IPCC WGII Fourth Assessment Report – Draft for Government and Expert Review

Chapter 16 - Small Islands

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Executive Summary

- This assessment confirms and strengthens previous observations reported in the TAR. New evidence makes it clear that small islands, be they located in the tropics or in high latitudes, are especially vulnerable to climate change and that the impacts will be largely adverse [Very high confidence] [16.1; 16.4; 16.7].
- Many islands are already experiencing some negative effects of global warming, sea-level rise and increased sea surface temperature, which are affecting both natural ecosystems and socio-economic conditions [Very high confidence] [16.4; 16.7].
- Small islands have low adaptive capacity and limited ability to recover from natural and man-induced shocks without external assistance, as recently demonstrated by hurricanes and the impact of internal conflicts and war on tourism [Very high confidence] [16.1; 16.4.6; 16.4.7].
- On small islands adaptation costs are high relative to GDP, though experience gained from coping with past climate variability and extremes may be beneficial to adaptation planning. In some small islands, traditional methods of coping with environmental change and hazards are being reintroduced [High confidence] [16.2.4; 16.5; 16.5.4].
- Climate projections suggest a general increase in surface air temperature for the regions of small islands but the increase is not uniform. Precipitation projections show no consistent trend, with increases and decreases of more than 10 percent projected for three 30-year periods by the end of this century [High confidence] [16.3.3.1].
- Water resources in small islands are especially vulnerable to future changes and distribution in rainfall. Any reduction in average rainfall will have serious impacts on water supply and island economies. For example, a 10 percent reduction in average rainfall (by 2050) would lead to a 20 percent reduction in the size of the freshwater lens on Tarawa Atoll, Kiribati. Reduced rainfall coupled with sea-level rise would compound this threat. [High confidence] [16.4.1].
- Recognising the vulnerable nature of water supplies, several small island countries have begun to invest in the implementation of adaptation strategies, including desalination, to offset current and projected water shortages [High confidence] [16.4.1].
- Sea-level rise will exacerbate inundation, erosion and other coastal hazards, threatening vital infrastructure, settlements and facilities that are predominantly based on the coast, thus compromising the socio-economic well-being of island communities and states. It will also negatively impact coastal ecosystems, such as coral reefs and mangrove forests, and commercial and artisanal fisheries based on those systems [High confidence] [16. 4.2; 16.4.5; 16.4.7].
- Islands have a unique biodiversity. With global warming some islands, especially those in high- and mid-latitudes will be colonized by non-indigenous invasive species previously limited by unfavourable conditions. In a few instances warming has already lead to extinction of some local species. [High confidence] [16.4 4].
- Tourism is a major contributor to GDP and employment in many small islands, and dominates the economies of some. Surveys suggest that deterioration in environmental conditions, for example through erosion of beaches or coral bleaching, will reduce numbers travelling to such destinations. [High confidence] [16.4.6].
- Climate-sensitive diseases in small islands include malaria, dengue fever, diarrhoeal disease, heat stress, skin disease, acute respiratory infections and asthma. Although some islands are at particular risk, especially from the vector-borne diseases, few studies linking these to climate change have been conducted. [High confidence] [16.4.5].
- While small islands must adapt to the consequences of climate change, their adaptive capacity is limited and is being further eroded by external factors such as the internationalisation of economic activity and internal population pressures. [Medium confidence] [16.5.4].

- People in small islands have historically adapted to variability in climate and sea conditions. It is not clear how valuable this experience will be in dealing with the longer-term mean changes in climate and sea level, especially since traditional mechanisms for coping with environmental hazards are being lost in many islands [High confidence] [16.5.4].
- In small islands energy is primarily from non-renewable sources, mainly imported fossil fuels. To enhance their resilience some islands have already embarked on initiatives aimed at ensuring that renewable sources constitute a significant percentage of the energy mix. [Medium confidence] [16.4.7].
- Use of insurance as an adaptation strategy for small islands has many constraints, including the size of the risk pool, lack of availability of financial instruments and services for risk management [Medium confidence] [16.5.3].
- Climate change will be a major impediment to the achievement of sustainable development in small islands, as all economic and social sectors are likely to be adversely affected, and the cost of adaptation will be disproportionately high, relative to GDP. In attempting to mainstream adaptation strategies into their sustainable development agendas, small islands will be confronted by many challenges including insufficient resources, equity considerations, prioritization of adaptation measures and uncertainties over climate change projections and adaptation strategies. [High confidence] [16.5; 16.5.3; 16.6].

16.1 Introduction

While acknowledging their diversity, the IPCC Third Assessment Report (TAR) also noted that small island states share many similarities (e.g. physical size, proneness to natural disasters and climate extremes, extreme openness of economies, low adaptive capacity) that enhance their vulnerability and reduce their resilience to climate variability and change. Analysis of observational data showed a total mean temperature increase of around 1.0°C (approximately 0.1°C per decade) during the 20^{th} Century, while mean sea level rose by about 2 mm yr^{-1} although sea level trends are complicated by the El Niño Southern Oscillation (ENSO). The rate of increase in air temperature in the Pacific and Caribbean during the 20^{th} Century exceeded the global average of about 0.6^{o}C. The TAR also found much of the rainfall variability appeared to be closely related to ENSO events, combined with seasonal and decadal changes in the convergence zones.

Owing to their high vulnerability and low adaptive capacity, small islands have legitimate concerns about their future, based on observational records, experience with current patterns and consequences of climate variability, and climate model projections. Although emitting less than 1 percent of global greenhouse gases, small islands have already been forced to re-allocate scarce resources away from economic development and poverty alleviation, to the implementation of strategies to adapt to the growing threats posed by global warming (e.g. Nurse and Moore, 2005).

While some spatial variation within and among regions is expected, sea level is projected to rise at an average rate of about 5.0 mm yr^{-1} over the 21st century. The TAR concluded sea-level change of this magnitude would pose great challenges, and high-risk especially to low-lying islands that might not be able to adapt. Given the sea level and temperature projections for the next 50–100 years coupled with other anthropogenic stresses, the coastal assets of small islands (e.g. corals, mangroves, sea grasses and reef fish), will be at greater risk. The natural resilience of coastal areas will be reduced, while the "costs" of adaptation would increase. Additionally, unfavourable shifts in the biotic composition of islands combined with the threat of invasive species may displace island endemics (Frenot *et al.*, 2005; Gritti *et al.*, 2006). Moreover, anticipated land loss, soil salinization and low water availability, will threaten the sustainability of island agriculture.

In addition to natural and managed system impacts, the TAR also drew attention to projected human costs. These included an increase in the incidence of vector and water-borne diseases in many tropical and sub-tropical islands, which were attributed partly to temperature and rainfall changes, some linked to ENSO. The TAR also noted most settlements and infrastructure of small islands are located in coastal areas, which are highly vulnerable not only to sea-level rise but also to high energy waves and storm surge. In addition, temperature and rainfall changes and loss of coastal amenities, could adversely affect the vital tourism industry. Traditional knowledge and other cultural assets (e.g. sites of worship and ritual) especially those near the coasts, were also considered to be vulnerable to climate change and sea-level rise. Integrated coastal management was proposed as an effective management framework in small islands for ensuring the sustainability of coastal resources. Such a framework has been adopted in several island states. More recently, the Organization of Eastern Caribbean States (OECS, 2000) has adopted a framework called '*island systems management*', which is both an integrated and holistic approach (rather than sectoral approach) to whole-island management including terrestrial, aquatic and atmospheric environments**.**

The TAR concluded that small islands should focus their efforts on enhancing their resilience, and implement appropriate adaptation measures as urgent priorities. Thus, integration of risk reduction strategies into key sectoral activities (e.g. sustainable development, disaster management, integrated coastal management and health care planning) should be pursued, as part of the adaptation planning process for climate change.

Building upon the TAR, this chapter assesses recent scientific information on vulnerability to climate change and sea-level rise, adaptation to their effects, and implications of climate related policies, including adaptation, to the sustainable development of small islands. Assessment results are presented in a quantitative manner wherever possible, with near, middle, and far time frames in this century, though much of the small islands' literature is not precise about the time-scales involved in impact, vulnerability and adaptation studies. Indeed, independent scientific studies on climate change and small islands since the TAR have been quite limited, though there has been a number of synthetic publications, regional resource books, guidelines and policy documents including: *Surviving in Small Islands: a Guide Book* (Tompkins *et al.*, 2005); *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* (Hay *et al.*, 2003); *Climate Change: Small Island Developing States* (UNFCC, 2005); and *Not If, But When*: *Adapting to Natural Hazards in the Pacific Island region: A Policy Note* (World Bank, 2006).

These publications rely heavily on the TAR, and on studies undertaken by global and regional agencies and contracted reports. It is our qualitative view that the volume of literature in refereed international journals relating to small islands and climate change since publication of the TAR, is rather less than that between the SAR in 1995 and the TAR in 2001. There is also another difference in that the present chapter deals not only with independent small island states but also with small islands in the continental and large archipelago countries, including those in high latitudes. Nevertheless the focus is still mainly on the small island states in the tropical and subtropical regions, a focus that reflects the emphasis in the literature.

16.2 Current sensitivity and vulnerability

16.2.1 Special characteristics of Small Islands

Small islands are highly vulnerable to climate change and sea level rise. By definition they comprise small land masses surrounded by ocean, and are frequently located in regions prone to natural disasters, often of a hydrometeorological nature. They host relatively large populations for the area they occupy with high growth rates and densities. Most small islands have poorly developed infrastructure and limited natural, human and economic resources, and many small island populations are dependent on marine resources to meet protein needs. Most of their economies are reliant on a limited resource base and are vulnerable to external forces, such as changing terms of trade, trade liberalization, and migration flows. Adaptive capacity to climate change is generally low.

16.2.2 Climate and weather

16.2.2.1 General features

The climate regimes of small islands are quite variable, generally characterised by large seasonal variability in precipitation and by small seasonal temperature differences in low-latitude islands and by large differences in high lataitude islands. In the tropics cyclones and other extreme climate and weather events cause the most damages to life and property.

The climates of small islands in the central Pacific are influenced by several contributing factors such as trade wind regimes, the paired Hadley cells and Walker circulation, seasonally varying convergence zones such as the South Pacific Convergence Zone (SPCZ), semi-permanent subtropical high-pressure belts, and zonal westerlies to the south, with the El Niño Southern Oscillation (ENSO) as the dominant mode of year to year variability (Fitzharris, 2001; Folland *et al.*, 2002; Griffiths *et* *al.*, 2003). The Madden-Julian Oscillation (MJO) also is a major mode of variability of the tropical atmosphere-ocean system of the Pacific on times scales of 30 to 70 days (Revell, 2004), while the leading mode with decadal time-scale is the Interdecadal Pacific Oscillation (IPO) (Salinger *et al.*, 2001). A number of studies suggest the influence of global warming could be a major factor in accentuating the current climate regimes and the changes from normal that come with ENSO events (Hay *et al.*, 2003; Folland *et al.*, 2003).

Caribbean climate can be broadly characterised as dry and wet seasons with orography and elevation being significant modifiers on the sub-regional scale. The dominant influences are the North Atlantic Subtropical High (NAH) and ENSO. During the northern hemisphere winter, the NAH lies further south with strong easterly trades on its equatorial flank modulating the climate and weather of the region. Coupled with a strong inversion, a cool ocean and reduced atmospheric humidity, the region generally is at its driest during the northern hemisphere winter. With the onset of the northern hemisphere spring, the NAH moves northward, the trade wind intensity decreases, and the region then comes under the influence of the equatorial trough.

In the Indian Ocean the climate regimes of small islands in the region are predominantly influenced by the Asian monsoon, the seasonal alternation of atmospheric flow patterns which result in two distinct climatic regimes; the southwest or summer monsoon and the northeast or the winter monsoon, with clear association with ENSO events.

The climates of small islands in the Mediterranean are dominated by influences from bordering lands. Commonly the islands receive most of their rainfall during the northern hemisphere winter months and experience a prolonged summer drought of 4-5 months. Temperatures are generally moderate with a comparatively small range of temperatures between the winter low and summer high.

