Persistence of Atoll islands under recent and projected sea-level rise

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Reports of a recent study showing that 43% of 27 central-Pacific Atoll islands have grown in net area over recent decades, with only 14% of these studied islands decreasing in net land area, have led to claims that risks to these islands from projected sea level rise due to global warming have been overstated. The comments of the authors of the paper cited by the press, often out of context, have contributed to this false impression. Indeed the authors warn:

> "While the islands are coping for now, any acceleration in the rate of sea-level rise could overtake the sediment build up" (New Scientist, 2 June 2010).

Given the persistence of Atoll islands in the Holocene during periods of sea level variations at rates not very different from those observed in recent decades, it is to be expected that these islands can respond dynamically to limited sea level rise and fall. However, the dynamics of atoll islands formation and persistence depends strongly on local conditions and morphology, as well as anthropogenic influence on shorelines, including infrastructure. Hence net increases in area may not correspond to enhancement of present resources and could also be associated with significant loss of useable area.

More importantly, acceleration of sea level rise is expected due to global warming. Recent estimates of the rate of sea-level rise by 2050 and 2100 are a factor of five higher than the observed rate over the study period. These expected rates of rise are about ten times higher than those found in reconstructions of sea level over the Holocene in periods where atoll islands are known to have formed and persisted in the longer term.

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Introduction

A recent study comparing satellite images with older aerial pictures of 27 central-Pacific Atoll islands found only 14% of the studied islands decreased in net land area, whereas 43% increased in net area. The study was published in the peer-reviewed journal Global and Planetary Change by authors Webb (South Pacific Applied Geoscience Commission, SOPAC, Fiji) and Kench (University of Auckland, New Zealand). These observations showed that the gross change in island area was generally much larger than changes in net area. This means most islands were observed to be 'dynamic': shorelines have shifted, with erosion on one side mostly compensated or overcompensated by accretion on another side, in most cases providing growth, of net land area.

Press reports have often lead with a bald claim like "Threat to low-level islands from global warming may be overstated, say scientists"[1], with others taking a more circumspect view[2]. Unfortunately such reporting has also fuelled long-standing science-denialist views[3]. Prominently cited was an interview in the New Scientists with author Kench:

> "It has been thought that as the sea level goes up, islands will sit there and drown. But they won't. The sea level will go up and the island will start responding."[4]

Atoll Island Response to Sea Level Changes

Atoll islands and coral reefs in general did not persist in the past during periods of rapid sea level rise following the melting and disintegration of ice sheets at the end of the last glacial period or ice age. Following the ending of the last glacial period, known as Termination I (Cheng et al. 2009), sea level rose by about 120 metres within about 10,000 years (Lea et al. 2002; Waelbroeck et al. 2002), or on average about 10-15 mm/year. In this period reefs were inundated (Blanchon and Shaw 1995). Present coral reefs and atolls did not form until the rate of sea level rise fell substantially. In the region of the Maldives, for example, reef growth resumed at around 8,000 years BP as the rate of sea level rise following Termination I slowed sufficiently. Following a further significant slow down to 1 mm/year about 6,500 years ago, islands started to form 5,500 to 4,500 years ago and have persisted since (Kench et al. 2009). The rate of sea level rise over the past several decades was about 2 mm/year and in recent years over 3 mm/year. Projected average rates over the 21st century for unmitigated climate change are of order 8-18 mm/year (Vermeer and Rahmstorf 2009).

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1 http://www.thefirstpost.co.uk/64168,news-comment,news-politics,pacific-islands-growing-not-sinking-climate-change-global-warming-study-finds#ixzz0rDbD1B9s

2 http://www.abc.net.au/news/stories/2010/06/03/2916873.htm and http://www.earthweek.com/2010/ew100611/ew100611a.html

3 http://nzclimatescience.net/index.php?option=com_content&task=view&id=14&Itemid=1

4 http://www.newscientist.com/article/mg20627633.700-shapeshifting-islands-defy-sealevel-rise.html

A first account of the theory that atoll or reef islands may be stable to sea level rise has been advanced by Kench et al (2005) based on a geological history of the Maldives Islands. Based on evidence at the time, the authors estimated a sea level rise in the region around the islands of 1.0-2.5 m in the period 4,000 – 5,500 years BP had occurred, before falling back to around modern levels. In this context, the authors proposed that the mechanism of island formation is likely to stabilize the atoll islands in the face of projected sea level rise of the order of 0.5 m over the 21st century, and hence "are expected to persist under current scenarios of future climate change and sea level rise". More recent work by Kench and colleagues indicates that the sea level high stand around the Maldives was close to 0.5 m in the period 4,000 to 2,100 years BP (Kench et al. 2009), before reducing to present levels. The original work of Kench et al (2005) appears to indicate that the Maldives Atolls maintained themselves in the face of sea level rise rates of around 0.5-1 mm/year within the past 5-6,000 years.

