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Aims and scope: The *Western Indian Ocean Journal of Marine Science* provides an avenue for the wide dissemination of high quality research generated in the Western Indian Ocean (WIO) region, in particular on the sustainable use of coastal and marine resources. This is central to the goal of supporting and promoting sustainable coastal development in the region, as well as contributing to the global base of marine science. The journal publishes original research articles dealing with all aspects of marine science and coastal management. Topics include, but are not limited to: theoretical studies, oceanography, marine biology and ecology, fisheries, recovery and restoration processes, legal and institutional frameworks, and interactions/relationships between humans and the coastal and marine environment. In addition, *Western Indian Ocean Journal of Marine Science* features state-of-the-art review articles and short communications. The journal will, from time to time, consist of special issues on major events or important thematic issues. Submitted articles are subjected to standard peer-review prior to publication.

Manuscript submissions should be preferably made via the African Journals Online (AJOL) submission platform (http://www.ajol.info/index.php/wiojms/about/submissions). Any queries and further editorial correspondence should be sent by e-mail to the Chief Editor, wiojms@fc.ul.pt. Details concerning the preparation and submission of articles can be found in each issue and at http://www.wiomsa.org/wio-journal-of-marine-science/ and AJOL site.

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Word from the Editor

The last couple of years have been a time of change for the Western Indian Ocean Journal of Marine Science. The journal has a new and more modern layout, published online only, and the editorial Board was increased to include more disciplines pertaining to marine sciences. While important challenges still lie ahead, we are steadily advancing our standard to increase visibility and dissemination throughout the global scientific community. The central objective of the journal continues focused on the Western Indian Ocean region and serving its growing scientific community.

We are pleased to start the publication of special issues of the journal, launched here with the publication of manuscripts from the University of Mauritius Research Week 2016. The special issues aim to contribute for advancing marine science in the WIO by focusing on specific themes, geographical areas or assembling contributions from scientific meetings. The editorial processes are exactly the same as for regular issues, with double peer-review, and guest editors are considered.

José Paula
Chief Editor

Editorial Note · Coral reefs of Mauritius in a changing global climate

The University of Mauritius Research Week (UoM RW) has been held on an annual basis since 2007 and was organized for the 9th time from 19-23 September 2016. The Research Week is geared towards dissemination of knowledge generated through research activities at the University and by relevant stakeholders in accordance with the UoM's vision of "*Excellence in Research and Innovation*". In line with national priorities, the UoM organizes this event to provide insightful research outcomes not only for the advancement of academic knowledge, but for the benefit of the community at large, through robust policy recommendations.

Out of the multiple submissions made during the UoM RW 2016, a number of manuscripts in the field of ocean/marine sciences were selected to be published in the Western Indian Ocean Journal of Marine Science (WIOJMS), as a special issue entitled "Coral reefs of Mauritius in a changing global climate". This issue is presented in the context of Mauritius being surrounded by a beautiful but delicate coral reef ecosystem, which provides ample ecosystem services contributing to the national economy, but which is subjected to extreme climatic events. Hence, in this special issue several contributions advancing our scientific understanding for sustainable use and management of marine resources in a globally changing marine environment are articulated. The original article by Mattan-Moorgawa *et al.* investigates the photo-physiology of diseased and non-diseased corals. Coral diseases are becoming more common on reefs worldwide due to both local and global stressors. Ramah *et al.* then present a short communication related to substrate affinity by two giant clam species found on the Mauritian coral reefs. Giant clams are under threat worldwide and information on their substrate affinity and habitat aims at providing insightful information towards their sustainable management. In addition, Nandoo *et al.*, in an effort to optimize nucleic acid extraction protocols from marine gastropods, present an original article based on a comparative study using the gastropod genera *Planaxis*, *Cypraea* and *Drupella*. These marine gastropods are ecologically important for coral reefs, especially the coral-eating *Drupella*. Moreover, given the importance of intertidal molluscs, Kaullysing *et al.* document the density and diversity of the benthic molluscs while comparing sheltered and exposed coastal habitats. Appadoo & Beeltah report on the biology of *Platorchestia* sp. (Crustacea, Amphipoda) at Poste La Fayette, Mauritius. Studies on Amphipod diversity and distribution are important especially since studies on marine biodiversity are scarce around Mauritius. Another original article by Ragoonaden *et al*. analyses the recent acceleration of sea level rise in Mauritius and Rodrigues. Such studies are more important than ever in the light of a globally changing marine environment with small island states faced with issues related to rising sea level. Two field notes, based on field observations, are presented by Bhagooli *et al.*, documenting a variety of coral diseases, and *Stylophora pistillata*-like morphotypes occurring around Mauritius Island, respectively. Kaullysing *et al.* also present a field note on coral-eating gastropods observed around Mauritius.

Apart from the local contributors, international collaborators also contribute two original articles in this special issue. Casareto *et al.* characterize the chemical and biological aspects of a coral reef of Mauritius focusing on benthic carbon and nitrogen fixation. These studies related to benthic productivity are important for understanding sustainability of coral reefs and/or lagoonal fisheries. On the other hand, Tokumoto *et al.* document the first detection of membrane progestin receptor (mPR)-interacting compounds from Mauritian coral reef and lagoonal seawater. They used cutting-edge technology to detect key regulators of reproduction in seawater. These contributions in terms of original articles, short communications, and field notes generate new scientific knowledge that may better inform policy and decision making in the field of coral reef studies and management in Mauritius, while contributing to the understanding of coral reefs in the wider Western Indian Ocean region.

Prof. Sanjeev K. Sobhee
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Recent acceleration of sea level rise in Mauritius and Rodrigues

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Abstract

Over much of the 20th Century, global mean sea level rose at a rate between 1.3 to 1.7 mm yr^{-1}. In the last decade, satellite and in situ data indicate that global sea level rise (SLR) has been accelerating to around 3.2 mm yr^{-1} due mainly to temperature increase, enhanced melting of the ice caps, with marked regional variation. Analysis of research-quality sea level data for Mauritius and Rodrigues also indicates a recent accelerated SLR, of more than the global average (5.0 mm yr^{-1} at Mauritius and 9.0 mm yr^{-1} at Rodrigues). Physical evidence and anecdotes indicate that coastal erosion has also increased in the region. However, no long term series of reliable data on coastal erosion is available to determine if there is any linkage between the recent accelerated SLR and the observed increase in coastal erosion in Mauritius and Rodrigues. Global sea level is set to rise more than expected in the light of new findings and continue during the next century. This will, no doubt, have regional and local impacts with severely disruptive consequences for human society and ecosystems in the Republic of Mauritius. Precautionary and proactive measures need to be undertaken to address this fundamental issue.

