costs and an increase in the prices of mining products.

The potential impacts of climate and sea-level variability and change on the construction sector would include the following:

- Imposition of building codes and standards;
- More reconstruction activities;
- Increased cost of construction; and
- More employment.

Raw materials such as sand and gravel will be increasingly difficult to access.

Commerce

One of the important activities for Pacific Island Countries in the commercial and service sectors is the tourism industry. Most tourism facilities are located so as to allow guests to appreciate the white sandy beaches, the clean ocean, waterfalls and so on. Storms, hurricanes, flooding and rising sea level may cause major damage to beaches, accommodation facilities, water and power supplies and to the surrounding natural environment, thereby having a negative effect on the attractiveness of these tourist destinations.

Transport

The transportation sector is vital to the economic development of Pacific Island Countries. It enables goods and services to be delivered into and within the countries as well as exported outside of the countries. It is also a vital element in the support of tourism, which has become a major foreign exchange earner for most countries in the region. Transportation is a major consumer of imported fuels in Pacific Island Countries and the sustainability of the transport sector in the island countries is very much dependent upon the availability and accessibility of affordable imported fuels.

Through phenomena such as floods, cyclones, droughts, rising temperatures and salt water intrusion, climate variability and change can potentially impact the transportation systems of Pacific Island Countries in the following manner:

- Closure of roads, airports and bridges due to flooding, land slides, etc;
- Damage to port facilities like wharves, ware houses and container sheds;
- Insufficient fuels for the transport and energy sectors; and
- Delays and cancellations of air flights.

The above would potentially result in the following:

- Stranded passengers;
- Delay in the supply of basic food items, health care facilities and building materials;
- Disruption to fossil fuel and power supplies; and
- Disruption to market supplies.

3.4 Integrated Assessments of Impacts

The preceding sections have revealed that most Pacific Island Countries are already experiencing disruptive changes consistent with many of the anticipated consequences of global climate change, including extensive coastal erosion, droughts, coral bleaching, more widespread and frequent occurrence of mosquito-borne diseases and higher sea levels making some soils too saline for cultivation of traditional crops. These, and other precursors of global climate change impacts now being experienced by Pacific Island Countries, provide some of the more compelling and tangible indications of the seriousness of global warming, certainly more than the often quoted projections of increased global temperature and sea level. The adverse consequences of climate change are already an unfortunate reality for many small island inhabitants. They highlight the serious and wide-reaching consequences future climate changes will have on Pacific Island Countries, likely exacerbating the existing adverse impacts of the extreme events and high variability that are inherent characteristics of their climate and related systems. The pervasiveness of those impacts is demonstrated in Table 3.5, including the consequences for human life, habitation and the economy.

Table 3.5. Major Disasters in Pacific Island Countries during the 1990s
Sources: Campbell (1999) and World Bank (2000)

Year	Country	Event Type	Population Affected	Number of Deaths	Houses Destroyed	Losses (million US$)
1990	Samoa	Cyclone Ofa				140
1991	PNG	Mudslide		200		NA
1991	Samoa	Cyclone Val	170,000			300
1992	Guam	Typhoon Omar			2,000	300
1993	PNG	Earthquake		48		NA
1993	Solomon Is	Cyclone Nina	88,500		11,992	NA
1993	Vanuatu	Cyclone Prema	9,000		1,200	NA
1993	Fiji	Cyclone Kina	150,000	21	2,000	140
1994	PNG	Volcanic Eruption	100,000	4		220
1997	Cook Is	Cyclone Martin	1,649	19		7.5
1997	Tonga	Cyclone Hina			648	14.5
1997	Fiji	Drought				160
1997	PNG	Drought & Frosts	1,200,000	"many"		50
1997	Marshall Is	Drought				6
1997	FSM	Drought				9
1997	Regional[a]	Drought				>275
1998	PNG	Tsunami	11,854	2,182		NA
1998	Tonga	Cyclone Cora				56
1998	French Polynesia				10	NA
1999	Fiji	Cyclone Dani	20,000	12		3.5

Note: Losses are not adjusted for inflation; NA indicates loss estimates are not available. Table includes only those events with significant losses.
[a] Regional drought estimates include those listed for Fiji, PNG, Marshall Is and FSM in 1997; most other Pacific Island Countries also experienced drought conditions in 1997/98, but loss estimates are not available.

Only one drought is recorded in the above table. This reflects a strong tendency towards the under-reporting of drought events in Pacific disaster statistics – unlike other extreme events they tend to occur without fanfare, being insidious and pervasive in nature.

Disasters incur significant financial and non-monetary costs for the Region. Total losses associated with the ten events for which data are provided in Table 3.5 exceed $US 1.4 billion. Consistent with trends observed internationally, disaster costs are almost certainly increasing in the Pacific Islands Region.

The combination of current and anticipated impacts of disasters, and of climate variability and change, for small island states in the Pacific is thus of great and urgent concern, given the extensive and growing evidence of the vulnerability of these countries and given the acknowledged limitations these countries have for coping with, and adapting to, such events and changes. Pacific Island Countries are likely to be among the countries most seriously impacted by climate change, including sea-level rise, despite being the smallest contributors to human-induced climate change. Typically they also have seriously limited capacity to adapt to the adverse consequences of these pressures.

In Section 3.2 it was emphasized that, in general, Pacific Island Countries have small, highly integrated environmental and economic systems, resulting in the interactions between components of natural systems and the sectors of economic activity being both rapid and strong. Therefore, while assessments of the potential impacts arising from climate change can be carried out and reported on a sector by sector basis, as has been done in the preceding sections, there is also a need to supplement such assessments through an integrated approach. The methods and tools described in Section 3.1.2 can assist this process.

The most comprehensive integrated assessment of the possible impacts of changes in climate on Pacific Island Countries was recently undertaken by the World Bank. Case studies involving Viti Levu, Fiji (representing a high island) and Tarawa atoll, Kiribati (representing a low island) were undertaken with the assistance of many national, regional and international partners. The analysis used an integrated impact assessment model, the Pacific Climate Change Impacts Model (PACCLIM), developed for the region by the International Global Change Institute as a contribution to PICCAP. PACCLIM links several sectoral impact models, population projections and baseline data such as historical climate records. Results indicated that among the most substantial impacts of climate change would be losses of coastal infrastructure and land, resulting from a combination of inundation, storm surges and shoreline erosion. Climate change could also be associated with more intense cyclones and droughts, the failure of subsistence crops and coastal fisheries, losses of coral reefs, and the spread of malaria and dengue fever.

Another dimension of integration was also achieved by expressing the impacts in monetary terms, in this case in 1998 $US equivalents, thereby providing an estimate of the overall cost of the impacts in the absence of any efforts to offset them. A high island such as Viti Levu could experience average annual economic losses of $US23 to 52 million by 2050, equivalent to 2 to 4% of Fiji's GDP. A low group of islands, such as Tarawa atoll, could face average annual damages of $US8 to 16 million by 2050, as compared to a current gross domestic product (GDP) of $US47 million. These indicative costs could be considerably higher in individual years when extreme events such as cyclones, droughts or significant storm surges occur (see Box 3.4). A cyclone might cause damages of about $US40 million, while a severe drought could cost Viti Levu some $US70 million. In years of strong storm surge 54% of South Tarawa could be inundated, with capital losses of as much as $US430 million. Further details are provided in Table 3.6.

Table 3.6. Estimated annual economic impact of climate change, 2050 (Millions of 1998 $US) Source: World Bank, 2000

Impact	Average Annual Damage		Likely Cost of an Extreme Event		Extreme Event
	Viti Levu	Tarawa	Viti Levu	Tarawa	
Impact on Coastal Resources					
Loss of coastal land and infrastructure to erosion	3-6	0.1-0.3	--	--	
Loss of coastal land and infrastructure to inundation and storm surge	0.3-0.5	7-12	75-90	210-430	Storm surge
Loss of coral reefs and related services	5-14	0.2-0.5	--	--	
Impact on Water Resources					
Increase in cyclone severity	0-11	--	40	--	Cyclone
Increase in ENSO related droughts		+	70-90	--	Drought
Replacement of potable water supply due to change in rainfall, sea-level rise and inundation	+	1-3	--	--	
Impact on Agriculture		+			
Loss of sugarcane, yams, taro and cassava due to temperature or rainfall changes and ENSO	14	+	70	--	Drought
Impact on Public Health					
Increased incidence of dengue fever	1-6	+	40	--	Large epidemic
Increased incidence of diarrhea	0-1	+	--	--	
Total estimated damages	**>23-52**	**8-16**			

\+ Likely to have economic costs, but impact not quantified
-- Not available

Gaining a detailed, integrated understanding of social impacts is important, but particularly difficult. People will cope with many of the effects of climate change as they are experienced or anticipated, but in different ways and with different consequences (see Section 4). Thus, for example, farmers may adopt new species or increase the use of pesticides, countries may build on existing natural disaster reduction capacities, and public health programmes may be improved. From this perspective, the impacts of climate change may be conceptualized as the costs of adaptation, or those effects for which the adaptive options are inadequate or non-existent.

BOX 3.4. Extreme Events and Natural Hazards

While much of our thinking about global warming is in terms of gradual, long-term changes in average conditions, it is also clear that people will feel the effects of climate change through changes in the patterns of short-term climate variability. One way of thinking about environmental variability is to relate it to human social and economic activities. Part (a) of the following figure illustrates this in terms of a set of average conditions, and the variability around this mean. People undertake social and economic activities that accommodate much of this variability. This is expressed as an adaptive range. Thus for example, a crop may be suited to average temperatures of 28°C, but can survive a range from 23°to 32°C. When temperatures occur outside this range the crop will be impacted adversely, and may even die. The instances when the variability falls outside the adaptive range may be considered as extreme events.

Climate change may cause conditions to fall outside the adaptive range in a number of ways. These are shown in part (b) of the figure, and include:

Changes in the mean with the same pattern of variation about the mean;
Changes in frequency of extremes;
events happen more often with an overall increase in losses; and
increased probability of strings of events occurring in close succession;
recovery is disrupted;
long periods without infrastructure or income;
Changes in magnitude of extremes;
greater losses and the possibility of catastrophic events becoming more common;
greater recovery duration;
increased length of periods without infrastructure;
increased length of periods with reduced subsistence and cash income;
length of periods between recovery and next event may be reduced;
A combination of these.

A further possibility is that new hazards will develop that do not currently exist, such as the introduction of new diseases.

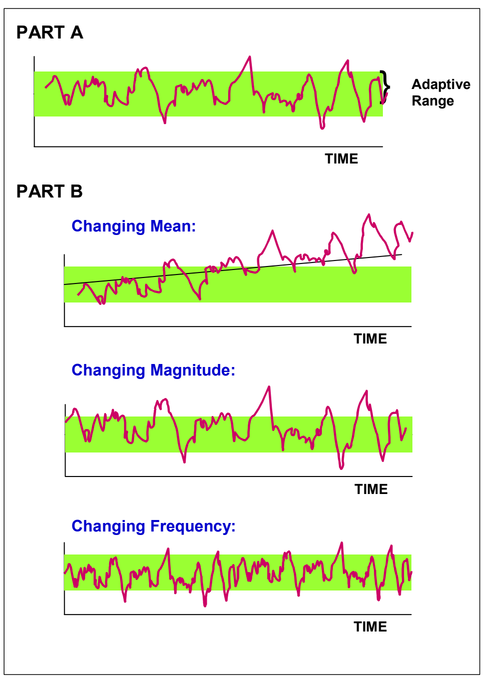


Figure left. Adaptive range: Part A – the adaptive range encompasses nearly all events under current conditions; Part B – the adaptive range cannot cover changes in mean conditions, in the magnitude of extreme events and changes in the frequency of extreme events.

It is also likely that many other changes taking place simultaneously will in some way exacerbate the adverse consequences of global warming. Changes that may need to be integrated into assessments of socio-economic effects of climate change effects include:

- Population growth (although outer islands may experience population decline);
- Urbanization;
- Increasing material possessions;
- Increasing poverty;
- Growth in tourism; and
- Changes in international aid regimes (including disaster relief aid).

Figure 3.9 provides an example by indicating some of the pathways through which changing population density in Funafuti will contribute to greater losses from tropical cyclone events, as a result of the population on Funafuti increasing due to people moving to seek work opportunities through government services and tourism development, and due to increased property exposure though increasing material possessions and a greater number of non-permanent dwellings. If either the intensity or frequency of tropical cyclones affecting Funafuti increases, or indeed if both were to occur, the losses would be even greater.

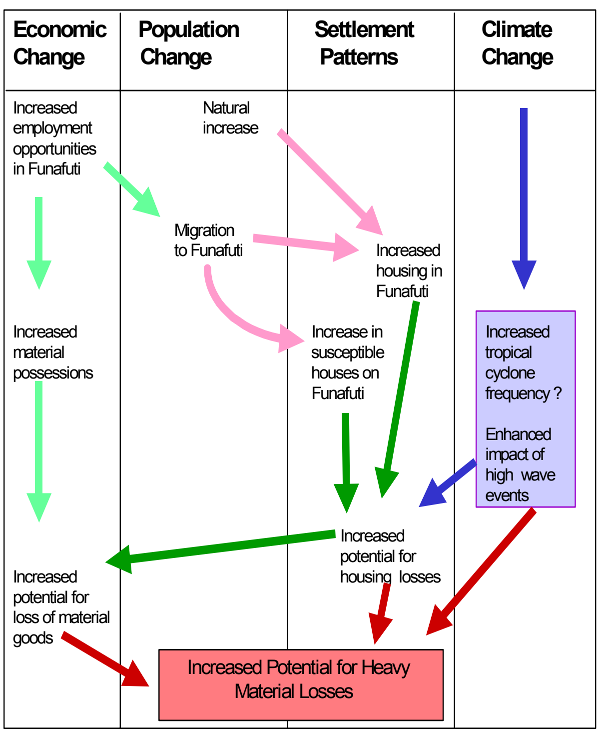
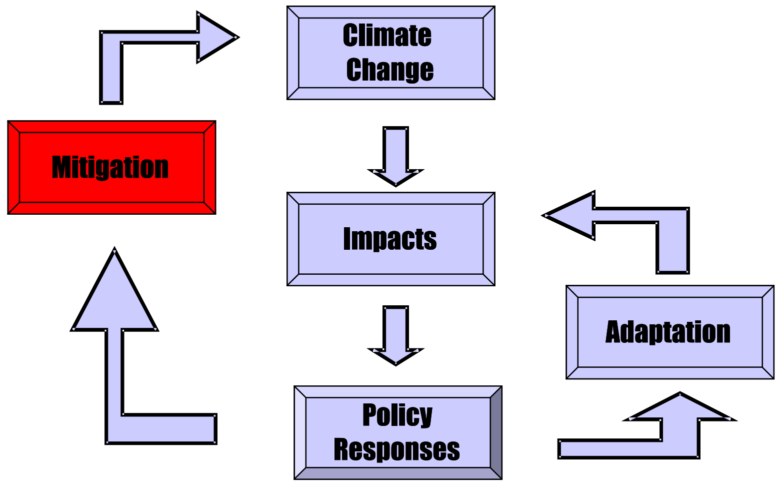


FIGURE 3.9. Integrated assessment of impacts and vulnerability in Funafuti, Tuvalu

In summary, it is important to emphasise that, in addition to long term trends in climatic conditions, global warming will almost certainly increase the likelihood of extreme events, and hence disaster risk. Even today, extreme events are a major impediment to sustainable development. While national and local development planning already addresses some risks, including those associated with financial shocks, national security, human health, transport services and food, water and fuel supplies, planning for a sustainable future must reflect both recurrent historical risks and new risks, including those associated with climate change. Effective risk management prevents precious resources from being squandered on disaster recovery and rehabilitation. As will be emphasised in Section 5, acting now to reduce the current vulnerability of Pacific Island Countries to natural climate extremes and variability, such as the El Niño-Southern Oscillation (ENSO), is one of the most effective ways to prepare for future changes in climate.

The ongoing uncertainty in the science related to estimating regional and local changes in atmospheric and oceanic conditions, combined with substantive and anecdotal evidence of contemporary changes, suggests the need to take a precautionary approach to adaptation, and recognition of this imperative by the international community.



Chapter 4. Regional, National and Community-based Responses to Climate and Sea-level Variability and Change - Mitigation

Key Findings:

- Most actions that slow the rate of climate change also contribute to sustainable development;
- National greenhouse gas emissions data can play a crucial role in national sustainable development planning, and in assessing the success of those strategies over time;
- On average, individual Pacific Islanders are responsible for producing approximately one quarter of the CO_2 emissions attributable to the average person worldwide;
- In common with most other countries, the energy sector is the largest source of greenhouse gas emissions in Pacific Island Countries;
- For Pacific Island Countries mitigation options fall into three broad, interrelated categories – fuel substitution, energy efficiency and forestry
- While more emphasis tends to be given to reducing greenhouse gas emissions, for some Pacific Island Countries there is also the opportunity to enhance the removal of carbon from the atmosphere, for example through new forest plantings;
- Mitigation activities in Pacific Island Countries are normally best implemented through collaborative partnerships involving at least some of the following key players: developed countries, government, the private sector, community-based organizations, investors, donors and the public at large; and
- Despite the small quantities of greenhouse gases emitted by Pacific Island Countries, internationally agreed emissions reduction mechanisms such as the Clean Development Mechanism are relevant to these countries, for the mechanisms are also designed to support sustainable development and, in some cases, adaptation.

4.1 Overview of Response Options

As indicated in Figure 1.2, and the diagram above, responses to climate variability and change fall into two broad categories, mitigation and adaptation (refer to Box 1.1). Mitigation options and interventions will be discussed in this section. Adaptation will be considered in Section 5. Technology transfer related to both mitigation and adaptation will be discussed at the end of the Section 5.

4.2 Mitigation

4.2.1 Overview

Climate and sea-level variability and change are taking their toll in Pacific Island Countries. Given their limited capacity and resources, it is critically important to continue monitoring and acting to reduce the adverse impacts, while at the same time identifying and implementing the opportunities for slowing the rate of climate change. The 2001 Pacific Island Forum has taken the lead in this area. When they met in 2001 the Forum Leaders called for:

- . … further commitments to reduce greenhouse gas emissions in the future and highlighted the importance that Forum members place on domestic action to reduce emissions;
- . … further recognition of the benefits of encouraging renewable energy and energy efficiency to advance the reduction of greenhouse gas emissions….