16.2.2.2 Observed Trends

Temperature

New observations and reanalyses of temperatures averaged over land and ocean surfaces since the TAR show consistent warming trends in all small islands' regions over the 1901 to 2004 period (Chapter 3, WG1 AR4). However, the trends are not linear. Recent studies in the southern Pacific region show that the annual and seasonal ocean surface and island air temperatures have increased by 0.6 to 1.0^{o}C since 1910 throughout a large part of the South Pacific, southwest of the South Pacific Convergence Zone (SPCZ) where as decadal increases of 0.3 to 0.5^{o}C in annual temperatures are only widely seen since the 1970, preceded by some cooling after the 1940, which is the beginning of the record, to the northeast of the SPCZ (Salinger, 2001; Folland *et al.*, 2003).

For the Caribbean, Indian and Mediterranean regions, analyses shows warming ranged from 0 to 0.5^{o}C per decade for the 1971 to 2004 period (Chapter 3, Working Group II).

Precipitation

Analyses of trends in extreme daily rainfall and temperature across the South Pacific for the period 1961 to 2003 show significant increases were detected in the annual number of hot days and warm nights, with significant decreases in the annual number of cool days and cold nights, particularly in years after the onset of El Nino, with extreme rainfall trends generally less spatially coherent than were those of extreme temperature (Manton *et al.*, 2001; Griffiths *et al.*, 2003). In the Caribbean, the percentage of days having very warm maximum or minimum temperatures increased strongly since the 1950s while the percentage of days with cold temperatures decreased (Petersen, *et al.*, 2002). The maximum number of consecutive dry days is decreasing and the number of heavy rainfall events is increasing. These changes were found to be similar to those changes reported from global analysis (Chapter 3, WG 1, AR4).

Tropical cyclones
Variations in tropical cyclones, hurricanes, typhoons in all small islands' regions are dominated by ENSO and decadal variability which result in a redistribution of tropical storms and their tracks, so that increases in one basin are often compensated by decreases in other basins. For instance, during an El Niño event, the incidence of tropical storms typically decreases in the Atlantic and far western Pacific and the Australian regions, but increases in the central and eastern Pacific, and vice-versa. The numbers and proportion of hurricanes reaching category 4 and 5 globally have in creased since 1970, while total number of cyclones and cyclone days decreased slightly in most basins. The largest increase was in the North Pacific, Indian and South-West Pacific Oceans.

In the tropical South Pacific, the distribution of tropical storms and their tracks are dominated by ENSO and decadal variability, with small islands to the east of the dateline highly likely to receive a higher number of tropical storms during an El Nino event compared to a La Niña event and vice versa (Brazdil *et al.*, 2002). In the Caribbean, intense hurricane activity was significantly greater during the 1950s and 1960s, in comparison with the 1970s and 1980s and the first half of the 1990s except, during 1988, 1989 and very recently during 1995. The years 1995 to 2000 experienced the highest level of North Atlantic hurricane activity in the reliable record.

Sea level
Analyses of the longest available sea level records which have at least 25 years of hourly data from 27 stations installed around the Pacific basin show the overall average mean relative sea level rise around the whole region is +0.77 mm per year (Mitchell *et al.*, 2000). The Caribbean region experienced on average a mean relative sea-level rise of 1 mm per year during the 20th century. Considerable regional variations in sea level were observed in the records due to large scale oceanographic phenomena such as the El Niño, coupled with volcanic and tectonic crustal motions of the Pacific Rim which affect the land levels on which the tide gauges are located. Similarly, recent variations in sea level on the west Trinidad coast indicate that sea level in the north is rising at a rate of about 1 mm/year while in the south the rate is about 4 mm/year, the difference being a response to tectonic movements (Miller, 2005). In the more stable Maldives, both the Male and Gan sea level sites show trends of about 4 mm/yr (Khan, *et al.*, 2002), with the range from three tidal stations over the 1990s decade being from 3.2 to 6.5 mm/yr (Woodworth *et al.*, 2002).

16.2.3 Other stresses

Climate change and sea-level rise are not unique contributors to the extreme vulnerability of small islands. In the Pacific vulnerability is also characterised as a function of external political and economic agendas, the impact of external forces on cultural norms and practices, the imposition of forms of social and economic organisation that differ from those practiced traditionally, and attempts to impose models of adaptation that have been developed for Western economies, and without sufficient thought as to their applicability (Cocklin, 1999).

Socio-economic stresses
Other contributors to vulnerability include external pressures such as terms of trade, impacts of globalisation, both positive and negative, financial crises and other international conflicts, rising external debt and internal local conditions, such as rapid population growth, rising incidence of poverty, political instability, unemployment, reduced social cohesion and a widening gap between poor and rich, together with the interactions between them (ADB, 2004).

Most settlements in small islands, with the exception of some of the larger Melanesian and Caribbean Islands, are located in coastal locations, with the prime city or town also hosting as the main port, international airport and centre of government activities. Heavy dependence on coastal resources for subsistence is also a major feature of many small islands.

Rapid and unplanned movements of rural and outer-island residents to the major centres is occurring throughout small islands, resulting in deteriorating urban conditions, with pressure on access to urban services required to meet basic needs. Concentrations of people in urban areas create various social, economic and political stresses, and makes people more vulnerable to short term physical and biological hazards such as tropical cyclones and diseases. It also increases their vulnerability to climate change and sea-level rise.

Globalisation is also a major stress though it has been argued that it is nothing new for many small islands since most have had a long history of colonialism, and more latterly, experience of some of the rounds of the transformation of global capitalism (Pelling and Uitto, 2001). Nevertheless, in the last few years the rate of change and internationalisation has increased, and small islands have had to contend with new forms of extra-territorial economic, political and social forces such as multinational corporations, trans-national social movements, international regulatory agencies and global communications networks. In the present context, these factors take on a new relevance, as they may influence the vulnerability of small islands and their adaptive capacity.

Pressure on island resources

Most small islands have limited sources of freshwater. Atoll countries and limestone islands have no surface water or streams and are fully reliant on rainfall and groundwater harvesting. Many small islands are experiencing water stress at current levels of rainfall input and extraction of groundwater is often outstripping supply. Moreover, pollution of groundwater is often a major problem especially on low islands. Poor water quality affects human health and carries water-borne diseases. Water quality is just one of several health issues linked to climate variability and change and their potential health effects on small islands (Ebi, *et al.*, 2004).

It is virtually certain that ecological systems of small islands, and the functions they perform, will be sensitive to the rate and magnitude of climate change and sea-level rise (e.g. ADB, 2004, in the case of the small islands in the Pacific). Both terrestrial ecosystems on the larger islands and coastal ecosystems on most islands have been subjected to increasing degradation and destruction in recent decades. For instance, analysis of coral reef surveys over three decades has revealed that coral cover right across reefs in the Caribbean has declined by 80 percent in just 30 years, largely as a result of continued pollution, sedimentation and over-fishing (Gardner *et al.*, 2003).

Interactions of human and physical stresses

Externally-oriented pressures that create vulnerability of small islands to climate change include energy costs, population movements, financial and currency crises, international conflicts, and increasing debt. Internal processes that create vulnerability include rapid population growth, attempts to increase economic growth through exploitation of natural resources such a forests and fisheries and beaches, increasing income inequality, unemployment, rapid urbanisation, political instability, a growing gap between demand for and provision of health care and education services, weakening social capital, and economic stagnation. These external and internal processes are related and combine together in complex ways to heighten the vulnerability of island social and ecological systems to climate change.

Natural hazards of hydrometeorological origin remain an important stressor and cause major impacts on economies of small islands. The devastation of Grenada following the passage of Hurricane Ivan on 7 Septemer 2004 is a powerful illustration of the reality of small island vulnerability (Nurse and Moore, 2005). In less than 8 hours, the country's vital socio-ecomic infrastructure, including housing, utilities, tourism related facilities and subsistence and commercial agricultural production, suffered incalculatable damage. The island's two principal foreign exchange earners, tourism and nutmeg production, suffered heavily. More than 90% of hotel guest rooms were either completely destroyed or damaged while in excess of 80% of the island's nutmeg trees were lost. One of the major challenges with regards to hydrometeorological hazards is the time it takes to recover from them. In the past it was common for social-ecological systems to recover from hazards as they were sufficiently infrequent and or less damaging. In the future climate change may create a situation where more intense and/or more frequent extreme events may mean there is less time to recover. Sequential extreme events may mean recovery is never completed meaning that there may be long-term deteriorations in affected systems (e.g. agricultural output decli`nes because soils never recover from salinisation, urban water systems deteriorate because storm damage cannot be fixed in time).

16.2.4 Current adaptation

Past studies of adaptation options for small islands have been largely focused on adjustments to sea-level rise and storm surges associated with tropical cyclones. There was an early emphasis on protecting land through 'hard' shore-protection measures rather than on other measures such as accommodating sea-level rise or retreating from it, although the latter has become increasingly important on continental coasts. Vulnerability studies conducted for selected small islands (IPCC, 2001) show that the costs of overall infrastructure and settlement protection is a significant proportion of GDP, and well beyond the financial means of most small island states, a problem not normally shared by the islands of metropolitan countries. More recent studies since the TAR have identified major areas of adaptation, including water resources and watershed management, reef conservation, agricultural and forest management, conservation of biodiversity, energy security, increased share of renewable energy in the energy supply, and optimized energy consumption. Proposed adaptation strategies have focused on reducing vulnerability and increasing resilience of systems and sectors to climate variability and extremes through mainstreaming adaptation (Shea *et al.*, 2001; Hay *et al.*, 2003; ADB, 2004; UNDP, 2005a, 2005b).

16.3 Assumptions about future trends

16.3.1 Climate and sea-level change

16.3.3.1 Temperature and precipitation

Since the TAR, future climate change projections have been updated (Ruosteenoja *et al.*, 2003). These analyses reaffirm previous IPCC projections that suggest a gradual warming of sea-surface temperature (SST) and a general warming trend in surface air temperature in all small islands' regions and seasons (Lal. *et al.*, 2002;). It must be cautioned however, that because of scaling problems, these projections for the most part apply to open ocean surfaces and not land surfaces. So the temperature changes especially may well be higher than current projections.

Ruosteenoja *et al.* (2003), using seven coupled atmosphere-ocean general circulation models (AOGCMs), the greenhouse gas and aerosol forcing being inferred from the IPCC SRES emission scenarios A1FI, A2, B1 and B2, projected changes in seasonal surface air temperature (Table 16.1) and precipitation (Table 16.2) for the three 30-year periods (2010-2039, 2040-2069 and 2070-2099) relative to the baseline period 1961-1990, for all the sub-continental scale regions of the world, including those of the small islands.

All seven models project increased surface air temperature for all regions of the small islands. Ruosteenoja *et al.*, (2003) projected that increases fall within previous IPCC surface air temperature projection assessments, except for the Mediterranean Sea. Although the increases in surface air temperature are projected to be more or less uniform in both seasons, for the Mediterranean Sea warming is projected to be greater during the summer than winter. Regarding precipitation, the range of projections is still large, and even the direction of change is not clear. For the South Pacific, Lal (2004) has indicated that the surface air temperature by 2100 is estimated to be at least 2.5^{o}C more than the 1990 level. Seasonal variations of projected warming are minimal. No significant change in diurnal temperature range is likely with rise in surface temperatures. An increase in mean temperature would be accompanied by an increase in the frequency of extreme temperatures. The models simulate only a marginal increase or decrease (10 %) in annual rainfall over most of the small islands in the region. During summer, more rainfall is projected while an increase in daily rainfall intensity causing more frequent heavier rainfall events is also likely (Lal, 2004).

