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An assessment of climate change impacts and adaptation for the Torres Strait Islands, Australia

**Donna Green · Lisa Alexander · Kathy Mclnnes ·
John Church · Neville Nicholls · Neil White**

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Abstract Adaptive practices are taking place in a range of sectors and regions in Australia in response to existing climate impacts, and in anticipation of future unavoidable impacts. For a rich economy such as Australia's, the majority of human systems have considerable adaptive capacity. However, the impacts on human systems at the intra-nation level are not homogenous due to their differing levels of exposure, sensitivity and capacity to adapt to climate change. Despite past resilience to changing climates, many Indigenous communities located in remote areas are currently identified as highly vulnerable to climate impacts due to their high level of exposure and sensitivity, but low capacity to adapt. In particular, communities located on low-lying islands have particular vulnerability to sea level rise and increasingly intense storm surges caused by more extreme weather. Several Torres Strait Island community leaders have been increasingly concerned about these issues, and the ongoing risks to these communities' health and well-being posed by direct and indirect climate impacts. A government agency is beginning to develop short-term and long-term adaptation plans for the region. This work, however, is being developed without adequate scientific assessment of likely 'climate changed futures.' This is because the role that anthropogenic climate change has played, or will play,

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D. Green (✉)
Climate Change Research Centre, University of New South Wales, Sydney 2052, Australia
e-mail: donna.green@unsw.edu.au

L. Alexander · N. Nicholls
School of Geography and Environmental Science, Monash University,
Clayton, Victoria, Australia

K. Mclnnes · J. Church · N. White
Centre for Australian Weather and Climate Research—A partnership between CSIRO
and the Australian Bureau of Meteorology, CSIRO Marine and Atmospheric Research,
Private Bag 1, Aspendale, Victoria, 3195 Australia

K. Mclnnes · J. Church · N. White
Antarctic Climate and Ecosystems Cooperative Research Centre, Hobart, Tasmania, Australia

on extreme weather events for this region is not currently clear. This paper draws together regional climate data to enable a more accurate assessment of the islands' exposure to climate impacts. Understanding the level of exposure and uncertainty around specific impacts is vital to gauge the nature of these islands' vulnerability, in so doing, to inform decisions about how best to develop anticipatory adaptation strategies over various time horizons, and to address islanders' concerns about the likely resilience and viability of their communities in the longer term.

1 Introduction

In order to facilitate risk assessments and the design of anticipatory adaptation strategies, a number of regional climate change projections and impact assessments have been carried out in Australia over the last few years (Hennessy et al. 2004; PIA 2004; Australian Greenhouse Office 2006; CSIRO and BoM 2007; Johnson and Marshall 2007). The majority of these studies have prioritised geographic areas with large infrastructural investments (e.g. Cairns and the Gold Coast, Queensland); sensitive industries (e.g. in the Murray Darling Basin, New South Wales and Victoria); dense populations (e.g. Sydney Coastal Councils, New South Wales) or coastal locations (e.g. Western Port, Victoria; the Great Barrier Reef, Queensland). However, there are some regions of Australia that are identified as having highly vulnerable human and natural systems, but which have had limited climate impact assessment work performed in them (Hennessy et al. 2007). A number of small coastal communities in northern Australia fall into this category. Many of these communities are predominantly Indigenous, and the majority of them have low socio-economic indicators (AIHW 2008:67).

The Torres Strait Islands are a specific and geographically bounded example of such 'highly vulnerable' communities. These remote islands are located between Papua New Guinea and Cape York, Australia. Over 7,000 people live in 18 communities on these islands, several of which are only a couple of metres above local mean sea level.

The Torres Strait rose to prominence on mainland Australia in 1992 when the Meriam people successfully fought to gain native title (recognition of the continued ownership of land by local Indigenous Australians) over Mer Island. This decision subsequently paved the way for native title claims to be made by Aboriginal people on mainland Australia.

Having successfully won native title over all the inhabited islands in the Torres Strait, Islanders are quite reasonably concerned that the impacts and risks associated with climate change may, amongst other things, affect their ability to continue living on their land in the longer term, and carrying out traditional subsistence harvesting from surrounding seas. These concerns have been raised in a number of national and international fora, including the most recent United Nations' Permanent Forum on Indigenous Issues that was focused on climate change. A major concern is how the unique *Ailan Kastom,* (Island Custom) that is the link between land, sea, environment and Torres Strait Islander culture, would be affected if Torres Strait Islanders were forced to move off their land (AHRC 2009).

Islanders' resilience to climate change is limited by pre-existing social and economic disadvantage that reduces these communities' capacity to adapt to rapid environmental change (Green 2006a). Similar to mainland Aboriginal communities, their sensitivity to relatively rapid change such as an increase in natural disasters, is compounded by inadequate transport and communications infrastructure, and health services (Ring and Brown 2002). In addition, specific cultural issues need to be considered. These include Islanders' belief in the connection between the health of their land and sea country, with their communities' and their own individual well-being (Green 2006b; Oliver-Smith 2008). This cultural dimension adds increasing complexity to comprehending the full impacts of climate change in this location. The following sections detail what is currently known about this region to enable an assessment of the exposure of the islands to climate impacts to be made.

1.1 The Torres Strait Islands

The Torres Strait region encompasses about 48,000 km^2 of open sea, including a shallow continental shelf between Papua New Guinea and Cape York, Australia and connecting the Arafura Sea with the Coral Sea. Protected from high swells by the northern-most extension of the Great Barrier Reef, the shelf itself has strong tidal currents and an irregular bathymetry, with numerous reefs and islands. The climate of the Torres Strait is characterised by two seasons, the monsoonal wet season (December to April), which is dominated by prevailing north-westerly winds, and the dry season (May to November), when south-easterly trade winds dominate.

Communities living on small low-lying islands, such as those in the Torres Strait, are particularly vulnerable to physical impacts of weather (Mulrennan 1992; Bessen 2005; ARUP 2006). Over 150 islands are located in the region, with about 17 permanently inhabited by Aboriginal and Islander communities (see Fig. 1). The islands can be roughly grouped due to their location and island form. These groups are: the eastern volcanic islands (Ugar, Erub and Mer), northwestern islands (Boigu, Dauan and Saibai), central islands (Iama, Masig, Poruma and Warraber), near western islands (Mabuiag, Badu and Moa) and inner islands (Hammond, Thursday, Prince of Wales and Horn). Of these inhabited islands the four central coral cay islands, and two low-lying, coral-based islands with sedimentary overlay have initially been identified as most vulnerable to climate impacts due to their generally low elevation above sea level.

About one fifth of Australia's total Torres Strait Islander population live on the islands in the Torres Strait. The island population is about 7,000. The majority of the mainland Torres Strait Island population lives in Queensland and the Northern Territory. The population growth rate for Indigenous Australians is significantly higher than the national average, for example, between 2001 and 2006, the estimated Indigenous resident population increased by 13% (AIHW 2008:68). There are however, many complexities in identifying the various components of this increase, for example the relatively recent phenomenon of increasing self-identification as Indigenous, and the relatively young profile of Indigenous Australians in comparison to the non-Indigenous population. In the short-term, this factor may cause difficulties for some islands (e.g. Poruma) that are already experiencing overcrowding in existing available housing, and lack land on which to build new houses. In addition, a large number of mainland Torres Strait Islanders regularly travel back and forwards to the islands to visit family and to maintain ties with their land. These activities can place further temporary strain on infrastructure at various times of the year.