Mitigating climate change will preferentially involve the energy and forestry sectors of Pacific Island Countries. Greenhouse gas emissions are mostly from the combustion of fossil fuels. Growing trees have the ability to remove carbon from the atmosphere.

4.2.2 Methods for Identifying and Assessing Mitigation Options and Interventions

The identification and assessment of mitigation response options are based on two inter-related activities:

- greenhouse gas inventory; and
- mitigation analysis.

A national inventory of greenhouse gas emissions is a stock take and detailed analysis of all the greenhouse gas sources in the entire economy. As in any other stock take, it must be accurate, timely, detailed and above all provide useful information such as past patterns or trends. The greenhouse gas inventory begins with an identification of the major sources of emissions, both human and natural. These are most likely to be from the following sources:

- Combustion of fossil fuels;
- Gases released during decomposition of biomass; and

- Greenhouse gases, principally methane, released by ruminant animals.

Quantifying the emissions from fossil fuel burning can be achieved more readily by following a "top down approach" based on national totals of fuel imports and any domestic supplies. Alternatively, the estimation can be based on a "bottom up approach", in which case emission estimates are derived from consumption data for end users. The latter include major consumers such as the power utilities, bus and shipping companies, factories and, collectively, households. The "bottom up" approach is more time consuming and data and labour intensive. The IPCC has prepared guidelines for completing a national greenhouse gas emissions inventory, using either approach. Depending upon national circumstance and available resources, it is desirable to use both approaches. Reconciling the findings will enhance the accuracy of, and confidence in, the inventory findings.

National greenhouse gas emissions inventories completed under the Pacific Islands Climate Change Assistance Programme (PICCAP) clearly identified the energy sector as the main source of greenhouse gases for Pacific Island Countries. Further analysis showed that the main sub-sectors were power generation and in-country transportation. The aggregated national data for 1998 indicated that, on a per capita basis, emissions by the energy sector equaled 0.96 tonnes of CO_2, with a range of 0.23 to 4.60 for the ten countries included in the analysis. Based on a total population of 7.1 million for the Pacific Islands Region, the region produces some 6.816 million tonnes (Mt) CO_2 per year. Comparable global CO_2 emissions arising from fossil fuel combustion only for 1996 were reported to be 22620.46 Mt of CO_2 per year, or 4.02 tonnes of CO_2 per capita per year.

Thus, on average, individual Pacific Islanders are responsible for producing approximately one quarter of the CO_2 emissions attributable to the average person world wide. The Pacific Islands Region as a whole accounts for some 0.03% of the global emissions of CO_2 from fuel combustion. This is despite having around 0.12% of the world's population. By way of a further comparison, and relative to the global figures, the OECD (Organisation for Economic Cooperation and Development) countries as a whole are responsible for nearly three times the per capita production of CO_2 through the burning of fossil fuels. In terms of total CO_2 emissions from fuel consumption, the 29 OECD countries account for just over 50% of the global total. However, the OECD countries have approximately 20% of the world's population.

There are a number of reasons why completion of national greenhouse gas emissions inventories is in the best interest of Pacific Island Countries. One reason is that the results of such inventories can be used to guide the positions taken in regional and international discussions, negotiations and cooperative programmes related to environmental protection and other aspects of sustainable development.

But arguably of greater importance is the use of the national emissions data in the preparation of national sustainable development strategies, and for assessing the success of these strategies over time. For example, the inventory can assist countries to recognise opportunities to increase the efficiency of existing energy supply systems and to consider opportunities for substituting less costly fuels. Decisions on which interventions should be pursued are best guided by a mitigation analysis – the assessment of the cost and other implications of reducing greenhouse gas emissions and enhancing removal of carbon from the atmosphere, through the use of various technological or policy interventions, including consideration of the associated economic impacts and the institutional and policy requirements.

Henceforth, the focus of this discussion will be on emission reduction, but it is important to recognize that strategies which enhance the uptake of greenhouse gases (e.g. new forest plantings) are implicit in the analysis.

Mitigation analysis involves:

- Deciding on emission reduction targets in terms of both the time horizon for reducing emissions and the volumes of emissions to be reduced;
- Selecting a shortlist of technological and policy options for emission reduction in the various sectors that emit greenhouse gases;
- Compiling the technological and policy-related information in order to assess the performance of a given intervention;
- Assessing the costs and other implications of each technology or policy intervention; and
- Building the various scenarios and strategies for achieving the desired emissions reductions.

There are thus five key steps to be completed in mitigation analysis (see Figure 4.1):

- Comprehensive evaluation of the national, social and economic development frameworks, particularly as they relate to climate change mitigation;
- Baseline scenario development;
- Mitigation scenario(s) projection;
- Assessment of costs and other implications of proposed intervention(s); and
- Consideration of implementation issues.

A significant part of mitigation analysis is assessing the economic impact of the suggested technological or policy options. These impacts should be considered in various ways, including effects on economic productivity, social impacts and balance of trade effects.

Another important requirement for conducting a mitigation analysis is a clear understanding of greenhouse gas emissions under normal economic activity trends – i.e. "business as usual" trends. This is called the baseline definition, and shows the economic development path under the "business as usual" scenario. It also assesses emissions of greenhouse gases under this path. Mitigation analysis seeks to identify the interventions that make the most appropriate reductions in emissions, relative to emissions under the business as usual path.

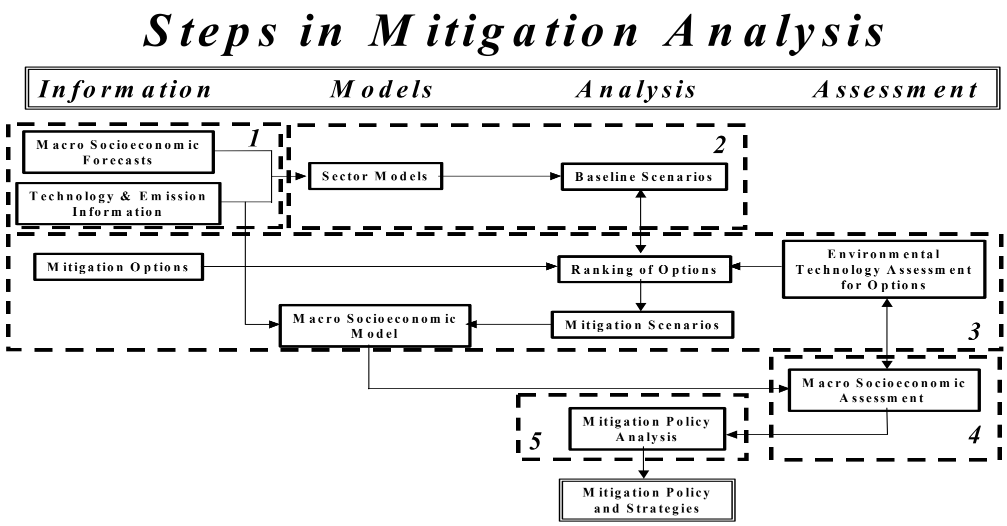


FIGURE 4.1. Steps in mitigation analysis.

A comprehensive mitigation analysis can involve working with large amounts of numbers and repeated calculations. As a result, computer-based analytical tools are often used. These could be models, or simple spreadsheets that the analyst constructs for a special purpose. Since a model must generate practical mitigation analysis results relevant to national circumstances, and must have data input requirements consistent with the existing data management structures, a simple spreadsheet-based model will normally suffice for developing countries where the energy sector typically dominates greenhouse gas emissions.

A typical approach using a spreadsheet routine might include:

- Establish a reference scenario based on macro-economic growth projections and emission data, guided by the overall business as usual assumptions inherent in national development plans;
- Select viable mitigation options and rank these according to cost and emissions, in comparison to the reference scenario; other non-monetary costs should also be considered;
- Develop a set of mitigation scenarios that include various sectors of the economy, and undertake an analysis that accounts for interactions between sectors;
- Assess the macro-economic and other impacts of the scenarios; and
- Evaluate the scenarios against the social, political, institutional and economic desirability of the options.

A national mitigation assessment should take into consideration the impacts of implementing climate change mitigation strategies, by comparing these with the "business as usual" baseline projection in which there are no policies in place to reduce greenhouse gas emissions. The climate change mitigation strategies should be seen as an integrated package that involves implementation of individual projects, sectoral strategies and comprehensive national action plans.

The major scenarios should include:

- Activity projections for the major greenhouse gas emitting sectors and for removals;
- Technological development related to business as usual in the main greenhouse gas emitting sectors and to removals;
- Technological development related to mitigation projects;
- Market behaviour and social, cultural and environmental aspects of implementing mitigation projects;
- Identification and characterization of assumptions, sensitivities and uncertainties; and
- Additional policy instruments for achieving sectoral- and national-level goals.

The criteria for assessing the various options for intervention, the basic information required for assessing mitigation technology options, including an example, and the typical content of a report on the assessment of a technology intervention are all included in Box 4.1.

An example of the mix of interventions that might be identified in a mitigation analysis can be seen in Table 4.1.

Table 4.1. Mitigation Options* for Public Buses

	Technological	Policy/Regulatory	HRD
CLEANER FUELS	***Fuel Substitution***		
	• engine adjustments to take lighter diesel, LPG, natural gas**, bio-fuel • improved fuel filtering	• adopt a standard fossil fuel specifications for all buses • preferential/ tax exemption on non-fossil fuel consuming buses	• twice yearly training for mechanics • annual meeting of bus owners and the Traffic Department
	Renewable Energy		
	• use bio-fuel alone or blend in varying proportions with diesel as the fuel for buses	• duty exemption on specialised parts such as filters which are required for bio-fuel and natural gas buses • mandate the Energy Office to investigate feasibility of solar-powered buses	• exposure visit to observe how hydrogen-fuelled buses are working in the US
ENERGY EFFICIENCY	***Supply Side Management (SSM)***		
	• influence bus designs to suit local roads, passenger capacity and local weather conditions • compulsory routine servicing of buses	• tax buses according to engine size • carbon tax on fossil fuel	• training workshop for bus owners on the various bus designs and features and their impacts on the fuel consumption • twice yearly training for mechanics • annual refresher training for bus drivers
	Demand Side Management (DSM)		
	• build main bus stations close to main market or hospital or school	• designated bus routes and bus stops • encourage use of public buses rather than private vehicles	• public awareness programme for bus passengers
FORESTRY	***Forestry***		
	• plant trees along road sides and between lanes	• subsidise seedlings	• village level training on the importance of trees

*The list in not exhaustive. This is only an illustration of where the options fit in the broader mitigation framework and does not necessarily mean that they are feasible and practical.
** See para 31 of the Chair's draft paper from the second session of the PreComm for the WSSD.

BOX 4.1. Criteria, Information Requirements and Reporting the Findings of a Mitigation Analysis

The criteria for assessing the various mitigation options for intervention include:

- the potential for large impacts on CO_2 or other greenhouse gases;
- the direct cost/benefit ratio of the intervention;
- the indirect economic impacts, such as changes in domestic employment and in the balance of payments;
- consistency with national environmental goals such as reducing emissions of local and regional air pollutants and effectiveness in limiting other adverse environmental impacts;
- potential ease of implementation;
- long-term sustainability of the intervention;
- consistency with national development goals;
- availability of information required for the evaluation, including characterization of the technology or policy intervention and costs of implementing the intervention; and
- other sector specific criteria.

The basic information required for assessing mitigation technology options include capital cost, discount rate, operating and maintenance costs, penetration or diffusion rate, emission factor for fuel used, for each gas and fuel consumption rate.

For example, the information requirements for a typical mitigation intervention in the energy sector would include engineering performance data (energy input and output, thermodynamic efficiency, performance limits, construction requirements), economic data (cost, financial environment) and environmental data (emissions and discharges, control alternatives, control costs).

A typical report on the assessment of a technology intervention will include capital, planning, design and setup costs, process efficiency, lifetime, operating and maintenance costs, fuel consumption, diffusion rates and limits, engineering data, environmental, social, cultural and policy implications, total greenhouse gas reductions per year, total greenhouse gas emissions reduced through to, say, 2030, cost of reduction, per tonne and energy savings.

Of the above, the two most important findings to report are the total greenhouse gas reduction (in tonnes) and the cost of the investment in the mitigation intervention, expressed relative to each tonne of greenhouse gas reduced (e.g. \$/tonne CO_2). The additional information items of importance are the time horizon, or reduction period, and the reduction targets.

It is very useful to construct a greenhouse gas mitigation cost curve for each intervention option. This can be done using a spreadsheet, as follows:

- in one column enter the total reduction costs;
- in the adjacent column list the resulting tonnes of CO_2 reduced;
- sort the data in both columns, using cost as the sort key; and
- plot a bar graph, with cost on the vertical axis and tonnes on the horizontal axis – this is the mitigation cost curve.

For a given mitigation scenario it is instructive to plot a graph showing emissions over time (say to 2030), for both the baseline emissions scenario and the emissions that will result if the mitigation intervention is implemented.

4.2.3 Mitigation Options

The greenhouse gas emissions inventories that have been completed under PICCAP, and the associated regional analyses of mitigation strategies, resulted in identification of three broad, inter-related categories of mitigation options:

- Fuel substitution[2] encompasses all those measures which can reduce greenhouse gas emissions by changing the type, or improving the quality, of fuels used. It includes the use of cleaner fuels and renewable energy technologies;
- Energy efficiency includes all measures that can reduce greenhouse gas emissions despite continued use of current fuels. It includes both supply- and demand-side management; and
- Forestry is all the measures to develop a sustainable supply of trees to supply fuelwood and/or to remove carbon from the atmosphere.

Table 4.1 shows examples of possible mitigation interventions under the above broad categories.

Fuel substitution

Fuel substitution offers Pacific Island Countries the opportunity to assess the full costs of the quality of fossil fuels that they are importing. It also offers the opportunity to exploit under-utilised indigenous and renewable energy resources to reduce reliance on fossil fuels whilst providing cleaner, affordable and reliable sources of electricity and other forms of energy.

<u>Cleaner fuels</u>

Cleaner fuel measures are closely linked with the renewable energy measures and would include close consultations between Pacific Island Countries and the oil industry, considering that the former do not have much influence over the quantity and quality of oil refinery outputs.

An example of a cleaner fuel initiative is the phasing out of leaded gasoline in Pacific Island Countries. In 1996 the Pacific Island Forum Secretariat's Petroleum Advisory Services initiated a project to phase out the use of leaded motor fuels in its member countries. The project was designed to align national gasoline needs with global trends to phase out lead-based additives that boost octane rating. Complementing this initiative was the announcement by the Government of Fiji (entreport to most Pacific Island Countries) that:

[2] These are the adopted definitions used throughout this discussion in order to draw a clear line between the three broad measures.

- As of February 1996 the standard for motor spirit to be used in Fiji up to the year 2000 required that the octane number (RON value) not fall below 96 while lead content would not exceed 0.3 grams per litre; and
- by the year 2000 the Fiji Government would impose a total ban on the importation of motor vehicles that required leaded fuel.

As a result of these and related initiatives, 97 RON motor spirit with 0.5g lead has been substituted with 92 RON with 0.2g lead, and lead free motor spirit is now widely available in Pacific Island Countries

Renewable energy

Identification of renewable energy measures relies on a full understanding of the renewable energy resource potentials and information on proven renewable energy technologies and fuels, both locally and abroad. The latter include proven power generation technologies such as solar, wind and mini-hydro and renewable energy fuels such as bio-fuel.

An example of a renewable energy initiative is the European Union-funded Pacific Regional Energy Programme [PREP] Photovoltaic Follow-up programme. Since 1984 the European Community has provided support to the Pacific Island Countries under the Lomé II PREP. The objectives of the PREP were to reduce dependency on fossil fuels and to prove the suitability of renewable energy technologies for the region.

The programme included installation of 250 photovoltaic lighting systems on the outer islands of Kiribati, and 50 photovoltaic lighting systems, 7 larger photovoltaic systems with domestic refrigerators, 8 vaccine refrigerators and the upgrading of 226 existing photovoltaic lighting systems in Tuvalu, complemented by a further 100 photovoltaic lighting systems funded under the Lomé III National Programme [3].

An evaluation of these two projects in 1998/99 showed that, apart from other socio-economic benefits, the projects resulted in a fuel import saving of $Aus40,000 per year in Kiribati and $Aus50,000 per year in Tuvalu. This is equivalent to a total of 163,000 litres or 408 tons of CO_2 per year, based on an approximate average conversion factor of 2.5 kg of CO_2 per litre of fuel saved.

Energy efficiency

Energy Efficiency offers Pacific Island Countries the opportunity to modify the efficiency and cost effectiveness of their energy use, for both supply and consumption.

[3] In addition were regional workshops, training and technical assistance, rehabilitation of 68 photovoltaic systems in Fiji, installation of 50 photovoltaic lighting systems in Tonga and a photovoltaic training and demonstration facility for Papua New Guinea.

Supply side management [SSM]

SSM measures involve improving the efficiency of producing energy from fossil fuels and of the supply side of transportation services. This would include measures such as regular servicing of generators, and changes to motor vehicle design. SSM should involve close consultations between energy suppliers and consumers, as the initial capital costs of supply side improvements would, under normal circumstances, be passed on to consumers.

An example of a SSM initiative is the Fiji Electricity Authority's [FEA] capital improvement project. The project involved the installation of a two 6 MW generator at Vuda, two 10 MW generators at Kinoya and a 3 MW generator in Labasa. These initiatives were part of an overall objective to increase the efficiency in the FEA's power generating plants, including improvement in the Monasavu hydro capacity. The FEA also examined ways of burning less fuel to generate a unit of electricity. It then established a team within its generation division to look at the best way of meeting demand in specific areas given the available generating plants. The team looked at plant efficiency and established an 'order of merits', with the most efficient plant used first in order to ensure the most efficient use of assets to meet demand. When FEA took over the Monasavu hydro plant only 71 MW of power was being delivered, instead of the installed capacity of 80 MW. Improvements lifted capacity by some five MW, resulting in some $F5 million savings on fuel annually. This translates to some 17857 tonnes of CO_2 per year.