Table 16.1: *Projected increase in air temperature (^{o}C) by region*

Regions	2010-2039	2040-2069	2070-2099
Mediterranean	0.60 to 2.19	0.81 to 3.85	1.20 to 7.07
Caribbean	0.48 to 1.06	0.79 to 2.45	0.94 to 4.18
Indian Ocean	0.51 to 0.98	0.84 to 2.10	1.05 to 3.77
Northern Pacific	0.49 to 1.13	0.81 to 2.48	1.00 to 4.17
Southern Pacific	0.45 t0 0.82	0.80 to 1.79	0.99 to 3.11

16.3.3.2 Sea levels

For small islands, sea level changes are of special significance, not only for the low-lying atoll islands but for many high islands where settlements, infrastructure and facilities are concentrated in the coastal zone. Estimates of global sea-level rise from 1-7 mm yr^{-1} provide a backdrop for regional variations and local differences dependent on several factors, including non-climate related factors such as island tectonic setting. While Morner *et al.*, (2004) suggest that the increased risk of flooding during the 21st Century for the Maldives has been overstated, Woodworth (2005) concludes that a rise in sea-level of approximately 50 cm during the 21st Century remains the most reliable scenario to employ in future studies of the Maldives.

Table 16.2: *Projected change in precipitation (%) by region*

Regions	2010-2039	2040-2069	2070-2099
Mediterranean	-35.6 to +55.1	-52.6 to + 38.3	-61.0 to + 6.2
Caribbean	-14.2 to + 13.7	-36.3 to + 34.2	-49.3 to + 28.9
Indian Ocean	-5.4 to + 6.0	-6.9 to + 12.4	-9.8 to + 14.7
Northern Pacific	-6.3 to + 9.1	-19.2 to + 21.3	-2.7 to + 25.8
Southern Pacific	-3. 9 to + 3.4	-8.23 to + 6.7	-14.0 to + 14.6

16.3.3.3 Extreme events

Global warming from anthropogenic forcing suggests increased convective activity but there is a possible trade-off between individual versus organised convection (IPCC, 2001). While increases in SSTs favour more and stronger tropical cyclones, increased isolated convection stabilises the tropical troposphere and this in turn suppresses organised convection making it less favourable for vigorous tropical cyclones to develop. Thus, the IPCC noted changes in atmospheric stability and circulation may produce offsetting tendencies.

Recent analyses (e.g., Bradzil *et al.*, 2002; Mason, 2004) since the TAR reaffirm these findings. Climate modelling with improved resolutions have demonstrated the capability to diagnose the probability of occurrence of short-term extreme events under global warming [see Chapter 11, IPCC WG I AR 4 (in prep)]. Vassie *et al.*, (2004) state that scientists engaged in climate change impact studies should also consider possible changes in swell direction and incidence and their potential impact on the coasts of small islands. With an increasing number of people living close to the coast, deep ocean swell generation, and its potential modifications as a consequence of climate change, is clearly an issue that needs attention, alongside the more intensively studied topics of changes in mean sea level and storm surges.

Although there is not yet convincing evidence in the observed record of changes in tropical cyclone behaviour, it is likely that the maximum tropical cyclone wind intensities could increase 5 to 10 percent by around 2050 (Walsh, 2004). Under this scenario, peak precipitation rates are likely to increase by 25 percent as a result of increases in maximum tropical cyclone wind intensities. Although it is exceptionally unlikely there will be significant changes in regions of formation, the rate of formation is very likely to change in some regions. Changes in tropical cyclone tracks are closely associated with ENSO and other local climate conditions.

Emmanuel (2005) defined an index for the potential destructiveness of hurricanes based on total dissipation of power integrated over the lifetime of the cyclone. This index is a better indication of tropical cyclone threat than storm frequency or intensity alone. Using this index, he found there is a marked increased in both frequency and severity of tropical cyclones since the mid-1970's with a near doubling of power dissipation over the period of record. This trend is due to both longer storm lifetimes and greater storm intensities. He also found that the record of net hurricane power dissipation is highly correlated with SST and suggests that future warming may lead to an upward trend in tropical cyclone destructive potential, and a substantial increase in hurricane-related losses in the 21st century.

Recent calculation presented a more concrete estimate, using a 20 km-mesh, high-resolution global atmospheric model (Oouchi *et al.*, in press). The tropical cyclone frequency observed in the warm-climate experiment is reduced by about 30 percent globally, compared to the present-day-climate experiment. However, it is likely that tropical cyclones will last longer in a warmer world and that the number of strong tropical cyclones will increase. The maximum surface wind speed of the stronger tropical cyclones is likely to increase both in the Northern and Southern Hemispheres although this scenario depends on trajectories of future emissions and the response of the climate system [see Chapter 11, WGI AR4 (in prep)]. These suggest a likely possibility of higher risks of more persistent and devastating tropical cyclones in a warmer world.

16.3.2 Other relevant considerations

Populations on many small islands have long developed and maintained unique lifestyles, adapted to their natural environment. Traditional knowledge, practices, and cultures, where they are still practiced, are strongly based on community support networks and, in many islands, a subsistence economy is still predominant. Societal changes such as population growth, increased cash economy, migration of people to urban centres and to other coastal areas, growth of major cities, increasing dependency on imported goods which create waste mangement problems and development of modern industries such as tourism have changed traditional lifestyles in many small islands. Trade liberalisation also has major implications on the economic and social wellbeing of people of small islands. For example, the phasing out of the Lome agreement and the implementation of the Cotonou agreement will be important. The end of Lome means prices the EU pays for certain agricultural commodities, such as sugar, will decline. Fiji, Jamaica and Mauritius are expected to experience significant contractions in GDP as a result of declining sugar prices paid by the EU (Milner *et al.*, 2004). In Fiji, for example, where 25% of the workforce is in the sugar sector, the Cotonou agreement is likely to result in significant unemployment and deeper impoverishment of many of the 23,000 smallholder farmers, many of whom already live below the poverty line (Prasad, 2003). Such declines in the agricultural sector affected by trade liberalisation heighten social vulnerability to climate change. These changes, together with the gradual disintegration of traditional communities will continue to weaken traditional human support networks, with additional feedback to social breakdown and loss of traditional values, social cohesion, dignity, and confidence, which have been a major component of the resilience of local communities in Pacific Islands.

16.4 Key future impacts and vulnerabilities

The special characteristics of small islands described in Section 16.2.1 make them prone to a large range of potential impacts from climate change, some of which have been recently experienced. Examples of that range, thematically and geographically are illustrated in Box 16.1. Further details on sectors that are especially vulnerable in small islands are expanded upon below.

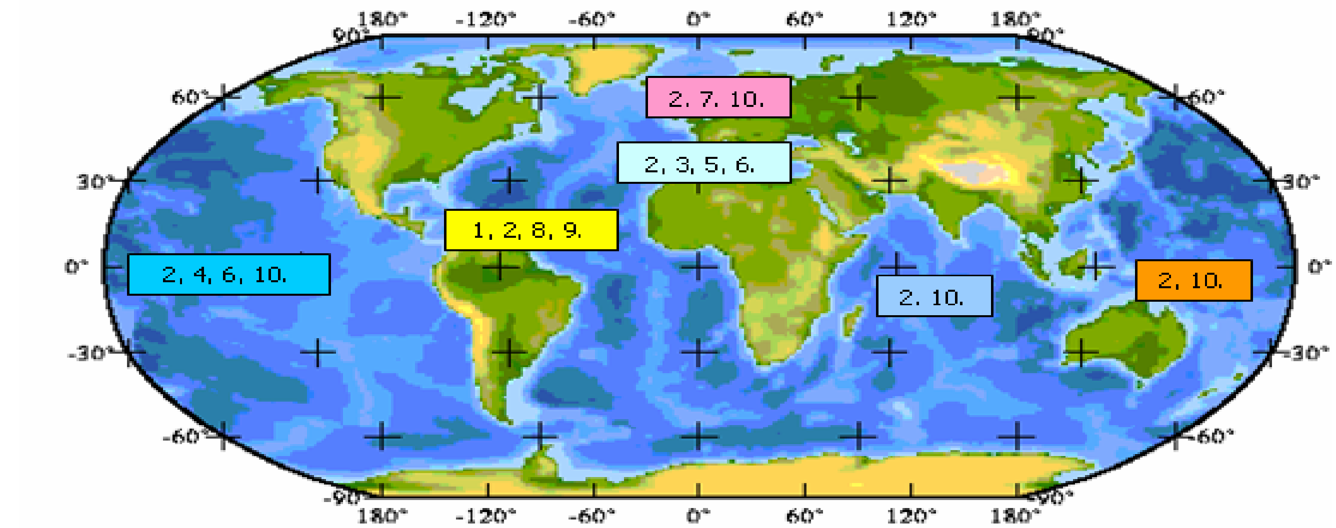
16.4.1 Water resources

Owing to factors of limited size, geology and topography, water resources in small islands are extremely vulnerable to changes and variations in climate, especially in rainfall (IPCC 2001). In most regions of small islands projected future changes in seasonal and annual precipitation are uncertain, although in a few instances precipitation is likely to increase slightly during DJF in the Indian Ocean and Southern Pacific and during JJA in the Northern Pacific. (see Ch. 11 AR4-WG1). Even so, the scarcity of freshwater is often a limiting factor for social and economic development in small islands. Burns (2002) has also cautioned that with the rapid growth of tourism and service industries in many small islands, there is a need for both augmentation of the existing water resources, and more efficient planning and management of those resources. Measures to reduce water demand and promote conservation are also especially important on small islands, where infrastructure deterioration resulting in major leakage is common.

This dependency on rainfall significantly increases the vulnerability of small islands to future changes and distribution of rainfall. For example model projections suggest that a 10 percent reduction in average rainfall by 2050 is likely to correspond to a 20 percent reduction in the size of the freshwater lens on Tarawa Atoll, Kiribati. Moreover, a reduction in the size of the island, resulting from land loss accompanying sea-level rise, is likely to reduce the thickness of the freshwater lens on atolls by as much as 29 percent (World Bank, 2000). Less rainfall coupled with accelerated sea-level rise would compound this threat. Studies conducted on Bonriki Island in Tarawa, Kiribati, showed that a 50 cm rise in sea-level accompanied by a reduction in rainfall of 25 percent would reduce the freshwater lens by 65 percent (World Bank, 2000). Increases in sea-level may also shift water tables close to, or above, the surface resulting in increased evapotranspiration thus diminishing the resource (Burns, 2000).

Low rainfall typically leads to a reduction in the amount of water than can be physically harvested, to a reduction in river flow, and to a slower rate of recharge of the freshwater lens, which can result in prolonged drought impacts. Recent modeling of the current and future water resource availability on several small islands in the Caribbean, using a macro-scale hydrological model and the SRES scenarios (Arnell, 2004) found many of these islands would be exposed to severe water stress under all SRES scenarios, but more so under A2/B2. Since most of the islands are dependent upon surface water catchments for water supply, it is highly likely that demand could not be met during low rainfall periods.