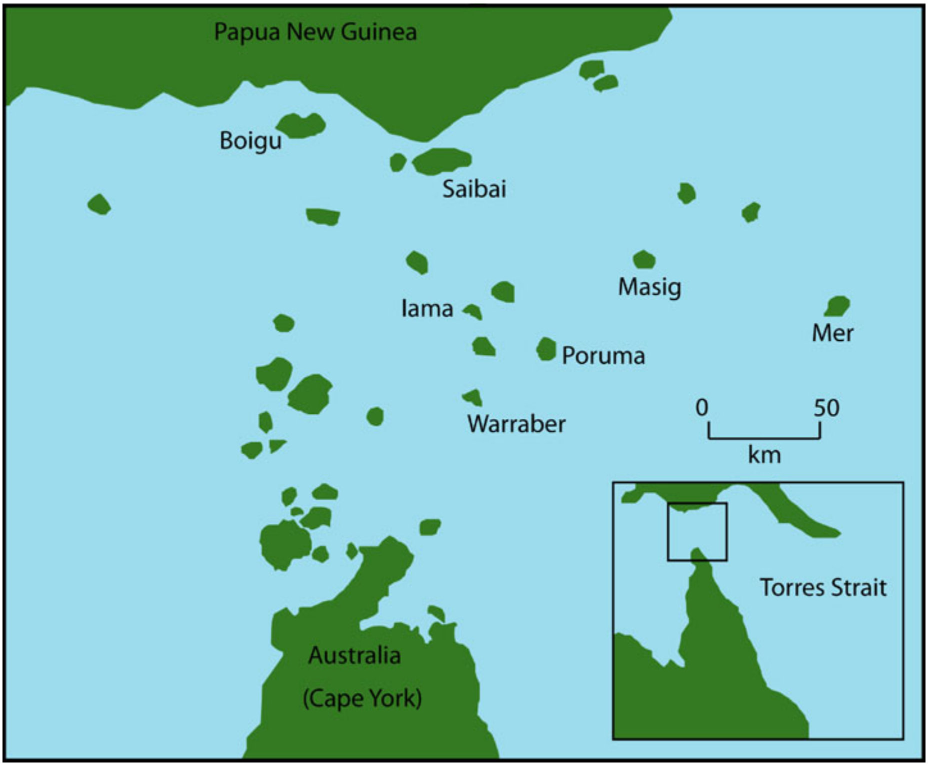

Fig. 1 Torres Strait region

In order to assess climate impacts from which adaptation strategies can be developed and then implemented, it is important to gauge whether existing scientific data for this region are adequate to plan adaptation strategies and to underpin reliable future climate projections. The following sections provide an overview of the state of this knowledge.

2 Changes in average climate conditions

The tropical location of the Torres Strait Islands means that average temperatures vary little throughout the year. The mean maximum (and minimum) temperatures vary from about 28 (22)°C to 32 (25)°C. Annual rainfall is approximately 1,800 mm, the vast majority of which falls during the monsoonal wet season. A key question is how these climate variables might change in the future due to climate change, and how this change might directly, and indirectly, impact the communities living there.

Climate models are the basis of most estimates of future climate change. To understand how future climate change might impact Torres Strait Islander communities, it is important to understand how the observed climate of the islands varies, and determine whether climate models are able to adequately simulate these changes and if not, why not.

Some of the uncertainties associated with simulating the climate of the islands are related to the inability of currently available global climate models (GCMs) to represent atmospheric and ocean features on a spatial scale less than several hundred kilometres. While regional climate model (RCM) simulations are able to resolve smaller scales (e.g. Whetton et al. 2001), even the coarser resolution GCMs may still provide useful information for impact assessments if used in conjunction with downscaling techniques (e.g. Wang et al. 2004).

Only a small amount of research focused specifically on climate change in the Torres Strait appears in scientific literature. Some climate change projections have been calculated for a wider area encompassing the region (e.g. Dunlop and Brown 2008; Sharing Knowledge 2008). These studies include the Interim Biogeographic Regionalisation for Australia (IBRA) region of 'Cape York Peninsula' (CYP) which is the IBRA region closest to the Torres Strait Islands. These reports project increases in average temperature, relative to the climate of 1990, of 0.5 to 1.2°C by 2030 and 1.0 to 4.2°C by 2070. Other regional studies have been performed in neighbouring Far North Queensland (Suppiah et al. 2007). The CSIRO is in the process of analysing the output from some high resolution (approximately 25 km) model runs covering the Torres Strait for a selection of future emissions scenarios (McGregor personal communication 2008). Preston et al. (2006) also developed projections for the Asia/Pacific region, including northern Australia, based upon Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC AR4) models.

The average dry-season rainfall for the CYP region is projected to decrease by 1% to 6% by 2030 and by 2% to 23% by 2070 (Sharing Knowledge 2008). The average wet-season rainfall is projected to increase by 0% to 4% by 2030 and by 1% to 13% by 2070. However, it is possible that these ranges may underestimate the magnitude of likely changes. Recent studies (e.g. Canadell et al. 2007; Raupach et al. 2007) show that recent rates of greenhouse gas emissions are currently above those considered by Dunlop and Brown (2008) and Sharing Knowledge (2008) in the form of the commonly used Special Report on Emissions Scenarios (SRES), described in Nakićenović and Swart (2000).

Projected changes to average wind speeds based on the simulations of 19 global climate models are presented in CSIRO and BoM (2007). Figure 2 (reproduced from CSIRO and BoM 2007), indicates that there is a better than even chance that mean wind speeds will increase in both the summer and winter seasons by 2070, although it should be noted that the magnitude is small for medium to high emissions (approximately 2%) and the uncertainty is large (±12%). The reason for the increase in wind speeds (either through increase in frequency of strong wind events or an increase in the average strength of the wind) is not certain without further analysis of the climate model output.

Increasing sea surface temperature (SST) threatens corals with regular coral bleaching anticipated south of the Torres Strait, in the Great Barrier Marine Park, within one to two decades (Hughes et al. 2003). The impacts of increasing SST on wider marine ecosystems are, however, not completely understood at this point (Johnson and Marshall 2007). Neither are the subsequent indirect impacts they

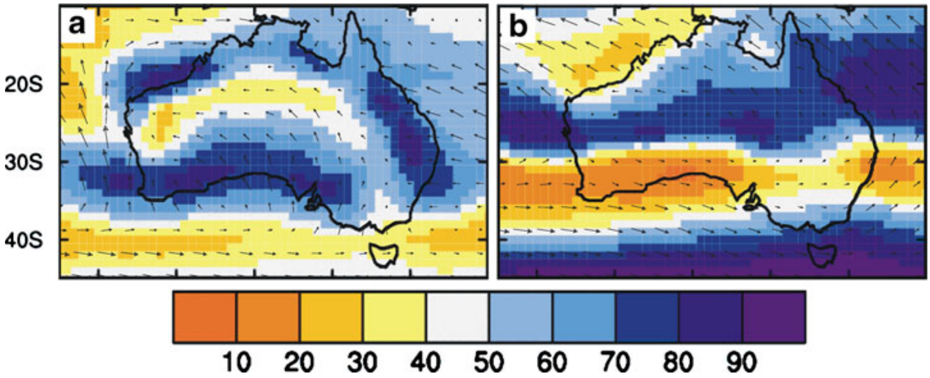

Fig. 2 Shaded areas show the risk (probability in per cent) that wind speed will increase in 2070 for **a** summer and **b** winter. Source (CSIRO and BoM 2007). Also shown are the wind vectors based on an average of the 1961 – 1999 10 m NCEP reanalyses (Kalnay et al. 1996)

create from, for example, changes in availability of sea grass meadows or mangrove development and the marine ecosystems that are dependent on them.

One of the significant consequences of climate change is an increase in the global averaged sea level. This increase comes principally from expansion of ocean waters as they warm (thermal expansion) and increases in ocean mass from melting of non-polar glaciers and ice caps, with additional contributions from the major ice sheets of Greenland and Antarctica.

Over the last century, global mean sea level has been rising at a rate of 1.7 ± 0.3 mm/year, about an order of magnitude larger than the rate of rise over previous centuries (Bindoff et al. 2007). Since 1870, global mean sea level has increased by about 0.2 m with the satellite–altimeter record indicating a faster rate of sea level rise from 1993 to the present (more than 3 mm/year). Whether this is a further sustained increase in the rate of rise or a part of natural temporal variability is not yet clear.

Projections of future sea level rise (SLR) have been published by the IPCC (Solomon et al. 2007). These include an increase of between 0.18 and 0.59 m by 2100 (2090–2099) relative to 1980–1999, based on the SRES scenarios. The projections do not include uncertainties in climate–carbon cycle feedbacks or the full effects of changes in ice sheet flow, therefore the upper values of the ranges should not be considered upper bounds for sea level rise. Solomon et al. (2007) advise that if ice sheet flow were to grow linearly with global average temperature then the upper bound of the SLR projections could be raised by a further 0.1–0.2 m, giving a range of 0.18–0.79 m, with larger allowances unable to be ruled out. However, limitations with their projections prevent definitive quantification at present.

