

Building social and ecological resilience to climate change in Roviana, Solomon Islands: PASAP country activity for Solomon Islands



Brief review: Climate change trends and projections for Solomon Islands

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Introduction

As part of the Australian Government's International Climate Change Adaptation Initiative (ICCAI), the Pacific Adaptation Strategy Assistance Program (PASAP) aims to enhance the capacity of partner countries to assess key vulnerabilities and risks, formulate adaptation strategies and plans, mainstream adaptation into decision-making, and inform robust long-term national planning and decision-making in partner countries. The Department of Climate Change and Energy Efficiency contracted University of Queensland (UQ) and University of California, Santa Barbara (UCSB) to lead the project: "Building social and ecological resilience to climate change in Roviana, Solomon Islands" (2010-2012). Under this project The WorldFish Center was subcontracted to undertake outputs 5 and 6 of Objective three: (5) Review of climate change evidence and projections for the study area and (6) Vulnerability and adaptation assessment for the study area. This report addresses the first of these and comprises a desktop review of climate change evidence and projections for the study area.

Published historical trends in climate data as well as projected climate data for the region of Solomon Islands are reviewed and some of the possible climate related changes that might be expected to occur in (primarily) marine ecosystems in the future are summarised. The brief review has been completed with the assistance of the Solomon Islands Ministry of Environment, Climate Change, Disaster Management and Meteorology (MECDM). It includes projections from the Pacific Climate Change Science Program report "Climate change in the Pacific; Scientific Assessments and New Research" (PCCSP, 2011), which carried out modeling under specific emission scenarios (IPCC, 2007). Specifically Volume 2, Solomon Islands Country Report was drawn upon.

This purpose of this review was to serve as a quick reference document for Roviana project partners at an early stage of the study. It was completed prior to the release of the final results from the PCCSP in late 2011. Following the PCCSP (2011) report release the projections were updated to incorporate this new information.

Climate change

"In the future no country will be immune from the impact of human-induced climate change". The Intergovernmental Panel on Climate Change (IPCC) is unequivocal in its pronouncement that global warming will cause significant climate changes throughout the world, including increases in air, sea surface and ocean temperatures and changed patterns of precipitation, wind flow and ocean salinity (IPCC 2007). The world is expected to experience increased climate variability as well as extreme weather events, such as prolonged drought, heavy rains and heat waves, and an increased frequency and intensity of tropical cyclones. Sea level rise is also predicted. The effects of such changes will be significant for all the Pacific Island Countries and Territories (PICTS), although "the nature and degree of the socioeconomic

impact of climate change cannot be predicted with any certainty at this point in time” (Lal et al. 2009).

Rising atmospheric greenhouse gas concentrations have increased global average temperatures by $\sim 0.2^{\circ}\text{C}$ per decade over the past 30 years, with most of this added energy being absorbed by the world’s oceans. As a result, the heat content of the upper 700 m of the global ocean has increased by 14×10^{22} J since 1975, with the average temperature of the upper layers of the ocean having increased by 0.6°C over the past 100 years. These changes are ongoing; global ocean surface temperatures in January 2010 were the second warmest on record for the month of January, and in the period June to August 2009 reached 0.58°C above the average global temperature recorded for the 20th century, 16.4°C (Hoegh-Guldberg & Bruno 2010).

In addition to acting as the planet’s heat sink, the oceans have absorbed approximately one-third of the carbon dioxide produced by human activities. The absorption of anthropogenic CO_2 has acidified the surface layers of the ocean, with a steady decrease of 0.02 pH units per decade over the past 30 years and an overall decrease since the pre-industrial period of 0.1 pH units. Although these increases appear small in terms of pH, they are associated with a substantial decline in the concentration of carbonate ions and represent a major departure from the geochemical conditions that have prevailed in the global ocean for hundreds of thousands if not millions of years (Hoegh-Guldberg & Bruno 2010).

Increases in the heat content of the ocean have driven other changes. These include; increased ocean volume (as a result of thermal expansion of the oceans as well as increased meltwater from terrestrial glaciers and ice sheets), more intense storm systems, greater stratification of the water column and reducing mixing in some parts of the ocean; consequently affecting nutrient availability and primary production and also affecting the behavior of ocean currents (Hoegh-Guldberg & Bruno 2010).

These physical effects of climate change are expected to result in significant effects on ecological systems such as coral reefs and on human populations, their livelihoods and well being (Figure 1, Tompkins et al. 2005).

Climate change trends and projections for Solomon Islands

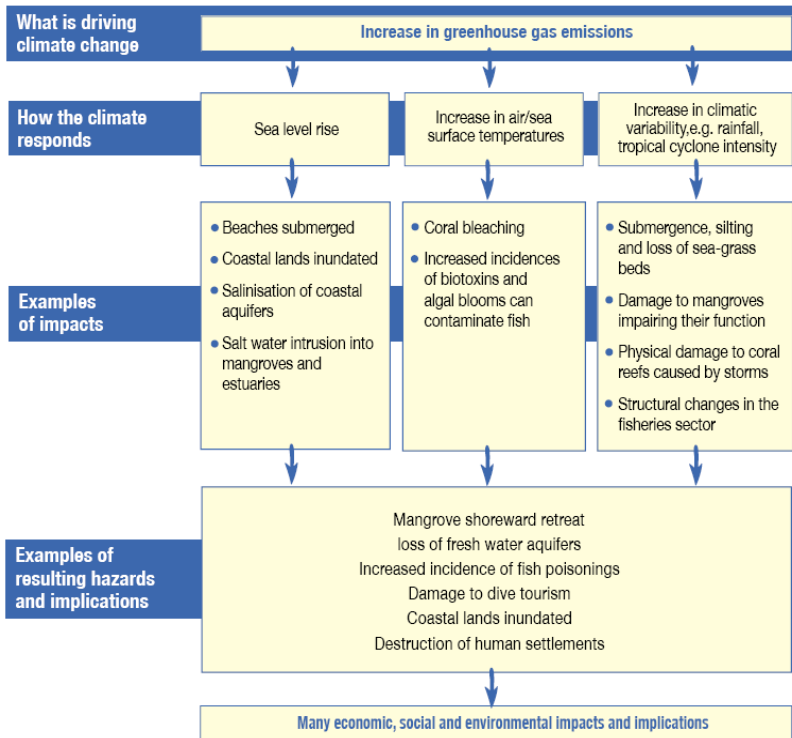


Figure 1. The potential impacts of climate change on coastal zones (Tompkins et al. 2005)

Climate change in the Solomon Islands

Solomon Islands are a group of over 990 islands grouped into 9 provinces (Figure 2).

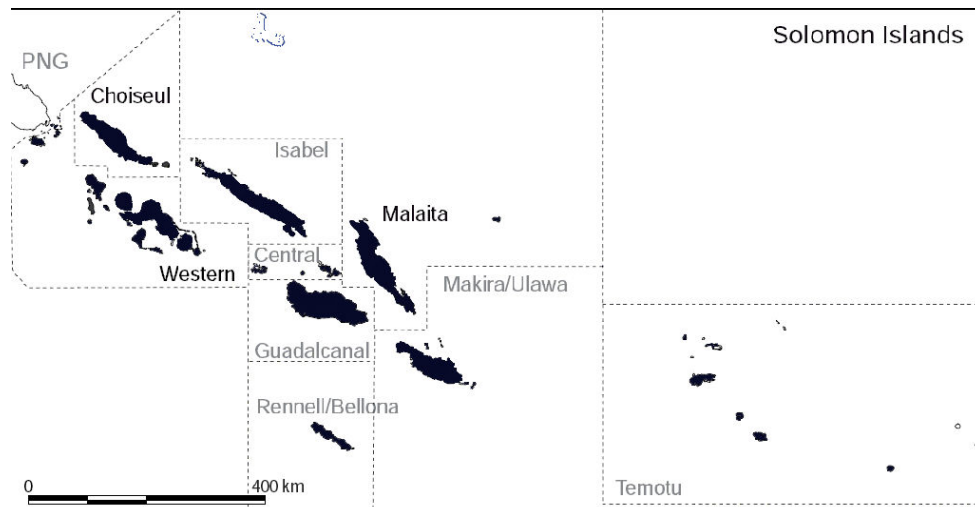


Figure 2. Map of Solomon Islands with provinces delineated by dotted lines.

Climate change trends and projections for Solomon Islands

The largest province in terms of area is Western Province and the most populated is Malaita. However, Central Islands Province has the highest population density, closely followed by Malaita (Table 1).

Table 1. Geographic and demographic data for Solomon Islands provinces (MECM/MFMR, 2010). HH – household.

Province	Capital	land Area (km ²)	# HH	Population	HH Size	Population density (km ⁻²)
Central	Tulagi	615	4209	24412	5.8	39.7
Choiseul	Taro Island	3837	5056	31347	6.2	8.2
Guadalcanal	Honiara	5336	14611	84743	5.8	15.9
Isabel	Buala	4136	4614	23531	5.1	5.7
Makira-Ulawa	Kirakira	3188	7524	50410	6.7	15.8
Malaita	Auki	4225	22115	141536	6.4	33.5
Rennell - Bellona	Tigoa	671	672	4435	6.6	6.6
Temotu	Lata	895	4300	23650	5.5	26.4
Western [Honiara]	Gizo	5475	13650	81900	6	15.0
			9984	[68889]	6.9	

Slow onset changes in climate

Slow onset changes are changes which happen gradually, over many years (such as sea level rise), as opposed to extreme sudden events such as storms.