Box 16.1: Range of Future Impacts and Vulnerabilities in Small Islands



Region and System at Risk	Scenario and Reference	Description of Vulnerability	Impacts
1. Caribbean (Bonaire, Netherlands Antilles) Sea turtle nesting habitats (hawksbill, leatherback, green and loggerhead	All SRES IPCC 2001 (A1B1, A1FI, A1, A2, B2) Fish *et al.*, 2005	Projected rise in sea level	➢ On average, up to 38% (±24% SD) of the total current beach could be lost with a 0.5m rise in sea level, with lower narrower beaches being the most vulnerable, reducing turtle nesting habitat by one-third.
2. All Small Islands Coral reefs	A2a B2a Donner *et al.*, 2005	Projected thermal stress Climate sensitivity of 3.0°C (2xCO2)	➢ Bleaching could become annual or bianual event for vast majority of world's coral reefs in next 30-50 years without increase in thermal tolerance of 0.2 °C to 1.0°C per decade
3. .Mediterranean Ecosystems	A1F1 B1 Gritti *et al.*, 2006	Alien plant invasion under climatic and disturbance scenarios	➢ Climate change impacts negligible in many simulated marine ecosystems. ➢ Invasion into island ecosystems an increasing problem. In the longer term, ecosystems will be dominated by exotic plants irrespective of disturbance rates.
4. Pacific(Fiji) Tourism	None (Survey) Becken, 2005.	Increased frequency and severity of extreme events	➢ Tourism highly vulnerable to climate change. ➢ Degradation of natural systems, e.g. coral reefs & forests further impacted by climate change
5. Mediterranean Migratory birds (Pied flywatchers – Ficedula hypoleuca	None (GLM/STATISTICA model) Sanz *et al.*, 2003.	Temperature increase, changes in water levels & vegetation index	➢ Some fitness components of pied flycatchers are suffering from climate change in two of the southernmost European breeding populations, with adverse effects on reproductive output of pied flycatchers.
6. Pacific and Mediterranean Sim Weed (Chromolaena odorata)	None (CLIMEX model) Kriticos *et al.*, 2005	Increase in moisture, cold , heat & dry stress	➢ Pacific Islands at risk of invasion by sim weed ➢ Mediterranean semiarid and temperate climates predicted to be unsuitable to invasion.
7. Higher latitude islands (Faroe Islands) Plant species (Calluna vulgaris, Empetrum nigrum, Racomitrium)	Scenario I: temperature increase by 2°C Scenario II: temperature decrease by 2°C Fosa'a, *et al.*, 2004.	Changes in soil temperature, snow cover and growing degree days	➢ Scenario 1: Species most affected by warming restricted to uppermost parts of mountains, especially *Salix herbacea*, *Racomitrium fasciculae* and *Bistorta vivipara*. For other species, effect will mainly be upward migration ➢ Scenario II: Species affected by cooling are those at lower latitudes, especially *Vaccinium myrtillus* and *Galium saxatilis*.
8. Caribbean (Bonaire, Barbados) Tourism	Uyarra, *et al.*, 2005	Changes to marine wildlife, health, terrestrial features & sea conditions	➢ Distinguishes between land and beach-based tourism (Barbados) and marine recreation (diving, Bonaire). - both affected negatively by climate change: beach erosion (Barbados); coral bleaching (Bonaire).
9. Caribbean (Trinidad) Coastal	None Miller *et al*, 2005.	Sea level rise	➢ Significant increase in sea level would prove catastrophic. ➢ Sea level in North Trinidad rising at a rate of about 1 mm/yr; sea level in south rising at approx. 4 mm a year.
10. All Small Islands	IS92a Lal, *et al.*, 2002	Climate change and sea level rise	➢ Area averaged annual mean warming approx. 2 °C or higher by 2050 & approx. 3 °C or higher by 2080s. ➢ Seasonal variation of surface warming minimal. ➢ Increase in mean temperature accompanied by increased frequency of extreme high temperatures. ➢ Marginal change (<10%) in annual mean rainfall.

The wet and dry cycles associated with ENSO episodes can have serious impacts on water supply and island economies. For instance the strong La Niña of 1998-2000 was responsible for acute water shortages in many islands in the Indian and Pacific Oceans (Shea *et al.*, 2001; Hay *et al.*, 2003;), which resulted in partial shut downs in the tourism and industrial sectors. In Fiji and Mauritius, borehole yields decreased by 40 percent during the dry periods, and export crops including sugar cane were also severely affected (World Bank, 2000). The situation was exacerbated due to lack of adequate infrastructure such as reservoirs and water distribution networks in most islands.

Increases in demand related to population and economic growth, in particular tourism, continue to place serious stress on existing water resources. Excessive damming, over-pumping and increasing pollution are all threats that will continue to increase in the future. Groundwater resources are especially at risk from pollution in many small islands (UNEP, 2000), and in countries such as the Comoros, the polluted waters are linked to outbreaks of yellow fever and cholera (Hay *et al.,* 2003).

Access to safe, potable water varies across countries. There is very high access in countries such as Singapore, Mauritius and most Caribbean Islands, whereas in states such as Kiribati and Comoros, it has been estimated that only 44 percent and 50 percent respectively, have access to safe water. Given the major investments needed to develop storage, provide treatment and distribution of water, it is evident that climate change would further decrease the ability of many islands to meet future requirements.

Several small island countries have begun to invest, at great financial cost, in the implementation of various augmentation and adaptation strategies to offset current water shortages. The Bahamas, Antigua and Barbuda, Barbados, Maldives, Seychelles, Tuvalu and others, have invested in desalination plants. However, in the Pacific, some of the systems are now only being used during the dry season, owing to operational problems and high maintenance costs. Options such as large storage reservoirs and improved water harvesting are now being explored more widely, although such practices have been in existence in countries such as the Maldives since the early 1900s. In other cases, countries are beginning to invest in improving the scientific database that will be used for future adaptation plans. In the Cook Islands, for example, a useful index for estimating *drought intensity* was recently developed based on the analysis of more than 70 years of rainfall data which will be a valuable tool in the long term planning of water resources in these islands (Parakoti and Scott, 2002).

16.4.2 Coastal systems and resources

The coasts of small islands are long relative to island area. They are also diverse and resource rich, providing a range of goods and services, many of which are threatened by a combination of human pressures and climate change and variation arising especially from sea-level rise, increases in sea surface temperature, and possible increases in extreme weather events. Key impacts will almost certainly include accelerated coastal erosion, saline intrusion into freshwater lenses and increased flooding from the sea. Extreme examples of the ultimate impact of sea level rise on small islands – island abandonment - has been documented by Gibbons and Nicholls (2006) in Chesapeake Bay.

It has long been recognised that islands on coral atolls are especially vulnerable to this combination of impacts, and that the long-term viability of some atoll states has been questioned. Indeed, Barnett and Adger (2003) argue that the risk from climate–induced factors constitutes a dangerous level of climatic change to atoll countries by potentially undermining their sovereignty (See Section 16.5.4).

Predicting the future of atoll island geomorphology has been undertaken using both geological analogues and simulation modelling approaches. Using a modified shoreline translation model, Kench and Cowell (2001) and Cowell and Kench, (2001) found that with sea-level rise ocean shores will be eroded and sediment redeposited further lagoonward, assuming that the volume of island sediment remains constant. Simulations also show that changes in sediment supply can cause physical alteration of atoll islands by an equivalent or greater amount than by sea- level rise alone. Geological reconstructions of the relationship between sea level and island evolution in the mid- to late- Holocene, however, do not provide consistent interpretations. For instance, chronic island erosion resulting from increased water depth across reefs with global warming and sea-level rise is envisaged for some islands in the Pacific (Dickinson, 1999), while Kench *et al.*, (2005) present data and a model that suggest uninhabited islands of the Maldives are morphologically resilient rather than fragile systems, and are expected to persist under current scenarios of future climate change and sea-level rise. The impact of the Sumatran tsunami on such islands appears to confirm this resilience (Kench *et al.*, 2006) and implies that islands that have been subject to substantial human modification are inherently more vulnerable.

On topographically higher and geologically more complex islands, beach erosion presents a particular hazard to coastal tourism facilities, which provide the main economic thrust for many small islands states. *Ad hoc* approaches to addressing this problem have recently given way to the integrated coastal zone management approach as summarised in the TAR (McLean, *et al.*, 2001), which recommends data collection, analysis of coastal processes and assessment of impacts. Daniel and Abkowitz (2003, 2005) present the results of this effort in the Caribbean which include the development of tools for integrating spatial and non-spatial coastal data, estimating long-term beach erosion/accretion trends and storm-induced beach erosion at individual beaches, identifying erosion-sensitive beaches and mapping beach erosion hazards.

While erosion is intuitively the most common response of island shorelines to sea-level rise, it should be recognised that coasts are not passive systems. Instead they will respond dynamically in different ways dependent on many factors including: the geological setting; coastal type, whether soft or hard shores; the rate of sediment supply relative to submergence; sediment type, sand or gravel; presence or absence of natural shore protection structures such as beach rock or conglomerate outcrops; presence or absence of biotic protection such as mangroves and other strand vegetation; and, the health of coral reefs. That several of these factors are interrelated can be illustrated by a model study by Sheppard *et al.*, (2005) who suggest that mass coral mortality over the past decade at some sites in the Seychelles has resulted in a reduction in the level of the fringing reef surface, a consequent rise in wave energy over the reef, and increased coastal erosion. Further declines in reef health are expected to accelerate this trend.

Global change is also creating a number of other stress factors that are very likely to influence the health of coral reefs around islands, as a result of increasing sea surface temperature and sea level, damage from tropical cyclones, and possible decreases in growth rates due to the effects of higher carbon dioxide concentrations on ocean chemistry. Impacts from those factors on coral reefs will not be uniform throughout the small island realm. For instance, the geographic variability in required thermal adaptation found in models and emission scenarios presented by Donner *et al.*, (2005) suggest that coral reefs in some regions, like Micronesia and western Polynesia, may be particularly vulnerable to climate change. In addition to these primarily climate-driven factors, the impacts of which are detailed in Chapter 6.2.1 (this volume), are those associated mainly with human activity, which combine to subject island coral reefs to multiple stresses, as illustrated in Figure 16.1.

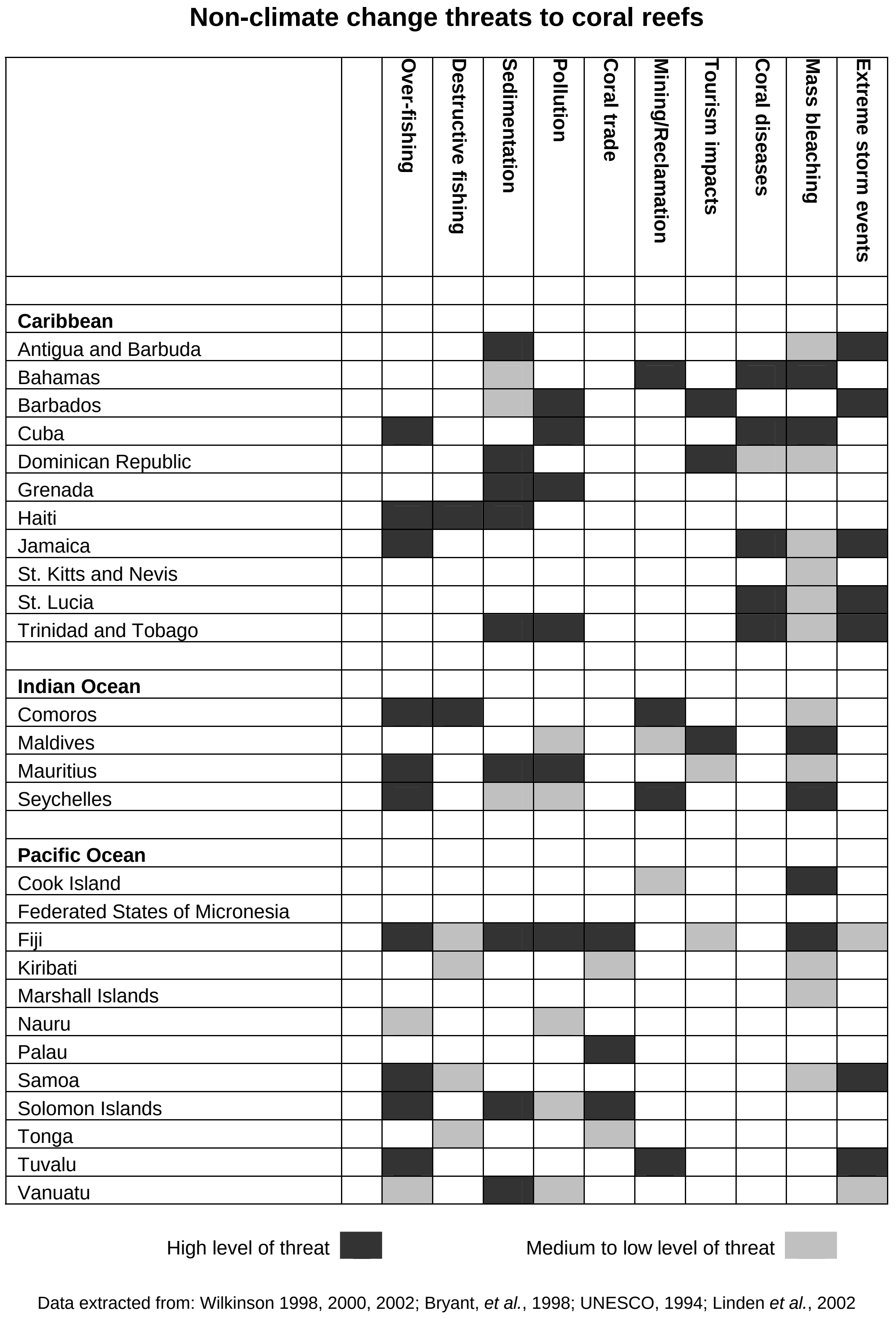


Figure 16.1: *Matrix showing the major non-climate change threats to coral reefs in selected small island states (after Payet, 2003). Note the level of threat is primarily a qualitative and relative assessment by the authors, and that gaps in the table do not necessarily mean the absence of threat but rather that it has not been documented in the recent literature. Some of the threats are also related to or interact with climate change-induced processes.*

16.4.3 Agriculture, fisheries and food security

Small islands have traditionally depended upon subsistence and cash crops for survival and economic development. Whilst subsistence agriculture provides local food security, cash crops (such as sugar cane, banana and forest products) are exported to earn foreign exchange. In Mauritius, the sugar cane industry has provided economic growth and diversification of the economy into tourism and other related industries (Government of Mauritius, 2002). However, exports have depended upon preferential access to major developed country markets which are slowly eroding. Many island states have also experienced decrease in GDP contributions from agriculture, partly due to the drop in competitiveness for cash crops, cheaper imports from larger countries, increased costs of maintaining soil fertility and competing uses for water resources, especially with tourism (FAO, 2004).