The upper end of the IPCC AR4 projections is very similar to the IPCC Third Assessment Report (TAR) projections, and observations indicate that sea level has been rising at close to the upper limit of the TAR projections since their start in 1990 (Rahmstorf et al. 2007). The upper limit of the TAR projections is for a 0.88 m rise between 1990 and 2100 (Church et al. 2001). However, it is not clear that the sea level will continue to track this upper limit; it could diverge either above or below it.

Sea level rise is an ongoing phenomenon. The IPCC 2001 Assessment gave a time series of changes in global mean sea level for various greenhouse gas emission scenarios. Similar time series were not given in the 2007 assessment, but it possible to scale the AR4 results to the TAR results if intermediate estimates are required (Hunter 2009). Of course, sea level rise will not stop in 2100 but will continue for centuries to millennia as a result of ongoing ocean thermal expansion and the potential contribution of melting of the Greenland and West Antarctic Ice Sheets, and on greenhouse gas emission pathways followed.

In addition to global average sea level rise, there will be significant regional variations associated with changes in ocean circulation. Examination of Figure 10.32 from IPCC 2007 which presents the mean local sea level variation from the global average from 16 global climate models for the twenty-first century for the SRES A1B scenario, suggests the Torres Strait may experience slightly greater (0.05 m) than global average sea level rise to 2090. A further issue in adapting to sea level rise is that variability in regional changes in sea level may mask the long-term sea level rise signal, a point discussed further in the following section.

In conclusion, changes in *average* climate conditions will likely have significant impacts on the Torres Strait Islands as the twenty-first century progresses, and beyond. However, the vulnerability of communities to climate variability and change over coming decades is likely to be even more dependent on changes in the intensity and frequency of weather and climate *extremes* (Lynch and Brunner 2007; ACECRC 2008).

3 Changes in climate extremes

Although there have been significant advances in our understanding of changes in extreme events over the past 15 years (Nicholls and Alexander 2007), knowledge gaps still remain, especially in relation to the detection and attribution of changes in extremes. By definition, extremes occur infrequently and so are difficult to study from a statistical point of view. Furthermore, some types of weather and climate extremes (e.g. extreme rainfall events and tropical cyclones) are not well simulated by GCMs. An added difficulty for both GCMs and RCMs is that there are complex interacting mechanisms, such as coupled ocean-atmosphere processes and large-scale circulation changes that drive change in climate extremes. These are not fully understood, and therefore difficult to simulate in climate models. For example, the interdecadal variability and associated teleconnections of the El-Niño Southern Oscillation (ENSO) that is a major influence on tropical cyclone frequency, winds and rainfall in the Australian region (Nicholls 1992), are not well simulated by most state-of-the-art climate models (Lin 2007). Understanding these processes and how they behave under current and future climate conditions would help scientists improve prediction, and subsequently aid policy-makers in developing beneficial adaptation strategies.

3.1 Temperature and precipitation extremes

Analysis of changes in temperature and precipitation extremes requires access to daily data as a minimum requirement, and in some situations, such as flooding, even higher temporal resolution data. There are a variety of sources that could be accessed for such analysis e.g. in-situ observations, reanalyses (data based on observations and model output), and satellite data. However, these methods all have various complications or downfalls. For example, reanalyses are known to be inhomogeneous around 1979 due to the introduction of satellite data at that time (Kalnay et al. 1996) making them unreliable for studying some long-term climate trends. Surface meteorological observations, which can span a much longer period than either reanalyses or satellite data, can have many periods of missing data and may not have been sufficiently quality controlled.

The Bureau of Meteorology (BoM) holds weather records for Torres Strait Island stations. In the past there have been up to 28 rainfall stations and five observing stations that also hold other records including temperature and wind speed. Of these however, only three rainfall and two temperature stations are still operating and most of the data records are only approximately 10 years in length. Thursday Island has daily rainfall data as far back as 1888, and daily temperature records from 1953 to 1996, but many of these data are missing. The lack of a high-quality, long-running meteorological records for the region is one reason why there have been no studies of temperature and precipitation extremes in the Torres Strait to date.

While it is not clear how long-term increases in average temperatures would affect temperature extremes in the Torres Strait Island region, there is evidence from other parts of Australia (and the Asia–Pacific region) that there have been significant increases in occurrences of hot days, warm nights and heat waves, and decreases in occurrences of cool days and cold nights over the past few decades (e.g. Collins et al. 2000; Manton et al. 2001; Griffiths et al. 2005; Tryhorn and Risbey 2006). An increase in temperature extremes can have significant impacts on human health (Nicholls et al. 2007; Loughnan 2008), these indirect health impacts are briefly discussed in Section 5.1. Bearing in mind that there are limited observed climate extremes data available for the region for validating climate models, some studies covering a wider region have been assessed.

Future projections for Australia as a whole show that changes in temperature and precipitation extremes, such as heat waves and rainfall intensity, are set to increase significantly in the future (Alexander and Arblaster 2009). In general, these changes in temperature and precipitation extremes scale with human-induced forcing i.e. the greater the increase in atmospheric greenhouse gas concentrations, the greater the response of the change in a particular extreme event. This is particularly true of northern Australia where multiple model simulations indicate more warming of temperature extremes and enhanced ‘dry’ and ‘wet’ extremes. Except for changes in heat waves and warm nights, there is little consistency between the model runs regarding whether these changes are significant.

CSIRO has also analysed the output of four GCMs in an investigation of future changes in extreme temperature over tropical Australia associated with climate change (CSIRO and BoM 2007). The four models show that hot spells (defined as 3 days in a row over 35°C) increase from 6 to 50 days by 2070.

While there is some evidence that Australia as a whole might experience changes in temperature and precipitation extremes, there is no specific information for the Torres Strait Islands. Given that GCMs cannot resolve climate changes at this local scale, it would seem that changes projected over Cape York would be a reasonably valid proxy for the region.

Given the health risks particularly that may be associated with changes in these types of extremes, it is clear that more work needs to be done on (1) monitoring temperature and precipitation extremes on the islands using high quality and homogeneous data records and (2) assessing how these variables might change in the future through targeted modelling studies in the region.

3.2 Tropical cyclones

There is no definitive evidence of a global trend in tropical cyclone frequency (Solomon et al. 2007), however, the frequency of the most severe tropical cyclones appears to have increased globally since the 1970s (Emanuel 2005; Webster et al. 2005). There are questions surrounding this evidence in regards to whether the data are sufficiently accurate to be credible, and if such an increase is part of a natural cycle in cyclone behaviour.

In the north-east of Australia, tropical cyclones tend to centre south of the Torres Strait Islands (around latitudes of 14–15°C south), in the Gulf of Carpentaria and off northern Queensland. Six cyclones have tracked directly through the Torres Strait since 1906 (BoM 2008). This is a relatively small number in relation to the total number of cyclones that have been recorded in north-east Australia over the same period. However, many more tropical cyclones have passed across Cape York (see Fig. 3) close enough to the Torres Strait to cause concern amongst Islanders. A study by Puotinen (2007) indicated that the potential for damage from tropical cyclones along the Great Barrier Reef was much less in the far northern region (i.e. the area closest to the Torres Strait) than elsewhere on the reef over the past 35 years.

In recent decades, the apparent increase in cyclone activity seen in Fig. 3 represents advances in technology e.g. satellite measurements and better observing practices rather than an actual increase in cyclone numbers in northern Australia.