Demand side management [DSM]

DSM measures include fossil fuel users, electricity consumers and transport owners, operators and users changing their energy consumption habits without unnecessary reductions in convenience and productivity.

An example of a DSM initiative is the Solomon Island Air Conditioner efficiency project. In 1996, the PIFS[4] and the Australian Department of the Environment, Sports and Territories (DEST) signed a grant contract, under which DEST initially provided $Aus200,000 for two pilot phase Joint Implementation Projects, with greenhouse gas mitigation as their primary objectives. The grant was to be disbursed equally for a Grid-Connected Photovoltaic Project and an Air Conditioner Efficiency Project. The project was implemented in 1997 through the Electricity Authority and Ministry of Energy. One objective was to determine the feasibility of reducing greenhouse gas emissions through the improvement of air conditioner operation and develop a methodology to achieve and demonstrate reductions in greenhouse gas emissions. The baseline data for this project showed that air conditioning was the biggest contributor to the Electricity Authority's peak load, thus offering the greatest potential for DSM. It also showed that 30% of the air conditioners in the government sector were left running overnight and over weekends, and that there was no regular maintenance programme.

[4] Formerly the Forum Secretariat and whose core energy programme was transferred to SOPAC in 1998.

Interventions were implemented for two government buildings. These consisted of occupant education and awareness, timer switches to control operating hours and regular housekeeping and maintenance. Electricity savings were equivalent to 46 tonnes of CO_2 per year. This result was extrapolated to all public sector buildings, and indicated savings could be as high as 680 tonnes of CO_2 per year.

Forestry

Climate change mitigation measures related to forestry are aimed at enhancing removal of carbon from the atmosphere. Other benefits include not only a potentially sustainable supply of wood but also such functions as wind breaks, shading and the prevention of erosion.

An example of a forestry project is the Tonga Tree Planting project. Tonga's Department of the Environment, and the Energy Planning Unit, have for some years, with local resources, provided free seedlings to the general public to plant more trees to prevent erosion, act as wind breaks, beautify the environment and to provide a future supply of fuel wood. This has been done on an annual basis, mostly in early June in conjunction with the National Environment Week which is tied to World Environment Day. While the baseline data for this tree planting initiative are not well established, and the benefits of the project have not been evaluated, most of the available seedlings were planted. Some trees are now more than ten years old, with many being harvested for forestry and domestic purposes.

4.2.4 Implementation of Mitigation Activities

Pacific Island Countries face a unique and challenging situation with respect to energy for sustainable development, since:

- Markets are very thin, difficult to serve, and without significant economies of scale;
- 70% of the regional population is without access to electricity, but access varies widely, from 10% to 100% at the national level;
- Pacific Island countries comprise a wide range of ecosystems, predominantly influenced by marine systems, that make infrastructure development difficult and environmental impacts significant;
- Most Pacific island countries do not have indigenous petroleum resources and only a minority have hydropower potential;
- Environmental damage, habitat loss and pollution resulting from development and use of conventional energy sources have significant effects on fragile island ecosystems;
- Energy supply security is vulnerable, given the limited storage for bulk petroleum fuels, which are sourced over a long supply chain at relatively high prices;

- The development of renewable energy resources has been limited by the availability of appropriate technology, poor institutional mechanisms, and the challenges of developing systems for small remote markets at reasonable cost;
- There is limited scope for market reforms considering the variation in size and density of markets; therefore, appropriate alternatives vary between countries; and
- The region has limited human and institutional capacity to respond to these challenges.

The majority of people within the region without access to electricity live in rural areas and on remote islands. These people often rely on biomass as their primary energy source. Petroleum products are also often not reliably and safely available at affordable prices in rural and remote island communities, thus reducing their potential for use in electricity generation and transportation.

The recently completed *Pacific Energy Policy and Plan* recognises that energy has a vital role in achieving sustainable development in the Pacific region. It is a fundamental input to most economic and social activity and a prerequisite for development in other sectors such as education, health, and communications. Responding to energy issues within the context of sustainable development involves many complex and interdependent factors addressed by this policy statement.

In general there is a wide sectoral variation in the consumption of energy throughout the Pacific. By weighted average the greatest proportion of energy is consumed in the transport sector followed by the production, transmission and distribution of electricity, and then, to a lesser degree, government, commerce, industry and agriculture. Given that making energy consuming systems more efficient will lead to reductions in costs, development and implementation of energy efficiency and conservation policy initiatives provides a prime opportunity to save energy and improve the long-term sustainability of the energy sector.

Petroleum fuels dominate the energy supply system in the Pacific, yet the region has very limited proven indigenous crude oil sources and these are predominantly exported. Competition in fuel supply is limited by monopoly terminal ownership. Fuel distribution arrangements within countries vary widely, with many governments choosing price regulation to ensure that fuel prices remain fair and equitable. The supply of fuel to remote locations and outer islands is not always reliable, is not always carried out in a safe manner and can result in very expensive fuel to a sector of the community least able to afford it. The environmental impacts of waste oil have the potential to significantly pollute the limited soil and ground water and near shore fisheries of Pacific Islands. The need for policy in this area arises from the need for energy security, the concentrated nature of the petroleum fuel supply industry, and the threat of climate change posed by the expanding use of petroleum fuels.

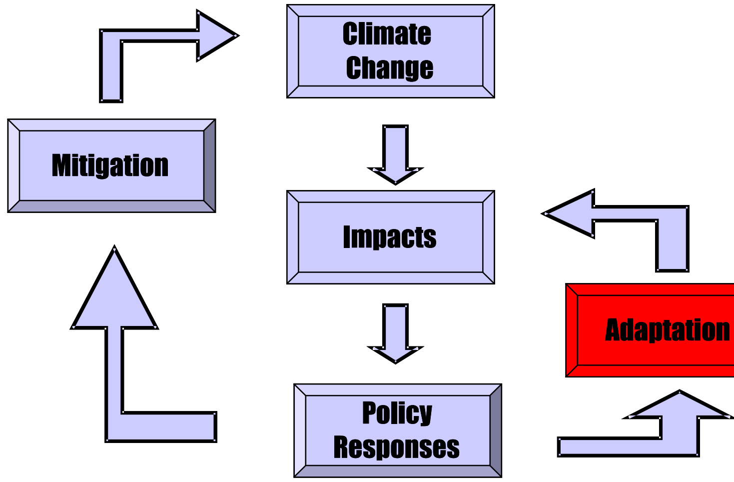
Energy development and use can adversely affect the earth, air, and water both regionally and globally. There are increasingly detrimental economic and environment impacts of energy use, particularly fossil fuels. By incorporating environmental considerations into energy sector planning, the negative environmental impacts can be lessened through fuel substitution, replacement by renewable energy, greater efficiency, and better management, among other approaches. In the *Pacific Energy Policy and Plan* the environmental policy goal is to reduce the negative environmental impacts of the development and use of energy sources within the region. This is to be achieved by:

- Requiring full life-cycle environmental assessment of proposed energy projects, including waste disposal and decommissioning;
- Incorporating mechanisms for waste oil management into fuel supply contracts;
- Promoting the environmental assessment of conventional and renewable energy projects, including assessment of impacts on bio-diversity, greenhouse gas emissions, and local air quality;
- Incorporating plans for the ultimate disposal of solar photovoltaic system components, batteries, and panels into programme designs;
- Integrating environmental regulations into all related energy sector plans, including transportation, power supply, and building codes;
- Continuing to support international action on reduction of greenhouse gasses; and
- Proscribing the use of nuclear energy in the region in recognition that it is inappropriate and unacceptable.

Despite the considerable potential of renewable energy in the Pacific Islands Region, and past efforts to promote its widespread use, progress has in general been rather slow. This is due to a number of policy, technical, financial, management, institutional and awareness barriers. Renewable energy sources in the form of hydropower, wind, solar, biofuel, geothermal and ocean thermal have considerable potential to be used to promote sustainable social and economic development, particularly in rural and remote areas, while reducing the dependence on fossil fuel for power generation and in transportation. Key issues in renewable energy include: a lack of technical expertise and weak institutional structures to plan, manage and maintain renewable energy programmes; the absence of clear policies and plans to guide renewable energy development; a lack of successful demonstration projects; a lack of understanding of the renewable energy resources potential; a lack of confidence in the technology on the part of policy makers and the general public; a lack of local financial commitment and support to renewable energy; and continuing reliance on aid-funded projects.

Partnership-based, cooperative approaches are key to the successful implementation of all mitigation activities. For example, Pacific Island Countries will often require access to new or improved technologies (see Section 5.9). Regional co-operation in energy policy and planning can help to overcome the disadvantages faced by the region, particularly in relation to its small size, dispersed communities, fragmented markets, environmental vulnerability, and limited institutional and human capacity. A regional co-operative approach to co-ordination will allow countries to share expertise, take advantage of economies of scale, harmonise policies and regulations, and mobilise increased official development assistance from international sources. Such technology transfer and uptake will be facilitated by collaborative programmes between developed and Pacific Island Countries, involving such key players as the private sector, government, investors and donors. Internationally agreed emissions reduction mechanisms, such as the Clean Development Mechanism (see Section 6), are of relevance to Pacific Island Countries even though their emissions are small on a global basis. Such mechanisms are designed to support sustainable development as well as the specifics of mitigating climate change.

Typically demand side mitigation projects will require public awareness and education programmes, often best implemented by community-based organizations.



Chapter 5. Regional, National and Community-based Responses to Climate and Sea-level Variability and Change – Adaptation

Key Findings:

- Even in the near future climate variability and change (including extreme events) are likely to impose untenable social, environmental and economic costs on Pacific Island Countries; importantly, such costs are inherently distributed inequitably, preferentially affecting the poor and other vulnerable groups;
- There is value in exploring and undertaking actions to adapt to current climate extremes and variability, both to deal with today's problems and as an essential step to building long term resilience to withstand the impending changes in climate;
- Failure to grasp the real and pervasive costs of climate-related disasters has made it difficult for policy and decision makers to gain support for diverting scarce resources from one part of the national, enterprise or community budget in order to support disaster reduction programmes;
- Moreover, uncertainties in climate change impact estimates, and even more so in the likely success of adaptive responses, have been judged too large for adaptation to be incorporated into national development planning in a meaningful way
- There is now hard evidence that climate extremes, variability and change are significant impediments to successful economic development – i.e. they represent real and significant risks to regional, national and local economies;
- This finding highlights the need to mainstream both disaster risk management and adaptation to climate variability and change, in a mutually consistent and supportive manner by ensuring disaster reduction management and adaptation are integral components of the national risk management strategy and, in turn, of the national development planning process;
- Many disaster and climate change response strategies are the same as those which contribute in a positive manner to sustainable development, sound environmental

management, and wise resource use; they are also appropriate responses to climatic variability and other present-day and emerging stresses on social, cultural, economic and environmental systems;

- If adaptation is reactive, as opposed to anticipatory, the range of response options is likely to be fewer and adaptation may well prove more expensive, socially disruptive and environmentally unsustainable;
- Many development plans and projects that are currently under consideration have a life expectancy that requires future climate conditions and sea levels to be given due consideration;
- Pacific Island Countries depend heavily on valuable and important ecosystems that are sensitive and hence vulnerable to climate change – it is easier to enhance the ability of ecosystems to cope with climate change if they are healthy and not already stressed and degraded;
- Adaptation requires enhancement of institutional capacity, developing expertise and building knowledge – all these take time;
- People will, as a result of their own resourcefulness or out of necessity, adapt to climate variability and change, based on their understanding and assessment of the anticipated or observed effects, and on the perceived options and benefits for response; in many cases such adaptations will be adequate, effective and satisfactory;
- However, under some circumstances such adaptation may not be satisfactory or successful; an external entity, such as central or local government, may need to facilitate the adaptation process to ensure that obstacles, barriers and inefficiencies are addressed in an appropriate manner; and
- Communities and countries in the Pacific Islands Region have already identified and implemented a range of both indigenous and imported practices that enhance resilience and reduce vulnerability to climate variability; this capacity needs to be strengthened, for it also forms part of a priority approach to preparing for longer term climatic change.

5.1 What is Adaptation?

Adaptation is one of the two general categories of response to climate change (see Figure 1.2 and that above). Adaptation can be defined as those actions or activities that people undertake, individually or collectively, to accommodate, cope with, or benefit from, the effects of climate *change* (see also Box 1.1). People are continually adapting to climate *variability*. Adaptation to climate change encompasses the additional actions or activities necessary to take climate change effects into account.

Natural systems also adapt to climate variability and change – this is termed "autonomous adaptation of natural systems".

And as with all other communities in the world, people in the Pacific Islands Region are engaged in a constant process of adapting to their environment (including its variability), as well as to a whole range of economic, social and political factors. This process of adaptation is reflected in systems of resource use, including agriculture, housing styles, settlement locations and the like. It is important to recognise that this process is a dynamic one as the influences people and communities adapt to, and their personal needs and wants, are constantly changing.

From this perspective, when we refer to adaptation in respect to climate variability and change we are referring to adjustments to existing coping strategies, that is additional adaptation beyond what would be the case if climate change had no incremental impacts on biophysical and socioeconomic systems.

From an integrated perspective that considers impacts on both the natural environment and society, adaptation may be seen as those measures that enable natural systems and communities to cope with the adverse effects of climate variability and change. It thus incorporates a wide range of measures that would increase the resilience of the environment and communities to the possible adverse effects of climate variability and change (Figure 5.1).

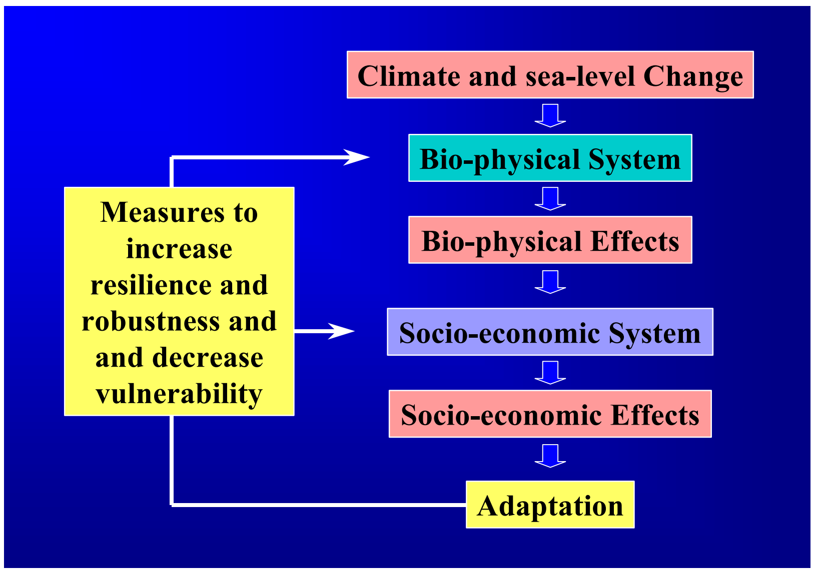


FIGURE 5.1. Adaptation as systems resilience- adaptation includes all measures that improve the ability of natural systems and communities to cope with the effects of climate change and sea-level rise.

5.2 When Should Adaptation be Implemented?

Two factors make adaptation unavoidable. Even if global greenhouse gas *emissions* were to be stabilised near their current levels, *atmospheric concentrations* would increase throughout the 21st century, and would continue to increase slowly for several hundred years afterwards. Substantial cuts in emissions, estimated to be at least 60%, are necessary to stabilise greenhouse gas concentrations in the atmosphere. But in reality, reductions in ongoing emissions will be small – implementation of the Kyoto Protocol will lead to a 5.2% reduction, at best!

The second factor is the serious consequences of climate variability and change for Pacific Island Countries, as revealed in Section 3. While there are significant uncertainties as to how the climate will change, both globally and in the Pacific Islands Region (Sections 2.5 and 2.6), and what the precise consequences might be, it is wise to develop and implement policies and plans that will ensure timely adaptations that reduce or even prevent the adverse effects of climate variability and change.

Therefore an anticipatory approach that is initiated as soon as possible is prudent, for five principal reasons:

- If adaptation is reactive, as opposed to anticipatory (Figure 5.2), the range of response options is likely to be fewer; adaptation may also prove more expensive, socially disruptive and environmentally unsustainable;
- Many adaptation strategies are consistent with sound environmental management, wise resource use, and are appropriate responses to natural hazards and climate variability, including extreme events – such "no regrets" adaptation strategies are beneficial and cost effective, even in the absence of climate change;
- Many development plans and projects that are currently under consideration have a life expectancy that requires future climate conditions and sea levels to be given due consideration;
- Pacific Island Countries depend heavily on valuable and important ecosystems that are sensitive and hence vulnerable to climate variability and change – it is easier to enhance the ability of ecosystems to cope with climate variability and change if they are healthy and not already stressed and degraded; and
- Adaptation requires enhancement of institutional capacity, developing expertise and building knowledge – all these take time.