Air temperature

Increases in surface air temperatures have been greater in the Pacific than global rates of warming. For example, since 1920, temperature has risen by 0.6-0.7°C in Noumea (New Caledonia) and Rarotonga (Cook Islands), which is greater than the mean global increase of 0.6°C (Tompkins et al. 2005) and in general, the central equatorial region has showed stronger warming effects than other areas from the equator (Lal et al. 2009). In the period 1981-1990 the southern Pacific experienced, compared to the past (1911-1920), a significantly drier and warmer climate (by 15 % and 0.8°C, respectively). The central equatorial Pacific experienced a similarly hotter climate over the same time period (0.6°C) (Hay et al. 2003).

In Solomon Islands an increase of maximum (Figure 3) and minimum temperatures with time has been recorded by MECDM (Griffiths et al. 2005) and this was found to be one of the

highest rates of increase in the region. The same study also reported a positive correlation between the maximum temperature and the frequency of hot days.

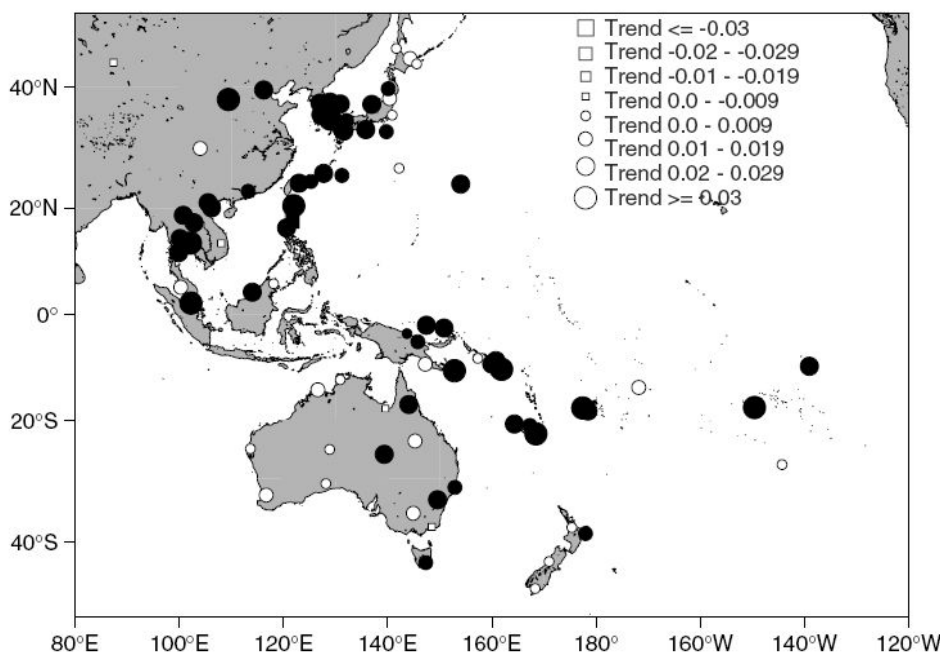


Figure 3. Trends in maximum temperature 1961–2003 in °C per year. Trends ranged between -0.04 °C per year and $+0.05$ °C per year and the significance of the trends is indicated by the size of the black ($p \leq 0.05$) and white ($p > 0.05$) symbols (Griffiths et al. 2005).

Solomon Islands air temperature data records (held by MECDM) are available for six provinces and date back to the 1960's in some instances. Trends in the raw data suggest that Malaita, Guadalcanal, Makira and Choiseul have experienced an increase in average daily temperatures of ca. 2 °C the last 40-50 years, while for Western and Temotu provinces, there appears to have been no, or little increase in over the recording period. Griffiths (2005) cautions that these data sets from Solomon Islands are not complete for all stations but were able to identify that Lata, in Temotu Province has in fact showed a significant decrease in hot days.

Future projections for air temperature

Air temperatures in the region of Solomon Islands are projected to increase further. Based on IPCC climate projections (IPCC 2001), Tompkins et al. (2005) (and see references within), summarised that the average warming in regions where small Pacific islands are located is likely to be between 2.0 and 2.8°C by 2050 (compared with 1990 temperatures). Leisz (2009) reviewed the projected climate data from a spatial viewpoint for Melanesia and examined the

Climate change trends and projections for Solomon Islands

projected changes in land surface temperature, sea-surface temperature, precipitation, cloud cover, and changes in the Degree Heat Weeks (DHW)¹ by geographically registering climate projections to a map base and spatially overlaying them. Warming projections were based on outputs from the MIROC-HIRES1 model (Hasumi & Emori 2004). It was projected that in the next 70 years Solomon Islands will be close to the high end of potential thermal stress in the region. By the end of 2040 land areas of Solomon Islands were projected to have a rise in overall average surface temperatures of between 0.5° and 1 ° C from present (Figure 4). More recently the Pacific Climate Change Science Program (PCCSP) refined projections through the use of a range of models. Under the IPCC A2 scenario, a slight increase (<1°C) in annual and seasonal mean temperature by 2030 was predicted by the majority of models, however almost all models simulated temperature increases of greater than 2.5°C by 2090 under the A2 (high) emissions scenario (PCCSP, 2011).

Possible local effects of higher air temperatures (i.e. at a smaller scale than shown by the predictive plots in Figure 4) will be higher sea surface temperatures, especially in shallow water areas and lagoons, effects on agriculture and consequently effects on the general well being of people.

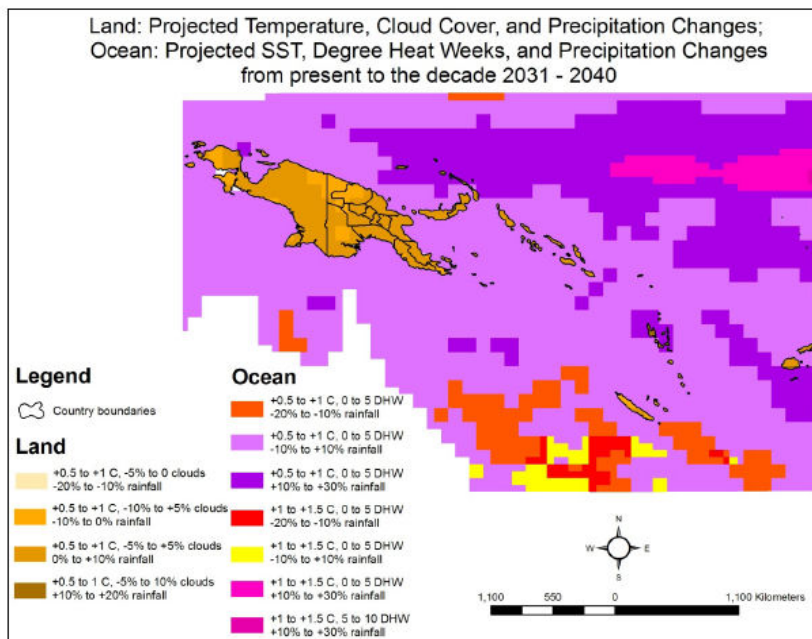


Figure 4. Projected changes from the present decade to 2031-2040 (Leisz 2009).

¹ The Degree Heat Weeks (DHW) is the number of weeks in which the sea surface temperature of an area exceeds its average thermal maximum by 1-2 °C.

Sea surface temperature

Sea-surface temperatures (SST) in north and south Pacific areas have increased by about 0.4°C (1981-1990 compared with 1911-1920) (Hay et al. 2003). In Solomon Islands, recent models show an increase of about 0.2°C in the last 30-60 years (Hoegh-Guldberg & Bruno 2010, Figure 5).

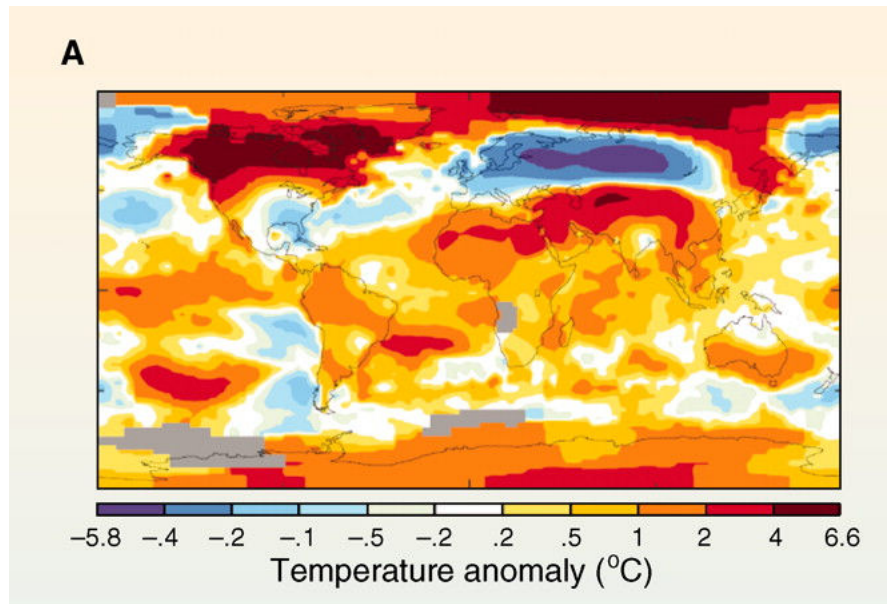


Figure 5. Recent changes in ocean temperature - Surface temperature anomaly for January 2010 relative to the mean for 1951-1980. From (Hoegh-Guldberg & Bruno 2010).