Even low intensity, relatively distant cyclones or even tropical lows in the Gulf of Carpentaria can cause problems when they occur in conjunction with the season

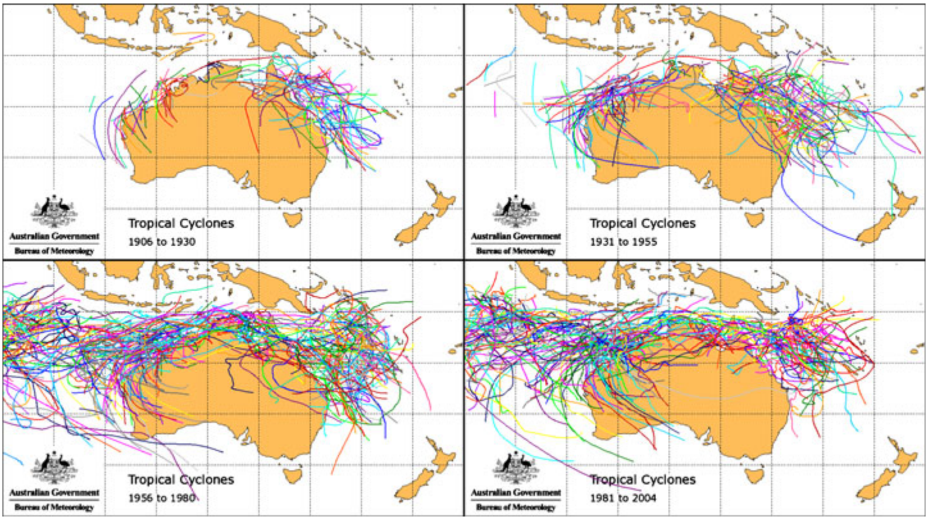

Fig. 3 Tropical cyclone tracks in the Australian region for each 25 year period since 1906 source: BoM (2008)

of prevailing north-west winds (during January and February) and at high tide. The impacts of a tropical cyclone are a serious concern to Islanders due to the amount of coastal damage caused by the energy of the waves during stormtides on some islands. These high energy waves can cause severe erosion to an island coastline in a matter of hours.

While tropical cyclones remain a major threat to northern Australia, the frequency of these events may have decreased somewhat in the region in recent decades, partly due to changes in the influence of the ENSO. However, this decrease may also be partly artificial, caused by changes in the ability of meteorologists to discriminate between tropical cyclones and other low-pressure systems, and to changes in the facilities available for observing cyclones (Nicholls et al. 1998; Buckley et al. 2003).

Paleoclimatic studies using the isotopic signature of tropical cyclone rains trapped in annually-layered limestone cave stalagmites and sediments of coral shingle, shell and sand ridges and sheets, have provided evidence of long-term changes in tropical cyclone activity around northern Queensland (Nott and Hayne 2001; Nott et al. 2007). The modern (post-1800) level of cyclone activity has been relatively quiet, compared to much more active periods from AD 1400 to 1800. Therefore, even without a human influence, it is possible to see a change in tropical cyclone activity as a result of natural climate variability affecting the Torres Strait in the future.

The detection and attribution of the possible effects of anthropogenic climate change on tropical cyclones is a controversial topic in current climate science (Walsh et al. 2008) and it is especially challenging to estimate future changes of cyclone activity in a projected warming world. If the intensity or frequency of tropical cyclones were to increase in a globally warmed world, there would be a significant increase in risk from more damaging storm surges and stormtides (see Section 3.3; Kossin et al. 2007; Landsea 2007; Emanuel et al. 2008; Knutson et al. 2008).

Solomon et al. (2007) consider it likely that due to climate change, tropical cyclone intensity will increase somewhat in the future, but a lack of regionally specific information means it is difficult to state how any change in tropical cyclone activity may impact the Torres Strait region. Therefore more research is needed to implement appropriate model experiments over the region to properly assess the risk from these types of extremes.

3.3 Extreme sea levels

Changes in extreme sea levels are a result of the combination of short-term variability such as storm surge and severe wind driven waves, interannual changes in sea level associated with climate variability, such as the ENSO, and other climate phenomena and ongoing sea level rise.

3.3.1 Stormtides

Wind waves and storm surge occur as a result of severe winds acting on the ocean surface. For storm surges, changes in atmospheric pressure also contribute to the sea level increases such that a decline in atmospheric pressure of 1 hPa relative to ambient pressure in the region leads to a 1 cm rise in sea level (the so-called inverse barometer effect). Storm surges in the Torres Strait are further exacerbated by the shallowness of the Torres Strait particularly to the west of about 144° E where water depths are typically less than about 15 m. Extreme sea levels from a storm surge are most severe when the surge combines with a positive astronomical tide. The combination of the waves, storm surge and astronomical tide is usually referred to as a stormtide.

Tropical cyclones are a major cause of severe storm surges and wind waves in the tropics, although other weather conditions such as sustained strong winds from distant weather events can also cause stormtides in the Torres Strait. As well as causing storm surges and waves, the wind stress from cyclones and other severe weather events acting on the surface of the ocean may enhance the current flow around the islands which, in combination with waves, can lead to significant coastal erosion.

Tides in the Torres Strait are a result of a complex interaction between the diurnal tides of the Gulf of Carpentaria (Church and Forbes 1981) and the semi-diurnal tides of the Coral Sea (Amin 1977; Church et al. 1985; Wolanski et al. 1988; Saint-Cast and Condie 2006). There is a strong demarcation in the phase and amplitude of the tides in Torres Strait that is concentrated along a north–south line between the northern most tip of Cape York and the southern most tip of Papua New Guinea. The tidal range between 142° and 143° E is typically between 4 and 5 m. Tidal currents are strong peaking at 1.5–3.0 ms^{-1} in shallow water, around the islands and in the narrow channels.

Tidal predictions are available at around 40 locations throughout Torres Strait (Aust. Nat. Tide Tables 2007). The tidal constants for many of the gauges have been obtained from short-term tide gauge deployments of a month or more by the Australian Hydrographic Office (AHO). Currently there are only five gauges, at Ince Point, Nardana Patches, Turtle Head, Goods Island and Booby Island operated by the Australian Marine Safety Authority that provide real-time sea level information and one gauge, operated by Queensland Transport, at Thursday Island. They are all located in or adjacent to the Prince of Wales Channel, the main shipping channel between the Gulf of Carpentaria and the east coast. A summary of the tide gauge data available in Torres Strait is given in Table 1 and their locations are indicated in Fig. 4.

A project is currently underway to improve the accuracy of the height datum, tide datum and geodetic datum at 17 locations at or near the inhabited islands of Boigu, Dauan, Saibai, Ugar, Erub, Mer, Thursday, Hammond, Iama, Poruma, Warraber, Masig, Badu, Moa (Kubin and St Pauls) and Mabuiag. This has led to the deployment of tide gauges for approximately a month by the Queensland Department of Natural Resources & Mines (QNRM) and Griffith University (GU). As well as providing short-term sea level observations at these islands, this project will enable more accurate tidal predictions to be made in the future. There is nevertheless a lack of permanent tidal stations across much of Torres Strait away from those situated in the southern shipping channels that can measure the incidence of extreme events as they occur, and hence provide valuable data to evaluate the likely incidence of extreme events in the future.

The data collected through the temporary tide gauge deployments will also contribute to the development of a new Geoid model for Australia by establishing geodetic connections to a number of permanent survey landmarks on the islands. A number of agencies are involved in this work including the AHO, the National Tidal Centre (NTC) of the Bureau of Meteorology and Geoscience Australia.

Table 1 Locations of tidal data in Torres Strait

Name	Longitude		Latitude		Year(s) in which data was collected	Agency
Alert Patches	142°	21′	−10°	29′	2000	HYDRO
Ashmore Reef	144°	30′	−10°	5′	1999	HYDRO
Aureed Is.	143°	17′	−9°	57′	1994	HYDRO
Bampfield Head	142°	6′	−10°	42′	1921	HYDUK
Booby Is.	141°	55′	−10°	36′	1972 onwards	MSQ
Carpentaria	141°	18′	−10°	44′	2000	HYDRO
Coconut Is.	143°	4′	−10°	3′	1992	HYDRO
Crab Is.	142°	7′	−10°	58′	1977	HYDRO
Darnley Is.	143°	46′	−9°	34′	2005/2006	HYDRO
Dugong Is.	143°	6′	−10°	31′	1997	HYDRO
Dungeness Reef	142°	58′	−9°	58′	1941	HYDRO
East Cay	144°	16′	−9°	23′	1996	HYDRO
East Strait	142°	27′	−10°	30′	1971	HYDRO
Gabba Is.	142°	37′	−9°	46′	1999	HYDRO
Goods Is.	142°	9′	−10°	34′	1974 onwards	MSQ
Hawkesbury Is.	142°	8′	−10°	23′	1971	HYDRO
Ince Point	142°	18′	−10°	31′	1971 onwards	AMSA
Kirkaldie Reef	142°	48′	−10°	19′	1988	HYDRO
Maer Is.	144°	2′	−9°	54′	1995	HYDRO
Moa Is.	142°	13′	−10°	14′	1978	NATMAP
Nardana Patches	142°	14′	−10°	30′	2005 onwards	AMSA
Papou Point	142°	20′	−10°	37′	1994	HYDRO
Pearce Cay	143°	18′	−9°	31′	2005	HYDRO
Phipi Reef	142°	32′	−9°	36′	1995	HYDRO
Poll Is.	142°	49′	−10°	15′	1994/1995	AMSA
Proudfoot Shoal	141°	28′	−10°	31′	1997	AMSA
Red Wallis Is.	142°	2′	−10°	51′	1994	HYDRO
Rennel Is.	143°	16′	−9°	46′	2005/2006	HYDRO
Round Is.	142°	12′	−10°	33′	1944	HYDUK
Saibai Is.	142°	37′	−9°	23′	1967	HYDRO
Stephens Is.	143°	33′	−9°	30′	2005/2006	HYDRO
Suarji Is.	142°	31′	−10°	10′	1941	HYDRO
Talab Is.	142°	13′	−9°	58′	1997	HYDRO
Tarilag Is.	142°	14′	−10°	45′	1994	HYDRO
Thursday Is.	142°	13′	−10°	35′	1983–2002	MSQ
Turtle Head	142°	13′	−10°	31′	1989 onwards	AMSA
Twin Is.	142°	26′	−10°	28′	1974/1975	MSQ
Unnamed Cay	143°	20′	−9°	22′	2005/2006	HYDRO
Varzin Shoal	141°	55′	−10°	33′	2002	HYDRO
Warrior Reef East	143°	9′	−9°	35′	1997	HYDRO
White Rocks	142°	1′	−10°	31′	2000	HYDRO
Yam Is.	142°	54′	−9°	54′	1994	HYDRO
Zagai Is.	142°	54′	−9°	52′	1994	HYDRO