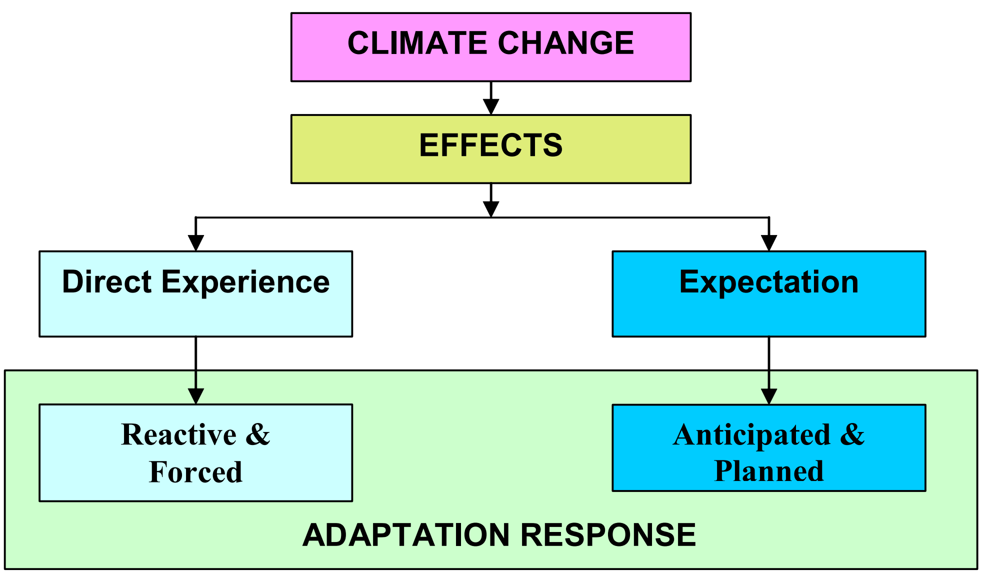


FIGURE 5.2. Planned versus reactive adaptation

5.3 Who Adapts to Climate Variability and Change?

People will, as a result of their own resourcefulness or out of necessity, adapt to climate variability and change, based on their understanding and assessment of the anticipated or observed effects, and on the perceived options and benefits for response. This may be considered to be *independent adaptation*. (see Figure 5.3). The entities who adapt in this way may be individuals, or members of groups such as households, extended families, clans, village or island councils, businesses, or in some cases, governments. This contrasts with *formally planned adaptation* that involves deliberate policy decisions, plans and implementation by *external* parties.

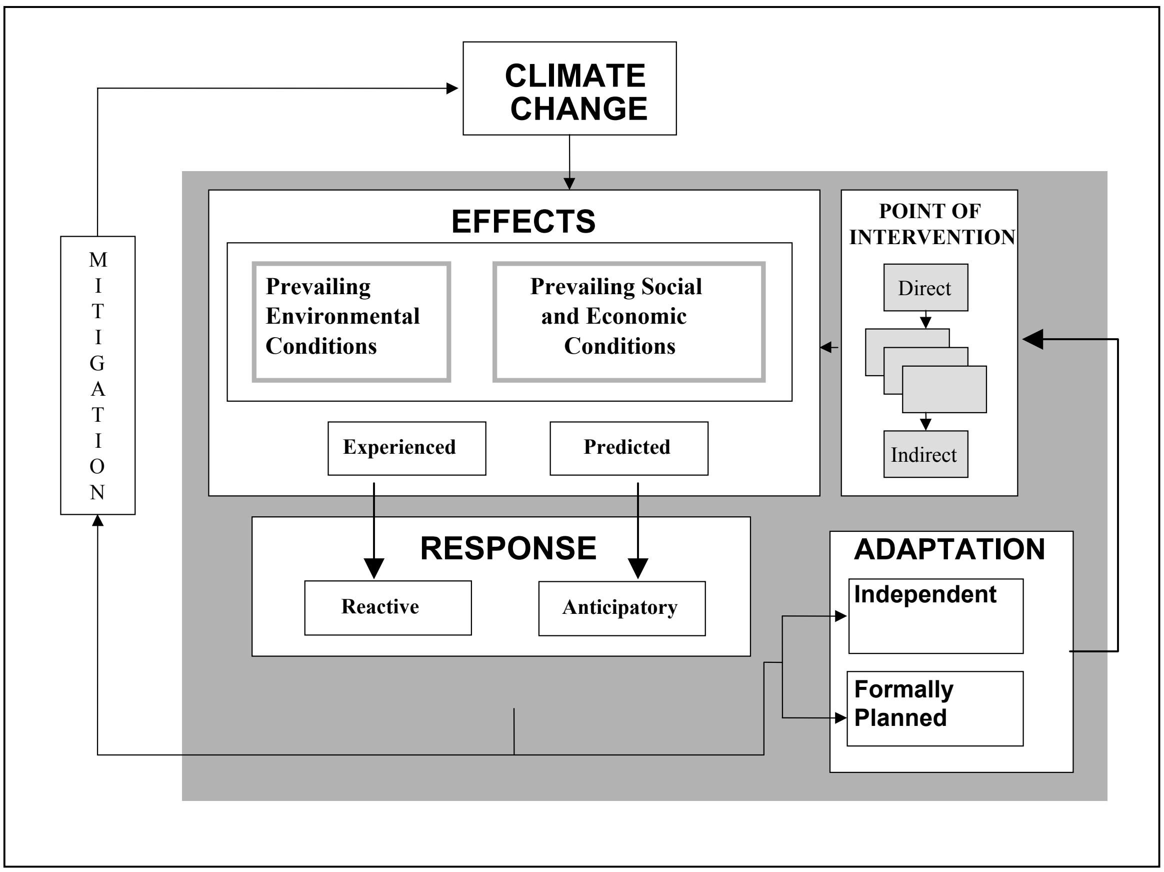


FIGURE 5.3. A generalised model of adaptation.

In many cases independent adaptations will be adequate, effective and satisfactory.

However, under some circumstances independent adaptation may not be satisfactory or successful, often for one or more of the following reasons:

- Understanding of climate variability and change effects may be limited or even erroneous;
- Understanding of the possible adaptation options may be limited or defective;
- Adaptation responses undertaken by one group may impact adversely on another group;
- The needs of future generations may not be taken into account;
- There may be cultural constraints to certain adaptation responses;
- Individuals or communities (or other groups or institutions) may not have adequate resources to implement the most desirable adaptation measures; and
- It may be more cost effective, and in other ways more efficient and effective, to implement certain adaptation responses on a more collective basis, rather than at the level of the individual or community.

In *formally planned* adaptation, the role of an external entity, such as central or local government, can be to facilitate the adaptation process to ensure that the above mentioned obstacles, barriers and inefficiencies are addressed in an appropriate manner. In the context of Pacific Island countries this might include:

- Facilitating adaptation through the provision of information about climate variability and change processes, effects and adaptation options;
- Through the provision of financial, technical, legal and other assistance, facilitating the implementation of adaptation options where those affected, such as communities or other organizations, do not have the resources to adapt effectively;
- Implementing adaptation options directly where the scale of response is most appropriately at a national level;
- Ensuring that adaptation options implemented do not have adverse environmental, social, economic or cultural outcomes;
- Ensuring that there is equity in the adaptation process and that some individuals are not unfairly affected either by the effects of climate change or as a result of adaptive actions; and
- Ensuring coordination, cooperation and equitable partnerships between a community, a local authority and central government in formulating and implementing adaptation plans.

Of course, governments must also take adaptive actions where their own property, resources and services are likely to be adversely affected by climate change.

5.4 Adaptation Processes and Strategies

Clearly, adaptation is considerably more than a discrete measure or action and is best seen as a multi-dimensional, evolving and dynamic process (Figure 5.4). This means that the definition of adaptation should be extended to include all the components that are involved in a wider process that would allow Pacific Island Countries to become more resilient to the effects of climate variability and change.

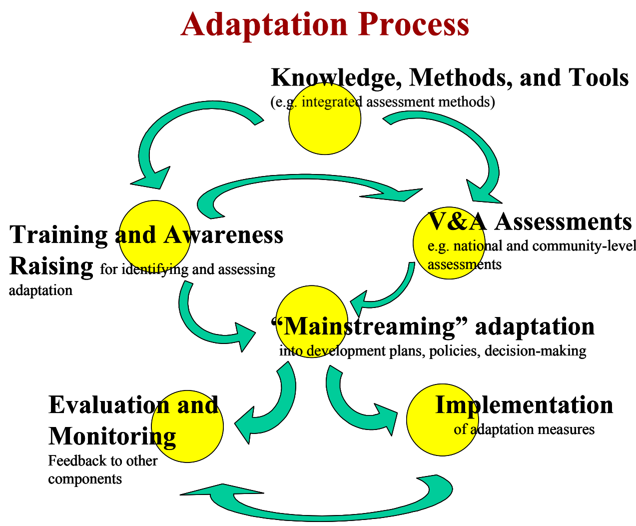


FIGURE 5.4. Adaptation as a process. Courtesy R. Warrick.

Firstly, for adaptation initiatives to be successful they must be founded on a solid knowledge base provided by comprehensive assessments of both the vulnerability to climate change, and of potential adaptation options. This requires professional training leading to development of in-country professional capacity to undertake climate change impact assessments and assessment of vulnerabilities. Building knowledge and capacity requires the development and application of a range of methods and tools that help further the understanding of climate change impacts, adaptation and vulnerability. In addition to this, increasing public awareness and knowledge is an essential component that empowers individuals, communities and governments cooperate in a concerted, multi-sectoral effort in order to develop and implement appropriate adaptation measures and facilitate the mainstreaming of adaptation responses. To ensure the sustainability, appropriateness and effectiveness of adaptation measures there is also a need for ongoing evaluation and monitoring following implementation.

Essential to effective adaptation is a continuing dialogue among technical experts, governments, resource managers and affected communities. This will facilitate a more thorough understanding of the consequences of climate variability and change, and identify and explore potential response options, evaluate the success of existing policies and programmes, revise such policies and programmes when necessary and identify new information needs.

Finally, such *formally planned* adaptation initiatives and processes should not occur as isolated activities. Instead they should be "mainstreamed" and implemented as an integral part of national and community development planning, environmental management and disaster management (see Figure 5.5).

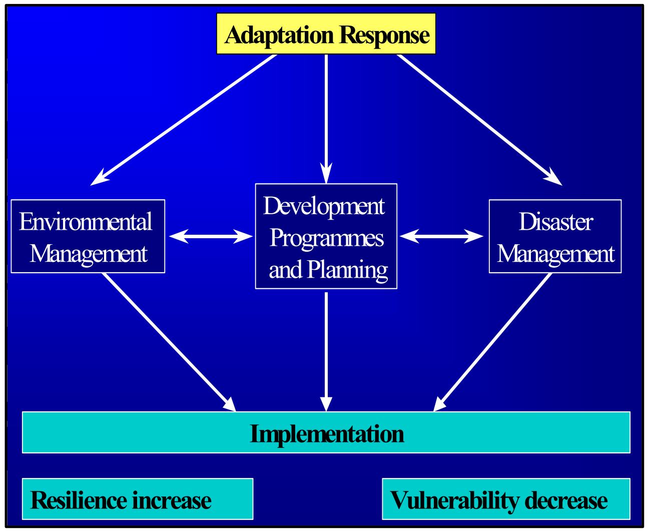


FIGURE 5.5. Mainstream components of adaptation.

A particularly important aspect to *formally planned* adaptation is to ensure that climate change and sea-level rise considerations are integrated into development activities. Throughout the development planning process there are many opportunities for decision-makers to take deliberate action to enhance resilience or reduce vulnerability, or both (see Section 3). With respect to development planning, four broad strategies to increase the resilience of Pacific Island countries may be considered (Figure 5.6):

1. Ensuring climate change and sea-level rise considerations are included in development projects, thereby helping to ensure sustainability of the outcomes – examples include infrastructure development, housing programmes, agricultural development and tourism development;
2. Implement specific adaptation options, such as coastal protection, breeding of drought/salt resistant varieties of key cash and subsistence crops;
3. Undertake capacity enhancement activities, to ensure there is the capability to address climate change and related issues - examples include education and training programmes in climate change science, research and development projects, technical training for vulnerability and adaptation assessment, training in policy development and implementation, and institutional strengthening;
4. Adopting co-management approaches in adaptation plans of a community or village.

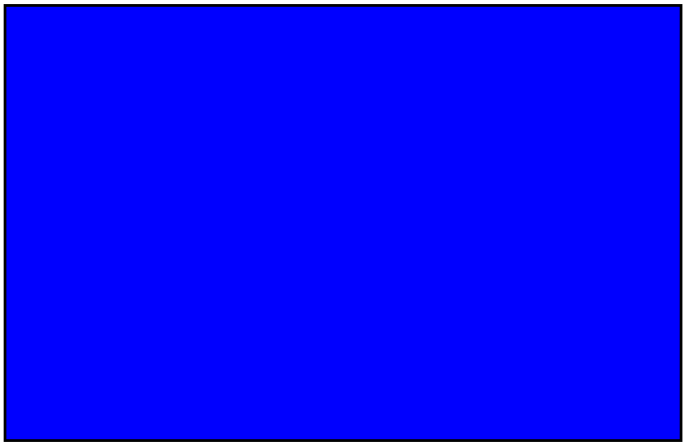


FIGURE 5.6. Three strategies for incorporating adaptation into development planning in Pacific Island Countries

Until recently, failure to grasp the real and pervasive costs of disasters made it difficult to convince most policy and decision makers to divert scarce resources from one part of the national, enterprise or community budget in order to support disaster reduction programmes. On top of this, uncertainties in climate change impact estimates, and even more so in the likely success of adaptive responses, were simply too large for adaptation to be incorporated into national development planning in a meaningful way.

The studies reported here, and other recent investigations, have been instrumental in three important regards: i) highlighting the high economic, social and environmental costs of climate related events, variability and change; ii) documenting how these costs have increased with time, and that this trend is likely to continue into the future; and iii) showing that confidence in the latter projection is improving. While the range given for anticipated costs is typically still large, the implications are clear – even in the near future climate variability and change (including extreme events) are likely to impose major incremental social, environmental and economic costs on Pacific Island Countries. Importantly, such costs are inherently distributed inequitably, preferentially affecting the poor and other vulnerable groups.

These findings highlight the need to mainstream both disaster risk management and adaptation to climate variability and change, in a mutually consistent and supportive manner. The key is to ensure disaster reduction and adaptation are integral components of the national risk management strategy and, in turn, of the national development planning process. Most countries already have policies and plans to manage financial risks, human health risks, biosecurity risks, agricultural risks, risks in the transport sector and energy supply risks. Disasters and climate change and variability should be included and addressed in the same portfolio of national risks.

This can best be achieved by having key players recognise that both disasters and climate change are significant impediments to successful economic development – i.e. they represent real and significant risks to the regional, national and local economies. The key concept is the existence of a continuum of potential events that may all be classed as hazards, ranging from extreme events of short duration (e.g. a tropical cyclone), through events associated with variations in atmospheric and marine conditions (e.g. ENSO-induced drought), to events resulting from long term changes, such as accelerated coastal erosion as a consequence of sea-level rise. These hazards originate in response to the mix of external (e.g. rising temperatures as a consequence of the enhanced greenhouse effect) and internal (e.g. growing demand for food as a result of population increases) pressures on both biophysical and socio-economic systems. Countries are already experiencing the manifestations of these risks, in the form of recent disasters, but also via climate variability. The most efficient and effective approach is to manage the risks in an integrated manner (Figure 5.7). This involves a seamless combination of disaster risk management and planned and proactive adaptation that focuses on "no regrets" strategies. Many disaster and climate change response strategies are the same as those which contribute in a positive manner to sustainable development, sound environmental management, and wise resource use. They are also appropriate responses to climatic variability and other present-day and emerging stresses on social, cultural, economic and environmental systems. Therefore, "no regrets" strategies, plans and actions are beneficial even in the absence of climate change. Risks associated with the full spectrum of hazards, from extreme events to the consequences of long-term climate change, should be managed in an holistic manner as an integral part of national development planning (see Figures 5.5 and 5.8).

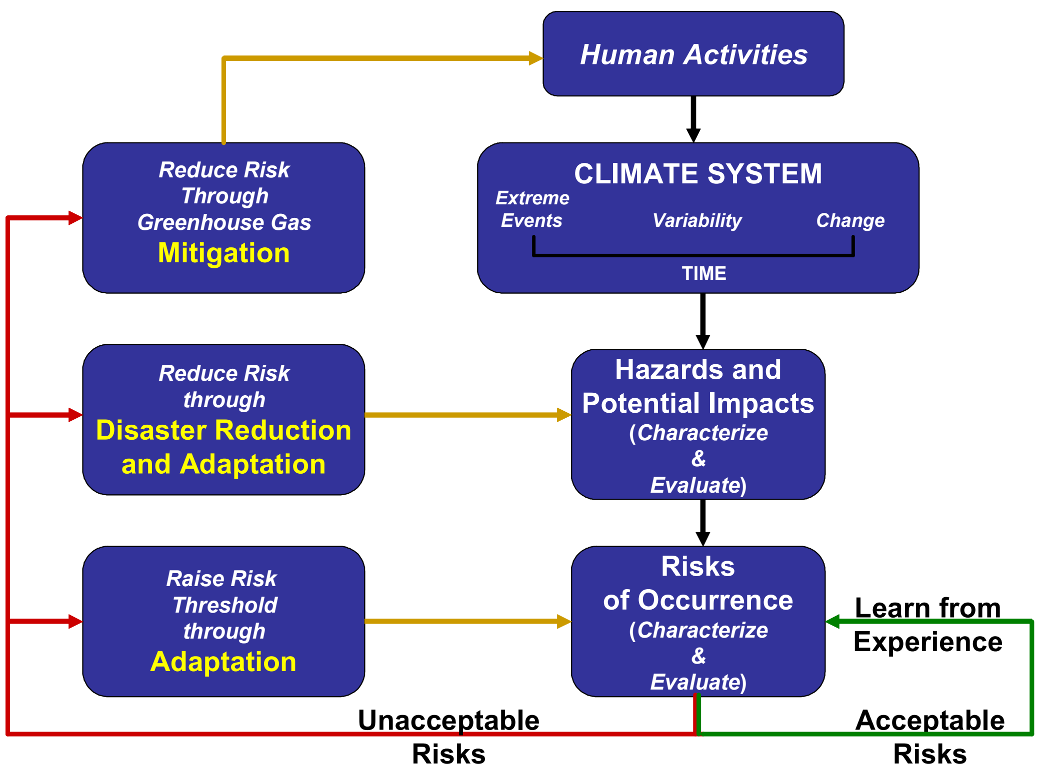


FIGURE 5.7. Key elements of an integrated, comprehensive approach to risk management related to disasters and climate variability and change, including sea-level rise. From Hay, 2002.