Local food production is vital to small islands even those with very limited land areas. In the Pacific islands subsistence agriculture has existed for several hundred years. The ecological dependency of small island economies and societies is well recognized (ADB, 2004). A report by FAO's Commission on Genetic Resources found that countries' interdependence with regard to plant genetic resources, range from 91 percent in Comoros, 88 percent in Jamaica, 85 percent in Seychelles to 65 percent in Fiji, 59 percent for Bahamas and Vanuatu 37 percent (Ximena, 1998).

Projected impacts of climate change include extended periods of drought, and on the other hand, loss of soil fertility as a result of increased precipitation, both of which will negatively impact on agriculture and food security. In the study on the economic and social implications of climate change and variability for selected Pacific Islands, World Bank (2000, 2002) found that in the absence of adaptation, a high island such as Viti Levu, Fiji, could experience damages of 23 million to 52 million USD per year by 2050, (equivalent to 2-3 percent of Fiji’s GDP in 2002). A group of low islands such as Tarawa, Kiribati, could face average annual damages of more than 8 million to 16 million USD a year (equivalent to 17-18 percent of Kiribati’s GDP in 2002) under SRES A2 and B2.

Extreme weather events, such as cyclones, freak storms, and droughts also cause irreparable damage to food crops. Extended drought conditions were recorded in Niue, which lasted for 18 months from July 1982 to December 1983. During this event, exports went down, and local cows were slaughtered for food and imports of farm produce increased. The drought also created conditions for leafhopper and aphid invasions on important export crops such as taro (Government of Niue, 2000).

Fisheries in small islands are important both for domestic and commercial purposes, and fish provide a most important local source of protein. Fisheries contribute 9.9 percent of the GDP of the Maldives (MOHA, 2001), and many small island states have become large exporters of fish, especially tuna in the last 20 years. There is however some volatility in fish catch and price.

Since fisheries contribute significantly to GDP in many island states, the socio-economic implications of the impact of climate change on fisheries will be important. Variations in tuna catches are especially significant during El Niño and La Niña years. For example in Maldives, during the El Niño years of 1972-73, 1976, 1982-83, 1987 and 1992-94, the skipjack catches decreased and yellow fin increased, whereas during the La Niña years skipjack tuna increased, whilst other tuna species decreased (MOHA, 2001). Changes in migration patterns and depth are two main factors affecting the distribution and availability of tuna during those periods and it is expected that changes in climate would cause migratory shifts in tuna aggregations to other locations (IPCC, 2001). Apart from the Lehodey *et al.* (2003) study of potential changes in the tuna fisheries, Aaheim and Sygna (2000) surveyed possible economic impacts in terms of quantities and values, and give examples of macroeconomic impacts. The two main effects of climate change on tuna fishing are likely to be a decline in the total stock and a migration of the stock westwards, both of which will lead to changes in the catch in different countries.

In contrast to agriculture, the mobility of fish makes it difficult to estimate future changes in marine fish resources. Furthermore, since the life cycle of many species of commercially exploited fisheries range from freshwater to ocean water, land-based and coastal activities will also likely affect the populations of those species. Coral reefs and other coastal ecosystems which may be severely affected by climate change will also have an impact on fisheries.

16.4.4 Biodiversity

Oceanic islands often have a unique biodiversity through high endemism caused by ecological isolation. Moreover, most small islands are heavily reliant for human well-being on ecosystem services such as amenity value and fisheries (Wong *et al.*, 2005). Historically, isolation by its very nature normally excludes threats such as invasive species from causing the extinction of endemics. However, in mid- and high-latitude islands, higher temperature, and retreat and loss of snow cover holds the possibility of enhancing conditions for the spread of invasive species (Smith *et al.*, 2003 see also Ch 15.6.3 this volume). For example, in species poor sub-Antarctic island ecosystems, alien microbes, fungi, plants and animals have been extensively documented as causing substantial loss of local biodiversity and changes to ecosystem function (Frenot *et al.*, 2005). With rapid climate change even more elevated numbers of introductions and enhanced colonization by aliens are likely, with consequent increases in impacts on these island ecosystems. Climate related ecosystem effects are also already evident in the mid-latitudes such as on the island of Hokkaido, Japan, where a decrease in alpine flora has been reported (Kudo *et al.*, 2004).

Under the SRES scenarios small islands are shown to be particularly vulnerable to coastal flooding and decreased extent of coastal vegetated wetlands (Nicholls, 2004). There is also a detectable influence on marine and terrestrial pathogens, such as coral diseases and oyster pathogens, linked to El Nino-Southern Oscillations events (Harvell *et al.*, 2002). These changes are in addition to coral bleaching which could become an annual or biannual event in the next 30-50 years without an increase in thermal tolerance of 0.2-1.0 ^{o}C (Donner *et al.*, 2005). Further, in the Caribbean sea level rise is predicted to decrease turtle nesting habitat up to 35% with a 0.5m rise in sea level (Fish *et al.*, 2005).

In islands with cloud forest or high elevations such as the Hawaiian Islands, large volcanoes have created extreme elevation gradients, ranging from nearly tropical to alpine (Foster, 2001; Daehler, 2005). In these ecosystems, anthropogenic climate change is likely to combine with past land-use changes and biological invasions to drive several species such as endemic birds to extinction (Benning *et al.*, 2002). This trend among Hawaiian forest birds shows concordance with the spread of avian malaria which has doubled over a decade at upper elevations, and is associated with breeding of mosquitoes and warmer summertime air temperatures (Freed *et al.*, 2005).

In the event of increasing extreme events such as cyclones (hurricanes) (see 16.3.3.3) forest and biodiversity could be severely affected as adaptation responses on small islands are expected to be slow, and impacts of storms may be cumulative. For example, Ostertag *et al.*, (2005) examined long-term subtropical moist forests on the island of Puerto Rico in the Caribbean. Hurricane induced mortality of trees after 21 months was 5.2 percent/year, more than seven times higher than background mortality levels during the non-hurricane periods. They show that resistance of trees to hurricane damage is not only correlated with individual and species characteristics, but also with past disturbance history, which suggests that in interpreting the effects of hurricanes on forest structure individual storms cannot be treated as discrete, independent events.

16.4.5 Human settlements and well-being

The concentration of large settlements along with consequential economic and social activities at or near the coast is a well-documented feature of small islands. On Pacific and Indian Ocean atolls, villages are located on low and narrow islands, and in the Caribbean more than half of the population lives within 1.5 km of the shoreline. In many small islands such as the north coast of Jamaica and the west and south coasts of Barbados, continuous corridors of development now occupy practically all of the prime coastal lands. Such land is also occupied by a range of other settlements, such as fishing villages, and on many small islands government buildings and important facilities such as hospitals are frequently located close to the shore. Moreover, population growth and inward migration of people is putting additional pressure on coastal settlements, utilities and resources and creating a series of problems in terms of pollution, waste disposal and housing. Changes in sea level, and any changes in the magnitude and frequency of storm events, are likely to have serious consequences for these settlements. On the other hand, rural and inland settlements and communities are more likely to be adversely affected by negative impacts upon agriculture, given that they are often dependent upon crop production for many of their nutritional requirements.

An important consideration in relation to settlements is housing. In many parts of the Pacific traditional housing styles, techniques and materials ensured they were resistant to damage or could be repaired quickly. Moves away from traditional housing have increased vulnerability to thermal stress, slowed housing reconstruction after storms and flooding, and in some countries increased use of air conditioning. As a result, human wellbeing in several major settlements on islands in the Pacific and Indian Oceans has changed over the past two or three decades, and there is growing concern over the possibility that global climate change and sea-level rise are likely to impact human health and well-being, mostly in adverse ways (Hay *et al.*, 2003).

Singh *et al.*, (2001) showed that, in the Pacific islands, there was a positive association between annual average temperature and the rate of diarrhoea, and a negative association between water availability and diarrhoea. Their second, more detailed investigation in Fiji, also showed positive associations between diarrhoea and temperature, as well as between diarrhoea incidence and extreme rainfall. These results confirmed other studies that indicate global climate change is likely to exacerbate diarrhoea illness in many Pacific countries.

Climate change is also likely to result in an increase in the incidence of vector-borne diseases such as dengue fever and malaria. The various mosquitoes that transmit these diseases, as well as other environmental factors in disease transmission, are clearly influenced by climate. In the small island Pacific, malaria is generally limited to the Melanesian islands, while dengue fever is more widespread in the Pacific as well as elsewhere. In the Caribbean, a retrospective review of dengue fever cases (1980-2002) was carried out in relation to ENSO events (Rawlins *et al.,* 2005). This showed there were greater occurrences of dengue fever in the warmer drier period of the first and second years of El Niño events, though there was no evidence of the impact of temperature increases. Normally, however, it is in the wet season that Caribbean countries are at greatest risk to dengue fever transmission, suggesting that vector mitigation programs should be targeted at this time of year to reduce mosquito production and dengue fever transmission (Rawlins *et al.*, 2005).

While shortages of fresh water and poor water quality during periods of drought, as well as contamination of fresh water supplies during floods and storms appear to lead to an increased risk of disease including cholera, diarrhoea, and dengue fever, ciguatera fish poisoning is common in marine waters, especially reefal waters. Although multiple factors contribute to outbreaks of ciguatera poisoning, including pollution, and other forms of reef degradation, warmer sea surface temperatures during El Niño events have also been linked to ciguatera outbreaks in the Pacific (Hales *et al.*, 1999)

16.4.6 Economic, financial and socio-cultural impacts

Small island states have special economic characteristics which have been elaborated in several reports (Atkins *et al.*, 2000; Grynberg & Remy, 2004; Briguglio and Cordina, 2004; ADB, 2004). Small economies are generally more exposed to external shocks, such as extreme events and climate change than larger countries, because many of them rely on one or few economic activities such as tourism or fisheries. Recent conflicts in the Gulf region have, for example, affected tourism arrivals in the Maldives and the Seychelles, though internal conflicts associated with coups had similar effects on the tourism industry in Fiji (Becken, 2004). In the Caribbean, hurricanes caused loss of life, property damage and destruction and economic losses running into millions of dollars (ECLAC, 2002; OECS 2004). The reality of *island vulnerability* is powerfully demonstrated by the near-total devastation experienced on the Caribbean island of Grenada, when Hurricane Ivan made landfall in September, 2004. Damage assessments indicate that in real terms, the country's socio-economic development has been set back at least one decade, by this single event that lasted for only a few hours (See Box 16.2).