Only five of the locations are currently monitoring tides in real time. The majority of the remainder of locations consist of short-term deployments of a tide gauge for a month or more to establish tidal constants for ongoing tidal prediction

HYDRO Australian Hydrographic Office, *MSQ* Maritime Safety Queensland, *HYDUK* The Hydrographer of the UK Navy, *AMSA* Australian Maritime Safety Authority, *NATMAP* National Mapping (source: Aust. Nat. Tide Tables 2007)

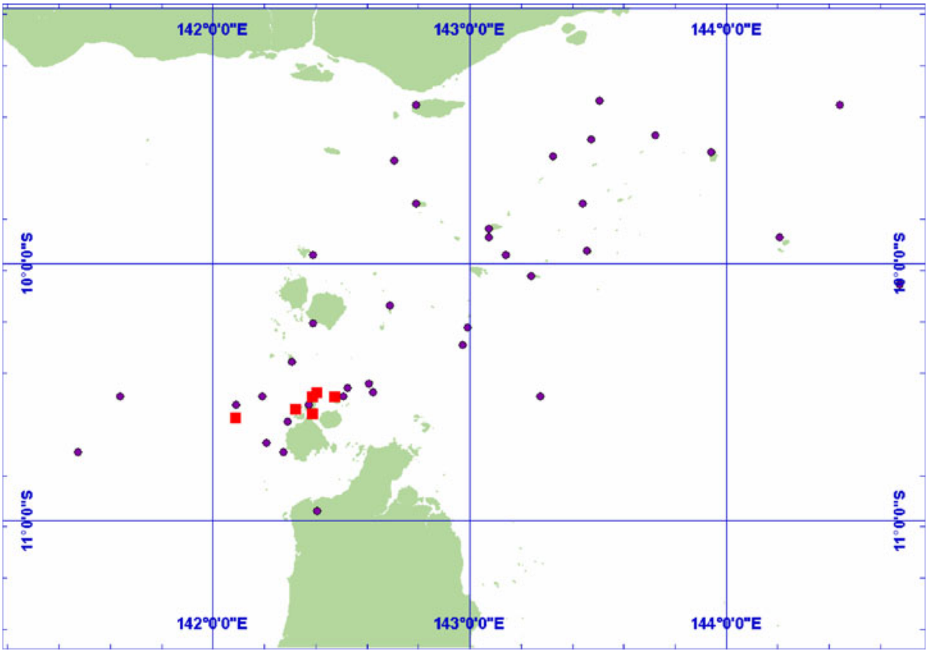

Fig. 4 Location of tide gauges in the Torres Strait with currently operational gauges (highlighted in *red*)

Higher mean sea levels combined with sea level extremes due to tides and storm surge will increase the severity and frequency of inundation. An assessment of the vulnerability of island settlements to inundation under future scenarios of sea level rise and storm surge requires accurate terrain height data. Currently, Digital Elevation Models (DEMs) derived from photogrammetry exist over Thursday, Hammond, Moa, St Pauls, Boigu, Dauan, Ugar, Mer, Masig Saibai, Badu, Mabuiag, Erub, Iama, Poruma, Warraber and Horn Islands. They were derived in 1998 from 1:4000 photography over the settlements and 1:8000 photography over the remainder of the islands leading to DEM vertical accuracies of 0.2 to 0.4m respectively (Brown personal communication 2008). In the development of these DEMs, an arbitrary datum was used on each island. The project described above between QNRM and GU should establish the necessary information to adjust this data to the standard Australian datum, which will allow more accurate projections of future inundation to be made. Furthermore, it will facilitate the collection of accurate digital elevation data in the future, which falls into the future plans of the Department of Emergency Services.

Enhanced coastal erosion may be another significant problem facing the Torres Strait Islands due to the effects of climate change particularly for the north western islands. For the coral cay islands, this erosive process can be tempered by accretion during these events. Indeed, these islands require inundation, or at least wave overtopping, for beach construction and maintenance (Parnell personal communication 2008). A project undertaken by researchers from James Cook University to look at the long-term management of erosion on the cay islands in Torres Strait notes that the impact of climate change on the overall sediment budget is not well understood. Along some coastlines, stronger waves and currents during extreme weather conditions may lead to net erosion while other coastlines may experience accretion (Parnell personal communication 2008).

Although storm surges occurring at the beginning of the year (January and February) cause the most concern on the islands due to the co-incidence of the strong north-westerly winds with high tides, these are not the only times that extreme events cause inundation. Strong sustained south-easterlies can also produce storm surges and significant stormtides in the region during high tides in July and August.

A recent example occurred on the 21st and 22nd of July 2005, where an exceptionally strong anticyclone, centred on Canberra, produced gale force south-easterlies through the Torres Strait causing higher than normal sea levels, leading to coastal inundation and damage to hundreds of houses in the Western and Gulf Provinces of Papua New Guinea (Callaghan personal communication 2008). The combination of high tides and strong winds inundated several houses on Mer Island.

Approximately six months later, further inundation events were reported in the media (Minchin 2006; Michael 2007) during the predicted king tides in January and February 2006 (Figs. 5 and 6). Sustained winds of 8 to 13m s-1 caused by a low-pressure system located over the Northern Territory combined with the expected north-westerly monsoon winds and with the high spring tides to produce a stormtide on the western side of Torres Strait (EPA 2006). Data provided through the NTC indicated that sea levels were 0.5m above predicted astronomical tide and exceeded Highest Astronomical Tide (HAT) by up to 0.3m. This caused significant impacts on several islands. A number of houses, sea walls, graveyards, roads and community buildings were inundated on Saibai, Boigu, Iama, Warraber and Masig during this event (EPA 2006).

These recent inundations caused much unease amongst communities, some of whom had only once before experienced such levels of flooding. On this occasion, a cyclone tracked straight through the Torres Strait on 6th–7th Jan 1948 (and a second tracked over Cape York between 10th and 15th Jan 1948). It is likely that the first cyclone combined with high tides to create a storm surge which inundated Boigu

Fig. 5 Saibai village after inundation due to stormtides in 2006 (photo credit: Rick Parmenter)

Fig. 6 Damage to the sea wall caused by a stormtides on Saibai in 2006 (photo credit: Donna Green)

and Saibai. At least two elderly Islanders on Boigu still remember this incident. In response to this event, some of the community decided to move off the island and onto mainland Australia. Many of the inhabitants of the Bamaga and Seisia community on the tip of Cape York are descendents of these relocated Islanders (Ober et al. 2000). However, this relocation did not take account of the potential cultural sensitivities of moving Islanders on to what is now recognised as Aboriginal land. These concerns would need to be at the forefront of any relocation negotiations in the future (Warusam personal communication 2006).