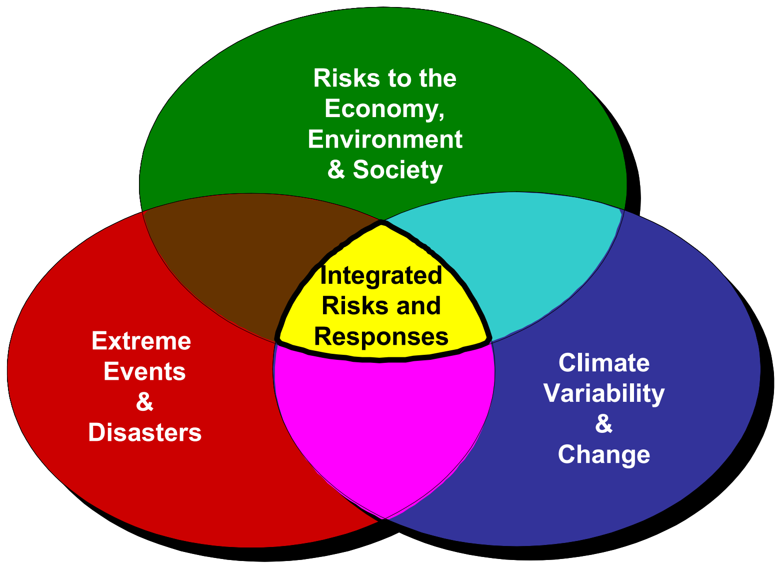


FIGURE 5.8. Risk-based assessments of, and responses to, extreme events, disasters and climate variability and change play an integral role in reducing economic, environmental and social vulnerability. From Hay, 2002.

It is important that national development plans, and sectoral plans, include disaster risk management strategies and climate change adaptation measures that will ensure risks are reduced to acceptable levels (Figure 5.7). These measures, and related strategies, will help strengthen decision making processes by requiring that specific programmes and projects include strategies and measures to manage risks associated with extreme events and with climate change and variability. Such mainstreaming can also be facilitated by undertaking institutional strengthening and reforms that result in Economic and Planning Ministries having a mandate and responsibility for ensuring that disaster reduction and climate change are reflected in national policies, plans, legislation, regulations and programmes.

5.5 Identifying Specific Adaptation Options

Table 5.1 lists some traditional forms of environmental adaptation. Many of these are still in use, in a variety of adaptations to contemporary social, economic and demographic circumstances. As the Table reveals, traditional knowledge systems play a critical role in the functioning of these various adaptations. Where traditional knowledge is being lost, or is being undermined, access to these adaptive options will decline.

Table 5.1. Traditional forms of environmental adaptation

Food security	• Growing resilient staple crops (e.g. yam and taro, compared with cassava) • Crop diversity • Use of forest food resources • Food storage and preservation
Settlements	• Location • Building materials • Building designs • Construction methods

Cooperation
• Among communities
 	
• Within communities
	
	• Exchange networks
	    ○ Resource trade
	    ○ Ceremonial exchange
	• Kinship networks
	• Political networks
	• Coordination of post disaster responses
	• Rebuilding
	• Rationing
	• Sharing resources

Knowledge systems	• Agriculture • Weather • Building • Fisheries

While an adaptation policy will be in the form of a general framework, the adaptations themselves will be much more specific in nature, reflecting the specific impacts that have occurred or will occur as a result of global warming. The specific impacts can relate to sectors such as health, tourism and agriculture but may also be cross-sectoral at a specific site. Figure 5.9 shows the ways in which the impacts of climate change are likely to be manifested at different scales for six different broadly-defined sectors of the Tuvalu economy and society. As the figure suggests, effective adaptation options will need to be implemented over a range of socio-economic and spatial scales, and for specific sectors.

FIGURE 5.9 Matrix showing the importance of scale in determining the effects of climate change in six different socio-economic sectors in Tuvalu. The selection of adaptation options must take these scale effects into account.

There is a very wide range of adaptive options that could be employed. Some adaptive options that might be considered are shown in Box 5.1.

BOX 5.1

Examples of Adaptation Options, by Sector

Coastal zone and marine ecosystems:

- Coastal protection including engineered structures, bio-engineered systems and traditional indigenous approaches;
- Research into appropriate assessment, monitoring and protection systems;
- Public awareness of the implications of building settlements in coastal areas likely to be affected by climate change and on sustainable coastal resource use that reduces damage to coral ecosystems; and
- Legislation to influence coastal land use and management of coastal and marine resources.

Human health

- Vector control;
- Improved epidemic preparedness and response; and
- Improve water supply and sanitation to reduce diarrhoeal disease.

Agriculture and food security

- Research to develop sustainable and flexible farming systems;
- Promotion of agro-forestry;
- Promotion of crop diversity and traditional practices; and
- Crop development.

Water resources

- Flood control and reduction of flood damage potential in settlements on flood plains;
- Reduce water leakage in supply systems;
- Develop legislation with stricter licensing and enforcement;
- Develop alternative water resources;
- User charges to reduce wastage; and
- Watershed improvement.

Climate disaster reduction

- Improve warning systems including use of technical and traditional warning systems and developing appropriate responses in the event of warnings;
- Building wind resistant dwellings and other structures;
- Maintaining crop diversity and reducing the recent and growing dependence on crops such as cassava that are highly vulnerable to high winds;
- Facilitating mutual cooperation within and between communities in post disaster situations; and
- Building on existing governmental capacity in natural disaster reduction through programmes to build awareness of disaster reduction options, developing timely and effective post-disaster assessment procedures and formulating policies for appropriate post-disaster relief and rehabilitation assistance.

In addition to the illustrative adaptation options described in Box 5.1 there are a number of more generic policy instruments that have important roles in reducing the impacts of climate change and enhancing adaptive capacity. These include such instruments as:

- Sustainable development policy;
- Population policy including not only population growth but also in relation to urbanization;
- Environmental legislation; and
- Public awareness building about climate change.

5.6 Evaluating Adaptation Options

Adaptation options can be categorised and evaluated in a number of ways. The following approach was used to evaluate adaptive options in a recent study of Fiji and Tuvalu.

First, the adaptations are assessed in terms of their benefits even if climate change impacts do not occur. These are referred to as "no regrets" or "win/win" actions. Clearly, such actions are useful as they fulfill important roles even if the climate change projections are wrong.

Second, the adaptations are classified in terms of their level of implementation.

1. Some adaptations, such as public awareness capacity building, can be seen as generic since they serve to build adaptive capability in all sectors and areas;
2. Other adaptations are more specific, being appropriate at the sectoral level only. An example is improving the health care system in response to the possibility of the increased incidence of dengue fever epidemics. Such measures would be taken across the country; and
3. The third group of responses are site specific. Examples here include building a sea wall, or dredging a river to reduce flooding. Such measures require a high degree of certainty about localised impacts.

Third, the adaptations are assessed in terms of whether they will be applied in a "top-down" manner, through government action, or whether they will be community based and hence "bottom up". Often, it is the community-based measures that are most appropriate and effective, or a combination of both. Thus there should be commitment from both the community and government.

Fourth, the measures are evaluated in terms of their environmental impacts. In an attempt to resolve one problem, it is important that adaptation measures do not create additional problems. Sea walls, for example, while protecting one stretch of coast, may accelerate coastal erosion immediately beyond the limits of the wall.

Fifth, it is important that the adaptations are culturally appropriate and do not cause a high level of social disruption.

Sixth, the timing of the measure is an important consideration (see Section 5.2). Does action need to start immediately, or can it be delayed? This may depend on the lifecycle of a planned activity (see Figure 5.10). For example, changing crops that are grown on an annual basis may not need to occur immediately, but a tree crop planting scheme, in which the tree life span may be several decades, may justify immediate action to take climate change into account. As a general rule, those adaptations which relate to long lifecycle activities should be given priority.

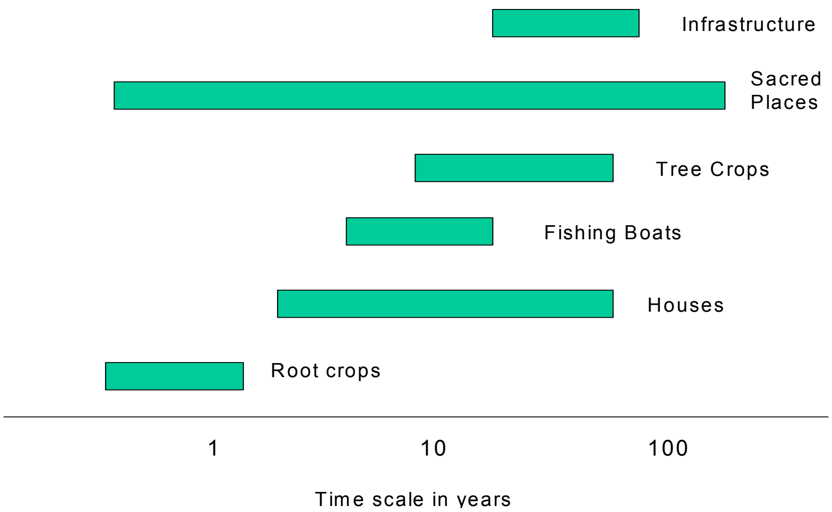


FIGURE 5.10. Life cycles or duration of various social resources in Pacific Island Countries. Resources that have long durations should be among those targeted for early adaptive action.

Seventh, where adaptive measures have implications for other sectors, or a range of climate change effects, it is important that an integrated, as opposed to sectoral, approach be taken. For example, one form of adaptation that is cross-sectoral involves development of legislation. Rather than several piecemeal laws being prepared it may be more appropriate to have a broad-ranging, comprehensive environmental law based on the principles of sustainability.

Table 5.2 provides a number of possible adaptations for the coastal, water resource, agriculture, public health, and tuna fisheries in the Pacific Islands region assessed using these criteria.

TABLE 5.2 ABOUT HERE

Caption: Selected examples of adaptation measures, and evaluation of their suitability. From World Bank, 2000.

Please extract from World Bank, 2000, p35

5.7 Adaptive Capacity

5.7.1 Background

Adaptive capacity refers to the ease with which a community, sector or the like is able to adapt to climate variability and change, including extreme events. Two important aspects of adaptive capacity are resilience and flexibility. Resilience implies ability to withstand change and return to some kind of normalcy, while flexibility implies the ability to change if required. These attributes appear to have been characteristics of traditional communities in the Pacific Islands. Importantly, the communities not only survived but prospered in what are often characterised as limited and unpredictable ecosystems. However, since the early days of colonization, through to the contemporary period of independence in a globalising world, there have been many changes to these traditional systems. These changes, shown in Figure 5.11, include those which have increased the exposure of Pacific Island communities to the likely effects of climate variability and change and those which have reduced their resilience and flexibility to respond to it.

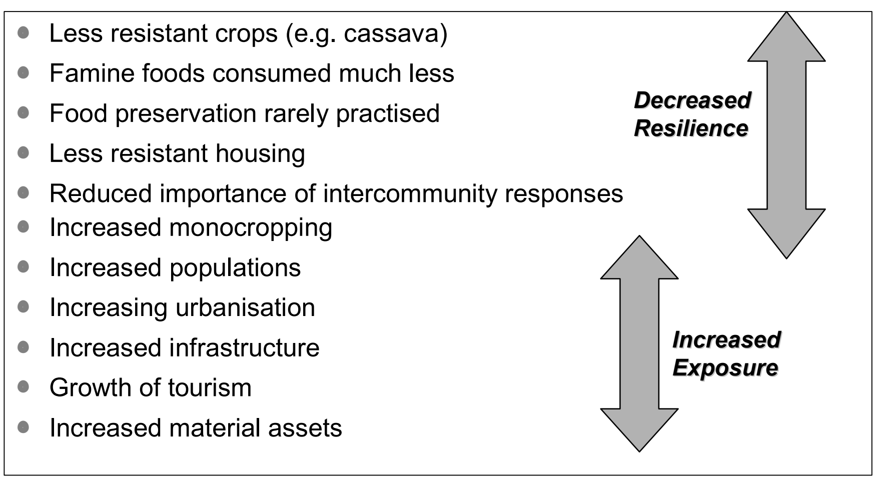


FIGURE 5.11. Characteristics of contemporary Pacific Island communities. While some changes have led to a reduction of the resilience of the communities to environmental variability and change others have served to increase there exposure. The combined effect is a reduction in adaptive capacity.

A critical element of effective adaptation in the Pacific Islands Region is development of policy which increases the adaptive capacities of both rural and urban communities by reversing some of the processes that have increased exposure to hazards and reduced resilience and flexibility. Such processes are often associated with inappropriate and non-sustainable development. Acting now to reduce the current vulnerability of Pacific Island Countries to natural climate extremes and variability, such as the El Niño-Southern Oscillation (ENSO) is one of the most effective ways to prepare for future changes in climate.

5.7.2 Enhancing Adaptive Capacity

In general, adaptive capacity can be enhanced by reducing the exposure to, and increasing the resilience of, communities, the private sector and governments. This can be achieved partly through sustainable development that seeks to promote improved well-being in the context of maintaining and enhancing environmental quality, and social and cultural equity, while reducing natural disasters. Figure 5.12 provides details of one approach to incorporating climate change and sea-level rise considerations into development proposals.

Seasonal and longer term forecasts that capture the significant aspects of climate variability are critical to effective decision making and provide a relevant way to more fully integrate climate information into decision making (see Section 6). For example, ENSO forecasts are being used in some countries, with significant benefits to sectors such as agriculture, water resources and fisheries. Forecasts, and other initiatives that enhance the utility of climate information, are important elements of building adaptive capacity.

5.8 Adaptation Responses in the Context of Sustainable Development and Equity.

Agenda 21 recognised that implementation of its proposed programmes would require a substantially increased effort, both by countries themselves and by the international community, including:

- Substantial new and additional financial resources;
- Transfer of environmentally sound technologies on concessional and preferential terms; and
- Education, capacity building and development of scientific capabilities.

Lack of means of implementation remains a major constraint to the realisation of the goals of Agenda 21. Urgent actions are required therefore, to finance and transfer technology, promote science and education, develop capacity building, and provide improved access to quality information for decision-making. To ensure sustainable development in the Pacific Island countries there is a need to:

- Reduce economic and environmental vulnerabilities, these being a major constraint facing the Pacific Island Countries as a result of the interplay of such factors as remoteness, geographic dispersion, marginalisation, susceptibility to natural disasters;

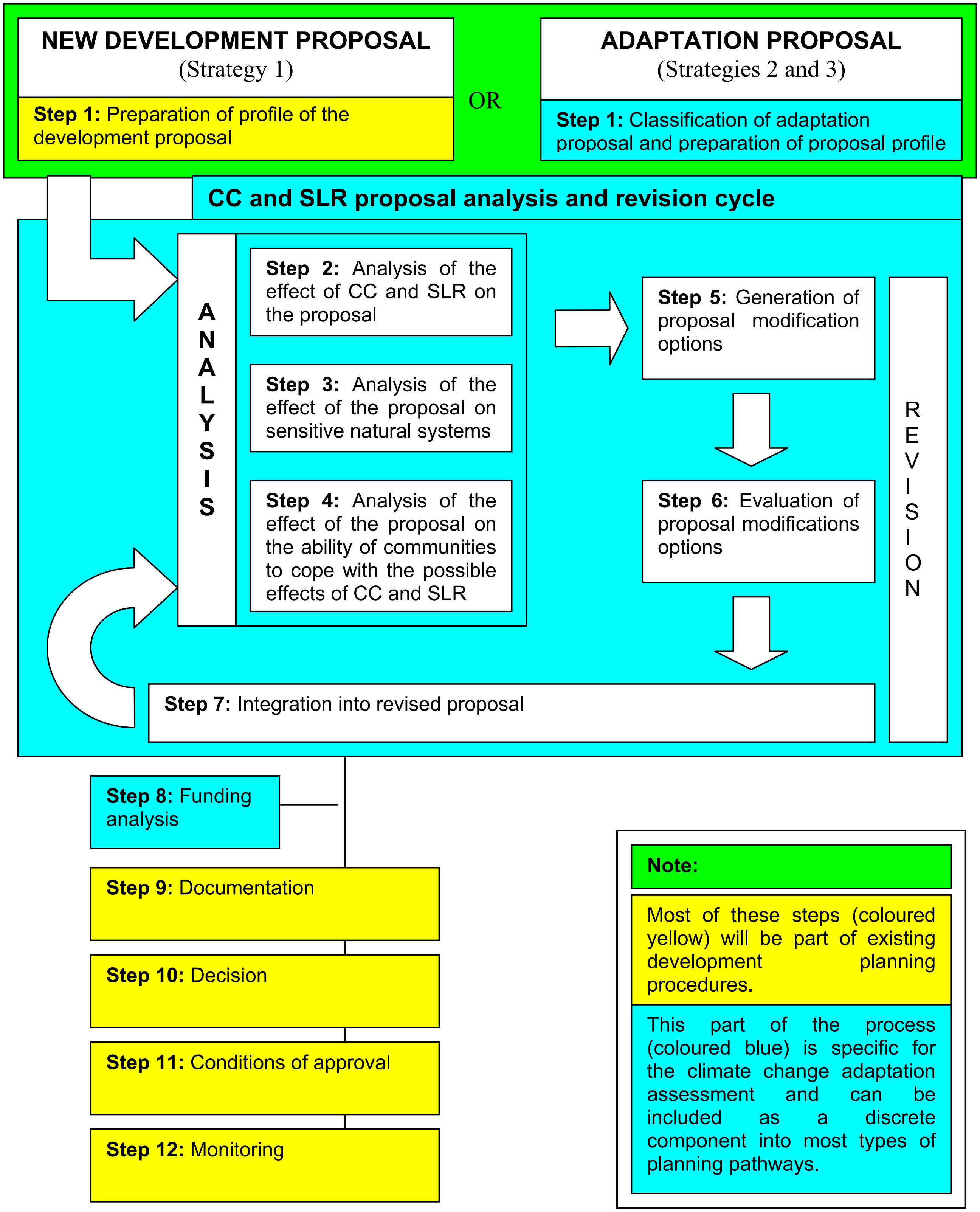


FIGURE 5.12. One approach to incorporating climate change and sea-level rise considerations into development proposals

- climate change, ecological fragility, exposure to economic shocks, small internal markets and limited natural resource endowments;
- Strengthen regional institutions and organisations in the Region that are involved in education, research, natural resource development and specialised capacity building initiatives;
- Support initiatives to accelerate national and regional implementation of the Barbados Programme of Action (BPoA), including mobilising the necessary financial resources, transfer of environmentally sound technologies and assistance for capacity building provided by the international community;
- Support regional fisheries management organisations to address sustainable fisheries management;
- Support Pacific Island Countries to manage in a sustainable manner their Exclusive Economic Zones;
- Support Pacific Island Countries in their efforts to adjust to globalisation and trade liberalization;
- Accelerate implementation of a sustainable energy programme;
- Promote tourism for sustainable development, including ecotourism;
- Support the early operationalisation of economic and environmental vulnerability indices; and
- Promote global initiatives to assist vulnerable countries to adapt to climate change as well as extreme weather events.