Keywords: Recent sea level rise, accelerated sea level rise, sea level rise in Mauritius and Rodrigues

Introduction

Warming of the climate system is unequivocal (IPCC, 2013). Since the 1950s, many of the observed changes have been unprecedented. The atmosphere and the ocean have warmed, the amount of snow and ice has diminished and the concentration of greenhouse gases has increased. There has been an overall decrease in the number of cold days and nights, and an overall increase in the number of warm days and nights at the global scale. The number of warm spells or heat waves has increased. It is very likely that all these changes are taking place because of human activities (IPCC, 2013). One of the direct consequences of global warming is Sea Level Rise (SLR). Only small amounts of warming are needed to have a significant effect on sea levels. SLR is becoming increasingly important as a hazard to humans and urban areas in the coastal zone worldwide as global climate change takes effect (Williams, 2013). There is strong agreement among scientists that sea levels will rise by as much as 1 m by 2100 in response to a warming climate (Willis & Church,2012). It is projected that anthropogenic warming and SLR will continue for centuries due to the time scales associated with climate processes and feedbacks, even if Greenhouse Gas (GHG) concentrations were to be stabilized (IPCC, 2007). Intertidal coastal ecosystems and resources are likely to be the first to experience SLR-related effects (Thorner *et al*., 2014)

Analysis of sea level data from in-situ observations and satellite altimeters since 1992 indicates an accelerated rise in sea level to more than 3.0 mm yr^{-1} (Dutton *et al*., 2015; Nerem *et al.,* 2010). SLR poses one of the most widely recognized climate change threats to low-lying coastal areas (Church & White, 2011; Nicholls & Cazenave, 2010). This is particularly important in small islands such as Mauritius and Rodrigues where the coastal zones play a central part in the socio-economic development of the countries.

Characteristics of Mauritius and Rodrigues

Mauritius forms part of the Mascarene group of islands comprising Rodrigues and Réunion (Fig. 1). Mauritius has an area of 1 865 km², was formed by volcanic activity some 12 million years ago and consists of basaltic rocks, except for the sandy beaches and fringing coral reefs, which surround most of the 322 km of coastline. It has a coral reef length of 150 km, which encloses a lagoon area of 243 km². The area of coral reef is about 300 km². The island's topography is characterized by undulating plains in the North, East and West, and an irregular Central Plateau with a mean elevation of 300-400 m with the highest peak rising to 828 m (SNC, 2010).

Rodrigues is 108 km² in size and is relatively hilly. It is dominated by a steep central ridge, which crosses the island from the East to the South West, tapering into a coral plain, with deep river valleys eroded into that ridge. The island is surrounded by the largest reef-enclosed lagoon of the Indian Ocean. The shoreline consists of 70% rocky coast, 21% of silt-clay coast and 9% of coral and sand beaches. The tidal range is a maximum of 1.5 m which results in parts of the lagoon and reef front drying at low tide. There is a marine park in the South East (SEMPA) and the setting up of four Marine Reserves is being planned (Republic of Mauritius (2016); MEO, 2011). Rodrigues forms part of the Republic of Mauritius and is located about 630 km to the east of Mauritius.

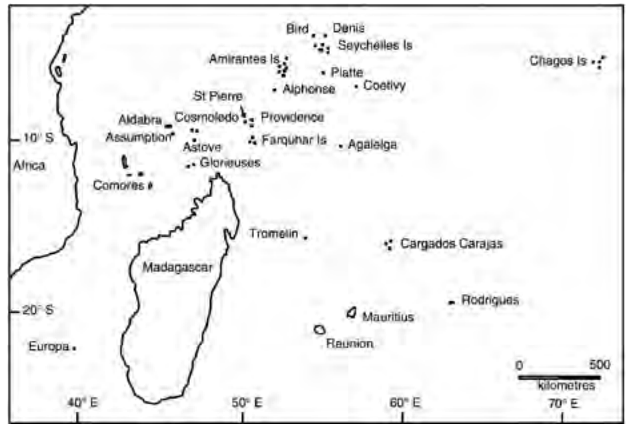


Figure 1. Map of the South West Indian Ocean

In both Mauritius and Rodrigues, the coastal areas support a number of activities including tourism, recreation, fisheries, trade, and industry. The total economic value is of the order of USD 28.5 Million, and constitutes one of the main assets in Mauritius (Landell Mills, 2009). The tourism industry, which is predominantly coastal based, contributed to 12% of GDP, and created direct employment for around 30 000 people in 2016 in Mauritius (GOM, 2016).

Sea level data used in the study, and methodology

Continuous sea level monitoring in the Western Indian Ocean (WIO) started in 1986, within the framework of

Table 1. Data information for the Port Louis (Mauritius) and Port Mathurin (Rodrigues) Sea level stations

Period	Instrument type
Mauritius (20° 09' S 57° 40' E)	
1986-1992	Leupold and Stevens model A-71 float and stilling well
1993 – October 2013	Handar 436-A, Encoder
October 2013 – December 2014	radar gauge (Vega Vegapuls 62)
Rodrigues (19° 30' S 56° 30' E)	
1986-1992	Leupold and Stevens model A-71 float and stilling well
1997-1998,2000	Handar 436B3 with datalogger
2009-2012	Radar gauge (Vega Vegapuls 62) with gaps filled with Sutron Stage Discharge Recorder
January 2013- October 2013	Handar 436-A, Encoder
November 2013- December 2013	Handar 436B3 with datalogger
2014	radar gauge (Vega Vegapuls 62)

Figure 2. Sea level Station at Port Mathurin (Rodrigues)
Courtesy: Mr. Nand Sooredoo

the 10-year Tropical Ocean Global Atmosphere programme (TOGA) from 1985 to 1995, a component of the World Climate Research Programme (WCRP) of the World Meteorological Organization (WMO), Intergovernmental Oceanographic Commission (IOC) of UNESCO and International Council for Science (ICSU). Under this programme, two float and stilling well sea level stations were established, at Port Louis (Mauritius) in August 1986, and Port Mathurin (Rodrigues) in November 1986, in order to obtain continuous analog data. From 1993, the two stations were upgraded to digital instrument type. They now form part of the WMO/IOC Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM) Global Sea Level Observing System (GLOSS) programme, the main aim of which is the establishment of global and regional sea level networks for oceanographic, climate change and coastal research purposes.

Table 1 shows the type of instrument providing the original data from the two stations. They are operated by the Mauritius Meteorological Services. Technicians from overseas under the GLOSS programme visit the stations, at least once every two years, for maintenance purposes.

Daily research-quality Sea Level data from 1986 to December 2014 were obtained from the University of Hawaii Sea Level Center (UHSLC) website (http://uhslc.soest.hawaii.edu/data/?rq). Monthly average values for each station were obtained from the average of all daily and annual average values from the average of all monthly values. For both Mauritius and Rodrigues, the daily or monthly means do not reveal any obvious reference level changes or trends. The vertical movement of the tide gauge equipment fixed on the Port quays in both Mauritius and Rodrigues (Fig. 2) is considered as negligible.

Data for 1986 have not been used as many months are missing. Timing errors have also been noted in the hourly data for Rodrigues, particularly for 1987, and the values for that year have also been ignored in the study. Additional information on the research data series for Mauritius and Rodrigues are available from the University of Hawaii Sea Level Center (UHSLC) website (http://uhslc.soest.hawaii.edu/data/?rq) and in Caldwell *et al.* (2015). Time series plotting of annual values for the period 1987 – 2014 for Mauritius and 1988 – 2014 for Rodrigues were constructed and lines of best-fit regression (Fig.3 a, b) were then added to the plots.