Future projections for SST

Areal projections made by Leisz (2009) projected that by 2040 the ocean areas around Solomon Islands will also experience an increase in the average sea-surface temperatures of between 0.5° and 1° C (Figure 4). The PCCSP (2011) study states the surface air temperature and sea-surface temperatures are closely connected and so a similar or slightly weaker level of warming is predicted for the surface ocean as for air temperature (that is <1°C by 2030 and >2.5°C by 2090). There is high confidence in this link between the two because over the past 50 years in the locality of the Solomon Islands there is close agreement in general between modelled and observed temperature trends, even though observational records are limited.

Rises in SST are likely to exacerbate existing problems of coral bleaching and diseases. Mangroves, sea grass beds, other coastal ecosystems are also likely to be adversely affected by rising temperatures and accelerated sea-level rise. For Pacific islands that rely on marine tourism and fisheries the consequences for society are significant. Without healthy reefs the diving industry is likely to suffer and the productivity of local fisheries is likely to be severely affected (Tompkins et al. 2005).

The most comprehensive assessment on bleaching and coral diseases for Solomon Islands now dates back to 2004. A geographically wide survey undertaken by the Nature Conservancy (TNC) in 2004 (Green et al. 2006) reported relatively healthy reefs with some places showing high crown of thorns densities (Turak 2006). Overall reef health in Solomon Islands was assessed as “good” in that most reefs visited were not impacted by human activities, which are usually of concern in other areas of the region. The main cause of reef damage was from crown of thorns starfish infestations. The coral eating snail *Drupella*, which when in full outbreak can cause serious damage to reefs, was seen at most locations. However, numbers were always very low and damage very limited. In addition, some evidence of damage following bleaching events in 2000-2001 was observed, as well as some minor current (at the time of the survey) bleaching damage. The TNC survey confirmed that damage from the 2000-2001 bleaching was overall limited and patchy and less extensive in comparison to places like Fiji.

Evidence of coral disease was occasionally seen though without widespread effect (Turak 2006). However at one site (Uepi, Western province), which is one of the popular tourist dive sites, significant mortality was seen with some diseased corals. Anecdotal information from locals indicated that a gradual spread of mortality was noted in the area over the two years preceding the survey (2002-2003), which was identified as possibly being the result of a coral pathogen.

Ocean acidification

Data collected in the Pacific region as a part of the Joint Global Ocean Flux Study/World Ocean Circulation Experiment CO₂ survey allow estimates to be made of the aragonite saturation states of seawater in the pre-industrial era and in the 1990s (PCCSP, 2011), although data coverage is poor for the region of Solomon Islands. In pre-industrial times, the saturation state values were above 4 throughout most of the sub-tropical and tropical Pacific Island region. By the mid 1990s, the uptake of anthropogenic CO₂ had resulted in a widespread decline in the aragonite saturation state, with values slightly above 4 only found in the region of the South Equatorial Current and in the western Pacific. Values of aragonite and other carbonate saturation states have continued to decline since the 1990s and only the surface waters of the South Equatorial Current now have aragonite saturation states that remain at or slightly above values of 4 (PCCSP, 2011).

Recent global models estimate the change in pH for the south west Pacific between pre-industrial times and present as -0.06 (Hoegh-Guldberg & Bruno 2010, Figure 6).

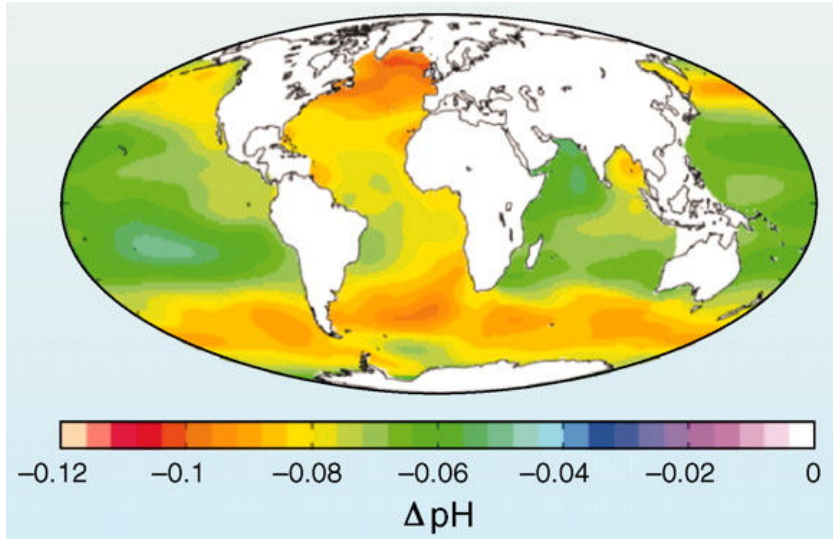


Figure 6. Changes in acidity - Estimated change in annual mean sea surface pH between the pre-industrial period (1700s) and the present day (1990s). From (Hoegh-Guldberg & Bruno 2010).

Future acidification projections

Leisz's (2009) projections showed that by 2040 ocean acidification will begin to impact the areas around Solomon Islands. One of the main parameters used to describe the change in carbonate ion concentration that results from ocean acidification, is aragonite saturation (Ω_{ar}). There is strong evidence to suggest that when Ω_{ar} of ocean waters drops below 3 (Langdon & Atkinson 2005) reef organisms cannot precipitate the calcium carbonate that they need to build their skeletons or shells, although note that Guinotte et al (2003) suggest that Ω_{ar} of above 4 is optimal for coral growth and the development of healthy reefs. To the south of Solomon Islands in Leisz's (2009) projections, Ω_{ar} was projected to fall to just below 3, a level at which corals may have trouble producing the calcium carbonate they need to build their skeletons. To the north of the country aragonite saturation levels were projected to remain at or slightly above 3 (Leisz 2009) (Figure 7).

The PCCSP (2011) report stresses that during the 21st century, acidification of the ocean will continue to increase. There is a very high confidence in this because the rate of ocean acidification is driven mainly by the increasing oceanic uptake of carbon dioxide as concentrations continue to increase in the atmosphere. Climate model results suggested that by 2045 the annual maximum aragonite saturation state for the Solomon Islands will reach values below 3.5 and continue to decline thereafter (PCCSP, 2011).

Despite the remaining uncertainty in critical thresholds, all these projections suggest that coral reefs will be vulnerable to actual dissolution as they will have trouble producing the calcium carbonate needed to build their skeletons. This will impact the ability of the reef structures to have growth rates that exceed natural bioerosion rates. Increasing acidity and decreasing

levels of aragonite saturation are also expected to have negative impacts on ocean life apart from corals; including calcifying invertebrates, non calcifying invertebrates and fish. High levels of CO₂ in the water are expected to negatively impact on the lifecycles of fish and large invertebrates through impacts on reproduction, settlement, sensory systems and respiratory effectiveness (Raven et al. 2005, Kurihara 2008, Munday et al. 2009a, Munday et al. 2009b). Consequently, the abundance of reef fish, those who earn their livelihoods from reef fisheries and those who rely on the fisheries as a significant food source are likely to be affected (Tompkins et al. 2005). The impact of acidification change on the health of reef ecosystems is likely to be compounded by other stressors including coral bleaching, storm damage and fishing pressure (PCCSP, 2011)

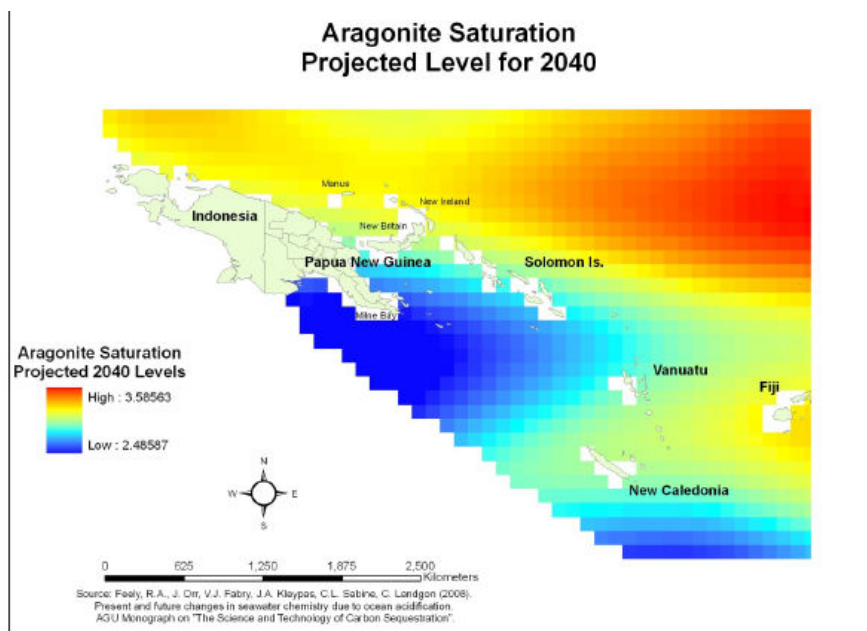


Figure 7. Projected aragonite saturation levels for 2040 (Leisz 2009). Projections drawn from Feely et al. (2008).