A number of specific measures may also be considered to enhance adaptive capacity. These include:

1. Reducing population pressure on resources and environmental degradation. Communities and their ecosystems are more likely to be adversely effected by climate change and variability where environmental degradation is already a problem.
2. Fostering community-based development and resource management initiatives, including maintaining the role of traditional knowledge and practices in adaptation.
3. Developing legislative and governmental structures that facilitate sustainable development, including climate change responses.
4. Address data and information needs. Data are required for: (a) adaptation research, such as trend studies, sensitivity studies, model building, scenario development, case studies; (b) development and testing of adaptation methods and (c) routine implementation of adaptation, such as planning of investments. Importantly, the free or low cost exchange of data is absolutely critical to dealing with climate variability and change, through both adaptation and mitigation
5. There is strong need for programmes such as the US Country Studies Program and PICCAP to be continued, enhanced and integrated into the development of adaptation measures. Adaptation studies must be initiated early, once broad vulnerability studies have been scoped, and integrated with the impact assessment. More reliable regional

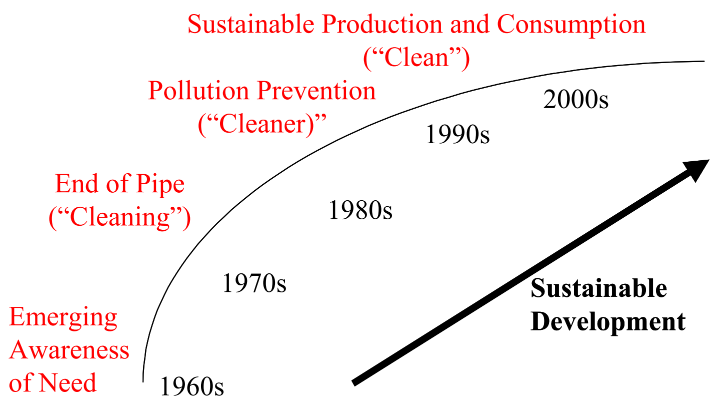
climate change scenarios need to be developed and used in assessments. Adaptation strategies should be developed as part of overall development planning, exploiting "no regrets" and "win-win" options.

6. Avoid maladaptation to climate change and variability. In particular, development planning initiatives should be evaluated for their likely vulnerability, often through use of environmental impact assessment procedures.
7. Education and awareness building can enhance adaptation. The creation of the Pacific Centre for Environment and Sustainable Development at The University of the South Pacific, the Training Centre at SPREP, the project on Basic Education at the Forum Secretariat, and the various training and research programs at South Pacific Applied Geosciences Commission (SOPAC), the Secretariat of the Pacific Community (SPC), World Wide Fund for Nature and other regional organisations are important regional initiatives in this regard. Concerted efforts must be made to ensure the sustainability of these initiatives.

5.9 Technology Transfer and Utilization

Wider use of both endogenous (i.e. *traditional*), conventional and innovative technologies to adapt to climate change, and to prevent it, can form an important part of our overall response to this global issue that will have significant regional, national and local repercussions. The development and transfer of environmentally sound technologies (Box 5.2) between and within countries is an important part of the global response to climate change, both to slow the process and to enable people and societies to adapt to the changes that do occur. To be successful, transfer of technology requires more than just the moving of high-tech equipment from the developed to the developing world. Other requirements include knowledge, management skills and technical and maintenance capabilities of those receiving the technology. Thus technology transfer is a broad and complex process if it is to avoid creating and maintaining the dependency of the recipient and if it is to contribute to sustainable and equitable development. The end result for the recipient must be the ability to use, replicate and, possibly, re-sell the technology. Technology transfer includes both the "hardware" of technology (the final products or services) and the relevant human capacities and skills, organization development and information networks (the "software" of technology).

Environmentally sound technologies (ESTs) have the potential for significantly improved environmental performance relative to other technologies. Their ability to reduce the environmental impacts of human activities, and to contribute to sustainable development, has changed over recent decades (see figure). ESTs protect the environment, are less polluting, use resources in a sustainable manner, recycle more of their wastes and products, and handle all residual wastes in a more environmentally acceptable way than the technologies for which they are substitutes. In other words, an EST is any technology that reduces the total life cycle impact of any activity, production process or consumptive behaviour, to a level that is consistent with the carrying capacity of the local, regional and global environment.



Evolution of environmentally sound technologies

Furthermore, ESTs are compatible with nationally determined socio-economic, cultural and environmental priorities and development goals. ESTs are not just individual technologies, but encompass total systems including know-how, procedures, goods and services, and equipment as well as organizational and managerial procedures.

Identifying ESTs is difficult. Even a conventional environmental technology that has been designed specifically to control or prevent the pollution generated by a particular technical process may not qualify for the label. Environmental performance cannot be assured; it must be established and reconfirmed for the entire life cycle and location of use, by employing accepted procedures and judging against established criteria.

Thus the environmental performance of any given technology is dependent on a wide range of factors, making identification of an EST somewhat problematic. A technology that is assessed to be environmentally sound in a given locale, culture, economic setting or stage in its life cycle may not be in another. Its performance may be influenced markedly by the availability of supporting infrastructure and by access to the expertise necessary for its management, maintenance and monitoring. Moreover, a technology that qualifies as being environmentally sound at one point of time, may not do so at another – the performance criteria against which it is assessed may change as a consequence of new information or changing values or attitudes; a technical and technological breakthrough may give rise to more desirable alternatives.

Technology Assessment is a broad concept that refers to the process of endeavouring to understand the likely impacts of the use of new or upgraded processes and technologies by an industry, municipality, country or society. This process of understanding implies both an element of scientific analysis and an element of communication amongst all stakeholders. Environmental Technology Assessment (EnTA) is a specific form of Technology Assessment that focuses on the effects of technology on the environment, including human health, ecological systems and natural resources. As a decision support tool, EnTA has been developed by the United Nations Environment Programme for the specific purpose of helping to ensure quality decisions are made in the selection of the most appropriate process or other technology for use in a specific locale and application. As a largely qualitative tool, EnTA minimises the need for detailed technical data and facilitates multi-stakeholder dialogues, leading to consensus decision making related to selecting a technology that will be the most environmentally sound, socially acceptable and economically viable, for a specified location and application. In these, and other ways, EnTA overcomes many of the acknowledged shortcomings of Environmental Impact Assessment. Through early recognition of key issues, possible alternatives, potential solutions and areas of consensus, EnTA allows further effort to focus on points of major conflict and dispute. This reduces information and time requirements and facilitates disclosure of all relevant information to decision makers, so a fully informed decision can be made.

A key element of this wider view of technology transfer is choice. There is no single strategy for successful transfer that is appropriate to all situations. If transfer of inadequate, unsustainable, or unsafe technologies is to be avoided, technology recipients should be able to identify and select technologies that are appropriate to their actual needs and capacities (see Box 5.2).

Many of the technologies that can help to address to the problem of climate change already exist. The challenge is to make them readily available, and effective, where they are needed most. In the context of climate change, the importance of and need for technology transfer is formally acknowledged in the United Nations Framework Convention on Climate Change. The Convention states that its Parties, especially developed countries, should "take all practical steps to promote, facilitate and finance, as appropriate, the transfer of or access to, environmentally sound technologies and know-how to other parties, particularly developing country parties ... [and] … support the development and enhancement of endogenous capacities and technologies of developing country Parties."

When discussing technology transfer in relation to climate change it is usually helpful to distinguish between technologies for mitigation (see Section 5) and those for adaptation (see previous parts of the present section). Mitigation technologies are those that focus on slowing climate change. As discussed in Section 4, three sectors are key in reducing the emissions of greenhouse gases in order to reduce the rate of global warming. These are energy (including transportation, industry and buildings), agriculture and, for some Pacific Island Countries, forestry. Section 4 illustrated the diversity of mitigation technologies, including energy efficient boilers and power generation equipment; wind, solar and other renewable energy technologies; low emission vehicles and more efficient public transport systems; and the improved energy efficiency of buildings.

Low greenhouse gas-emitting energy technologies are included in strategies to accelerate the reduction in costs and increase the market share of the following technologies:

- photovoltaic for grid-connected bulk power and distributed power (grid reinforcement and loss reduction) applications;
- advanced biomass power through biomass gasification and gas turbines;
- advanced biomass feedstock to liquid fuels conversion processes;
- solar thermal-electric technologies in high insulation regions, initially emphasising the proven parabolic trough variant for electric power generation;
- wind power for large-scale grid-connected applications;
- fuel cells, initially for mass transportation and distributed combined heat and power applications; and
- advanced fossil fuel gasification and power generation technologies, initially to include integrated coal gasification/combined cycle technologies.

Relating to the above are the several alternative pathways for powering vehicles. These include non-motorised transport, fuel-cell or battery operated 2 and 3 wheelers, hydrogen-powered fuel cell or battery operated vehicles, internal combustion engine-hybrid buses and advanced technologies for converting biomass feedstock to liquid fuels.

Adaptation technologies are those that reduce vulnerability to the adverse effects of climate change, and include a plethora of hard and soft measures and strategies, as indicated in earlier parts of this section. Many such technologies not only reduce vulnerability to climate change but also reduce the risks associated with climate variability, while also making an overall contribution to sustainable development. In these ways adaptation technologies can produce immediate benefits, as well as increasing the capacity to cope with future climate change. Development based on the transfer of environmentally sound technologies, whether the goal be to address climate change or for some other purpose, offers many opportunities for developing countries to avoid past unsustainable practices of the developed nations and to go directly to a more sustainable form of development.

5.9.1 Traditional and Imported Adaptation Technologies

Most of the adaptation options designed to avoid the adverse impacts of climate change, or enhance its benefits, involve technology either directly or indirectly. Examples include water catchment and storage facilities, the design and construction of infrastructure in ways that avoid and limit flood damage, the design and placement of settlements and houses, hazard warning systems, coastal protection, crop and animal breeding and husbandry systems and land and fisheries management programmes.

Over time communities have developed ways to cope with weather and climate extremes. This experience now provides a foundation of traditional knowledge and practices that can often form the basis of appropriate responses to climate change and its consequential impacts.

Examples of traditional and cultural practices are provided below.

Food and water supplies

Polynesians used to preserve food, particularly breadfruits and bananas, by burying them underground in holes up to 2 m deep and covered with green banana leaves. The food can last for months although they will turn ripe. In times of drought and other adverse conditions leading to food shortages, the stored food is dug up and cooked. Drying and smoking of fish and octopus is a common method for preserving sea food for days when bad weather or other conditions prevent access to fresh fish supplies.

Pacific Islanders have dug holes on the stem of big trees for water collection. Further, special species of vines in rainforests provide a drinkable fluid when cut. Such vines were never uprooted.

" 'Api fa'a toe tu'u ai 'a e teve" (translated as "in the well-stocked farm still stands the teve") is a Tongan description of a smart farmer. Even though he is likely to have an oversupply of food, since he has grown almost all the valued crops like the yams, taro and kumara, he still plants the "teve", a lowly graded root crop that is most resistant to harsh weather conditions, particularly droughts.

Land, farm and coastal area management

In Kiribati and Tuvalu, where fertile land for cultivation is in very short supply, holes are dug and filled with bio products to decompose and provide good soil for taro planting. In other places with more fertile soils, such as in Fiji and Samoa, weeding of sun-sensitive crops such as taro is not done during the dry season, allowing the weeds to provide some protection from the sun and thereby conserve soil moisture.

In Tonga big trees were never uprooted but were left in the garden as wind breaks and were only pruned. Planting of fruit trees along one's land's boundary was customarily compulsory in some communities, for they not only provide a wind break, but also food.

House construction

Traditional housing structures in the Pacific have been very much influenced by the climate. The open-walled design of houses in Kiribati and Samoa, and the planting of trees around the houses, has kept the houses cool. Traditional houses in Fiji, Kiribati, Samoa and Tonga are oval-shaped towards the usual direction of cyclone force winds, thereby reducing the wind load on the building.

5.9.2 Examples of "Hard" and "Soft" Adaptation Technologies

In addition to the distinction between traditional and imported technologies, a distinction is sometimes made between "soft" and "hard" technologies. As noted above, the latter typically embraces infrastructure while the former includes a spectrum of actions from policy responses through to management practices. For example, in the context of coastal protection hard technologies include:

- Dikes, levees and floodwalls;
- Seawalls, revetments and bulkheads;
- Groynes;
- Detached and submerged breakwaters;
- Flood gates and tidal barriers; and
- Saltwater intrusion barriers.

On the other hand, soft technologies used for coastal protection include:

- Coastal management planning
- Beach replenishment;
- Dune creation and restoration;
- Ecosystem (e.g. mangrove) restoration and enhancement; and
- Coastal tree planting.

5.9.3 Assessment, Transfer and Uptake of Technologies

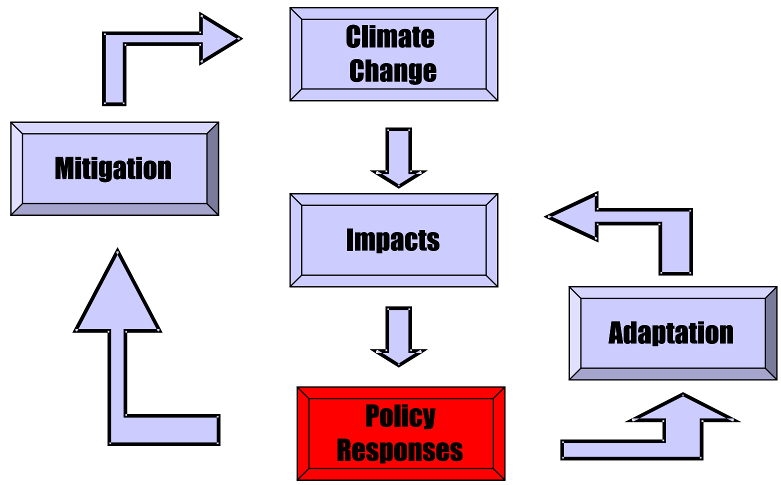
Pacific Island Countries have experienced a plethora of hard and soft technologies offered or imposed in an attempt to facilitate their sustainable development, including mitigation of, and adaptation to, climate change. In most instances those in the recipient country who are charged with the responsibility to manage the technology transfer do not have access to independent, credible and relevant performance data with which to access the environmental soundness of the technology. Consequently the environmental impacts of a proposed technology investment are often overlooked, or misapplied, by those advocating or regulating the adoption of a new or upgraded technology. In other instances, Pacific Island Countries do not have the capacity to successfully manage these technology transfer projects, resulting in a non-appreciation and non-attainment of their full environmental and sustainable development benefits.

Given the reliance of Pacific Island Countries on the uptake of environmentally sound technologies there is an urgent need to put in place the appropriate management and institutional capacity as well as set out a assessment criteria, protocols and standards that governments, the private sector, community based organizations and other key players and stakeholders, both within and outside the Pacific Islands Region, can use to identify and transfer technologies that are environmentally sound and will make highly effective contributions to their sustainable development (see Box 5.2).

The transfer and effective uptake of environmentally sound technologies are considered critical to the sustainable development of Small Island Developing States (SIDS), as documented in *Agenda 21*, the *Barbados Programme of Action* and in its recent review. In part due to the extreme vulnerability of SIDS to climate change and sea-level rise, the recent IPCC *Special Report on Methodological and Technological Issues in Technology Transfer* provides a foundation from which SIDS can examine the issues of technology transfer. But the latter report assessed what is known about technologies on a global level only, not the technologies that are specifically appropriate for Pacific Island Countries. Currently there is no comprehensive assessment of technologies that provides evidence of those which will be environmentally sound within the settings and unique circumstances of Pacific Island Countries. However, a preliminary framework and guide to good practices can be found in *Technology Assessment and Transfer for Pacific Island Countries*.

Under the many international environmental agreements, developed countries are obligated to promote, facilitate and finance the transfer of environmentally sound technologies that will contribute to the sustainable development of SIDS. For this reason both developed countries and the recipient SIDS have a vital interest in ensuring the long-term efficacy of the processes of technology transfer and uptake.

In many cases the adaptive actions that are most likely to succeed are those which have been developed locally and thereby take local environmental, social and cultural circumstances into account and are more likely to be adopted by local communities. However, there will also be a need for the transfer of adaptation technologies from other countries. This is likely to include environmental adaptations that are already used elsewhere, as well as technologies for adaptation that are likely to be developed in the years ahead. Any transfer of technologies should be subject to the same kinds of evaluation process such as that outlined in Section 5.6.



Chapter 6. International Responses to Climate and Sea-level Variability and Change

Key Findings:

- The United Nations Framework Convention on Climate Change, and its related Protocol and procedures, provide important and effective means for ensuring a coordinated international response to climate change, through both mitigation and adaptation;
- The financial mechanism for the Convention, the Global Environment Facility, has been mandated to provide financial resources to developing country Parties, in particular to the Least Developed Countries and Small Island Developing States, for implementing adaptation planning and assessment activities and for establishing pilot or demonstration projects, amongst other responses;
- The Alliance of Small Island States has been effective in highlighting and promoting the interests of Pacific Island Countries at the international level;
- The Barbados Programme of Action was the first real opportunity for the international community to give practical effect to the agreements of the Rio Earth Summit, in that it acknowledged that Small Island Developing States have unique problems and special vulnerabilities, and need support to overcome them;
- Monitoring networks and climate information systems (including seasonal and longer term forecasts) in the Pacific Islands Region are making an important contribution, not only to helping Pacific Island Countries address climate related issues, but also to international understanding of climate variability and change, including extreme events; and
- National, regional and international efforts to enhance the use of indigenous renewable energy technologies, and decreasing reliance on imported petroleum and

other energy products, are critical to the sustainable development of Pacific Island Countries, while also contributing to global efforts to slow the rate of climate change;

6.1 Overview

International activities can be classified into four groups: international policy and politics, scientific assessment, research and monitoring and regional activities (Figure 6.1).