It is noted that a sudden rise occurred at the beginning of 2000s for both Mauritius and Rodrigues. Time series plotting of annual values for the two periods (1987 – 2003 and 2003 to 2014 for Mauritius and 1988 – 2002 and 2002 to 2014 for Rodrigues) were constructed and lines of best-fit regression (Fig.4 a,b) were then added to the plots.

Results of the study

Figures 3 a and b show the rising sea level trend for Mauritius and Rodrigues. The Mean SLR (MSLR) for Mauritius is 3.8 mm yr^{-1} and 6.5 mm yr^{-1} for Rodrigues (Table 1). It is noted that there could have been a datum shift in the Rodrigues time series in around 2002, explaining why the rise at Rodrigues is much more than that of Mauritius. Nonetheless, the steep rise as from 2002 is clear.

On the other hand, it can be observed from Fig. 4 a and b that there was a sea level fall (- 0.7 mm yr^{-1}) from 1987 to 2003 for Mauritius and a slight rise (+ 0.8 mm yr^{-1}) from 1988 to 2002 for Rodrigues,

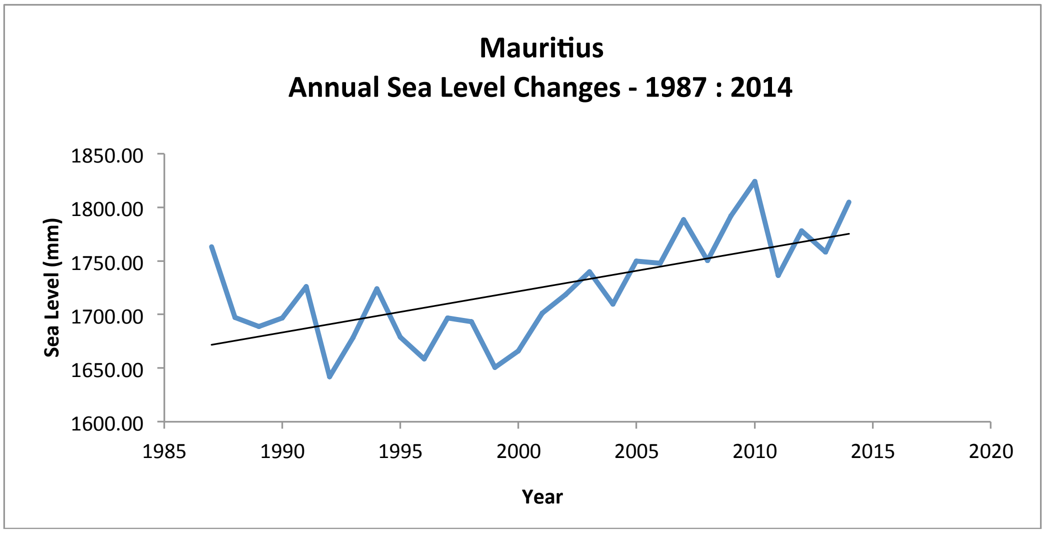


Figure 3a. Annual sea level changes for the period 1987 to 2014 at Mauritius

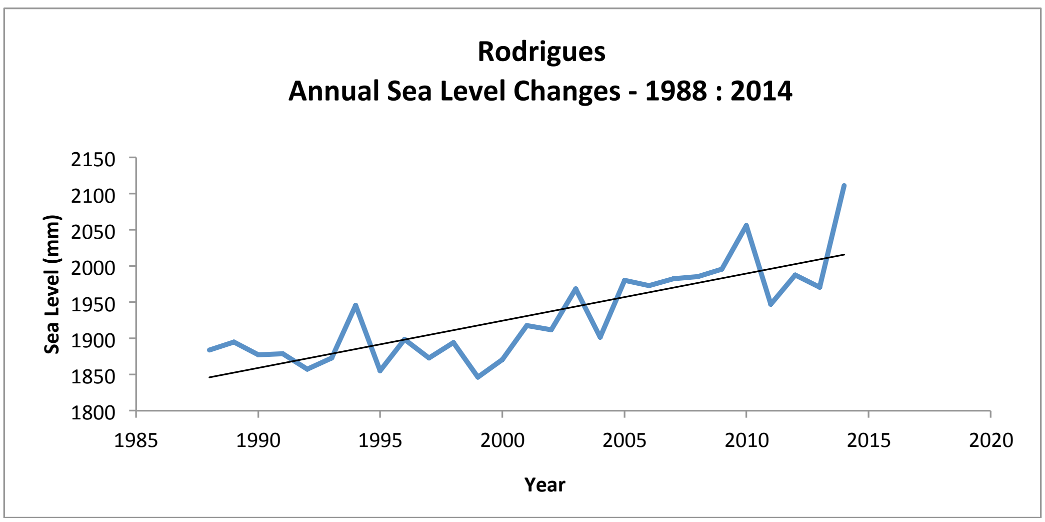


Figure 3b. Annual sea level changes for the period 1988 to 2014 at Rodrigues

confirming what Ragoonaden (2006) and Church *et al.* (2006) had observed. However, after these periods, the sea level rose quite sharply with an average rate of 5.0 mm yr^{-1} for Mauritius and 9.0 mm yr^{-1} for Rodrigues (Table 2).

The annual mean varies from year to year, and in some cases quite significantly. A large drop in sea level occurred from 2010 to 2011 for both Mauritius and Rodrigues and the difference was 8.7 cm and 10.9 cm respectively. A significant rise of 14.0 cm occurred in Rodrigues from 2013 to 2014. The rise was also observed in Mauritius but with a value of only 4.7 cm. The average inter-annual range is 17.2 cm and 14.4 cm for Mauritius and Rodrigues respectively. Other information is given in Table 3.