Although the recent inundation events have not been linked to climate change, they serve as an indication of the kind of events that may occur more frequently in the future as a result of mean sea level rise. In view of the potential coastal impacts, most notably inundation and erosion, that are caused by strong currents, waves and stormtides, that are generated by a range of weather events described in this section, further analysis of the likely changes to the frequency and intensity of severe wind associated with weather events such as tropical cyclones, monsoon depressions and intense wintertime anticyclones. Climate projections of changes in future wind speed, an example of which is shown in Fig. 2, are relevant to determining how the storm surges that occur due to severe and sustained winds may change, either during the monsoon or the trade wind seasons in the future. However, analysis of such changes to date have been limited.

3.3.2 Sea level rise

As with other aspects of climate change, the impact of rising sea levels will be felt most acutely through extreme events. Even if the variability of sea level about the mean does not change, an increase in mean sea level would likely result in an increase in the frequency of high (flooding) sea level events. This change can be estimated from multi-decadal sea level records (Church et al. 2008a). However, the sea level records from the Torres Strait are too short and fragmented to complete this analysis. Any increase in intensity of weather events will further exacerbate the impacts of extreme sea level events.

Satellite altimeter data indicate significant regional variations in the rate of sea level rise since the start of the record in January 1993 (see Fig. 7). The faster rate of rise in the western Pacific/eastern Indian Oceans since 1993 (more than double the

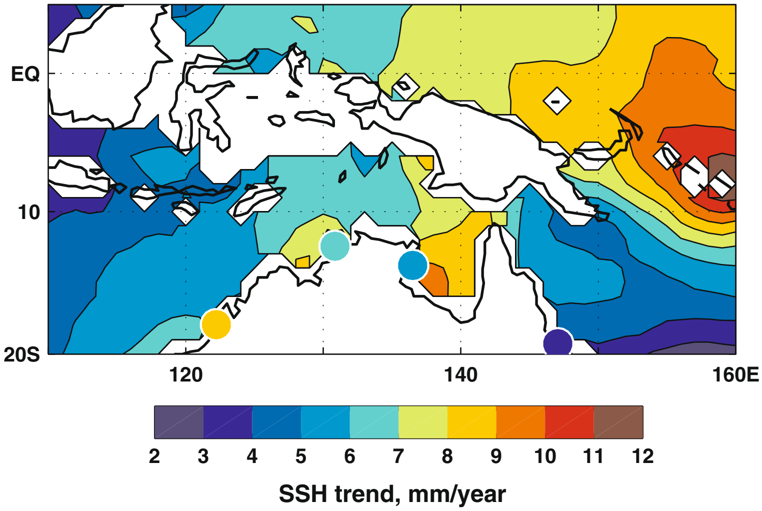

Fig. 7 Sea level trends in the region estimated from satellite altimeter data from January 1993 to December 2007. Sea level trends from tide gauge data from the National Tidal Centre are indicated by the *coloured dots*. The sea level data have been corrected for vertical land motion associated with glacial isostatic adjustment but not for changes in atmospheric pressure

global average at about 8 mm/yr in the Torres Strait region) is primarily a result of interannual climate variability associated with the ENSO phenomenon. Time series of altimeter measured sea level at individual locations in the Torres Strait region and near Darwin also demonstrate this rapid rate of rise from 1993 to 2007 (about 9 and 8 mm/yr, respectively; Fig. 8b and c) and that sea level rises and falls by up to about 0.1 m during an El Niño event. Examination of the longer Darwin tide gauge record (Fig. 8a) shows similar variability to the shorter altimeter records but a much smaller trend (about 1.6 mm/yr from 1960 to 2007). Smaller trends over longer (multi-decadal) time spans would be expected due to averaging over a few cycles, rather than getting a trend for a fraction of a cycle. On decadal periods, the only study of the historical regional distribution of sea level rise to date (Church et al. 2004) also indicates a non-uniform distribution of sea level rise but with much smaller spatial variability than the shorter satellite altimeter record.

To estimate statistical extremes for flooding, a minimum of about 30 years of (near) continuous data is required (Hunter personal communication 2008). Given this data requirement is problematic for the Torres Strait region, one option to consider is the effect sea level rise on the distribution of extremes for flooding vulnerability at nearby locations. Darwin and Cairns are the closest of the 29 stations with data records of this length, and Church et al. (2008a, b) shows that a sea level rise of 0.1 m would lead to around a threefold increase in the frequency of extreme high events (this is close to the Australian average which is a factor of 3.1 for 0.1 m sea level rise). For a 0.5 m rise, which is roughly the centre of the IPCC projected range for 2100, this translates to an increase of frequency by a factor of about 240. This increase in frequency of extreme events means that an inundation event of a particular magnitude that currently happens every few years might happen every few days in 2100 (Church et al. 2008b).

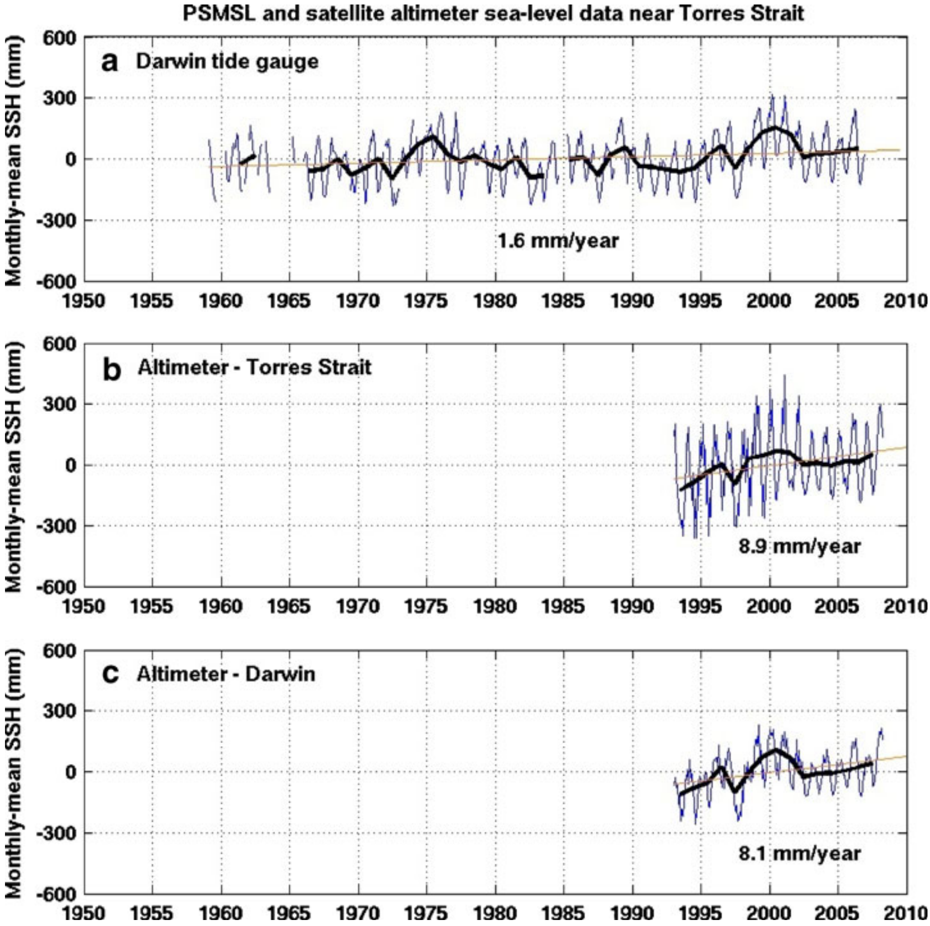

Fig. 8 Monthly averaged sea levels as measured by a tide gauge at Darwin (**a**), and as measured by satellite altimeter in Torres Strait (**b**) near Darwin (**c**)

In addition to changing sea level, the land itself can move vertically as a result of large-scale changes in the loading of the Earth's surface from changes in the mass of glaciers, ice sheets and oceans, and local tectonic motions. These large-scale changes are likely to be small for the Torres Strait and little is known about local tectonic motions.