Sea-level rise

Satellite altimeter data reveal that the average global sea level changed at a rate of 3.3 ± 0.4 mm/year (over the period 1993–2006)(Cazenave & Llovel 2010). This is consistent with tidal gauge data. Further estimates of future sea level rise by 2100 range from 0.5 to 1.4m, tracking and exceeding the highest projections of the fourth assessment report of the IPCC (Rahmstorf 2007, Cazenave & Llovel 2010). This scenario does not take into account the melting of the ice sheets. Changes in ice sheet volume have important implications for sea level rise, with an expected overall contribution of up to 12 m to mean sea levels if both Greenland and the West Antarctic Ice Sheet were to melt completely (Hoegh-Guldberg & Bruno 2010).

Projected sea-level response to global warming is not spatially uniform with some regions experiencing higher or lower sea-level changes than the global average. Satellite altimetry shows that Solomon Islands has been experiencing the high end of the range of global sea-level rise (Figure 8) at a rate of 8-10 mm per year (Hoegh-Guldberg & Bruno 2010).

Sea level in the Solomon Islands is projected to rise by a range of 5 – 15 cm by 2030 (PCCSP, 2011). Under higher emissions scenarios (A2 and A1B) increases of 20 – 60 cm are indicated by 2090. Sea level rise varies according to regions. Factors influencing this regional variability include wind and waves associated with weather phenomena, ocean and mass changes and local tectonic motions.

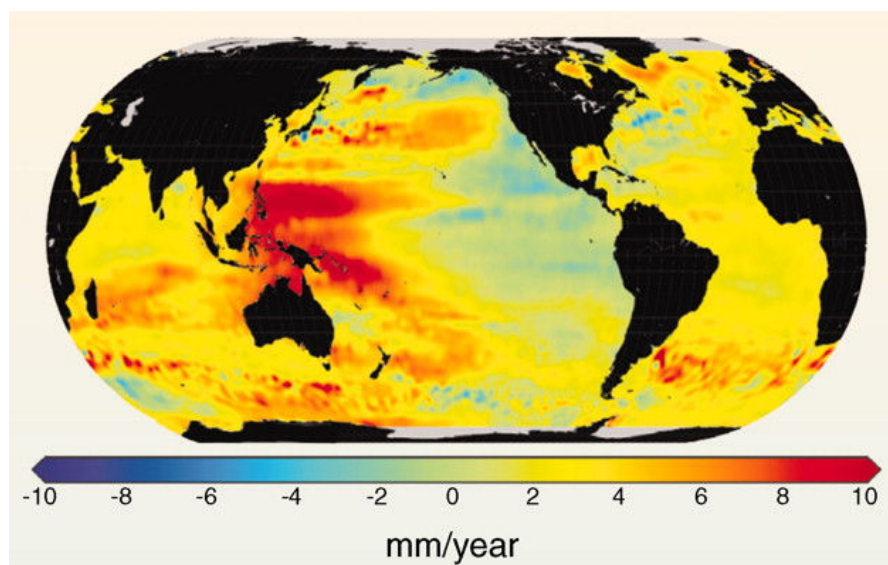


Figure 8. Average rate of global sea level rise (1993–2010) from TOPEX/Poseidon and Jason satellite altimetry data, shown as a map (Hoegh-Guldberg & Bruno 2010).

As part of the AusAID-sponsored South Pacific Sea Level and Climate Monitoring Project (SPSLCMP; “Pacific Project”) for the South Pacific Forum region (the Cook Islands, Federated States of Micronesia, Fiji, Kiribati, Marshall Islands, Nauru, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu and Vanuatu), in response to concerns raised by its member countries over the potential impacts of an enhanced greenhouse effect on climate and sea levels in the South Pacific region, a **SEAFRAME** (**S**ea **L**evel **F**ine **R**esolution **A**coustic **M**easuring **E**quipment) gauge was installed in Honiara, Solomon Islands in July 1994. According to the Pacific country report on sea level and climate for Solomon Islands in 2009 (<http://www.bom.gov.au/pacificsealevel/picreports.shtml>), the gauge had been returning high resolution, good scientific quality data since installation and the trend in sea-level rise near Honiara was calculated at 7.7 mm per year (Figure 9).

The most striking oceanic and climatic fluctuations in the equatorial region are interannual changes associated with the El Niño Southern Oscillation (ENSO). These affect virtually

every aspect of the system, including sea level, winds, precipitation, and air and water temperature. An illustration of this shown in Figure 10 where the lowest sea level anomalies (i.e. sea levels were much lower than average) over a 15 year period occurred during the 1997/1998 El Niño.

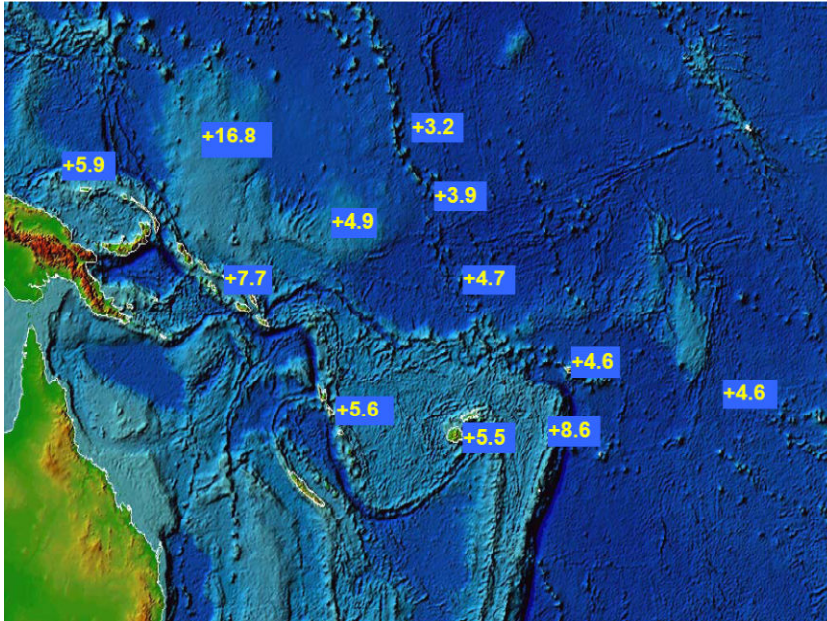


Figure 9. current trends in sea-level rise around the Solomon Islands (Pacific country report on sea level & climate: their present state, Solomon Islands, 2009; <http://www.bom.gov.au/pacificsealevel/picreports.shtml>).

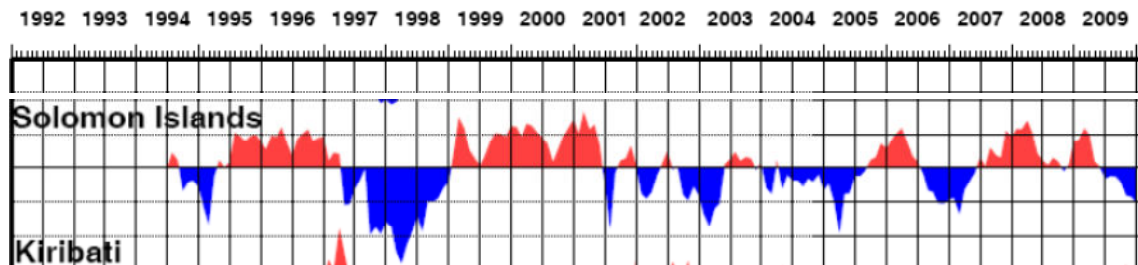


Figure 10. Sea-level anomalies for Honiara (Pacific country report on sea level and climate: their present state, Solomon Islands, 2009; <http://www.bom.gov.au/pacificsealevel/picreports.shtml>). A sea-level anomaly is the difference between the total sea-level and the average sea-level for this time of year in this case after tides, seasonal cycles and trends have been removed.

As highlighted in the Solomon Islands NAPA (MECM 2008) sea level rise may potentially create severe problems for low lying coastal areas, atolls such as Ontong Java and artificial islands dwellers. With sea-level rise increased salt water intrusion into coastal areas is expected and people living in low laying atolls such as Ontong Java have already complained about the effects of king tides and salt water intrusion to their gardens (Hilly et al. 2010).

The projected sea-level rise of 5-15cm by 2030 is likely to increase rates of coastal erosion and loss of land. For communities living in the coastal zone there is a potential for loss of infrastructure and property, potential dislocation of people, increased risk from storm surges and possible saltwater intrusion into freshwater resources. The danger of soil salinisation, coupled with the existing limited area of arable land, makes agriculture, both for domestic food production and cash crop exports, highly vulnerable to climate change (Tompkins et al. 2005).

Accurately assessing the effect of sea level rise on land inundation in Solomon Islands will require precise map-based predictions of water level rise vs. actual land elevation. In Solomon Islands such estimates have been made for Choiseul Province by TNC (Richard Hamilton pers comm.) and in specific sites in Roviana and Vonavona Lagoons as part of this study (UQ, this study).

Examples of sudden, extreme events

Tropical cyclones and other storms

Solomon Islands are considered to have a relatively low cyclone risk with an average of 0.1 cyclones per year (Figure 11). However, the frequency of cyclones grows exponentially with latitude with the southernmost provinces the most cyclone-prone (Table 2; Figure 12).

Table 2. Number of tropical cyclones in vicinity of the Solomon Islands' provinces between 1969-2007 (Bureau of Meteorology Australia & Australian government 2010b). Data is relative to a point in the middle of each province.