Discussion

Over much of the 20th Century, global mean sea level rose at a rate of between 1.3 to 1.7 mm yr^{-1} (IPCC, 2013). The average global sea level trend for the period between 1962 and 1990 was 1.5 ± 0.5 mm yr^{-1}, in agreement with previous estimates of late twentieth-century sea level rise (Merrifield *et al.,* 2009). However, they found that after 1990, the global trend increased to the most recent rate of 3.2 ± 0.4 mm yr^{-1}, matching estimates obtained from satellite altimetry. This was confirmed by Church & White (2011), who found that since the start of the altimeter record in 1993, global average sea level, after correcting for glacial isostatic adjustment, rose at the estimated rate of 3.2 ± 0.4 mm yr^{-1} from satellite data and 2.8 ± 0.8 mm yr^{-1} from in situ data. Furthermore,

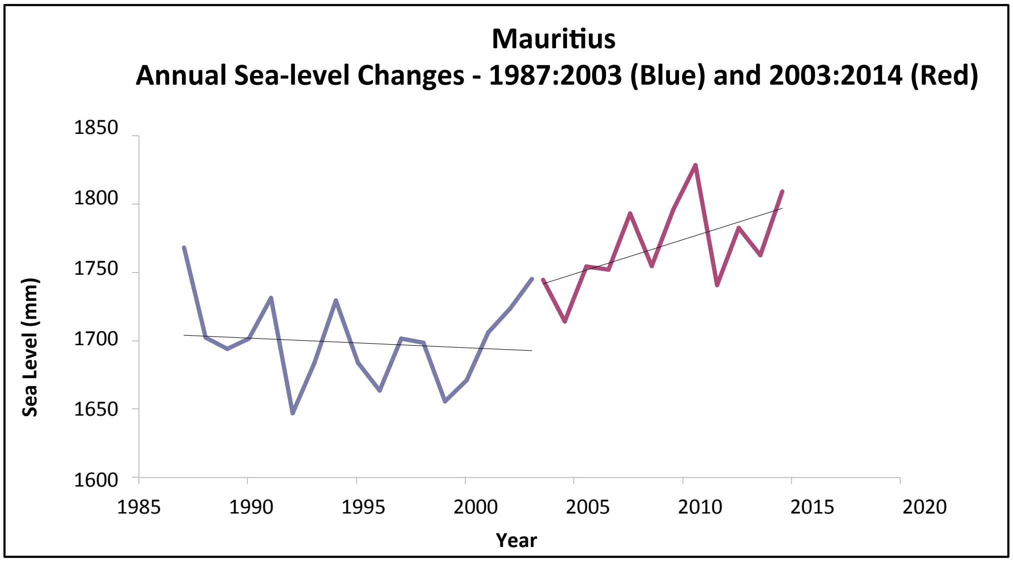


Figure 4a. Annual Sea level changes at Mauritius

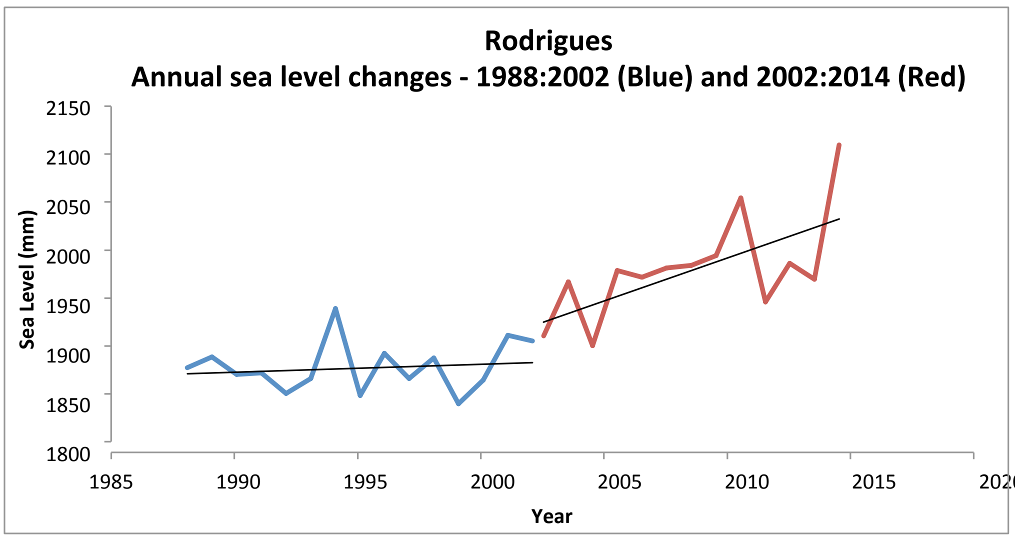


Figure 4b. Annual sea level changes at Rodrigues

applying probabilistic techniques to more recent tidal-gauge data (between 1993 and 2010), a mean SLR of 3 mm yr^{-1} in that period has been estimated, almost exactly the same as that from satellite data, thus confirming that sea levels are now rising more than previously (Hay *et al.,* 2015).

Over the period 1993 to 2010, global mean SLR was, with high confidence, consistent with the sum of the observed contributions from ocean thermal expansion due to warming (1.1 mm yr^{-1}), from changes in glaciers (0.76 mm yr^{-1}), Greenland ice sheet (0.33 mm yr^{-1}), Antarctic ice sheet (0.27 mm yr^{-1}), and land water storage (0.38 mm yr^{-1}). The sum of these contributions is 2.8 mm yr^{-1} (IPCC, 2013).

Rates of SLR are, however, not uniform across the globe and large regional differences have been detected, including in the Indian Ocean and tropical Pacific, where in some parts rates have been significantly higher than the global average (Meyssignac & Cazenave, 2012). In the tropical western Pacific, where a large number of small island communities exist, rates up to four times the global average (approximately 12 mm yr^{-1}) have been reported between 1993 and 2009 (IPCC, 2013).

In the region of Diego Garcia in the Central Indian Ocean, the secular trend is about 3 mm yr^{-1} with a standard error of about 0.6 mm yr^{-1} (Woodworth, 2014). The trend observed is similar to the reported global average of 3.2 ± 0.4 mm yr^{-1} over a comparable

Table 2. Average Rate (mm yr^{-1}) of sea level rise for Mauritius (1987- 2014) and Rodrigues (1988-2014)

Station	Period/average annual rate (mm yr^{-1})	Period / average annual rate (mm yr^{-1})	
Mauritius	1987 -2014	1987-2003	2003-2014
	3.8	0.7	+5.0
Rodrigues	1988-2014	1988- 2002	2003-2014
	6.5	+0.8	+9.0

period (IPCC, 2013). On the other hand, Palanisamy *et al.* (2014) estimated SLR in the Indian Ocean (20°E - 140°E, 30°N-35°S) over a period of 60 years from 1950 to 2009 to be 1.5 mm/yr, and over most of the individual locations to be within the mean SLR.

Satellite altimetry is now providing accurate regional sea level data on a large scale. A series of satellite missions that started with TOPEX/Poseidon (T/P) in 1992 and continued with Jason-1 (2001–2013) and Jason-2 (2008–present), estimate global mean sea level every 10 days. Figure 5 shows clearly the SLR in the region of the Mascarenes Islands.

By analyzing an improved historic tide gauge data set, for the period January 1900 to December 2006, filling gaps in 178 records of sea level change and satellite altimetry to extrapolate local sea level change to global fields, Wenzel & Schroter (2014) found global mean sea level change since 1900 to be 1.77 ± 0.38 mm yr^{-1} on average. However, positive local trends were identified with the highest values found in the western tropical Pacific and in the Indian Ocean east of Madagascar where it reaches about + 6 mm yr^{-1}.

Probable causes of the observed accelerated sea level rise

The timing of the global acceleration corresponds to similar sea level trend changes associated with upper ocean heat content and ice melt (Merrifield *et al.*, 2009). The Earth is continuously gaining energy from greenhouse gases. It is gaining perhaps as much as 1 Watt of heat for every square meter of surface area. Most of this heat is fortunately absorbed by the ocean through its large depth. Evidence of sub surface ocean temperature increase has been obtained recently by the Argo fleet of floats which is scattered across the globe measuring temperature down to 2,000 meters. Figure 6a shows ocean temperature anomaly between 0 and 100 m, and 6b shows heat content anomaly between 0 and 2000 m.