4 Data requirements

While climate model projections are needed to indicate what the future climate might be like in the Torres Strait, ensuring that they adequately represent the current climate is important to build confidence in these projections. In addition to the uncertainties in climate projections derived from climate models that are forced by different scenarios of greenhouse gas emissions into the future, is the lack of direct

Table 2 Summary of available climate change data and its priority for future impacts research

Factor	A[a]	B[b]	Currently available data		Data needed to improve level of knowledge
			Observations	Models	
Change in average climate conditions	Med	Med	The Bureau of Meteorology (BoM) has meteorological records for 3 rainfall and 2 temperature stations which are still operating	IPCC model runs (from PCMDI) from >20 models. CSIRO and BoM results using 19 models. CCAM RCM (25 km) runs (1951–2000 downscaling from NCEP, and 1961–2100 downscaling from Mk 3.0 for A2 and A1B	High quality and homogeneous data from observing stations for monitoring climate variables. Improvement of GCMs and RCMs through better understanding of large scale processes which affect the islands e.g. ENSO. RCM and GCM runs which take account of above improved understanding with targeted modelling experiments for the region
Change in climate extremes: Temperature	Med	Low	As above	IPCC model runs from a selection of models for a selection of indices. Output from 4 model runs (CSIRO and BOM)	As above including dynamical downscaling studies to estimate the future risk of extremes with multiple realisations to give probabilistic estimates
Change in climate extremes: Precipitation	Med	Low	As above	IPCC model runs from a selection of models for a selection of indices	As above
Tropical cyclones	High	Low	Tropical cyclones tracks recorded for Australia are available from 1906 to present from BoM tropical cyclone web pages (BoM 2008)	No known specific Torres Strait modelling studies. Modelling for other regions, although still somewhat rudimentary, suggests an increase in the most intense systems in the future throughout tropics	Better understanding of the natural processes which drive changes in tropical cyclones and therefore a better estimation of what role human factors may play in future changes. Implementation of appropriate model experiments over the region to properly assess the risk from these types of extremes

Table 2 (continued)

Factor	A[a]	B[b]	Currently available data		Data needed to improve level of knowledge
			Observations	Models	
Storm surge	High	Low	AMSA, National Tidal Centre and QDNM-GU (see Table 1)	No storm surge modelling studies performed yet for the region	Long-term tide gauge data for improvements to storm surge modelling. Long-term, high quality tide gauge data for benchmarking storm surge models. Storm surge modelling studies of the Torres Strait
Sea level rise	High	Low	AMSA, National Tidal Centre and QDNM-GU (see Table 1). Global satellite altimeter data is available from 1993	Coarse resolution climate models of ocean thermal expansion are available. A higher resolution model of ocean conditions from 1993 to the present is available for the Australian region	Long-term, high-quality tide gauge data for more accurate sea level estimation. Model experiments to estimate the future risk of very high sea level events

[a] Usefulness of factor in impact assessment
[b] Level of knowledge

observations in the Torres Strait with which to validate climate models. This may also decrease confidence in future projections in the region.

The importance of observations, whether they are related to ecosystem change and function, climatological, meteorological, topographic, bathymetric, land motion or sea level cannot be underestimated. For example, while some long meteorological records exist, they have not been quality controlled and would therefore not be reliable for climate change studies or model validation (Trewin personal communication 2008). In addition, storm surge modelling could only be reliable if the bathymetry of the region was sufficiently well known, and there remain large regions of the Strait where bathymetric data are sparse (Hemer et al. 2004).

There are projects underway to enhance monitoring of the region such as the short-term tide gauge project mentioned previously (QDNMS/GU), although at present there does not appear to be a concerted plan to use this information to develop resilience-building activities, nor have resources yet been earmarked at state or federal government levels to carry such activities out. The most recent natural disaster risk management study performed for the islands highlights the seriousness of any potential increase in inundation incidents. This report qualifies the use of island inundation maps contained within it due to the lack of accuracy of the data used to make them (ARUP 2006). Despite the short term tide gauge deployments, there remains a lack of permanent tidal stations in the Torres Strait to provide continuous sea level monitoring across a more extensive region.

Projects that use local knowledge about weather and climate observations, such as phenological data that may be useful in identifying climate trends, are just beginning in this region (Sharing Knowledge 2008). The Sharing Knowledge project directly engages with Islanders, identifying their local observations of environmental change. It is currently documenting phenological observations through video documentation on seven of the Torres Strait Islands. This recording work is part of a process developed by an Indigenous organisation that incorporates techniques to maximise capacity building within the community relating to data management and storage as well as from the material itself (for further information on these techniques see TKRP (2009)).

Observations that have been noted include the changing flowering times of certain trees; changes in weather patterns, specifically that the winds and rain are no longer following the ‘traditional’ seasonal calendar as passed on through generations; and also a change in the abundance and mating of turtles and dugong (Sharing Knowledge 2009). A more in depth discussion of this local knowledge is beyond the scope of this paper, although ongoing project updates will be made available at the Sharing Knowledge website.

From the review performed here on the status of climate change information currently available for the Torres Strait Islands, it is clear that there are several areas of research that require urgent attention if we are to properly assess the risk posed from potential changes in climate in the future. In Table 2, we identify the climate variables that pose a present and future ‘threat’ to the islands and identify possible areas for further research.

It is obvious that our knowledge is severely limited regarding the current or future impact of most of these climate variables on the Torres Strait. However, GCM and/or RCM runs already exist which would allow a study to be performed on the likely future changes in temperature and precipitation specifically focussed on the islands. It may also be possible to use existing data to estimate the future risk of very high sea level events. In addition, current storm surge models could be used to focus specifically on the Torres Strait region. Again, testing the quality of, and building confidence in, these simulations requires long-term tide gauge data, bathymetry and digital elevation data. Whatever models are used, their ability to represent the relevant physical process in the Torres Strait, would also have to be properly assessed in order to make accurate uncertainty estimates of the risks posed from future climate change. In all cases, continued improvements to monitoring and assessment of the quality of data is essential. It is clear though that there are already risks to the community from their current exposure to extreme weather regardless of how much climate change factors into these events.

What is much more certain is that increases in sea level, leading to a subsequent increase in extreme sea level events as well as possible increases in the severity of tropical cyclones caused by climate change will occur regardless of immediate greenhouse gas mitigation efforts. Failure to mitigate will result in even larger impacts.

5 Island vulnerability

The previous section identified the data requirements, and subsequent analysis, which is needed to undertake a comprehensive assessment of the Torres Strait Islands' exposure to climate change impacts. Without this, identifying the nature and extent of the Islands' vulnerability to climate impacts is extremely difficult. However, not withstanding this lack of information, it is clear that these communities are concerned about their vulnerability to climate change. Some likely areas of concern in relation to climate impacts are outlined below to help prioritise further research needs as well as to inform adaptation discussions.

5.1 Human health

Across Australia, changes in precipitation extremes, such as the occurrence of heavy rainfall events, are regionally dependent (e.g. Hennessy et al. 1999; Haylock and Nicholls 2000; Gallant et al. 2007). There is some evidence that the trends of the most extreme events of both temperature and precipitation are changing more rapidly than are the trends for more moderate extreme events (Alexander et al. 2007). This is problematic because more extreme rain in the monsoon season could increase the chance of injury (McMichael et al. 2003). This is particularly the case if the increases in rainfall at this time are linked to increases in the number and/or intensity of tropical cyclones, which is likely to increase the risk of injuries and accidental death. Due to the extremely remote nature of the region, emergency rescues are particularly difficult to perform in short timeframes and thus further exacerbate the potential risks associated with more extreme weather in the future.

The combined impact of precipitation and temperature changes on a range of infectious disease transmission rates is complex because those rates tend to be very locally specific, depending on a combination of several physical factors and the presence of the necessary 'vector' host (for example: fleas, mosquitoes, birds or mammals). Increasing temperature and humidity is also likely to impact on the time taken for the pathogens to develop to an infectious stage in the vector host (Currie 2001; Patz and Olson 2006).

Increases in extreme temperatures can lead to health concerns including increases in incidence of heat rashes, heat exhaustion and even heat stroke (McMichael et al. 2003). In the worst-case scenarios, increases in heat waves and particularly warm, humid nights can cause heart attacks and death (Nicholls and Alexander 2007; Loughnan 2008). Elderly people and those with poor cardiovascular health and low physical fitness are at highest risk (McMichael et al. 2003). The latter concerns are disproportionately prevalent in Indigenous communities, such as those of the Torres Strait (McMichael et al. 2008).

Dengue fever is already a major concern on many of the islands, and increases in extreme weather, in combination with the prevalence of water tanks near houses (that can facilitate mosquito breeding if they are not covered), may make this disease an increasing problem if adequate preventative measures are not taken.