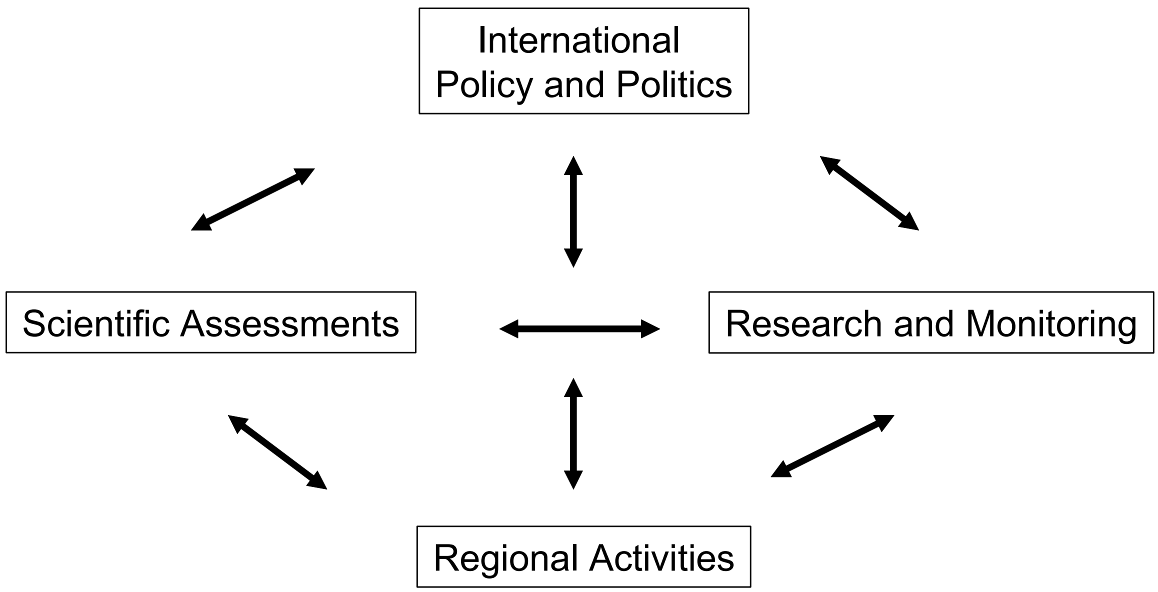


FIGURE 6.1. General categories of international programmes and activities.

6.2 International Policy and Politics

6.2.1 The UN Framework Convention on Climate Change and the Kyoto Protocol

By 1990 numerous international conferences had issued urgent calls for a binding global treaty addressing the problem of climate change. Issues of concern included the increasing concentrations of greenhouse gases resulting from human activities, the resulting additional warming of the Earth's surface and atmosphere and the likely adverse effects on natural ecosystems and humankind. Of particular concern were the possible adverse effects of sea-level rise, making low-lying and other small island countries particularly vulnerable to the adverse effects of climate change.

The United Nations Environment Programme (UNEP) and the World Meteorological Organisation responded by establishing an intergovernmental working group to prepare for treaty negotiations and subsequently the UN General Assembly established an Intergovernmental Negotiating Committee (INC). Some 150 States and numerous intergovernmental and non-governmental organisations participated in five negotiating sessions held from 1990 to 1992. In May 1992 the INC adopted the UN Framework

Convention on Climate Change and a month later it was signed by 154 states and the European Community at the UNCED Earth Summit.

Fifty ratifications were required for the Convention to enter into force. The fiftieth instrument of ratification was received by the UN on 21 December 1993, and the Convention entered into force three months later on 21 March 1994. Parties that ratify the Convention become legally bound by its terms. Typically the Parties meet annually, to assess the scientific understanding and progress in implementing Convention mechanisms and to negotiate further legal instruments and mechanisms. At the Third Conference of the Parties, held in Kyoto, Japan, in late 1997, delegates from 170 countries agreed to the first legal instrument which contained legally binding targets for greenhouse gas emissions reductions to avert the threat of climate change, thereby strengthening considerably the commitments contained in the UNFCCC. The Kyoto Protocol, as the instrument is called, mandates an aggregated emissions reduction target for industralised countries of 5.2% of the main greenhouse gases by 2012, relative to 1990 emissions (Table 6.1). For many developed countries this means cuts of up to 30% from business-as-usual scenarios. The Protocol contains cutting edge legal mechanisms (the "flexibility mechanisms") such as emissions trading, joint implementation and the Clean Development Mechanism. But from an environmental perspective the 5.2% reduction looks meagre compared with the 60 to 80% reduction pronounced necessary by the IPCC if the principal objective of the UNFCCC is to be achieved, namely to stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.

TABLE 6.1. Background to the Kyoto Protocol

Target Greenhouse Gases	CO_2, CH_4, N_2O, HFC, PFC, SF_6
Base Year	1990 (1995) for HFC, PFC, SF_6
First Commitment Period	2008 to 2012
Commitment	Overall, a 5.2% reduction below 1990 emissions for developed country Parties and Parties with economies in transition
Sinks	Removals by directly managed land use change, afforestation and reforestation, since 1990
Kyoto Mechanisms	Emissions Trading, Joint Implementation and Clean Development Mechanism

The Fourth Conference of the Parties saw agreement on a two year work programme to make the Kyoto Protocol operative, but it was not until the Seventh Conference of the Parties, held in 2001, that all developed country Parties, with the exception of the United States, finally agreed to the detailed implementation provisions of the Kyoto Protocol (see Box 6.1).

BOX 6.1. Key Elements of the Kyoto Protcol

- A climate change fund;
- A fund for least developed countries, and an adaptation fund through the Clean Development Mechanism;
- Identification of eligible sink activities such as revegetation and management of forests, croplands and grazing lands;
- Setting of country quotas – overall sinks can count for half the Kyoto targets;
- Rules governing the flexibility mechanisms, with energy efficiency, renewable energy and forest sink projects qualifying under the Clean Development Mechanism, but not nuclear facilities;
- A compliance committee with facilitative and enforcement branches;
- Agreed penalty for non-compliance - for every ton of greenhouse gas a country emits over its target, it will be required to reduce an additional 1.3 tons during the Protocol's second commitment period starting in 2013;
- Eligibility requirements for use of the flexibility mechanisms; and
- A system of international trading of greenhouse gas reductions, especially between the developing and developed countries through the Clean Development Mechanism.

Most developed country Parties have agreed to expedite their ratification of the Kyoto Protocol. For the Protocol to come into force it must be ratified by 55 countries accounting for 55% of global greenhouse gas emissions. As the United States is by far the world's single biggest greenhouse gas emitter, accounting for approximately 24% of global emissions, the absence of that country from the agreement makes ratification of the Protocol difficult and its entering into force somewhat hollow. Another issue still to be faced is the role of developing countries in mitigating climate change. Such countries will also have to reduce the growth in their emissions of greenhouse gasses in the future if the problem of climate change is to be minimized. This will require suitable arrangements for developing countries to achieve economic development with less emissions of greenhouse gases – a major challenge for technology developers and providers, and for international negotiators.

However, in terms of key international initiatives under the UNFCCC, the following outcomes of the Sixth and Seventh Conference of the Parties are of particular relevance to Pacific Island Countries:

- The Global Environment Fund (GEF), the financial mechanism for the UNFCCC, is requested to adopt a streamlined and expedited approach to financing activities consistent with the framework for capacity building in developing countries;
- The GEF should provide financial resources to developing country Parties, in particular to the Least Developed Countries (LDCs) and Small Island Developing States, for implementing adaptation planning and assessment activities and establishing pilot or demonstration projects;
- Establishment of an expert group on technology transfer;
- The GEF should support activities on information and methodologies, and on vulnerability and adaptation;

- Establishment of a work programme for Least Developed Countries, to strengthen existing and establish national climate change secretariats, provide training in negotiating skills and language and support the preparation of National Adaptation Programmes of Action.

6.2.2 Alliance of Small Island States

A negotiating group that has been effective in highlighting and promoting the interests of Pacific Islands Countries at the Conference of the Parties to the UNFCCC is the Alliance of Small Island States (AOSIS). AOSIS is a coalition of small island and low-lying coastal countries that share similar development challenges and concerns about the environment, especially their vulnerability to the adverse effects of global climate change. It functions primarily as an ad hoc lobby and negotiating voice for Small Island Developing States (SIDS) within the United Nations system.

AOSIS has a membership of 43 States and observers, drawn from all oceans and regions of the world: Africa, Caribbean, Indian Ocean, Mediterranean, Pacific and South China Sea. Thirty-seven are members of the United Nations, close to 28 percent of developing countries, and 20 percent of the UN's total membership. Together, SIDS communities constitute some five percent of the global population.

AOSIS was established in the context of the Second World Climate Conference in Geneva in November 1990. Concern about climate change and its feared impacts, especially sea-level rise, was the motivating force which brought small island States together. It was clear that by acting together as a group they had far better prospects of being heard and for effective advocacy for their concerns. At that Conference, SIDS were able to obtain some recognition of their unique position and the risks to their islands and communities.

In the negotiations leading to the UNFCCC, AOSIS was guided by the following principles:

- the principle of preventive action;
- the precautionary principle;
- the polluter pays principle and State responsibility;
- duty to cooperate;
- equity;
- the principle of common but differentiated responsibility; and
- commitment to binding energy conservation and the development of renewal energy sources.

6.2.3 Climate Change and Sustainable Development

The acknowledged vulnerabilities of SIDS have also highlighted the necessity for small island States to pay special attention to their sustainable development needs. Functioning together as a group through AOSIS, small island States sought to give emphasis to this during the 1992 Earth Summit in Rio de Janeiro. Agenda 21 now recognises SIDS as a special case both for environment and development, for they are ecologically fragile and vulnerable.

A direct outcome of the Rio process was the convening of the Global Conference on the Sustainable Development of Small Island Developing States held in Barbados in 1994. A main focus of SIDS activities in the past five years has been the implementation of the Barbados Programme of Action (BPOA), as produced by the Conference.

The BPOA was the first real opportunity for the international community to give practical effect to the agreements of the Rio Earth Summit. It acknowledged that SIDS have unique problems and special vulnerabilities, and need support to overcome them. It was clear that SIDS themselves had the primary responsibility for development. At the same time, the BPOA called for a partnership approach, between SIDS and the international community, as well as the essential support of the United Nations system. This partnership is vital in tackling island problems and the realisation of sustainable development.

For SIDS, the BPOA is perhaps the single most important framework for determining development strategies and policies, at the national, regional and international levels. It contains a comprehensive range of actions and measures for implementation over the short, medium and long terms. The BPOA presents a basis for action in 14 agreed priority areas including:

- climate change;
- natural and environmental disasters;
- management of wastes;
- coastal and marine resources;
- freshwater resources;
- land resources;
- energy resources;
- tourism resources;
- biodiversity resources;
- national institutions and administrative capacity;
- regional institutions and technical co-operation;
- transport and communication;
- science and technology; and
- human resource development.

In September 1999 the United Nations General Assembly held a special session to conduct the first five-year review of the BPOA. By way of a Declaration the Assembly called on the international community to provide adequate predictable, new and additional financial resources, in accordance with Agenda 21 and the BPOA, particularly in tackling complex issues such as environmental protection and support for capacity and institutional-building programmes and projects in SIDS. They also called for increased efforts to assist them in obtaining the transfer of the environmentally sound technology needed for achieving sustainable development and implementing the BPOA. Among the key actions recommended for further implementation of the BPOA, small islands and the international community were urged to continue to improve island capacity to respond to climate change. International support was particularly required to identify adaptation options.

Further successful implementation of the BPOA requires action by all partners in the following areas:

- Fostering of an enabling environment for investment and external assistance;
- Resource mobilization and financing;
- Transfer of environmentally sound technologies; and
- Capacity-building, including education, training, awareness-raising and institutional development.

6.3 Monitoring Networks, Climate Forecasting and Information Systems

The Global Climate Observing System (GCOS) was established in 1992 to ensure that the observations and information needed to address climate-related issues are obtained and made available to all potential users. GCOS is intended to be a long-term, user-driven operational system capable of providing the comprehensive observations required for monitoring the climate system. The applications associated with this involve the detection and attribution of climate change, for assessing the impacts of climate variability and change, and for supporting research toward improved understanding, modelling and prediction of the global climate system. GCOS builds upon, and works in partnership with, other existing and developing observing systems such as the Global Ocean Observing System, the Global Terrestrial Observing System, and the Global Atmospheric Watch network of observatories.

There is great international concern that the existing global observational network is declining and that if this decline is not stopped we may, say twenty years from now, be in a worse situation than today, when trying to determine to what extent and how climate is changing. There could be less capability to clarifying the extent to which ongoing climate change might be the result of human activities or an expression of natural variability in the climate system.

In response to this recognised decline in observing networks, regional workshops were held to assist developing nations to identify the actions required to stem the decline. The first such regional workshop was conducted in 2000 in Samoa. That workshop was jointly organised by GCOS and the SPREP. An important outcome of the Apia workshop was a formal resolution in which participants agreed to develop a Pacific Island GCOS Regional Action Plan to address priority climate observing system needs for the region that included not only atmospheric observations, but also the vital oceanographic and terrestrial components that comprise GCOS. The resulting Action Plan comprises a set of five specific objectives that lead to actions, projects, improvements, and the identification of resources that should lead to an improved GCOS system in the Pacific.

The Global Ocean Observing System (GOOS) provides important baseline information for determining the impacts of climate change and sea-level rise, through the linking of national and regional monitoring efforts. Pacific-GOOS is the regional component of the international effort. GOOS was established by the Intergovernmental Oceanographic Commission in 1991, in response to the desire of many countries to improve management of seas and oceans, and to improve climate forecasts. Both required improved observations dealing with physical, chemical and biological aspects of the ocean, in an integrated way. Agenda 21 specifically called for GOOS to be developed to meet the needs of coastal states for the sustainable development of seas and oceans.

GOOS is part of an Integrated Global Observing System (IGOS) in which the UN agencies (UNESCO and its IOC; WMO, UNEP and the Food and Agriculture Organisation) work together with the International Council of Scientific Unions and satellite agencies (via the Committee on Earth Observation Satellites). As noted above, GOOS forms the ocean component of the Global Climate Observing System (GCOS) and the marine coastal component of the Global Terrestrial Observing System.

A component of GOOS that is of great importance to Pacific Island Countries is the Global Sea Level Observing System (GLOSS). This is an international programme for the establishment of high quality global and regional sea-level networks for application to climate, oceanographic and coastal sea-level research. The main component of GLOSS is the global core network of 287 sea-level stations around the world, for long term climate change and oceanographic sea-level monitoring.

A major long term programme to monitor sea level variations in the Pacific region was implemented in 1991. The project was a response to Forum Island governments' concerns about global warming and its associated consequences of climate change and sea level rise, both of which have the potential to impact adversely the countries of the Pacific region. High-resolution sea level gauges and associated monitoring equipment have now been deployed and are operating in 12 countries of the region.

The Pacific Meteorological Services Needs Assessment Programme (PMSNAP) forms part of SPREP's initiative to identify the requirements of the National Meteorological Services of twenty Pacific Island SPREP member countries and territories, and, amongst other assessments, recommend projects for aid consideration. The central goal of the PMSNAP project is to support continued strengthening of the capability of National Meteorological Services in the Pacific region to meet growing public demand for improved weather and climate services and products. Climate information and prediction services were identified as one of the key priority needs of users, particularly in the forestry, fisheries and agriculture sectors, and for disaster management. Most users desire more regular updates and accurate predictions of El-Niño/La-Niña and associated weather and climate extremes (e.g. probability of tropical cyclone occurrence). Developing and applying the ability to predict seasonal to interannual rainfall and other climate anomalies in the Pacific region, largely reflecting ENSO, is thus a high priority for the region. Experience has shown that statistical predictions can work well for the coming season (0-3 months) while forecasts from climate models become more useful at longer lead times. Currently statistical predictions are not made for or by most Pacific Island Countries. Nor is Web-based information from climate models readily available for members who do not have Web access. Moreover, there is little guidance on how this broader picture relates to specific locations within the region. A combination of statistical and climate model forecasts together can provide the basis for a very useful climate prediction service.

Recently the Australian Bureau of Meteorology (through its National Climate Centre), in conjunction with the Fiji Meteorological Service, developed a PC-based stand-alone statistical prediction scheme for seasonal rainfall in Fiji. A comprehensive assessment of the skill of the scheme was also produced. The Fiji Meteorological Service is now using this scheme operationally in their monthly climate outlook. The only on-going input required for this scheme is the latest monthly value of the Southern Oscillation Index, a readily available, single number. This scheme therefore provides an extremely simple but highly useful starting point and potential back bone for seasonal forecasting operations, especially in countries with limited staff resources and/or experience in interpreting output from more complicated systems. The statistical scheme has demonstrable forecasting skill out to a few months. Similar results have been obtained in studies undertaken in Australia and U.S. and French affiliates. It is very likely the scheme will have skill in the those countries in the region which do not currently have the capacity to make such forecasts.

Another obstacle to the widespread and prudent use of seasonal to interannual forecasts in the Pacific Islands Region is that their availability and potential usefulness is not widely appreciated by the general public. There is therefore a strong need for education and training in a wide range of issues both within the National Meteorlogical Services and amongst the wider community. A new climate prediction service is of limited value if it is not used in decision making by governments and industry, or if the results are not used properly due to an imperfect understanding of the advice provided.