Province	Latitude (°S)	Longitude (°E)	Number of cyclones within		
			50 km	100 km	200 km
Choiseul	7	156.9	1	1	5
Isabel	8	159	3	3	6
Western	8.33	157.27	0	1	8
Central	9.1	160.15	2	5	9
Malaita	9.05	161	1	4	9
Temotu	10.7	165.8	0	3	10
Guadalcanal	9.6	160.15	2	6	13
Makira-Ulawa	10.6	161.8	2	10	19
Rennell - Bellona	11.65	160.3	5	12	25

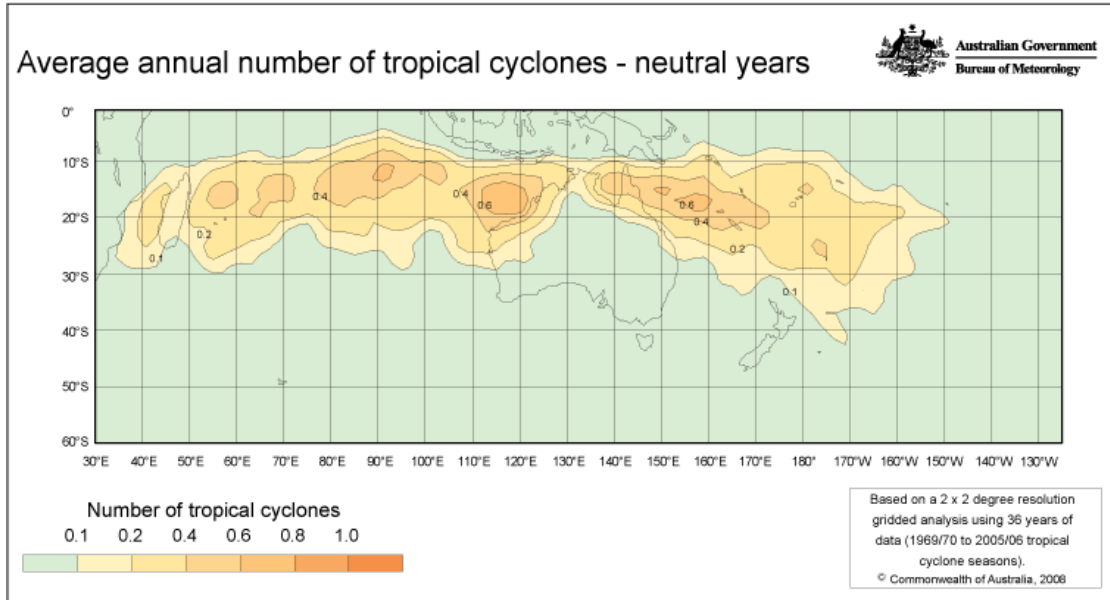


Figure 11. Average tropical cyclone frequency for the southwest Pacific during neutral years, i.e. excluding El Niño and La Niña events (Bureau of Meteorology Australia & Australian government 2010a).

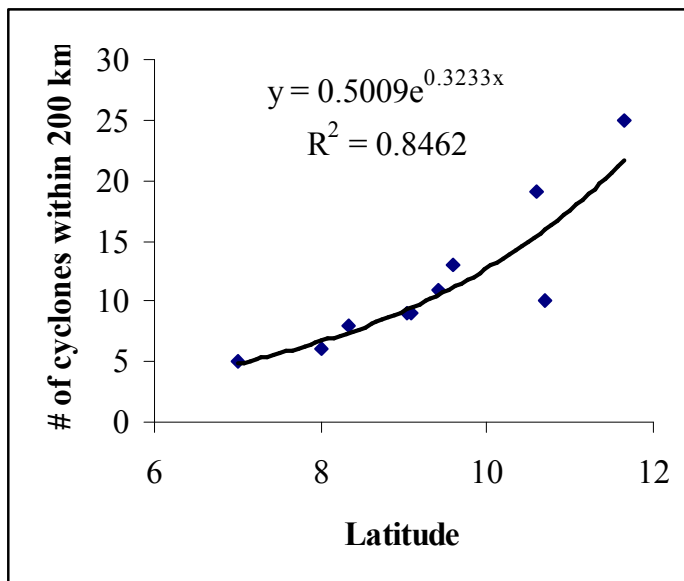


Figure 12. Correlation between the numbers of tropical cyclones within 200 km (1969-2007) to the latitude of Solomon Islands' provinces (data from table 2).

The impact of tropical cyclones on the physical environment of Pacific Islands depends on their frequency, intensity, speed of movement, longevity, size and proximity to the island groups and how the physical features of the affected islands influence their response to the geomorphic and hydrological processes triggered by the cyclone. Emanuel (2005) has shown that the dissipation force of a cyclone is correlated to SST and will probably increase with increasing sea surface temperature (Figure 13), moreover, the number of high intensity

cyclones (categories 4 and 5) in the Western, North Pacific has increased in the last 30 years (Figure 14, (Webster et al. 2005)) and (Oouchi et al. 2006, Knutson et al. 2010) state that this trend is predicted to continue to increase regardless of a general decrease in cyclone frequency. However, it is worth noting that Kuleshov et al. (2010) showed that for the South Pacific region there is no significant trend in cyclone frequency nor intensity.

The most recent projections available for the region (PCCSP, 2011) are consistent with Oouchi et al. (2006) and Knutson et al. (2010) in projecting with moderate confidence that the numbers of tropical cyclones in the south-west Pacific Ocean basin (0- 40°S, 130°E- 170°E) will decline over the 21st century and that there is an indication in an increase in the number of the most severe cyclones.

Low-lying coral islands, such as those on atolls, are the most vulnerable to cyclone related impacts. These islands consist of unconsolidated heaps of coralline sands and gravel on top of reef foundations and are prone to overtopping by storm surge and wave action generated by cyclones. On mountainous volcanic islands, characterized by rugged topography and weathered clay soils, heavy cyclonic rainfall can result in landslides on hills and deposition of sediment in valley bottoms. Tropical cyclones usually have less impact on limestone islands, because these have no significant relief on which slope failures can occur and no surface drainage channels that can be flooded.

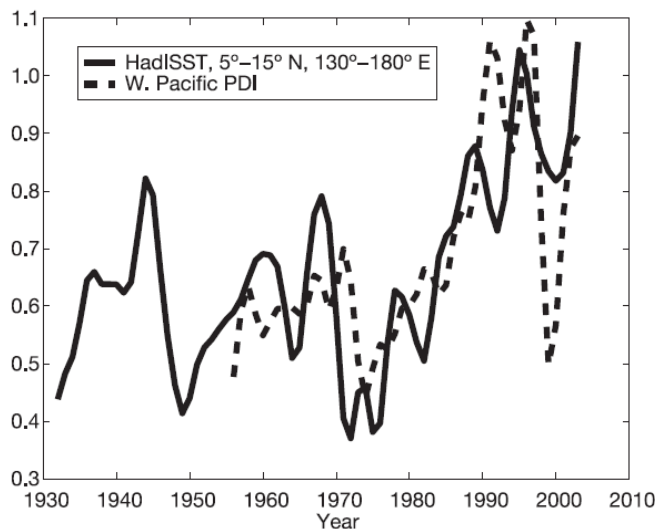


Figure 13. Annually accumulated Power Dissipation Index for the western North Pacific (dashed line), compared to July–November average SST (solid line) (Emanuel 2005).

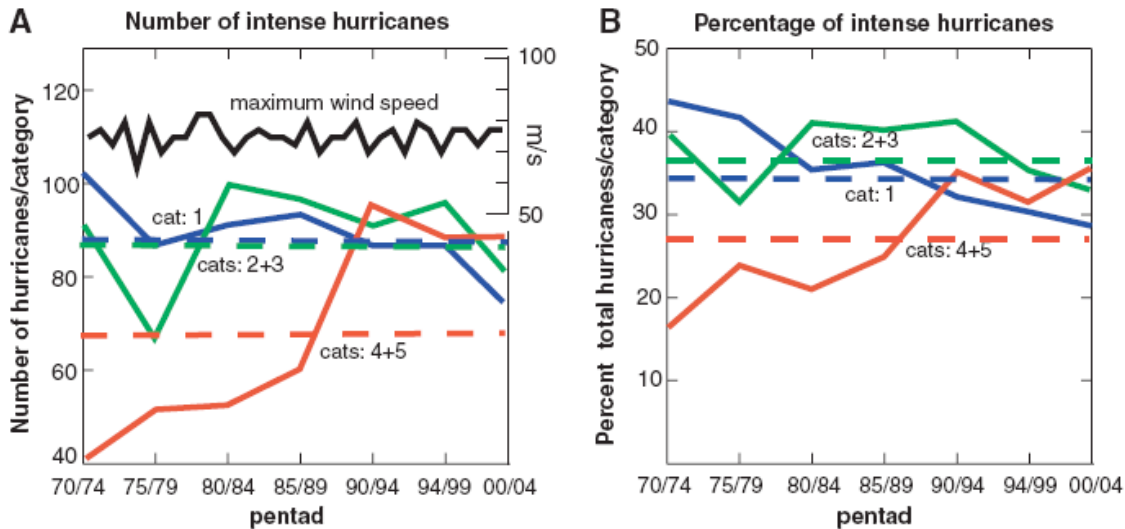


Figure 14. Intensity of hurricanes according to the Saffir-Simpson scale (categories 1 to 5). (A) The total number of category 1 storms (blue curve), the sum of categories 2 and 3 (green), and the sum of categories 4 and 5 (red) in 5-year periods. The bold curve is the maximum hurricane wind speed observed globally (measured in meters per second). The horizontal dashed lines show the 1970–2004 average numbers in each category. (B) Same as (A), except for the percent of the total number of hurricanes in each category class. Dashed lines show average percentages in each category over the 1970–2004 period (Webster et al. 2005).