Box 16.2: Grenada and Hurricane Ivan

Hurricane *Ivan* struck Grenada on September 7, 2004, as a category 4 system on the Saffir-Simpson scale. Sustained winds reached 140 mph, with gusts exceeding 160 mph. An official OECS/UN-ECLAC Assessment reported the following:

- 28 persons killed
- Overall damages calculated at EC$ 2.2 billion, or twice the current GDP
- 90 per cent of housing stock damaged totalling EC$ 1,381 million, or 38 percent GDP
- 90 per cent of guest rooms in tourism sector damaged or destroyed, totalling EC$ 288 million, or 29 percent of GDP
- Losses in telecommunications – 13 percent of GDP
- Damage to schools and education infrastructure - 20 percent of GDP
- Losses in agricultural sector equivalent to 10 percent of GDP. The two main crops, nutmeg and cocoa which have long gestation periods, will make no contribution to GDP or earn foreign exchange for the next 10 years.
- Damage to electricity installations totalling 9 percent of GDP
- Heavy damage to eco-tourism and cultural heritage sites, resulting in 60 percent job losses in the sub-sector
- Prior to Hurricane Ivan, Grenada was on course to experience an economic growth rate of approximately 5.7 percent, but negative growth of around -1.4 percent is now forecast.

(Source: OECS, 2004)

Tourism is a major economic sector in many small islands, and this tendency is increasing. Since their economies depend so highly on tourism, the impacts of climate change on the tourism resources will have significant effects, both direct and indirect. Sea-level rise and increased sea water temperature are projected to accelerate beach erosion, cause degradation of coral reefs including bleaching, and result in loss of cultural heritages on the coasts by inundation and flooding. These impacts will in turn reduce attractions for coastal tourism. For instance, the sustainability of island tourism resorts in Malaysia is expected to be compromised by rising sea level, beach erosion and saline contamination of coastal wells, a major source of water supply for island resorts (Tan and Teh, 2001). Shortage of water and increased danger of vector-borne diseases may steer tourists from small islands, while warmer climates in the higher latitude countries may also reduce the number of people who want to visit small islands in the tropical and subtropical regions.

Tourism in small island states is also vulnerable to climate change because it may result in detrimental changes in relation to extreme events, sea-level rise, transport and communication interruption. In a study of tourist resorts in Fiji, Becken (2005) has suggested that many operators already prepare for climate-related events, and therefore are adapting to potential impacts from climate change. She also concludes that reducing greenhouse gas emissions from tourist facilities is not important to operators; however, decreasing energy costs for economic reasons is practised.

Climate change may also affect important environmental components of holiday destinations, which could have repercussions for tourism-dependent economies. The importance of environmental attributes in determining the choice and enjoyment of tourists visiting Bonaire and Barbados, two Caribbean islands with markedly different tourism markets and infrastructure, and possible changes resulting from climate change (coral bleaching and beach erosion respectively) have been investigated by Uyarra *et al.*, (2005). They concluded that such changes would have significant impacts on destination selection by visitors, and that island-specific strategies, such as focussing resources on the protection of key tourist assets, may provide a means of reducing the environmental impacts and economic costs of climate change.

16.4.7 Infrastructure and Transportation

Like settlements and industry, the infrastructural base that supports the vital socio-economic sectors of island economies tends to occupy coastal locations. Hay *et al.*, (2003) have identified several challenges that will confront the transportation sector in Pacific island countries, as a result of climate variability and change, such as closure of roads, airports and bridges due to flooding and landslides, damage to port facilities. The resulting disruption would not be confined to the transportation sector alone, but would impact other key dependent sectors and services including tourism, agriculture, the delivery of health care, freshwater, food security and market supplies.

In most small islands energy is primarily from non-renewable sources, mainly from imported fossil fuels. In the context of climate change the main contribution to greenhouse gas emissions is from energy use. The need to introduce and expand renewable energy technologies in small islands has been recognised for many years though progress in implementation has been slow. Oftentimes, advice small islands receive on options for economic growth is based on strategies from larger countries where resources are much greater and inputs significantly less costly. It has been argued by Roper (2005) that small island states could set an example on green energy use, thereby contributing to local reductions in greenhouse gas emissions and costly imports. Indeed, some have already begun to become 'renewable energy islands' La Desirade (France) Fiji, Samsoe (Denmark) Pellworm (Germany) and La Reunion (France) are cited as presently generating more than 50 % of their electricity from renewable energy sources (Jensen, 2000).

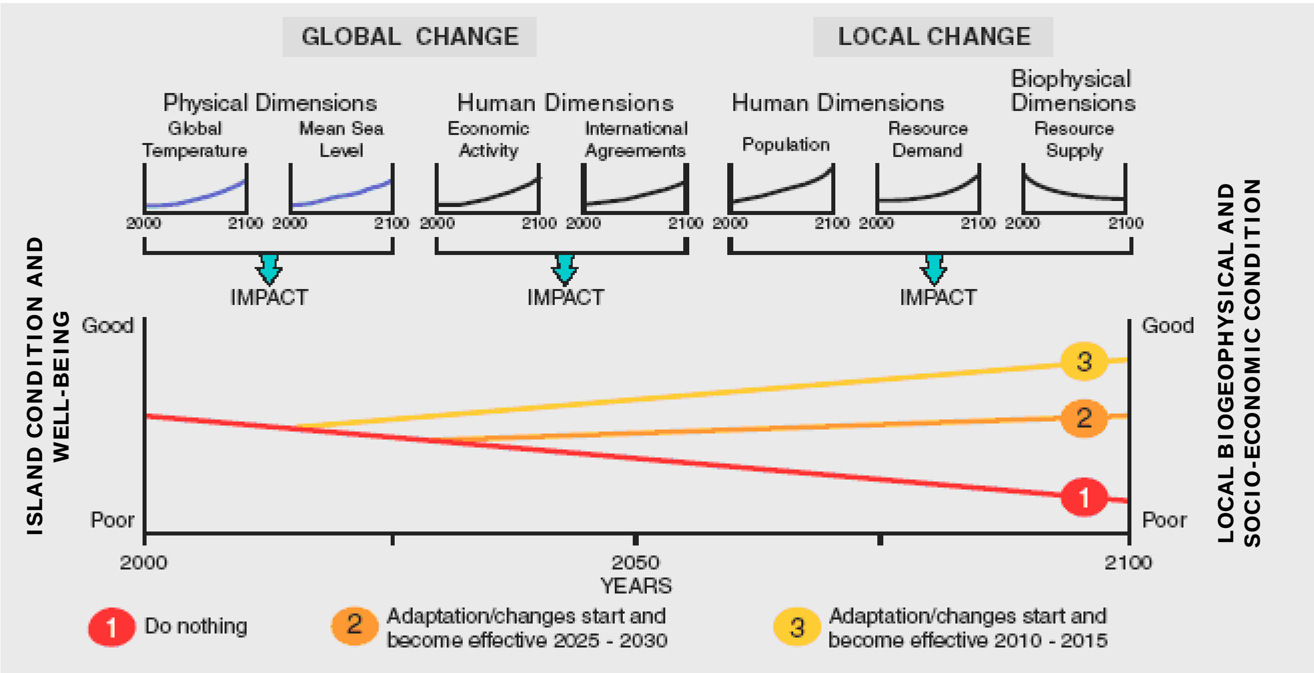
Almost without exception, international airports on small islands are sited on or within a few km of the coast, and on tiny coral islands. Likewise, the main, and often only, road network runs along the coast. In the South Pacific region of small islands, Lal (2004) estimates that since 1950, mean sea level has risen at a rate of approximately 3.5 mm per year, and projects a rise of 25-58 cm by the middle of the current century. Under these conditions, much of the infrastructure in these countries would be at serious risk from inundation, flooding and physical damage associated with coastal land loss. While the risk will vary from country to country, the small islands states of the Indian Ocean and the Caribbean, and countries such as Malta and Singapore, may be confronted by similar threats.

The threat from sea-level rise to infrastructure on small islands could be amplified considerably with the passage of tropical cyclones (hurricanes). It has been shown for instance that port facilities at Suva, Fiji, and Apia, Samoa, would experience overtopping, damage to wharves and flooding of the hinterland if there were a 0.5 m rise in sea level combined with waves associated with a 1/50 year cyclone (Hay *et al.*, 2003). In the Caribbean, the damage to coastal infrastructure from storm surge alone has been severe. In November 1999, surge damage in St. Lucia associated with Hurricane Lenny was in excess of US$ 6.0 million, even though the storm was centred many kilometres offshore.

16. 5 Adaptation: practices, options and constraints

It is clear from the foregoing that small island states are presently subjected to a range of climatic and oceanic impacts, and that these impacts will be exacerbated by on-going climate change and sea-level rise. Moreover, the TAR showed that the overall vulnerability of small island states is primarily a function of four interrelated factors: (1) the degree of exposure to climate change; (2) their limited capacity to adapt to projected impacts; (3) the fact that adaptation to climate change is not a high priority given more pressing problems that small islands have to face; and (4) the uncertainty associated with global climate change projections and their local validity (Nurse *et al.*, 2001). Several other factors that influence vulnerability and impacts on small islands have also been identified in the present chapter, including both global and local processes. This combination of drivers is unlikely to lessen in the future, and this raises the possibility that environmental and socio-economic conditions on small islands will worsen unless adaptation measures are put in place to reduce impacts as illustrated in Box 16.3.

Box 16.3: Future Island Condition and Well-Being: The Value of Adaptation



Global change and regional/local change will interact to impact small islands in the future. Both have physical and human dimensions. Two groups of global drivers are identified above: First, climate change including global warming and sea-level rise. And, second, globally driven socio-economic changes such as globalisation of economic activity and international trade, where the major driver is external to the island. There are also global influences on the management of various small island environments, such as world heritage or marine protected areas resulting from international agreements. In addition to these global processes, small islands are also subject to important local influences, such as population pressure and urbanization which increase demand on local resources.

In general both global and local drivers will show increases in the future, and as displayed in the diagram, this will result in a declining supply of island resources. Implicitly, the '*island condition and well-being*' will decline and with it the local biogeophysical condition (e.g. coral reefs, indigenous forests) and socio-economic condition. This situation reflects a '*do nothing*' option and is illustrated by Line 1. In order to improve island conditions, appropriate adaptations must be put in place and, as shown, the earlier this is done, the better the outcome (Line 3). If the adaptation measures are delayed there will be a poorer outcome (Line 2).

While it is clear that implementing anticipatory adaptation strategies early on is desirable (Box 16.3) there are obstacles associated with the uncertainty of the climate change projections. To overcome this uncertainty, Barnett (2001) has suggested that a better strategy for small islands is to enhance the resilience of whole island socio-ecological systems, rather than concentrate on sectoral adaptation, a theme that is expanded upon in section 16.5.4 and is also the policy of the Organization of Eastern Caribbean States (OECS, 2000). Inhabitants of small islands, individuals, communities and governments, have continually adapted to inter-annual variability in climate and sea conditions, as well as to extreme events, over a long period of time. There is no doubt that this experience will be of value in dealing with the inter-annual variability in climate and sea conditions that will accompany the longer-term mean changes in climate and sea level. Certainly, in Polynesia, Melanesia and Micronesia, the socio-ecological systems have historically been able to adapt to environmental change (Barnett, 2001). However, it is also true that in many islands traditional mechanisms for coping with environmental hazards is being, or has been, lost though paradoxically the value of such mechanisms is being increasingly recognised in the context of adaptation to climate change (e.g. MESD, 1999; Nunn and Mimura, 2005).

Mossler (1996) makes two similar points in suggesting that small island states, often with limited financial, natural and human resources, must: (1) alter their perception of hazards and disasters to move beyond superficial preparedness and costly response and recovery; and (2) make "a particular commitment to efficient, effective vulnerability reduction and increased harmony with dynamic insular environments."