The ocean heat content has increased significantly since the 1950s with sea surface temperatures higher during the past three decades (EPA, 2014). The ocean warming is largest near the surface, and the upper 75 m warmed by 0.11 °C per decade over the period 1971 to 2010 (IPCC, 2013). Glaciers worldwide have been losing mass since at least the 1970s and the rate at which glaciers are losing mass appears to have accelerated since then. Arctic sea ice in September 2012 had the lowest extent on record, 49 percent below the 1979-2000 average of that month. Greenland, which has the potential to raise sea level by 6 m if all its ice melts and flows to the oceans, is losing 350 giga tonnes of ice annually; 50% from ice melt, and 50% from glaciers moving into the ocean, gradually raising the global sea level each year (EPA, 2014).

Table 3. Inter- annual and intra-annual sea level at Mauritius (1987-2014) and Rodrigues (1988-2014)

	Mauritius	Range (cm)	Rodrigues	Range (cm)
Highest sea level	6 February 2014	69.8	20 December 2013	77.8
Lowest sea level	15 August 1995		21 September 1993	
Highest monthly sea level	December 2012	43.9	December 2014	57.0
Lowest monthly sea level	July 1992		September 1993	
Highest annual sea level	2010	18.2	2014	26.5
Lowest annual sea level	1992		1999	

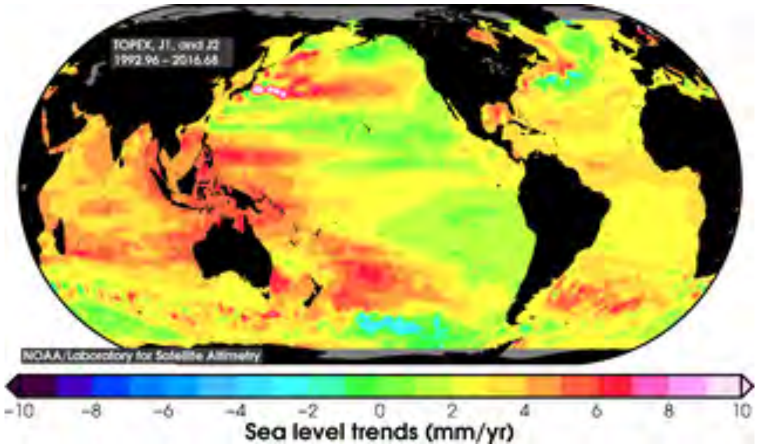


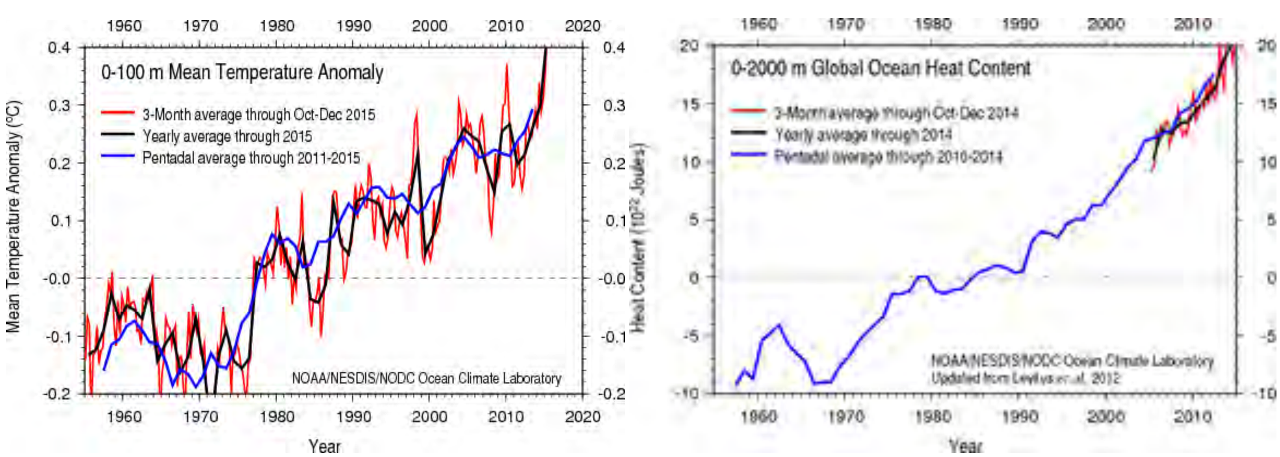
Figure 5. Sea level variation trend from altimetry data
Source: NOAA/N/ESDIS/STAR (2015).

At the regional level, analysis of two and a half decades of data of ocean surface height measurements from the Gravity Recovery and Climate Experiment (GRACE), satellite has shown a substantial and abrupt increase in decade-long sea level trends in the Indian Ocean region from 2002 (Thompton *et al*, 2016), as shown in Fig. 7. Using computer simulations of ocean circulation to understand the shift, they argued that trade winds in the Indian Ocean were weaker north of the equator compared to the south, causing colder and deep water to move in from the Northern Hemisphere. This had a net cooling effect on the ocean leading to the suppression of SLR during the 1990s and early 2000s, as found also in sea level records from Mauritius and Rodrigues. Since that period, the situation had reversed, causing heat to build up in the northern Indian Ocean and enhancing the rate of sea level rise. The study provides some evidence that interaction between the ocean and atmosphere could cause sea level to rise sporadically.

Impacts of sea level rise

It is very likely that mean SLR will contribute to upward trends in extreme coastal high water levels in the future (IPCC, 2013; Menéndez & Woodworth, 2010). Locations currently experiencing adverse impacts such as coastal erosion and inundation will continue to do so in the future due to increasing sea levels, given that all other contributing factors remain equal. Contribution of mean SLR to increased extreme coastal high water levels, coupled with the likely increase in tropical cyclone maximum wind speed, is a real threat to tropical small island states.