During the 1950-2004 period cyclones alone accounted for 76 % of the reported disaster events in the Pacific, accounting for almost 90 % of total direct costs and 79 % of fatalities (World Bank 2005). The majority of other natural disasters are accounted for by floods, droughts and storm surges (Lal et al. 2009). Tropical cyclones already have damaging impacts on agriculture, infrastructural development and wider commerce. Tourism, which is an important source of income and foreign exchange for many islands, inevitably faces severe disruption after major cyclones. Human health is also affected by cyclone activity through human exposure to diseases and stress, both during the event and throughout the recovery period which can take years. Cyclones may also damage infrastructure, boats and the reef itself (Tompkins et al. 2005).

Rainfall patterns

Because convection and thunderstorms preferentially occur over warmer waters, the pattern of sea surface temperatures influences the distribution of rainfall (and tropical cyclones) in the tropics and the associated warming of the atmosphere through the release of latent heat when changing the water phase from vapour to liquid (Hay et al. 2003). The heating drives the large-scale monsoonal type circulations in the tropics, and consequently influences the wind patterns. As climate change is projected to lead to global changes in SST it may also lead to periods of very intense rainfall, leading to flash floods and landslides.

PCCSP (2011) presented a “most likely” future as well as a “largest change” future based on selected models. Under the IPCC A2 and A1B scenarios the “largest change” projected future change for rainfall in Solomon Islands was for a wetter climate; with an increase in annual rainfall by >5%. However the “most likely” climate future for Solomon Islands was for little change in annual and seasonal rainfall (-5% to 5%) by 2030 (PCCSP, 2011).

In Solomon Islands between 1961 and 1998 the number of rain days has decreased at all meteorological stations, with Honiara, Kira Kira and Munda showing significant decreases (Manton et al. 2001). However at Honiara, the proportion of annual rainfall from extreme rainfall has increased significantly (Manton et al. 2001). If this trend continues longer drought periods in the dry season and more severe flood events in the rainy season may be expected. However in general the incidence of drought is expected to decrease over the 21st century (PCCSP, 2011). The inconsistency between the projected increase in annual rainfall (“largest change”) and the recent declining trend observed from Honiara may be related to local factors not captured by the models, or the fact that the projections presented by PCCSP (2011) represent an average over a very large geographic region, and so are not necessarily universally applicable to specific sites.

Changes in rainfall patterns and extreme events, such as floods and drought will affect subsistence and commercial agriculture and food security as well as physical infrastructure important to the market chain. Floods also affect the incidence of water- and vector-borne diseases and human health. Rainfall in general, plays an important role in spreading or reducing malaria cases. While cases of malaria increase during the rainy season, higher rainfall in La Niña years and lower rainfall in El Niño years increases and reduces malaria transmission respectively. Climate change may increase malaria incidence (Hay et al. 2003, Abawi et al. 2009), however, seasonal variability due to ENSO has been recommended as the focus of control programs in the Solomon Islands (Abawi et al. 2009).

Islands with very limited water supplies are already vulnerable to periods of droughts. They are likely to become increasingly vulnerable to the impacts of climate change on water supplies. Moreover, fresh water flooding will affect sea water quality as well as sea-grass and coral health and survival (Tompkins et al. 2005). Across the Pacific region, atoll dwellers speak of having to move their houses away from the ocean because of coastal erosion; of having to change cropping patterns because of saltwater intrusion; of changes in wind, rainfall, and ocean currents (Tompkins et al. 2005).

El Niño southern oscillation (ENSO)

El Niño weather patterns have become more frequent since 1977, bringing an increase in rainfall in the Northeast Pacific and a decrease in rainfall in the Southwest. Each El Niño event in the past has resulted in water shortages and drought in some parts of the Pacific (e.g., Papua New Guinea, the Republic of the Marshall Islands, Samoa, Fiji, Tonga and Kiribati),

and increased precipitation and flooding in others (e.g. Fiji, Solomon Islands). In El Niño years ocean conditions also change and the western Pacific warm pool expands generally eastwards in the tropical waters. In northern equatorial waters on the other hand, warm pools contract slightly westwards. In La Niña years the warm pool is largely constrained to the western tropical Pacific, while expanding slightly to the east in northern equatorial waters. These oceanic patterns influence primary and secondary productivity in the Pacific and define core habitats of the marine flora and fauna species, including tuna.

Interannual rainfall over Solomon Islands is strongly influenced by ENSO in the current climate. There have been predictions that with global warming, El Niño events are expected to become more frequent (Lal et al. 2009); accordingly the variations expected to be brought about by climate change (including changes in rainfall and more extreme weather conditions). However caution is urged in interpreting such predictions as more recently, climate projections from PCCSP (2011) recommended assuming no change in climate variability associated with ENSO due to a lack of consensus in ENSO projections.

The frequency of extreme temperatures (e.g. heatwaves)

Globally, extreme temperatures have been shown to be increasing since suitable records have been available in the 1960's. Since 1960 the number of hot days (frequency of days when temperature is above the 1961-1990 mean 99th percentile) has increased throughout the southeast Asia region (Figure 15, 16, (Manton et al. 2001, Griffiths et al. 2005)). 'Degree Heat Weeks' (DHW) has become a key operational metric for reef monitoring and management. In Solomon islands DHW is projected to be between 0-5 until 2040 (Figure 4, Leisz 2009).

The intensity and frequency of days of extreme heat are also reported as the "1-in-20 year hot day". According to the PCCSP (2011) study, the majority of models simulate an increase of about 1°C in the temperature of the 1-in-20 year hot day under IPCC B1 emissions scenario by 2055; and an increase of over 2.5°C by 2090 under IPCC A2 emissions scenario. The increase in intensity of extreme heat is consistent with the physical effects of rising greenhouse gas concentrations (PSSCP, 2011).

Increased temperatures and increased humidity due to increased rainfall can raise the incidence of heat strokes, asthma and other respired illnesses, affecting human productivity.

Climate change trends and projections for Solomon Islands

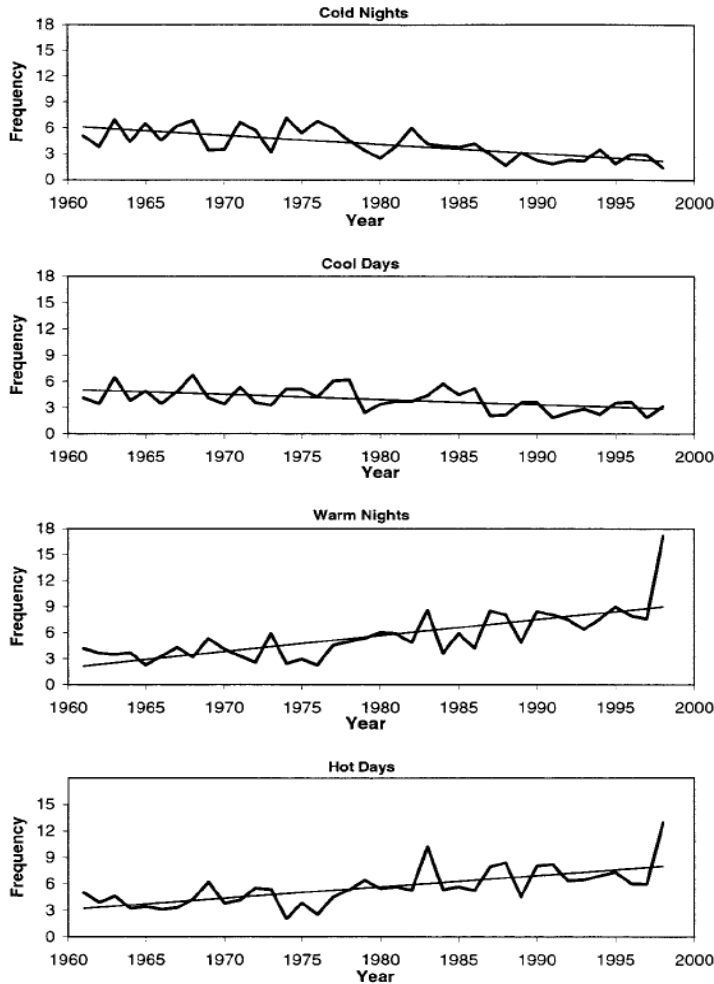


Figure 15. Time-series of the south east asia regional averages of the frequency of hot and cold days and nights. The thin line is a trend-line computed by linear regression (Manton et al. 2001).

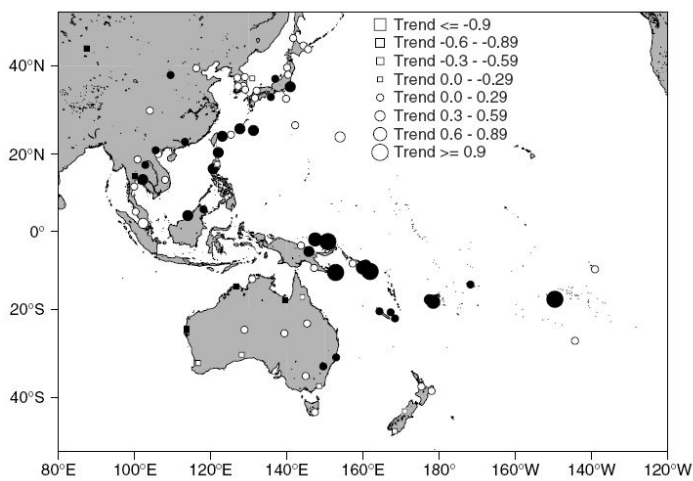


Figure 16. Trends in hot days 1961–2003. Trends as indicated in the scale (days per year). Trends ranged between -0.2 days per year and $+2.2$ days per year and the significance of the trends is indicated by the size of the black ($p \leq 0.05$) and white ($p > 0.05$) symbols (Griffiths et al. 2005).