16.5.1 Adaptation in dynamic insular environments

One group of natural 'dynamic insular environments' comprise the tropical rainforests and savannahs and wetlands that occupy the inland, and often upland, catchment areas of the larger, higher and topographically more complex islands, such as Mauritius in the Indian Ocean, Solomon Islands in the Pacific, and Dominica in the Caribbean. Very little work has been done on the potential impact of climate change on these high biodiversity systems, or on their adaptive capacity. On the other hand, the potential impact of global warming and sea-level rise on natural coastal systems, such as coral reefs and mangrove forests, is now well known, though it is less clear how these impacts will be able to be separated from future human activities. For these ecosystems several possible adaptation measures have been identified. In those coral reefs and mangrove forests that have not been subjected to significant degradation or destruction as a result of human activities, natural or 'autonomous' or 'spontaneous' adaptation, that is triggered by changes in climatic stimuli, can take place. For instance, corals may be able to adapt to higher sea-surface and air temperatures by hosting more temperature-tolerant algae. They can also grow upwards with the rise in sea level, providing vertical accommodation space is available (Buddemeier, *et al.*, 2004). Similarly, mangrove forests can migrate inland, as they did during the Holocene sea-level transgression, providing there is horizontal accommodation space, and they are not constrained by the presence of infrastructure and buildings, that is by 'coastal squeeze' (Alongi, 2002).

The natural adaptation of ecosystems is rarely considered in most island states, where attention has been mostly focussed on protecting those ecosystems that are projected to suffer as a consequence of climate change and sea-level rise, and on rehabilitating degraded or destroyed ecosystems that have resulted from socio-economic developments. But, "while development has a strong tendency to undermine ecosystem resilience" Barnett (2001) has observed that "the wealth it confers [on small island states] paradoxically tends to enhance resilience, particularly when it is equitable and when it leads to enrichment of the states."

16.5.2 Adaptation options, priorities and their spatial variations

Since the TAR there have been a number of National Communications to the UNFCCC from small island states that have assessed their own vulnerability to climate change and in-country adaptation strategies. These communications give an insight into the concern about climate change, the country's vulnerability, and the priorities that different small island states place on adaptation options. They also suggest that to date adaptation has been reactive, and has been centred on responses to the effects of climate extremes. Moreover, the range of measures considered, and the priority they are assigned, appear closely linked to either the country's key socio-economic sectors, key environmental concerns, or the most vulnerable areas to climate change and/or sea-level rise. Some island states such as Malta (MRAE, 2004) emphasise potential adaptations to economic factors including power generation, transport, and waste management, while agriculture and human health figure prominently in communications from the Comoros (GDE, 2002), Vanuatu (1999), and St. Vincent and the Grenadines (NEAB, 2000). In these instances, sea-level rise is not seen as a critical issue, as it is in the low-lying atoll states such as Kiribati, Tuvalu, Marshall Islands and the Maldives (See Box 16.4). On the other hand, all National Communications emphasise the urgency for adaptation action and financial resources to support such action.

In spite of differences in emphasis and sectoral priorities, there are two common themes. First, fresh water is seen as a critical issue in all small island states, both in terms of water quality and quantity. Clearly, water is a multi-sectoral resource that impinges on all facets of life and livelihood including security. It is a problem at present and one that will increase in the future. Second, many small island states, including all of the Least Developed Countries, see the need for more integrated planning and management, be that related to water resources, tourism, health or coastal zone management. In the case of tourism in Fiji for instance, Becken (2004) argues that while the current tourism policy focuses on adaptation and measures are predominantly reactive rather than proactive, climate change measures that offer win-win-win situations should be pursued. These include adaptation, mitigation and wider environmental management, examples of such measures being reforestation of native forest, water conservation, and the use of renewable energy resources (Becken, 2004).

The need to implement adaptation measures in small islands with some urgency has been recently reinforced by Nurse and Moore (2005), and was also highlighted in the TAR where it was suggested that risk-reduction strategies together with other sectoral policy initiatives in areas such as sustainable development planning, disaster prevention and management, integrated coastal zone management and health care planning should be employed. Since then a number of projects on adaptation in several small island states and regions have adopted this suggestion. Projects aim to build capacities of ind-ividuals, communities and governments so that they are more able to make informed decisions about adaptation to climate change and to enhance their adaptive capacity in the long run (See Box 16.5).

Box 16.4: Adaptive Measures in The Maldives

Adaptation options in low-lying islands of the Maldives, which have been identified as especially vulnerable, are limited and response measures to climate change or its adverse impacts are potentially very costly. In the Maldives adaptation covers two main themes: (1) Physical adaptive measures targeted at the sectors that are regarded as the most vulnerable; and, (2) the necessity of enhancing the capacity of the Maldives to adapt to climate change and sea-level rise.

Vulnerable area	Adaptation response
Land loss and beach erosion	Coastal protection
	Population consolidation i.e. reduction in number of inhabited islands
	Ban coral mining
Infrastructure and settlement damage	Protection of international airport
	Upgrading existing airports
	Increase elevation in future
Damage to coral reefs	Reduction of human impacts on coral reefs
	Assigning protective status to more reefs
Damage to tourism industry	Coastal protection of resort islands
	Reduce dependency on diving as a primary resort focus
	Economy diversification
Agriculture and food security	Explore alternate methods of growing fruits, vegetable and other foods
	Hydroponic system
Water resources	Protection of groundwater
	Increasing rainwater harvesting and storage capacity
	Use of solar distillation
	Management of storm water
	Allocation of groundwater recharge areas in the islands
Lack of capacity to adapt	Human resource development
	Institutional strengthening
	Research and systematic observation
	Public awareness and education

Source: MOHA (2001)

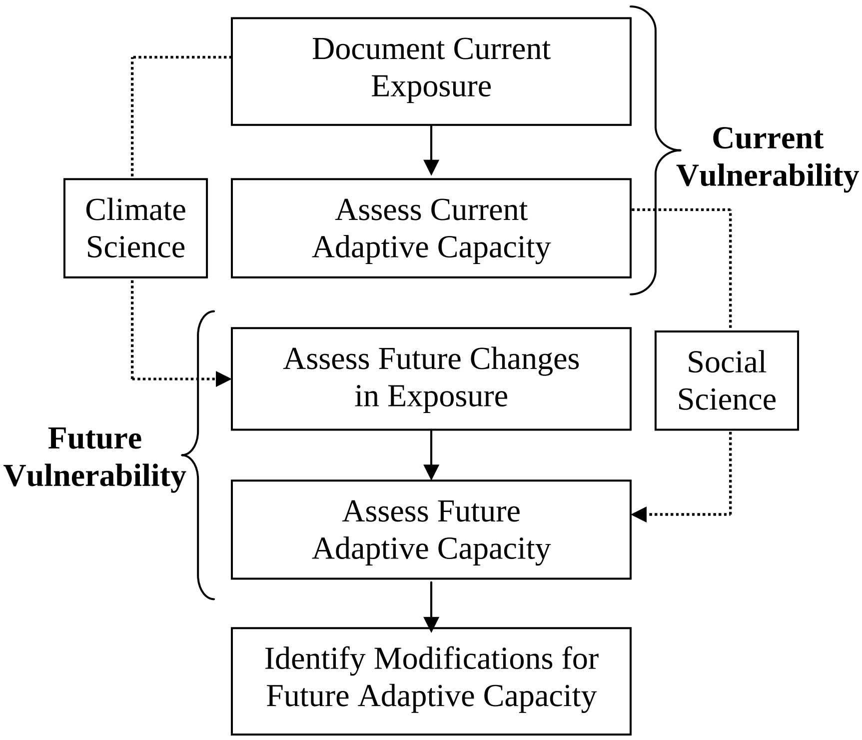
16.5.3 Constraints to adaptation

Underlying this last need is a common constraint confronting most small island states; the lack of in-country adaptive capacity. There are at least two areas where resources are insufficient: financial and human. In most cases the cost of adopting and implementing adaptation options will be prohibitive, and will call on financial resources that are generally not available to government. Similarly, there are inadequate human resources available at present to accommodate, cope with or benefit from the effects of climate change, partly because of migration of skilled workers (Voigt-Graf, 2003). To overcome this deficiency the adaptive capacity of small island states will need to be built up in four important areas: human resource development, institutional strengthening, research and systematic observation, and public awareness and education.

An extreme example of these needs is Timor Leste (East Timor) which is generally vulnerable to climate change as evidenced by existing sensitivities to climate events, for example drought and food shortages in the western highlands, and floods in Suai. Barnett, *et al*., (2003) note that relevant planning would address present problems as well as future climate risks, and conclude that activities that promote sustainable development, human health, food security and renewable energy can reduce the risk of future damages caused by climate change as well as improving living standards. In short, "change in climate is a long-term problem for Timor Leste, but climate change policies can be positive opportunities".

Box 16.5: Capacity Building for Development of Adaptation Measures in Small Islands: a Community Approach

Capacity-building for development of adaptation measures in Pacific island countries uses a Community Vulnerability and Adaptation Assessment and Action approach, which is participatory, aims to better understand the nature of community vulnerability, and identifies opportunities for strengthening the adaptive capacity of communities. It promotes a combination of bottom-up and top-down approaches to implementation, and supports the engagement of local stakeholders at each stage of the assessment process. This enables integration or 'mainstreaming' of adaptation into national development planning and local decision-making processes. The main steps are outlined below.



Several pilot communities in the Cook Islands, Fiji, Samoa and Vanuatu are already using this approach to analyse their options and decide on the best course of action to address their vulnerability and adaptation needs.

Adopted from Sutherland *et al.* (2005)

16.5.4 Building resilience through adaptation

This last theme is also developed by Pelling and Uitto (2001) who suggested that change at the global level is found to be a source of new opportunities, as well as constraints, for building local resilience to natural disasters. This is equally applicable to climate change. They argue that small island populations have been mobile both historically, and at present, and that remittances from overseas relatives help moderate economic risks and increase family resiliency on home islands. They also recognise that this is a critical time for small islands, which must contend with ongoing developmental pressures, in addition to growing pressures from risks associated with climate change and sea-level rise and economic liberalisation that threaten the physical and economic security of islands. They conclude, following a case study of Barbados, that efforts to enhance island resilience must be mainstreamed into general development policy formulation, and that adaptations should not to be seen as separate and largely engineering or land-use planning based realms (Pelling and Uitto, 2001).

Many small island societies have proved resilient in the past to social and environmental upheaval (Barnett, 2001). The key parameters of this resilience include, in addition to opportunities for migration and subsequent remittances; traditional knowledge, institutions and technologies; land and shore tenure regimes; the subsistence economy; and, linkages between formal state and customary decision-making processes. However, this resilience may be undermined as the small island states become increasingly integrated into the world economy, through for example, negotiations for fishery rights in the EEZ and international tourism (Barnett, 2001).

These global economic processes, together with global warming, sea-level rise and possibly increased frequency and intensity of extreme weather events, make it difficult for small island states to achieve an appropriate degree of sustainability, which is one of the goals of adaptation to climate change. Indeed, for the most vulnerable small island states, Barnett and Adger (2003) suggest that this combination of global processes interacting with local socio-economic and environmental conditions puts the long-term ability of humans to inhabit atolls at risk, arguing further that from a social science perspective this risk constitutes a 'dangerous' level of climatic change that may well undermine their national sovereignty (See Box 16.6).

This discussion highlights the role of resilience, both its biophysical and human aspects, as a critical component in developing the adaptive capacity of small island states, a role that has effectively emerged since publication of the TAR. In a recent study by Tompkins (2005) in the Cayman Islands, it was found that self-efficacy, strong local and international support networks, combined with a willingness to act collectively and to learn from mistakes, appeared to have increased the resilience of the Cayman Islands Government to tropical storm risk, implying that such resiliency can also contribute to the creation of national level adaptive capacity.