Many countries around the globe are already experiencing the adverse effects of sea level rise. Vanuatu



a) 0-100 m Mean Temperature Anomaly **(b) 0-2000 m Global Ocean Heat Content**

Figure 6. (a) Mean Ocean Temperature Anomaly from 0 to 100 m (b) Global Ocean Heat Content from 0 to 2000 m
Courtesy: NOAA/NESDS/NODC Ocean Climate Laboratory

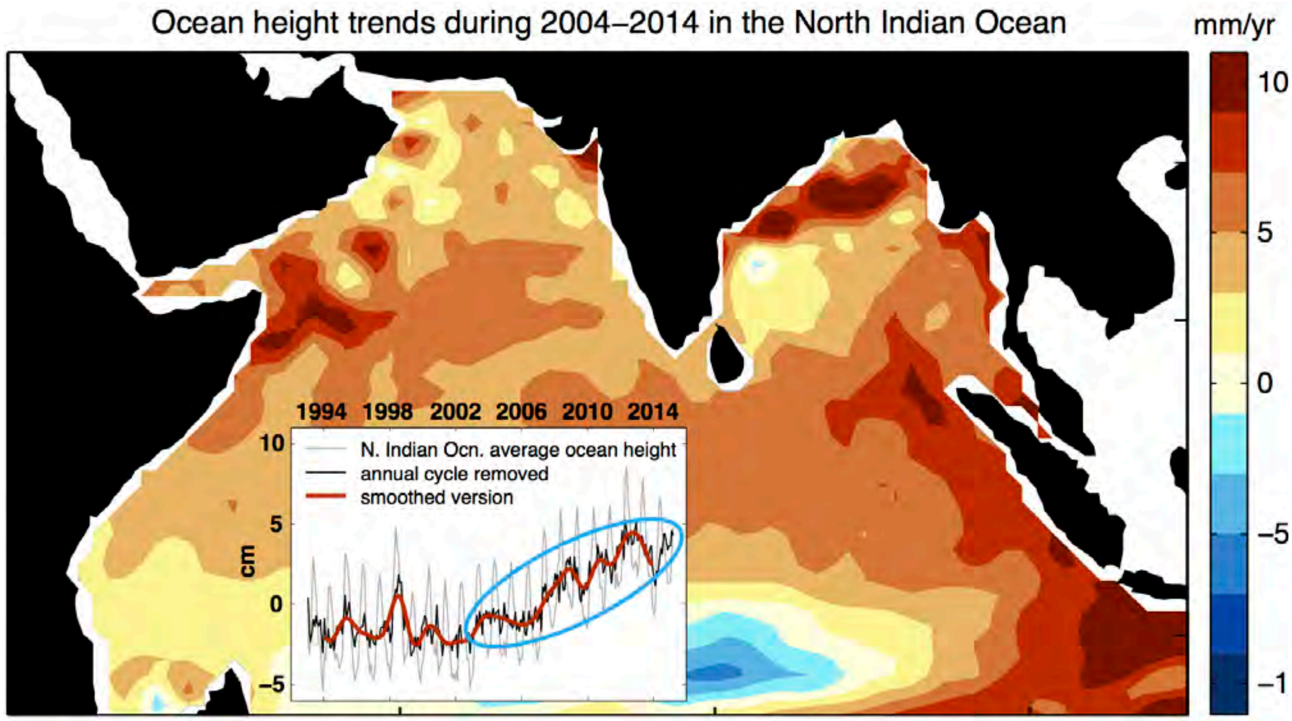


Figure 7. Ocean height over the equatorial and northern Indian Ocean during 2004-2014. The inset shows the average ocean height since 1994 from satellites data
Source: Thompson *et al.*(2016)

communities have been displaced due to increasing inundation of low-lying settlement areas due to a combination of tectonic subsidence and sea-level rise (Ballu *et al.,* 2011). Hoeke *et al*. (2013) describe a 2008 widespread inundation event that displaced some 63,000 people in Papua New Guinea and the Solomon Islands. That event was primarily caused by remotely generated swell waves, and the severity of flooding was greatly increased by anomalously high regional sea levels linked with ENSO and on-going sea-level rise.

Salt water intrusion due to sea level rise

It is generally agreed that SLR will cause intrusion of saltwater into groundwater systems by changing the elevation of the freshwater-saltwater interface, though some studies (e.g. Chang *et al.,* 2011) show sea-level rise will have no long-term impact on salt water intrusion in confined aquifers, and a lesser influence in unconfined systems. On the other hand, Carretero *et al.* (2013) found that the impact on water resources of a potential 1 m rise in sea level in the low-lying coast region can result in saltwater penetrating landward between 25 and 40 m, and even in excess of 200 m or more in some other conditions.

In Mauritius, sea water intrusion has been observed (Republic of Mauritius (2016); FAREI, 2015) in the water ponds on farms in the south eastern and south coastal belts (areas such as Belle Mare, Palmar, Quatre Soeurs and Deux Frères, Bambous Virieux and Pomponette). To address the problem, farmers have been trained in salinity management through monitoring of salinity of irrigation water of the ponds prior to irrigation especially during drought periods. To cope with the salinity conditions occurring in the summer months, farmers in these areas have adopted saline-tolerant crop varieties, such as eggplant, chili, tomato and creepers, and planting on raised beds for efficient drainage, and the use of organic manure for soil amendment to improve the water infiltration rate. In Rodrigues, sea water intrusion is also affecting coastal agriculture (TNC, 2016).

Coastal erosion

Accelerated coastal erosion has already been observed in many regions around the globe. On the tropical islands of Kauai and Maui, Hawaii, Romine & Fletcher (2013) found that shoreline change was highly variable over the last century but that recently, chronic erosion predominated with over 70% of beaches now being eroded. Romine *et al.* (2013) found that Maui Island in Hawaii has been eroding (13 cm yr^{-1}) far more than the Oahu Island (3 cm yr^{-1}) and concluded that SLR may be the main force driving beach erosion. Ford's (2013) investigation of Wotje Atoll, Marshall Islands, also found shoreline variability between 1945 and 2010, but, from 2004 to the present, 17 out of 18 islands became net eroding, potentially coinciding with the high sea levels in the region over the last 10 years.

Sea level rise constitutes a real threat to coastal resources in Mauritius and Rodrigues, in particular to sandy beaches, which are the main tourism attractions. The tourism industry contributes around 12% to the GDP. A study on coastal erosion for fourteen sites (JICA, 2015), which included sandy beaches and cliffs, using aerial photographs under the Environment, Climate Change Adaptation and Disaster Management Scheme funded by the Japanese International Cooperation Agency (JICA), showed that about 17% of the beaches are suffering from long term erosion and that around 23% are being accreted. The remaining beaches are considered stable. Eighteen coasts show an erosion rate of the shoreline of 0.2 m yr^{-1} or greater on a long term basis, with short term change of 0.5 m yr^{-1} on average. At Pointe aux Cannoniers, in the north of the island, the shoreline has retreated by 10 m on average and up to 18 m within the 45 years from 1967, with the volume of sediment loss amounting to 10,000 m^3. The degradation has been caused by rapid erosion resulting mainly from cyclones and heavy swells generated by polar lows far to the south of the Mascarenes Islands.

The degradation of coral reefs (MEO, 2011) might be one of the reasons for the decrease of sand supply and one of the causes of beach erosion, due to reduced protection of the coastal zone. The erosion process could also have been exacerbated by rapid development in the coastal zone, construction within the dynamic beach zone, and previous lagoonal sand mining activities. It is very likely that SLR has also contributed to the aggravation of coastal erosion.