Combined effects – coral reefs stress as an example

The different stresses manifested and predicted by climate change may interact and cause greater stresses on ecosystems than if operating independently. As an example, Guinotte et al. (2003) combined projected SST with aragonite saturation levels to produce a map depicting the predicted stress on coral reefs. Solomon Islands are projected to be in the high stress zone for this combination (Figure 17).

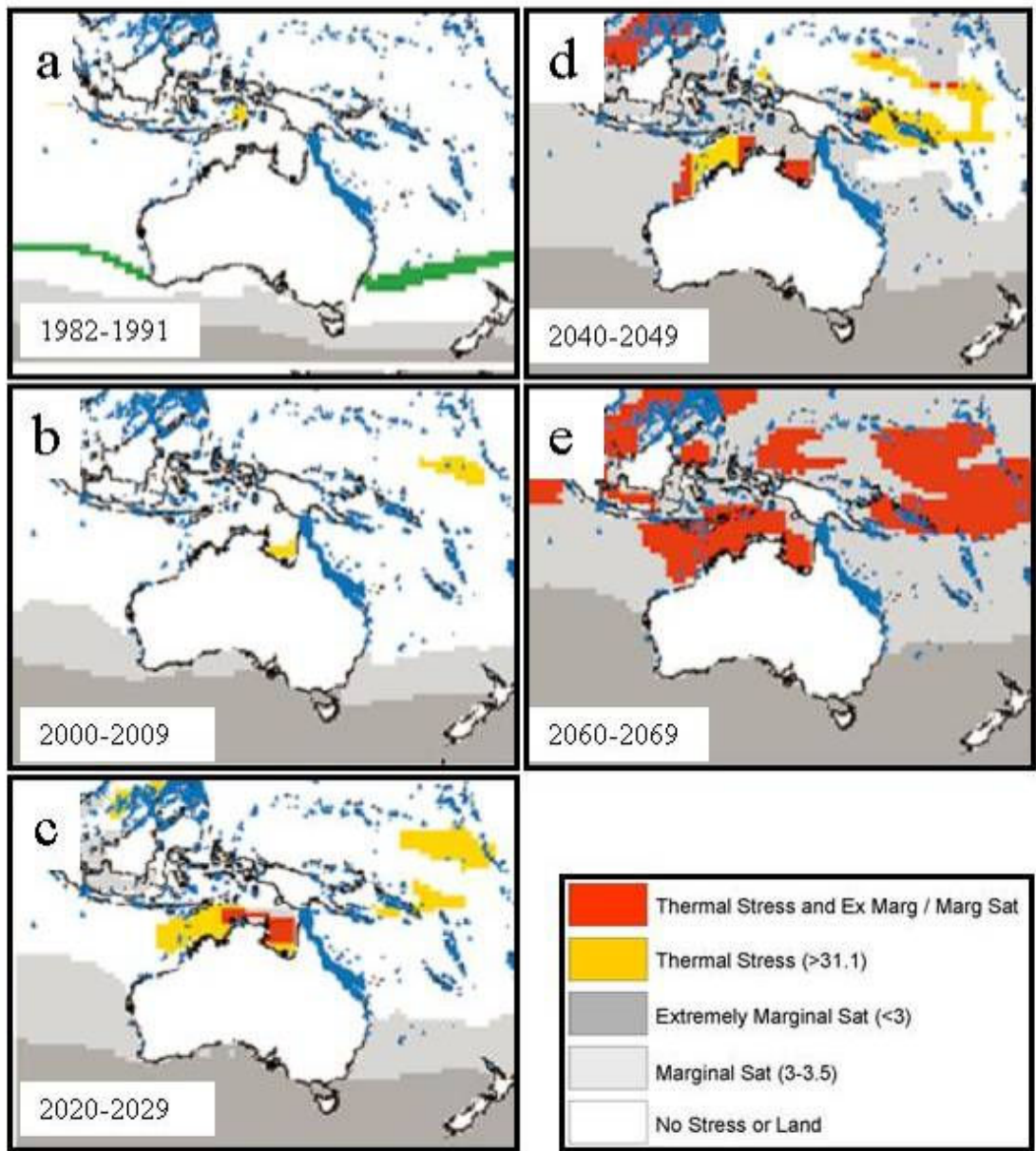


Figure 17. Projections of thermal stress, CaCO₃ saturation state, and combined effects of both by decade through 2069 (Guinotte et al. 2003). In regards to thermal stress, it should be noted that these projections have the underlying assumption that upper thermal threshold for coral bleaching are fixed values; this is not the case however, since temperatures that induce coral bleaching range up to nearly 10°C depending on region.

Roviana and Vonavona lagoons

The Roviana and Vonavona lagoons are located adjacent to the island of New Georgia in the Western province of Solomon Islands (Figure 18). At the time of writing, pertinent climate-change related data such as SST, sea levels and pH for the region are at this stage were only able to be based on broad scale predictions for the region as described above. It was possible however to focus in on the region for some parameters using measured climate related data from the Munda weather station in Roviana lagoon.

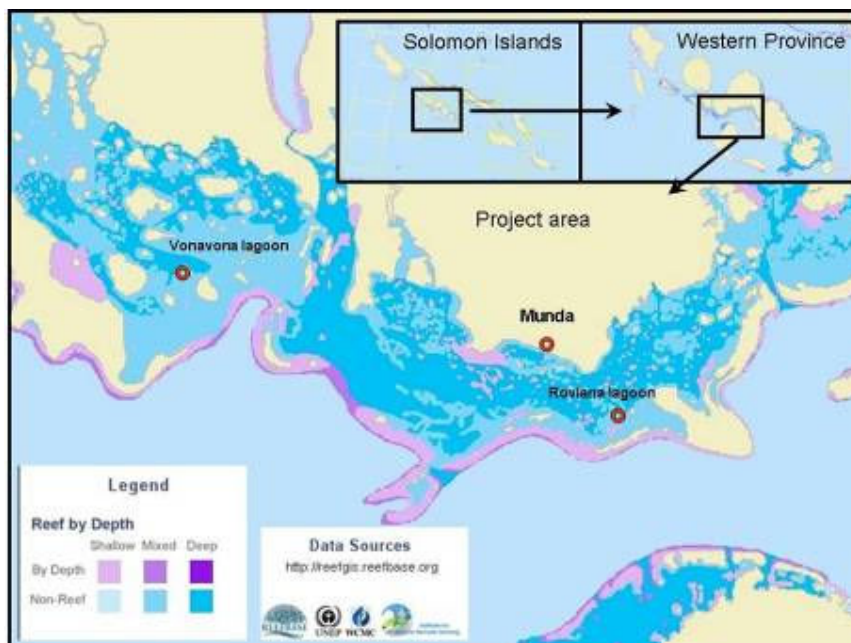


Figure 18. Map showing the location of the Roviana and Vonavona lagoons and the location of the weather station in the town of Munda.

The Munda weather station has been operating since 1962 and records temperature, precipitation and wind speed and direction. When daily minimum and maximum temperatures supplied by MECDM are plotted there is a trend for both to be increasing over time (data not shown). The data suggests that maximum air temperatures have increased over the last 50 years by about 0.4 °C on average and the minimum temperature by about 0.7 °C on average. Precipitation levels (mm rain) at Munda show no trend to increase or decrease and fluctuate around a mean of 3565 mm (MECDM data). Note however that between 1961 and 1998 the number of actual rain days has decreased at all stations in the Solomon Islands, with Honiara, Kira Kira and Munda having significant decreases (Manton et al. 2001).

Past cyclone activity for the region has been generated for two locations using Bureau of Meteorology Australia & Australian government (2010b) (Table 3) and is consistent with the Western province in general (Table 2 above).

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Table 3. Cyclone tracks frequency in the vicinity of the project sites (1969-2006).

site	Latitude (°S)	Longitude (°E)	Number of cyclones within			
			50 km	100 km	200 km	400 km
Vonavona						
lagoon	8.30	157.31	0	1	8	25
Roviana lagoon	8.33	157.17	0	1	8	25

Summary

The best projections available for the Roviana and Vonavona region at the time of writing were those that can be extrapolated from regional models described above and the most recent are those published by PCCSP in 2011. Specific site models have not been utilized for the Roviana and Vonavona region, although they would be able to be generated through SolCLIM (a customized version of the climate change impact and adaptation assessment software tool SimCLIM) or a similar tool. SolCLIM software has previously been purchased and used by MECDM but the software is currently out of date. SolCLIM has the potential to generate digital elevation models for each province, a full suite of IPCC Fourth Assessment Report Global Circulation Models, plus SimCLIM impact models including extreme event analysis, sea level rise scenario generator and site and spatial precipitation and temperature scenarios. However, the models will only be as good as the scale of data that is available. Table 4 summarizes the available data presented in this report and identifies missing data. Most current trends and projected changes are available only on a global or regional scale. These usually consider oceanic conditions and are not very accurate for coastal and lagoonal areas. There is very limited data available at a provincial level or smaller scale.