The remoteness of the islands, the difficulty and expense of transportation, limited health services, and in at least one case, competing demands on health services (e.g. use of health services on Boigu by Papua New Guinean nationals) all contribute to a high level of stress on medical practitioners on the islands.

The psychological effects of climate impacts on Islander culture have not been considered to date. Despite this, it is clear that the cultural impacts of relocating from the Islands would cause significant concern amongst Islanders (Beckett 1987).

5.2 Inundation and changing shorelines

As noted in the previous section, a key short-term concern of Islanders relates to extreme weather and storm surge events generated by tropical cyclones, particularly if they occur simultaneously with high tide. The impacts of these events will slowly be exacerbated as sea level rises. Some data is captured on the topographic maps of areas prone to inundation in the sustainable land use plans, although these have primarily been designed to inform future development patterns on the islands (Conics 2009).

Adaptation to rising seas by retreating from the shoreline is not an option on some of the islands due either to limited land (e.g. Poruma) or lack of high land (e.g. Saibai, Boigu). Other islands that do have higher land which could potentially be subdivided for relocation of infrastructure is in some cases limited either due to its extreme slope, or a lack of resolution over how to deal with the intricacies of land ownership and permission to subdivide or gain access to potential areas for subdivision (e.g. Mer, Iama).

Saibai is currently susceptible to inundation due to the location of its built infrastructure that is largely located on the only high strip of land lying between the seawall and marshes towards the interior of the island. The existing culvert under the main road, along with main road itself, is unlikely to be adequate to cope with any future increases in extreme weather.

The existing built infrastructure on Boigu gains some protection from marsh water by the higher land of the airstrip that runs parallel to the coastline, but behind the major area of built infrastructure (unlike Saibai the airstrip is built roughly parallel—not perpendicular—to the main coast road). Much of the sea wall on Boigu is also of a much stronger construction than on Saibai, however it appears that several sections of this wall are not built high enough to withstand current HAT (Doust personal communication 2008) and Akiba (2009).

There are several aspects of reef-island topography that affect an island's susceptibility to sea level rise, and a great number of complications in identifying the exact nature of the relationship of the land to the highest water level (Woodroffe 2007). Woodroffe (2007) suggests a 'morphodynamic approach' to identify coral island resilience to enable a framework in which human activity (which may have conflicting impacts on natural shoreline dynamics) could be modelled. This would be an important activity prior to designing significant adaptation activities such as re-vegetation of beaches or of mangrove areas, nourishment of shorelines or construction of seawalls or break waters for the central coral cay islands.

5.3 Water shortage

All inhabited islands are currently facing water shortages; the most significant factor contributing to this problem is changes in usage habits and possibly, to some degree, changing climate (Lui personal communication 2008). As the climate projections indicate greater extremes in precipitation that may lead to longer dry seasons and/or more intense downpours, future considerations about water management need to be discussed.

It is important to note that water shortages are not a new problem in the Torres Strait. In the early 1940s, it was necessary for islanders to row from Poruma to Warraber to collect water (Billy personal communication 2008). In recent years though, many of the islands have become dependent on water desalinators. With ever increasing fuel prices, this option will become increasingly expensive for the Island councils.

6 Discussion

As previously identified, Islanders may be less resilient to the impacts of climate change than other communities in parts of Australia due to the combined risk from multiple interacting weather and climate extremes, low social and economic indicators and their cultural sensitivity to the health of their land and sea 'country'.

Torres Strait Islanders' response to climate change is, however, just as likely to be determined by social processes (e.g. decision-making) as scientific ones (e.g. what will happen with sea level). In coming years Torres Strait Island communities must attempt to prioritise a number of competing concerns of which the impacts of climate change are just one of many pressing problems requiring financial and human resources.

Like many other remote Indigenous communities, it is the community itself that is in the best position to judge what are the key priorities and to understand the context in which these decisions must be made. In the past, Torres Strait Islanders adapted to changing climate and resource constraints through various practices including temporary or permanent relocation—either on the same island, to other islands, or to the mainland (Billy and Lui personal communication 2008). This approach would be difficult today for various reasons. Relocation to other areas of an island would be extremely expensive due to major re-investment in infrastructure that would be needed, if the space was there to do so. Relatively recent land claim settlements would also make subdivisions on new areas of some islands difficult to negotiate. Relocation to other islands would not only encounter financial and land rights difficulties, but also significant cultural problems. Islanders do not want to move off their islands, and it is clear that the impact of just one community moving would impact the region by affecting the cultural, social and economic resilience of other island communities.

These kinds of adaptation strategies raise issues of equity in adaptation and climate policy more generally. For further discussion of procedural and distributive equity see Preston (2008) or Davies and Hossain (1997). It is worth noting that there are both positive adaptation activities as well as maladaptive practices that can unintentionally occur. Overlaying western concepts of community participation, for example, can lead to unreasonable expectations about community inclusion in decision-making for some Indigenous communities (see for example the Borroloola case study in Green et al. (2009)) for a discussion about problems relating to different perceptions of what can be understood as a ’community’ and how this relates to self-identified community identity based upon cultural group). Despite this, there are several existing levels of formal organisation that could be engaged with to further discussions about adaptation priorities. These include: clan leaders for each island, Prescribed Body Corporates (the holders of the Native Title for the respective Island), Island Councillors, the Torres Strait Island Regional Council (TSIRC—state level government) and the Torres Strait Regional Authority (TSRA—federal level government).

Despite the identification of the Torres Strait as one voice through the TSIRC and TSRA, each island in the Torres Strait has a unique set of circumstances and needs. Concern over the differing needs and priorities between communities living on different islands and concerns over whether resources are being distributed appropriately is an ongoing source of concern for many Island councillors.

While there is currently not enough information to assess how significant the direct and indirect impacts will be on each island, it is clear that risk management strategies in the absence of scientific certainty need to be developed. However, there are limits and barriers to adaptation that are being faced. These include severe resource limitations that constrain the ability of Islanders to be able to engage appropriate consultants to provide them with knowledge and recommendations about priorities and risks due to climate change.

In the short to medium term, alternative strategies for reducing risk could include ‘climate proofing’ significant public service infrastructure and buildings, increasing communication infrastructure and transport infrastructure on the islands. But possibly the most important strategy is to increase social and economic resilience of the communities themselves. This strategy would serve to reduce the chronic economic stress and social disadvantage that has previously been highlighted as a major barrier to responding to climate impacts.

Many Pacific Island communities have begun discussions about relocating communities off their Islands in the mid term (50–60 years). They have been working through bilateral relations with neighbouring countries with immigration requests as well as through more formal UN channels (Kelman 2008; Sercombe and Albanese nd). For some of the low-lying communities in the Torres Strait, a similar activity in this timeframe might be one option ACECRC (2008). Consideration of a relocation strategy as one of several options needs to begin now given the expense and planning that would be involved in such an endeavour.

Such an activity would in no way suggest that infrastructure and other government service investments in the communities should not be maintained or expanded, but would rather allow communities the opportunity to discuss options and alternatives for their long-term future. These decisions could only be made after adequate information is provided to Island leaders about climate impacts so that they can discuss with their community the likely risks, and come to consensus and an informed decision about their preferences for future planning and development.

At this point, there is no specific federal policy framework for these kinds of discussions to be initiated. The Torres Strait Coastal Management Committee (run through the TSRA's Land and Sea Unit) has made two submissions to the House of Representatives Standing Committee on Climate Change, Water, Environment and the Arts (Inquiry into climate change and environmental impacts on coastal communities) relating to the problems of coastal erosion and climate change. However, one of the most difficult questions to address relates to where the responsibility of decision-making actually lies. This question has not adequately been addressed to date.

One issue is clear: community-level discussions about adaptation preferences need to be clearly informed by the best available climate science as well as understanding the resources that might be available to carry out activities. Complexities occur with respect to whose expertise to rely on given the differences in culture and resources amongst the stakeholder groups (see Dessai et al. 2004). Initial studies in other regions of Australia have attempted to move beyond top-down assessments, including focus group discussions that include community participation (Kinrade and Justus 2008). Where policy is currently unclear, albeit sorely needed, it is important to ensure that once those preferences are established, there is a system by which Torres Strait Islanders are able to call upon the necessary resources to implement their decisions.

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