Coral bleaching as a consequence of global warming will also become more frequent exacerbating local stresses driving reefs increasingly towards the tipping point for functional collapse (Hoegh-Guldberg *et al.,* 2007), hence contributing to a decrease in beach and lagoon sand supply. There is very high confidence (IPCC, 2014) that coral bleaching and mortality will increase in frequency and magnitude over the next decades (Logan *et al.,* 2014; van Hooidonk *et al.,* 2013). Although the coral reefs of Mauritius largely escaped the severe warming in 1998, most probably due to massive cloud cover during the critical months, some 70% bleaching and some 40 - 50% mortality of corals were recorded between January and March 2009. The bleached tabular Acroporids suffered almost 100% mortality (Bhagooli & Sheppard, 2012).

In Mauritius, coastal erosion is becoming gradually more pronounced with several popular beaches impacted (Box 1) and coastal inundation occurrences more frequent.

At La Preneuse, located on the central western coast of Mauritius, a marked change in the position of the shoreline from 2011 to 2014 has been observed (Fig. 8). The green grass line, which is an indication of sea water penetration, can clearly be seen to have receded landward, resulting in significant beach loss. At Riviere des Galets in the south, coastal inundation is becoming a regular feature as a consequence of more frequent heavy southerly swells generated by the passage of polar lows far to the south of the region, putting at risk the life of about 100 families of the small village. A protection gabion wall was erected about 15 years ago but it did not prove effective against the repeated swell occurrences. A few years later, a second vertical boundary wall was constructed. Though it reduced the wave effects, it did not stop overtopping and flooding of the village. Riviere des Galets has been identified as an urgent case regarding protection under the Climate Change Adaptation Programme (Ministry of Social Security, National Solidarity, and Environment and Sustainable Development). A rehabilitation project is now underway. Climate change impacts and accelerated SLR are being taken into consideration in the design of the protection structure.

Future sea level rise

Warming will most likely continue beyond 2100 (IPCC, 2013). The IPCC Fifth Assessment Report (AR5), which was the first coordinated intergovernmental assessment that included carbon cycle emissions and concentrations to diagnose carbon cycle feedbacks to the Earth system using the Representative Concentration Pathways (RCP) concept (Moss *et al.*, 2010), to predict the future, has updated previous prediction. Global surface temperature change for the end of the 21st century is likely to exceed 1.5°C relative to 1850 to 1900 (IPCC, 2013). Global mean SLR for 2081–2100 relative to 1986–2005 (Fig.9) will likely be in the range of 0.32 to 0.63 m for RCP 4.5, which assumes an intermediate stabilization leading to 4.5 W/m^2 radiating forcing by 2100 (IPCC, 2013). For RCP 8.5 that assumes very high GHG emissions

Coastal erosion and inundation in Mauritius and Rodrigues

According to the World Risk Report 2016, Mauritius is ranked as the 13th country (14th in 2014) with the highest disaster risk exposed to natural hazards, including storms and floods. The impacts of climate change and accelerated sea level impacts are already being felt through increase in frequency and intensity of extreme weather events and accentuated beach erosion. Coral bleaching occurred in 1998, 2003, 2004 and 2009. In 2003, the percentage of coral bleaching in Ile aux Benitiers, Poudre d'Or and Belle Mare was 56%, 22% and 11% respectively. Through surveys, it has been found that 17% of the beaches are suffering from erosion, representing about 13 km of beaches. Thirteen beaches having long term long term erosional characteristics and vulnerable to climate change and sea level rise have been examined to determine setback distance. At Mon Choisy in the north, for instance, comparing aerial and satellite photographs in 1967 and 1980, it was found that the shoreline has eroded by 12 m on average and the maximum value during the 45 years period was 18 m.

Coastal inundation is expected to worsen. The settlements and infrastructure at risk from coastal inundation are given in the table below:

Coastal Inundation	Mauritius	Rodrigues
Built-up land (km^{2})	12.2	0.56
Expansion areas (km^{2})	11.8	-
Primary roads (km)	60	22
Secondary roads (km)	80	23

The cost of damages to building and infrastructures for coastal inundation in 50 years (2070 horizon) have been estimated to be around 1.4 Billion USD for Mauritius and 43 Million USD for Rodrigues.

Sources: Ministry of Environment and Sustainable Development (2012). JICA (2015)

leading to 8.5 W/m^2 radiating forcing, a rise by the year 2100 of 0.52 to 0.98 m, with a rate during 2081 to 2100 of 8 to 16 mm yr^{-1}. Other studies have found that global mean sea level could rise 32 cm in the next 40 years (Rignot *et al.*, 2011) and reach 75 to 190 cm over the next century (Vermeer & Rahmstorf, 2009).

The projected rise in sea level will most likely have profound impacts on coastal zones. Taking into consideration a projected rise of 1 m, a value which is being adopted in many countries, it is estimated that, as a consequence of equilibrium response to SLR (Bruun, 1962), about 100 to 200 m of beaches will be eroded by the end of this century. Hence, coastal erosion around Mauritius and Rodrigues may be expected to increase dangerously and consequently threaten many coastal infrastructures and settlements.

Coastal loss as a consequence of sea level rise for the Mauritian islands

Sea level rise for Mauritius has been projected for different time horizons to 2050, 2080 and 2100, taking the IPCC SRES A1F1 emission scenario in the Second National Communication (SNC, 2010). The expected SLR amounts to 16 cm, 35 cm and 49 cm, respectively. This will result in permanent loss of beaches. As such, infrastructure in the coastal zone is at risk and will likely result in coastal environment degradation such as erosion and the deterioration of the coral-reef ecosystem. The biophysical, physical and socio-economic activities associated with the coastal zone will be placed under increased stress with the impacts of the projected SLR combined with projected increase in the intensity of extreme events.

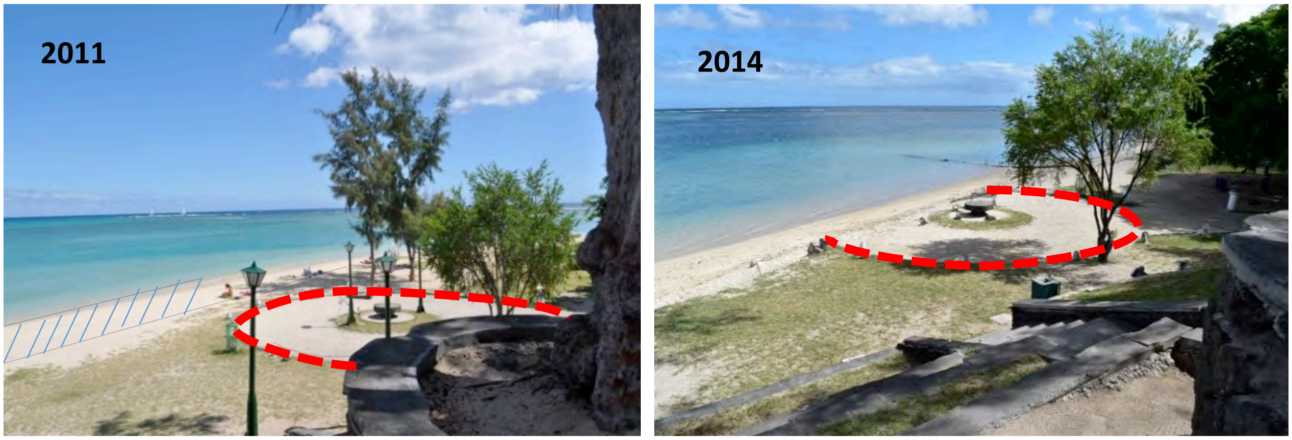


Figure 8. Shoreline change from 2011 to 2014 at La Preneuse located on the western coast of Mauritius
Source: Ministry of Environment, Sustainable Development, Disaster and Beach Management (2015)

To estimate coastal loss due to a SLR of 1 m around Mauritius, different available Digital Elevation Models (DEMs) (Republic of Mauritius (2012) with a resolution of 10 m have been used. The risk map (Fig. 10) shows that most of the investigated coastal perimeter is at risk, limited to a strip that is usually less than 100 m inland, particularly in the north east and in the region of Le Morne, in the south west. The higher risk areas are mainly represented by wetlands, low lying islets, or areas close to river inlets.