In Vonavona and Roviana lagoons at the start of this study measured climate data was available only from Munda. Other key elements that would help to predict the effect of climate change on specific locations include detailed computerized elevation mapping of the land which could help to predict the effect of sea level rise and inundation did not exist. Some additional weather stations to be deployed by MECDM and data collected by University of Queensland will be able to update this information to some extent by project end.

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Table 4. Data available for exposure characters in three geographic scales, global, Solomon Islands area and within provinces in 2010. C – current trends; P – projections; na – non available; Superscript numbers depict sources as follows: 1 - Griffiths et al. 2005; 2 - Hoegh-Guldberg & Bruno 2010; 3 - Leisz 2009; 4 – SIG MECDM weather stations data; 5 - Coles 2008; 6 - Leisz et al. 2009; 7 - Bureau of Meteorology Australia & Australian government 2010; 8 - Emanuel 2005; 9 - Lal et al. 2009; 10 - Manton et al. 2001; 11- Pacific country report on sea level & climate: their present state, Solomon Islands, 2009; <http://www.bom.gov.au/pacificsealevel/picreports.shtml>; 12- PCCSP, 2011.

Character	Global or pacific data	SI area data	Munda and surrounding area
Air temp	C ^{1,9,10} , P ^{6,9}	C ⁴ , P ³ , P ¹²	MECDM
Sea surface temp	C ² , P ^{5,6}	C ³ , P ³	na
Acidity	C ² , P ^{3,5,6}	P ³ , P ¹²	na
Sea level rise	C ^{2,6} , P ⁶	C ¹¹	na
Cyclone frequency	C ⁷	C ⁷	C ⁷
Cyclone intensity	C ⁸	Na	na
Storms frequency	na	Na	na
Precipitation	C ¹⁰ , P ⁹	C ³ , P ³ , P ¹²	MECDM

References

- Abawi Y, Dutta S, McClymont D, White S, Pahalad J (2009) Developing climate resilient systems in the Asia Pacific region *Presentations from Intl Workshop on the Content, Comm and Use of Weather and Climate Products and Services for Sustainable Agriculture*, Toowoomba, Australia, May 2009
- Bureau of Meteorology Australia, Australian government (2010a) Average annual information for Tropical cyclones. http://reg.bom.gov.au/jsp/ncc/climate_averages/tropical-cyclones/index.jsp
- Bureau of Meteorology Australia, Australian government (2010b) Tropical Cyclone Information for the Southern Hemisphere. http://www.bom.gov.au/cgi-bin/silo/cyclones_sh.cgi?region=spacifico&year=2006&eyear=2006&cyclone=all&loc=1
- Cazenave A, Llovel W (2010) Contemporary sea level rise. *Annual Review of Marine Science* 2:145-173
- Emanuel K (2005) Increasing destructiveness of tropical cyclones over the past 30 years. *Nature* 436:686-688
- Feely, RA, Orr J, Fabry VJ, Kleypas JA, Sabine CL, and Landgon C. (2008). Present and future changes in seawater chemistry due to ocean acidification. AGU Monograph on "The Science and Technology of Carbon Sequestration".
- Green A, Lokani P, Atu W, Ramohia P, Thomas P, Almany J (eds) (2006) Solomon Islands Marine Assessment: Technical report of survey conducted May 13 to June 17, 2004., Vol. TNC Pacific Island Countries Report No. 1/06.

- Griffiths GM, Chambers LE, Haylock MR, Manton MJ, Nicholls N, Baek HJ, Choi Y, Della-Marta PM, Gosai A, Iga N, Lata R, Laurent V, Maitrepierre L, Nakamigawa H, Ouprasitwong N, Solofa D, Tahani L, Thuy DT, Tibig L, Trewin B, Vediapan K, Zhai P (2005) Change in mean temperature as a predictor of extreme temperature change in the Asia–Pacific region. *Int J Climatol* 25:1301
- Guinotte JM, Buddemeier RW, Kleypas JA (2003) Future coral reef habitat marginality: temporal and spatial effects of climate change in the Pacific basin. *Coral Reefs* 22:551-558
- Hasumi, H, Emori S (2004). K-1 Coupled GCM (MIROC) Description, Center for Climate System Research (CCSR), University of Tokyo; National Institute for Environmental Studies (NIES); Frontier Research Center for Global Change (FRCGC) <http://www.ccsr.u-tokyo.ac.jp/kyosei/hasumi/MIROC/tech-repo.pdf> (Accessed October 9, 2007).
- Hay J, Mimura N, Cambell J, Fifita S, Koshy K, McLean RF, Nakalevu T, Nunn P, N. de Wet (2003) 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. South Pacific Regional Environment Programme (SPREP), Apia, Samoa
- Hilly, Z., Schwarz, A., Boso, D., Oeta, J. (2010) Livelihoods and socio-economic analysis of the communities of Pelau and Luaniua, Ontong Java. WorldFish Center -Solomon Islands, Report prepared for the Solomon Islands Ministry of Fisheries and Marine Resources
- Hoegh-Guldberg O, Bruno JF (2010) The Impact of Climate Change on the World's Marine Ecosystems. *Science* 328:1523-1528
- IPCC (2001) Climate Change 2001. Third assessment report (2001): Working Group II: Impacts, Adaptation and Vulnerability.
- IPCC (2007). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Avery T, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.
- Knutson TR, McBride JL, Chan J, Emanuel K, Holland G, Landsea C, Held I, Kossin JP, Srivastava AK, Sugi M (2010) Tropical cyclones and climate change. *Nature Geoscience* 3:157-163
- Kuleshov Y, Fawcett R, Qi L, Trewin B, Jones D, McBride J, Ramsay H (2010) Trends in tropical cyclones in the South Indian Ocean and the South Pacific Ocean. *J Geophys Res* 115:D01101
- Kurihara H (2008) Effects of CO₂-driven ocean acidification on the early. *Mar Ecol Prog Ser* 373:275-284
- Lal PN, Kinch J, Wickham F (2009) Review of economic and livelihood impact assessments of, and adaptation to, climate change in Melanesia, Secretariat of the Pacific Regional Environment Programme

- Langdon C, Atkinson MJ (2005). Effect of elevated pCO₂ on photosynthesis and calcification of corals and interactions with seasonal change in temperature/irradiance and nutrient enrichment, *Journal of Geophysical Research*, 110 (C09S07).
- Leisz SJ (2009) Locations in Melanesia most vulnerable to climate change, Bishop Museum
- Manton MJ, Della-Marta PM, Haylock MR, Hennessy KJ, Nicholls N, Chambers LE, Collins DA, Daw G, Finet A, Gunawan D (2001) Trends in extreme daily rainfall and temperature in Southeast Asia and the South Pacific: 1961-1998. *Int J Climatol* 21:269-284
- MECM/MFMR (2010) Solomon Islands Coral Triangle Initiative National Plan of Action, SIG, Honiara, Solomon Islands.
- MECM (2008) Solomon Islands National Adaptation Programmes of Action. Ministry of Environment, Conservation and Meteorology, November 2008.
- Munday PL, Crawley NE, Nilsson GE (2009a) Interacting effects of elevated temperature and ocean acidification on the aerobic performance of coral reef fishes. *Mar Ecol Prog Ser* 388:235-242
- Munday PL, Dixson DL, Donelson JM, Jones GP, Pratchett MS, Devitsina GV, Døving KB (2009b) Ocean acidification impairs olfactory discrimination and homing ability of a marine fish. *Proceedings of the National Academy of Sciences* 106:1848
- Oouchi K, Yoshimura J, Yoshimura H, Mizuta R, Kusunoki S, Noda A (2006) Tropical cyclone climatology in a global-warming climate as simulated in a 20 km-mesh global atmospheric model: frequency and wind intensity analyses. *J Meteorol Soc Jpn* 84:259-276
- PCCSP (2011) Climate change in the Pacific; Scientific Assessments and New Research. Volume 2, Country Reports, Chapter 13, Solomon Islands. Australian Government Pacific Climate Change Science Program Report.
- Rahmstorf S (2007) A semi-empirical approach to projecting future sea-level rise. *Science* 315:368-370
- Raven J, Caldeira K, Elderfield H, Hoegh-Guldberg O, Liss P, Riebesell U, Shepherd J, Turley C, Watson A (2005) Ocean acidification due to increasing atmospheric carbon dioxide.
- Tompkins EL, Nicholson-Cole SA, Hurlston LA, Boyd E, Hodge GB, Clarke J, Gray G, Trotz N, Varlack L (2005) *Surviving climate change in small islands: A guidebook*. Tyndall Centre for Climate Change Research, Norwich, UK
- Turak E (2006) Coral Communities and Reef Health. In: Green A, Lokani P, Atu W, Ramohia P, Thomas P, Almany J (eds) *Solomon Islands Marine Assessment: Technical report of survey conducted May 13 to June 17, 2004*. TNC Pacific Island Countries Report No. 1/06., pp 65-109
- Webster PJ, Holland GJ, Curry JA, Chang HR (2005) Changes in tropical cyclone number, duration, and intensity in a warming environment. *Science* 309:1844-1846
- World Bank. (2005) *Natural Disaster Hotspots: A Global Risk Analysis*. Hazard Management Unit. Washington, DC.