Another example of the way in which climate forecasting and information dissemination has benefited the Pacific Islands Region is provided by the Pacific ENSO Applications Center (PEAC). It was established in 1994, as a pilot project to provide ENSO forecasts and information to the US Affiliated Pacific Islands. The University of Guam, the University of Hawaii, the Pacific regional Office of the US National Weather Service, the US Office of Global Programs at the National Oceanic and Atmospheric Administration and the Pacific Basin Development Council developed PEAC as a joint venture. It has consisted of several types of coordinated research and applications activities. The former has been aimed primarily at developing statistical rainfall models and synoptic climatologies, in order to address the inability of coupled ocean-atmosphere models to produce useful information with the spatial resolution required by people in the region. Development of the public information and education programme involved extensive collaborative efforts, including workshops, focus group meetings and local briefings. PEAC staff also made presentations at relevant regional meetings. One outcome of these activities was greater clarify as to the concerns of Pacific Islanders regarding the actual and potential impacts of ENSO events, and details as to the kinds of ENSO forecast information that are required.

PEAC has established a partnership with what is now the Disaster Management Unit of SOPAC, resulting in development of methods to assess the impact of the 1997-98 El Niño and of drought mitigation plans for the South Pacific. The collaboration has also resulted in a manual that includes methods for quantifying the impacts of cyclones, floods and droughts on various social and economic sectors, calculating return periods for these extreme events in relation to historical ENSO events, using climate forecasting capacity to respond to droughts and storms and development of more effective disaster response and mitigation plans.

6.4 Contributions of Pacific Island Countries to International Understanding and Responding to Climate Variability and Change

The following examples illustrate, in relation to climate variability and change, some of the contributions of the Pacific Islands Region to international understanding and to international responses to global environmental challenges such as climate change. They represent incremental benefits that arise as a result of bilateral or multilateral assistance, typically combined with regional cooperation and coordination.

6.4.1 Draft Framework for Regional Action

A draft framework for regional action on climate change has been developed by a wide number of stakeholders in the Pacific Islands Region. The basis for the draft framework was developed by Pacific Island Countries themselves in a regional meeting held in Rarotonga, Cook Islands, during early December 1999. From that time the draft has been elaborated upon, particularly in the areas related to the framework objectives, and action oriented areas, with major progress being made at the Pacific Islands Conference on Climate Change, Climate Variability and Sea-Level Rise, held in the Cook Islands in April, 2000.

The draft framework is a manifestation of the Pacific Island Region's view that a coordinated and systematic approach to understanding and responding to climate change, including sea-level rise, will assist and enhance measures taken by countries and relevant agencies and organisations in addressing regional and international concerns related to this critical issue.

6.4.2 Collaboration of Meteorological Services

Since 1993 Pacific Meteorological Service Directors have been meeting annually. The principal purpose of the meetings has been to identify the ways and means of strengthening the capability of National Meteorological Services in the Pacific Region to meet the growing public demands for improved weather and climate services and products that ensure the safety, security and general well-being of the people, to contribute to achieving sustainable development and to fulfil national commitments and obligations under regional and international conventions and other agreements.

The Tropical Cyclone Committee for the South Pacific and the South East Indian Ocean (Region V of the World Meteorological Organisation) was established in recognition of the need for regional cooperation and coordination in the operation of early warning systems. While coupled ocean-atmosphere climate model simulations do not suggest that tropical cyclone numbers will change with global warming, a general increase in tropical cyclone intensity, expressed as possible increases in wind speed and decrease in central pressure of 10–20% at the time of CO_2 doubling, now appears likely. How this affects the risk posed by severe storms still needs to be determined on a regional basis. Such findings add importance to increasing the capacity of the Pacific Island Countries to better predict the occurrence and characteristics of tropical cyclones.

The Tropical Cyclone Committee is responsible for the formulation and implementation of the regional Tropical Cyclone Operational Plan. The purpose of the Plan is to improve the capability of National Meteorological Services to provide accurate and timely tropical cyclone warning services.

An important aspect of the Tropical Cyclone Programme is the regionally coordinated training of tropical cyclone forecasters. This is considered to be essential for a sustained strengthening of the tropical cyclone warning services provided to the public by National Meteorological Services. In accordance with decisions of the United Nations Commission on Sustainable development, the training of forecasters in the tropical cyclone basins of Small Island Developing States is a priority.

The Cyclone Warning Upgrade Project is improving information, resources and communications for tropical cyclone warning services in the Pacific region

Recent moves by most Pacific Island governments towards self reliance have involved diversifying their economies into areas that are extremely weather and climate dependent, such as forestry, fishing, water resources, industry, transportation and tourism. These initiatives have increased demands on National Meteorological Services. The Plan provides a mechanism for coordinating the support of the World Meteorological Organisation, donors and others who can assist in meeting the identified and agreed needs of the National Meteorological Services.

6.4.3 Promotion of Renewable Energy Development and Forestation

Promoting the use of indigenous renewable energy technologies, and decreasing the dependence on imported petroleum and other energy products is also a priority in the energy sector plans of most, if not all, Pacific Island Countries. Such initiatives are consistent with the need to reduce the emission of greenhouse gases and thereby limit the rate and extent of climate change. For this reason, and as part of their reporting requirements under the UNFCCC, Pacific Island Countries have identified regional and national greenhouse gas mitigation options, consistent with their national development priorities.

In this context, significant work has already been undertaken on a regional basis with a view to identifying and facilitating the use of sustainable renewable energy sources. A Pacific Regional Assessment was undertaken in 1992. Other initiatives are the Lomé II and III Pacific Regional Energy Programmes, the Pacific rural Renewable Energy France-Australia Common Endeavour (PREFACE) and the recently approved GEF-funded Pacific Islands Renewable Energy Project (PIREP). These and other regional cooperation activities have resulted in creation of a significant body of experience, knowledge and information on renewable energy, in training programmes focussing on the design and management of renewable energy projects, implementation and coordination of major renewable energy projects in the region and in the sharing of information, experiences and expertise among Pacific Island Countries. This regional cooperation has also extended to drafting the Pacific Energy Policy and Plan, assisting Pacific Island Countries to develop their national energy policies and plans, to the provision of technical assistance and policy advice on the sustainable management and development of the energy sectors of Pacific Island Countries and to the coordination of major donor-funded energy sector initiatives in the region. The Regional Energy Policy and Plan recently completed for the Pacific Islands Region will further enhance the ability of countries to address energy sector and planning issues.

The PIREP is a recent regional initiative a cooperative approach to promoting the use of renewable energy by removing barriers to its use, including identification of ways to reduce the initial capital and installation costs. Again this will produce benefits at the national level, by sharing the experience and expertise that exists in the Pacific Islands Region.

New forest plantings have the potential to mitigate climate change through the storage of carbon. While there are many unresolved technical and policy-related issues associated with this response option, the possibility of some Pacific Island Countries using forestry as one component of their climate change response policy is very real. These new initiatives could build on the existing national and regional initiatives to enhance the role played by forestry in national development planning. In the Pacific there are a number of regional projects that are adding value to national initiatives related to forestry.

6.4.4 Disaster Reduction and Climate Change

Pacific Island Countries have made repeated requests for greater efforts to reduce vulnerability to hazards that have the potential to cause negative impacts on communities. These can be natural or human caused, and include cyclones, floods, volcanoes, earthquakes, tsunamis, drought, and debris slides. The risks associated with many of these hazards are assuming greater importance as a consequence of global warming. Disaster management provides the collective activities needed to reduce risk and vulnerability in respect of natural and human hazards, and the consequences for communities.

For example, the 1995 Madang Forum Meeting developed a regional vision – overcoming vulnerability to the effects of natural hazards, environmental damage and other threats. Achievement of the vision requires integration of effective risk and vulnerability reduction strategies within regional and national development plans. To facilitate a regional response to this challenge, the three year South Pacific Disaster Reduction Project has been assimilated within a new regional Disaster Management Unit. The Unit coordinates regional activities in order to add value to national disaster management programmes directed at reducing vulnerability. It also liaises with regional response agencies in order to ensure that key lessons learned from emergency responses become well known within the region and are incorporated in the disaster management strategies of all countries.

6.5 Implications of International Agreements and Initiatives for Pacific Island Countries

6.5.1 Climate Change Convention and Kyoto Protocol

Neither the UNFCCC, nor its Kyoto Protocol, require developing countries to agree to compulsory reduction targets for greenhouse gas emissions. As noted in Section 4.2, island countries of the Pacific are "minor" emitters, in both a relative and absolute sense. Thus any voluntary steps they take to reduce their emissions will have negligible effect on atmospheric composition, and hence on the rate of global warming. Furthermore, the small reductions in carbon emissions that might be gained through Clean Development Mechanism projects makes such initiatives financially and technically challenging, even if implemented on a regionally aggregated basis.

But other quite distinctive reasons may well give rise to a country taking concerted voluntary actions that lead to reduced emissions.

Economic factors may, for example, drive the decision to increase the efficiency of existing energy supply systems and to consider opportunities for substituting less costly fuels. The information available as a result of the greenhouse gas inventory required to be undertaken by all Parties to the UNFCCC will help determine the cost effectiveness of the various mitigation options and, in turn, guide decision making related to investment and other initiatives.

Political factors may also influence the decision to reduce emissions through improved efficiencies and/or use of fuels that produce emissions with a lower global warming potential. For example, the credibility of a country, or the region as a whole, will be enhanced if there is a demonstrated willingness to act in concert with other countries rather than pleading special circumstances. The efforts of minor emitters of greenhouse gases in the Pacific islands region to reduce their emissions would act as a moral imperative and provide impetus for other countries to take some domestic action in reducing their overall emissions.

Moral considerations may, in themselves, lead to a decision to reduce emissions. The atmosphere is part of the global commons. Thus a country may well decide to act as a good global citizen and reduce its emissions, no matter how small the inventory data show those emissions to be.

Available data also reveal that some Pacific Island Countries (notably those with larger volcanic islands as opposed to a predominance of small atolls) have the potential for greenhouse gas removals through appropriate land and forest management practices. Forests have the potential to provide greenhouse gas mitigation through the use of the wood as a cooking and industrial fuel and through increases in the standing biomass. Hence the re-establishment of forests is an effective mitigation measure, while a mature forest with stable biomass is neutral in terms of emissions and removals. On the other hand, forests that are being harvested, cleared for agriculture or damaged by fire are net emitters of greenhouse gases.

Continued use of fuel wood, rather than a shift to electricity or fossil fuels for cooking and water heating, is advantageous from a mitigation perspective. Rural people in particular should therefore be encouraged to maintain adequate supplies of fuelwood.

6.5.2 The Montreal Protocol – a Example to be Followed?

Though the Montreal Protocol on Substances that Deplete the Ozone Layer does not aim at reducing greenhouse gases, Pacific Island Countries are demonstrating their commitment to environmental protection through proactive engagement in activities related to implementation of the Protocol. This sets an example for the climate change Convention. The Montreal Protocol is an international environmental agreement that obligates the Party countries to phase out, within a stipulated time schedule, their use of ozone depleting substances (ODS) that are harmful to human and animal life. Fiji has become the first country in the Pacific Islands Region to launch serious actions to protect the stratospheric ozone layer. It has committed itself to phase-out such chemicals well ahead of the phase-out schedule of 2010 set by the Montreal Protocol, probably as early as the end of 2002. With financial support from the Multilateral Fund the country is well on target. Fiji's contribution to the total assessment consumption of Chlorofluorocarbons (CFCs) is only 13 tonnes (1999) as compared to about 150,000 tonnes consumed annually all over the world today. However, in Fiji CFCs are used for critical applications such as food preservation.

Many other Pacific Island Countries are also working towards implementation of a regional strategy to expedite implementation of the Montreal Protocol. The regional strategy is aimed at developing and implementing a regional phase- out strategy for ODS in the Pacific Islands Region. It includes the following countries that are Party to the Protocol: Fiji, Kiribati, the Marshall Islands, the Federated States of Micronesia, Papua New Guinea, the Solomon Islands, Tonga, Tuvalu, Vanuatu, and Western Samoa. Four countries that are not Party to the Protocol (Cook Islands, Nauru, Niue and Palau) have also expressed interest in participating in the strategy. The economies of Small Island Countries are dependent on fisheries and tourism, two critical economic sectors that rely on refrigeration and air-conditioning. Ozone depleting substances including chlorofluorocarbons (CFCs) are commonly used in these applications.

Chapter 7. Retrospect and Prospects

This *Resource Book* attempts to provide policy- and decision-makers in Pacific Island Countries with pertinent information on the Pacific Island Region's resilience and vulnerability to climate and sea-level variability and change. It is also designed to present educators, outreach and related practitioners with an integrated and functional resource portfolio for use in formal education and professional development programmes and in support of efforts to enhance political and public awareness of the implications of global and regional variability and change for the Pacific Islands Region.

The Small Island Developing States of the Pacific are sensitive microcosms of the Earth system. As such they can be considered a bell weather to the rest of the world. But more importantly, the people who inhabit these islands can be rightly portrayed as the "innocent victims" of global warming. On average, individual Pacific islanders are responsible for producing approximately one quarter of the CO_2 emissions attributable to the average person world wide; expressed another way, the Pacific islands region as a whole accounts for some 0.03% of the global emissions of CO_2 from fuel combustion despite having around 0.12% of the world's population

But such facts are small comfort to those who are already experiencing disruptive changes consistent with many of the anticipated consequences of global climate change, including extensive coastal erosion, droughts, coral bleaching, more widespread and frequent occurrence of mosquito-borne diseases and higher sea levels making some soils too saline for cultivation of traditional crops. These and other precursors of global climate change impacts now being experienced by Pacific Island Countries provide some of the more compelling and tangible indications of the seriousness of global warming, certainly more than the often quoted projections of increased global temperature and sea levels. The adverse consequences of climate change are already an unfortunate reality for many small island inhabitants. They highlight the serious and wide-reaching consequences future climate changes will have on small island countries, likely exacerbating the existing adverse impacts of the high natural variability of the climate and related systems.

The combination of current and anticipated impacts of climate variability and change for Pacific Island Countries is thus of great and urgent concern, given the extensive and available and growing evidence of the vulnerability of these countries to climate change and given the acknowledged limitations these countries have for adapting to climate change. Countries of the Pacific Islands Region are likely to be among the countries most seriously impacted by climate change, including sea-level rise, despite being the smallest contributors to human-induced climate change; but they have seriously limited capacity to adapt to the adverse impacts of climate change.

Variability and change are ubiquitous in the Pacific Islands Region. As a result, both natural systems and human societies in the Region are in some ways remarkably well attuned to relatively large variations in environmental conditions, and have in the past been able to cope with many of the repercussions of environmental change. However, the cumulative pressures on the closely integrated biophysical and human systems of the

Pacific, many of which are resulting from rapid increases in total and urban population and in unsustainable production and consumption patterns, mean that these systems are less well placed to accommodate the unprecedented changes in climate and related environmental conditions that are anticipated to occur during the remainder of the current century.

The large uncertainties in specifying the future conditions that will stress both natural and human systems leads to a preference to use scenarios rather than attempt to make precise predictions. However, any plausible climate change scenario will require Pacific Island Countries to implement adaptation measures due to the unparalleled and potentially devastating nature of the resulting changes. The most desirable adaptive responses are those that address the adverse impacts of present day climate variability (including extreme events) and augment actions which would be taken even in the absence of climate change, due to their contributions to sustainable development. Similarly, while climate change mitigation initiatives undertaken by Pacific Island Countries will have insignificant consequences climatologically, they should nevertheless be pursued because of their valuable contributions to sustainable development.

By making even greater efforts to implement these strategies, Pacific Island Countries will further enhance their international leadership in the integration of climate information into near term decision making and longer term planning, to the benefit of international, regional and local communities.

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Section 6:

International Responses to Climate and Sea-level variability and Change

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Hay, J.E., 2000. Climate Change in the Pacific: Science-based Information and Understanding. In *Climate Change in the South Pacific: Impacts and Responses in Australia, New Zealand and Small Island States.* Gillespie, A. and W.C.G. Burns (eds.). Kluwer Academic Publishers, Dordrecht and Boston., pp269-288.

Mimura, N. and H. Harasawa. 2000. Data *Book of Sea-level Rise*. Centre for Global Environmental Research, National Institute for Environmental Studies, Japan,128 pp.

Gillespie, A. and W.C.G. Burns (eds.), 2000. *Climate Change in the South Pacific: Impacts and Responses in Australia, New Zealand and Small Island States.* Kluwer Academic Publishers, Dordrecht and Boston., 385pp.

World Bank, 2000. Cities, Seas and Storms. *Managing Change in Pacific Island Economies. Volume IV Adapting to Climate Change*. World Bank, Washington, DC, USA, 73pp.

Chapter 9. Selected Web Sites

AOSIS: Alliance of Small Island States – www.aosis.org
BOM: Bureau of Meteorology (Australia) – www.bom.gov.au
CSIRO: Commonwealth Scientific and Industrial Research Organisation – www.csiro.au
EWC: East-West Center – www.ewc.hawaii.edu
FFA: Forum Fisheries Agency – www.ffa.int
FORSEC: Pacific Islands Forum Secretariat – www.forumsec.org.fj
GEF: Global Environment Facility – www.gefweb.org
NIWA: National Institute of Water and Atmospheric Research – www.niwa.cri.nz
NOAA: National Oceanic and Atmospheric Administration (USA) – www.noaa.gov
NTF: National Tidal Facility – www.ntf.flinders.edu.au
IGCI: International Global Change Institute – www.waikato.ac.nz/igci/
IPCC: Intergovernmental Panel on Climate Change – www.ipcc.ch
ORSTOM: L'institut Francais de Recherche Scientifique pour le Developpement en Cooperation – www.orstom.fr
PIDP: Pacific Island Development Program – www.ewc.hawaii.edu/pidp/
PPA: Pacific Power Association – www.ppa.org.fj
SIDSNET: Small Island Developing States Network – www.sidsnet.org
SOPAC: South Pacific Geoscience Commission – www.sopac.org.fj
SPC: Secretariat for the Pacific Community – www.spc.org.nc
TCSP: Tourism Council of the South Pacific- www.tcsp.com
UNDP: United Nations Development Programme – www.undp.org
UNESCO: United Nations Educational Scientific and Cultural Organization – www.unesco.org
UNEP: United Nations Environment Programme – www.unep.org
UNFCCC: United Nations Framework Convention on Climate Change – www.unfcc.de
UNITAR: United Nations Institute for Training and Research – www.unitar.org
USP: The University of the South Pacific – www.usp.ac.fj
WB: World Bank – www.worldbank.org
WMO: World Meteorological Organisation – www.wmo.ch