Moreover, if the proposed rise in Mean Sea Level for the different horizons, coupled with ongoing storm surges, results in higher over topping levels, then it can be expected that there will be extensive inundation in the coastal areas, which would be both damaging and detrimental to infrastructure and the economy. The tourism industry is mostly coastal-based and will be predominantly affected, putting much pressure on the economy.

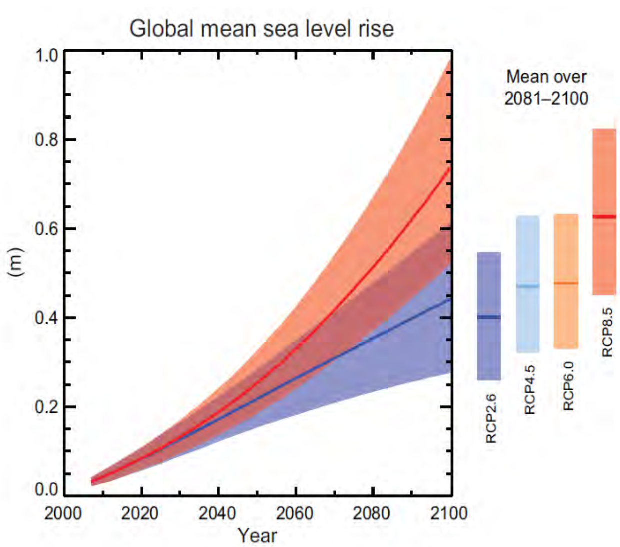


Figure 9. Projected global average sea level rise up to 2100
Source: IPCC (2013)

Concluding remarks

In the past decade, as shown above, global, regional and local SLR has been accelerating. This period is, however, too short to state with certainty that the current global rate of change is unprecedented in historical times. There are indications of similar rates of rise in the period 1930–1950 (Woodworth *et al.*, 2009). Past sea level changes cannot be simply extrapolated to determine future shoreline response. It is not possible to state with confidence, on the basis of 29 years of data, whether the present accelerated trend in the region of Mauritius and Rodrigues will continue. According to the IPCC, at least 50 years of continuous rise is needed to establish a statistically robust trend. Hence, the Mauritius and Rodrigues Sea Level stations need to be maintained properly and sustainably to obtain a longer term series of sea level data.

On the other hand, it is most likely that atmospheric warming will continue and cause further ice loss. Antarctica alone has the potential to contribute more than a metre of sea-level rise by 2100 and more than 15 metres by 2500 (DeConto & Pollard, 2016). Hansen *et al.* (2016) found from paleoclimate evidence and ongoing observations that a 2 °C global warming above the preindustrial level could be dangerous and that rapid SLR may begin sooner than generally assumed-with increased shoreline erosion and increased flooding during cyclones (Passeri *et al*, 2015). Various studies have contributed to an improved understanding of island shoreline processes and change since IPCC AR5, and the warning of increased vulnerability of small island shores and low-lying areas to inundation and

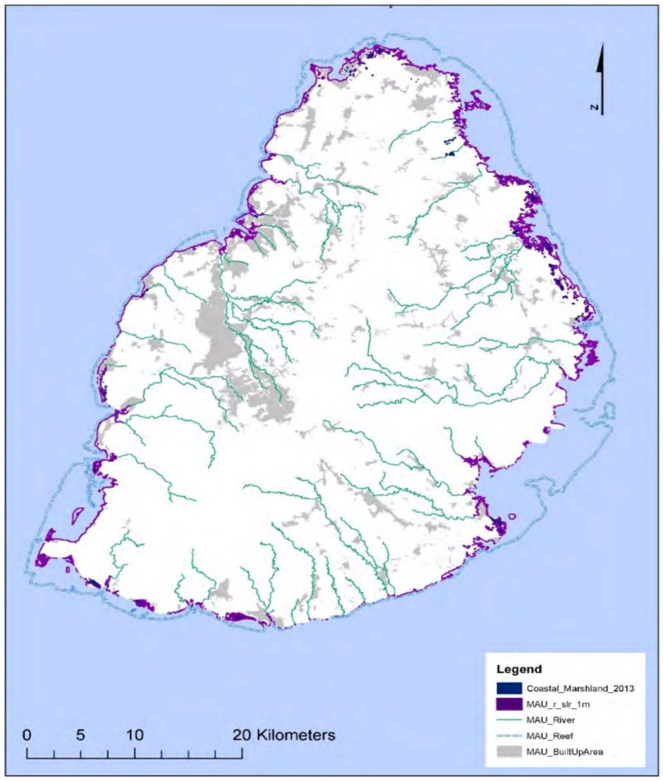


Figure 10. Risk map of sea-level rise inundation based on a 10 m Digital Elevation Model for Mauritius
Source: Republic of Mauritius, (2012)

erosion in response to sea-level rise and other potential climate change stressors has been underscored.

Consequently, precautionary and proactive measures need to be taken to protect coastal infrastructure and resources from projected SLR to sustain the goods and services of coastal ecosystems and resources for the welfare of the population. For medium and long term planning under future sea level predictions, coastal scientists and engineers need reliable information and data to make informed decision for managing human and natural communities.

This study has provided an indication on the possible impacts of future sea level rise. However, there is still much to be done to consolidate the findings for optimum application. The rate of SLR needs to be refined by taking into consideration ex-situ factors such as Global Sea Level Change and Regional Tidal Elevation Surface and in-situ factors such as atmospheric pressure and Localized Vertical Land Changes, and Historical Local Relative Sea Level Trends. In addition, a comprehensive and inclusive monitoring system, to obtain a reliable long time series of appropriate data including seasonal and annual rates of coastal erosion, needs to be put in place. In the meantime, the impact of a SLR scenario of 1 m needs to be considered for the planning of coastal projects such as coastal roads, waste water treatment and other developments where public health and safety are at risk. The study needs also to be expanded to cover all GLOSS Sea Level stations in the Western Indian Ocean (WIO) to obtain a regional picture similar to the one done for the North Indian Ocean (Fig. 6).

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