Box 16.6: Climate Dangers and Atoll Countries

"Climate change puts the long-term sustainability of societies in atoll nations at risk. The potential abandonment of sovereign atoll countries can be used as the benchmark of the 'dangerous' change that the UNFCCC seeks to avoid. This danger is as much associated with the narrowing of adaptation options and the role of expectations of impacts of climate change as it is with uncertain potential climate-driven physical impacts. The challenges for research are to identify the thresholds of change beyond which atoll socio-ecological systems collapse and to assess how likely these thresholds are to be breached. These thresholds may originate from social as well as environmental processes. Further, the challenge is to understand the adaptation strategies that have been adopted in the past and which may be relevant for the future in these societies".
Source: Barnett and Adger (2003)

Resilience can also be strengthened through the application of traditional knowledge. In the TAR, Nurse *et al.*, (2001) noted that some traditional island assets, including subsistence and traditional technologies, skills and knowledge and community structures, and coastal areas containing spiritual, cultural and heritage sites, appeared to be at risk from climate change and particularly sea-level rise. They argued that some of these values and traditions are compatible with modern conservation and environmental practices.

Since then several examples of such practices have been described. For instance, Hoffman (2002) has shown that the implementation of traditional marine social institutions, as exemplified in the *Ra'ui* in Rarotonga, Cook Islands, is an effective conservation management tool, and is improving coral reef health, while Aswani and Hamilton (2004) show how indigenous ecological knowledge and customary sea tenure may be integrated with modern marine and social science to conserve the bumphead parrotfish in Roviana Lagoon, Solomon Islands. Changes in sea tenure, back to more traditional roles has also occurred in Kiribati (Thomas, 2001).

The utility of traditional knowledge and practices can also be expanded to link with, not only biodiversity conservation, but also tourism. For instance, in a coastal village on Vanua Levu, Fiji, the philosophy of *vanua* (which refers to the connection of people with the land through their ancestors and guardian spirits) has served as a guiding principle for the villagers in the management and sustainable use of the rainforest, mangrove forest, coral reefs, and village gardens. Sinha and Bushell (2002) have shown that the same traditional concept can be the basis for biodiversity conservation, because the ecological systems upon which the villagers depend for subsistence, are the very same resources that support tourism. These indicate that traditional knowledge, and management frameworks and skills are important as components of adaptive capacity in small islands.

In terms of integrating risk management and adaptation, several areas are outlined, including land use planning, development and field testing of climate change adaptation planning frameworks, sharing of best practices and guidelines, and consideration of climate change concerns/risks at the planning phase of investment and development projects (e.g. Shea, 2003). Risk management also implies actions that can include insurance to meet the specific needs and concerns of developing countries with respect to adverse effects of climate change, especially in Small Island Developing States.

Indeed, while the question of insurance is increasingly being discussed, major identifiable constraints for efficiency of transferring or sharing of risk in small islands include the small size of the risk pool, and the lack of availability of financial instruments and services for risk management. Thus, the implementation of specific instruments and services for risk sharing is needed, as most small islands cannot afford fully domestic insurance services. Perhaps recent initiatives on financial risk transfer mechanisms through traditional insurance structures and new financial instruments, such as catastrophe bonds, weather derivatives and micro-insurance, might provide the flexibility to adapt, to an individual country (Auffret, 2003; Hamilton, 2004; Swiss Re, 2004).

Migration is also seen by some as an effective adaptation strategy. For instance, Adger *et al.,* (2003) argued that migration could be considered as a feasible climate adaptation strategy in particular circumstances, including in small islands. However, given current inequities in labour flows, particularly for international migration, this is likely to be contested, implying that migration may be a limited option in many parts of the world even for small island developing states. Thus, other means of supporting adaptive capacity and enhancing resilience would be required, building on existing coping strategies, or by introducing innovation in terms of technology or institutional development.

Given the urgency for adaptation in small island states there has been an increase in *ad-hoc* stand alone projects, rather than a programmed or strategic approach to the funding of adaptation options and measures. It can be argued that successful adaptation in small islands will depend on supportive institutions, finance, information and technological support. However, as noted by Richards (2003), disciplinary and institutional barriers mean that synergies between the climate change adaptation and poverty reduction strategies remain underdeveloped. Adger *et al.*, (2003) stated that climate change adaptation has implications for equity and justice because "the impacts of climate change, and resources for addressing these impacts, are unevenly distributed." These issues are particularly applicable to small islands, which have a low capacity to deal with, or adapt to, such impacts.

16.6 Conclusions: Implications for sustainable development

The economic, social and environmental linkages between climate change and sustainable development have been highlighted in various studies (e.g. Huq and Reid, 2004; Hay *et al.*, 2003; Munasinghe, 2003) and these are highly relevant to small islands. Indeed, it is true to say that many low-lying small islands view climate change as one of the most important challenges to their achievement of sustainable development. For instance, in the Maldives Majeed and Abdulla (2004) argue that sea-level rise would so seriously damage the fishing and the tourism industries that GDP would be reduced by more than 40 percent.

In another atoll island setting, Ronneberg (2004), uses the Marshall Islands as a case study to explain that the linkages between patterns of consumption and production, and the effects of global climate change pose serious future challenges to improving the life of the populations of small island developing states. Based on this case study, Ronneberg (2004) proposes a number of innovative solutions which could promote the sustainable development of small island developing states and at the same time strengthen their resilience against climate change.

The sustainable development of small islands which are not low-lying (e.g. Malta), is also likely to be impacted by climate change. Briguglio and Cordina (2002) have shown that the climate change impacts on the economic development of Malta, are likely to be widespread, affecting all sectors of the economy, but particularly tourism, fishing and public utilities.

Sperling (2003) contends that the negative impacts of climate change are so serious that they threaten to undo decades of development efforts. He also argues that the combined experience of many international organisations suggests that the best way to address climate change impacts is by integrating adaptation measures into sustainable development strategies. A similar argument is advanced by Hay *et al.*, (2003), in the context of the Pacific small island states, as follows: "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". Adaptation measures may be conducive to sustainable development, even without the connection with climate change. The link between adaptation to climate change and sustainable development, which leads to the lessening of pressure on natural resources, improving environmental risk management, and increasing the social well-being of the poor, not only reduces the vulnerability of small island developing countries to climate change, but also may put them on a path towards sustainable development.

Mitigation measures could also be mainstreamed in sustainable development plans and actions. In this regard Munasinghe (2003) argues that "ultimately, climate change solutions will need to identify and exploit synergies, as well as seek to balance possible trade-offs, among the multiple objectives of development, mitigation, and adaptation policies". Hay *et al.*, (2003) also argue that 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.

Many small islands states have considerable experience in taking measures against climate variability. In the case of Cyprus, Tsiourtis (2002) explains that the island has consistently taken steps to alleviate the adverse effects arising from water scarcity, which is likely to be one of the important effects of climate change. This experience already features in development strategies adopted by Cyprus. A similar argument has also been made by Briguglio (2000) with regard to the Maltese Islands, referring to the islands' exposure to climatic seasonal variability, which historically, has led to individuals and administrations taking measures associated with retreat, accommodation and protection strategies. For example, residential settlements in Malta are generally situated away from low-lying coastal areas, and primitive settlements on the island tended to be located in elevated places. Maltese houses are built of sturdy material, generally able to withstand storms and heavy rains. Temperatures and precipitation rates in Malta change drastically between mid-winter and mid-summer, and this has led to the accumulation of considerable experience in adaptation to climate variability.

However, as eluded to earlier, there are difficulties for small islands to mainstream climate change into their sustainable development strategies, including their very limited resources, especially given the indivisibilities of overhead expenditures and sunk costs involved in adaptation measures, particularly in infrastructural projects. Another problem relates to possible social conflicts. Agrawala *et al.*, (2003), for example, explain that in Fiji, the conservation of mangroves for climate change adaptation purposes is not without distributive costs, given that the creation of mangrove land could occur at the expense of land used for agricultural, tourism and settlement purposes. In addition, given the existing land tenure system, such changes could also create cultural conflicts. The groups that benefit from mangrove destruction and conservation could therefore be different.

Although decisions regarding energy use, transportation infrastructure and land-use in small islands states will not have any meaningful influence on the rate and magnitude of climate change worldwide, they will have a significant moral and ethical impact. Decisions about energy choices, transportation infrastructure and land-use, will and could therefore critically affect future global greenhouse gas emissions, and thereby the rate and magnitude of climate change. Climate change, in turn, poses additional challenges for natural and socio-economic systems which are already subject to natural climate fluctuations such as El Niño, which cause widespread disruptions in society's ability to harness natural resources or even survive.

16.7 Key uncertainties and research gaps

Based on the present assessment, the following key uncertainties and research gaps have been identified for small islands.

1. Observations and Climate Change Science

- Small islands are sensitive to climate change and sea-level rise and can be considered an early warning to the rest of the world, because the adverse consequences of climate change are already a reality for many inhabitants of small islands. Therefore, ongoing observation is required to monitor the *rate* and *magnitude* of changes and impacts, over different spatial and temporal scales.

- Though the future prediction for mean air temperature is rather consistent among climate models, predictions for changes in precipitation, tropical cyclones and sea level are still uncertain, which is critical for small islands. Thus, advanced models with higher resolution are needed to set reliable climate scenarios for small islands. Regional Climate Models (RCMs) are therefore potentially useful tools in this regard. These have much higher resolution than GCMs, hence the outputs may lead to improved vulnerability assessments and the identification of more appropriate adaptations options at the scale of islands. The ongoing application of the PRECIS[1] model and various forms of statistical downscaling by the Caribbean Community Climate Change Centre in Belize[2], is an acknowledgement of the potential value of RCMs to climate change research in small islands.

- Supporting efforts by small islands and their metropolitan country partners to arrest the decline of, and expand observational networks, should be continued. The Pacific Islands-Global Climate Observing System (PI-GCOS), and the Intergovernmental Oceanographic Commission Sub-Commission for the Caribbean and Adjacent Regions - Global Ocean Observing System (IOCARIBE-GOOS) are two examples of regional observing networks whose coverage should be expanded to cover other island regions.

2. Impacts and Adaptation

- As future changes in socio-economic conditions have not been well presented for small islands in the existing assessments (e.g., IPCC, 2001; UNEP, 2002; Millennium Ecosystem Assessment, 2003), it is necessary to develop more appropriate scenarios for assessing the impacts of climate change on these countries. In the development of these scenarios, close attention should be paid to the traditional technologies and skills that have that have allowed island communities to cope successfully with climate variability in the past.

- Methods to project exposures to climate stimuli and other non climate stresses at finer spatial scales, should be developed, in order to further improve understanding of the potential consequences of climate variability and change, particularly extreme weather and climate events, at the local, country and regional level. In addition, further resources need to be applied to the development of appropriate methods and tools for identifying critical thresholds for both biogeophysical and socio-economic systems on islands.

- Local capacity should be strengthened for environmental assessment and management, modeling, sustainable economic and social development, equity and institutional analyses related to climate change, and adaptation and mitigation in small islands. This objective should be pursued through the application of participatory approaches to capacity building and institutional change.

All climate change scenarios will require small islands to implement adaptation strategies due to the unprecedented magnitude of the potential impacts. Responses to climate change and sea-level rise could be coordinated with mainstream policies of socioeconomic development and environmental conservation to facilitate sustainable development**.**

Natural and human-use systems in small islands will continue to face pressures that are not climate related, including population growth, limited carrying capacity and resources, ecosystem degradation, social change and economic transformation (Adger *et al*, 2005; Uyarra *et al*, 2005). Therefore, island communities may wish to consider integrated approaches toward sustainable development in which multiple stresses and enhancement of resilience are taken into consideration and framed as climate risk management. Equally, continued development of climate friendly and environmentally sound energy services, including renewable energy sources and energy-saving policies, appear to be

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[1] Providing Regional Climates for Impact Studies (PRECIS) is a product of the Hadley Centre, UK Meteorological Office.

[2] Regional modeling, including statistical downscaling, is being used in the GEF-funded 'Mainstreaming Adaptation to Climate Change in the Caribbean' (MACCC) project (2004-2007).

appropriate strategies for consideration by small islands. The process should include investigations of the environmental and socio-economic impact of these systems on islands, and barriers to their implementation.

Further development of community based initiatives to promote the transfer and implementation of '*no regrets*' mitigation projects in small islands are needed. Similarly, there is a need to investigate the feasibility and merits of various mitigation mechanisms such as those of Clean Development Mechanism (CDM) as well as assessing the economic impacts of mitigation policies and measures on the economies of small islands.

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