This theory is supported by the new study of Webb and Kench (2010). Only 14% of studied islands in the Central Pacific have decreased in area of the past decades, against a background sea-level rise of about 2 mm/yr. The authors noted the dynamics of atoll islands depend strongly on local conditions and morphology, as well as anthropogenic influence on shorelines, including infrastructure. Notwithstanding this sensitivity to local conditions, the study argues the results can be generalized to other locations and atoll islands, although the authors acknowledge the small sample size in the study (27 islands out of an estimated 20,000 worldwide). The study recommends governments to study in detail local morphology and interaction with erosion and accretion, to better estimate future impacts of sea-level rise for adaptation purposes, discouraging the assumption that all atoll island will loose area as sea level rises further in the coming decades to centuries.

Two critical issues

At least two critical issues arise in relation to the implied extension of this theory of atoll island stability in the past to stability in the face of projected accelerating sea level rise in the future.

Firstly the rate of sea level rise projected over the 21st century appears to be distinctly higher than during the period of island formation in the past and is within the range of SLR rates when it is known that atoll islands did not persist and that coral reef growth failed to keep up with this rise. Kench et al (2009) reconstructed regional sea-level rise during the Holocene (past 10,000 years) in the Maldives. The results show that Atoll islands in the Maldives formed 4,500 to 5,500 years ago, after sea-level rise slowed down sharply around 6,500 years ago, from about 7 mm/yr to 1 mm/yr. Since formation these island have persisted against a background rate of sea-level rise of 1 mm/yr, including through a high stand of 0.5 m above current levels, between 2,000 and 4,000 years ago. Hence the 'proven' rate of sea-level rise under which Maldivian island form can persist over long time periods is in the order of 1 mm/yr. The tolerable rate of sea-level rise may be higher, but this has not (yet) been recorded or reported

for the geological past. The recent results of Webb and Kench extend this to about 2 mm/year over a few decades.

The average rate of sea-level rise in the central Pacific in the (Webb and Kench) study-period (20 years for 63% of the studied islands, up to 60 years for some, all ending in 2003-2004) was about 2.0 mm/yr, but varied according to the location of the studied island. The global rate of sea-level rise was about 1.8 mm/yr over the past 50 years. Between 1992 and 2001, global sea-level rise has been observed to accelerate to about 2.8 mm/yr (Church and White 2006), part of which may be linked to an acceleration of ice sheet mass loss (Velicogna 2009)[5]. The most recent modelling estimates for total global sea-level rise (Jevrejeva et al. 2009; Vermeer and Rahmstorf 2009), show an expected rate of sea-level rise of about 10 mm/yr by 2050 and 2100. For the Vermeer and Rahmstorf projections, the average rate over the 21st century is in the range of 8-18 mm/yr, with higher rates in the latter half of the century. These projected rates are at least a factor 5 higher than the rate over the (Webb and Kench) study period and are around 10 times higher than found in reconstructions of sea level over the past 10,000 years (Kench et al. 2009) for periods where atoll islands have proven to be able to persist in the longer term (centuries to millennia). The rates of sea level rise projected for the 21st century appear to be more consistent with periods when atoll islands and coral reefs failed to keep up with sea level at the end of the last ice age.

Secondly, the increasing CO_2 in sea water appears likely to reduce the calcification capacities of coral reefs, and this would appear to have adverse effects on reef building to keep pace with sea level rise (Anthony et al. 2008; Cao and Caldeira 2008; Hoegh-Guldberg et al. 2007; Manzello et al. 2008; Silverman et al. 2009). Reduced growing and dissolving or coral reefs as a result of acidification also undermines the structural protection coral reefs provide to shorelines. Hence the morphological response of island area and shape may be influenced by ocean acidification.

Conclusions

The means of formation of the Maldives and recently studied Pacific atoll islands is not well understood. Whilst the mechanisms proposed by Kench et al (2005) and Webb and Kench (2010) advance understanding in this area, it would appear to be unwise to conclude that the mechanisms that either built the islands or allowed them to keep up with SLR in the past, will be sufficient in the future. Indeed the authors warn that "… while the islands are coping for now, any acceleration in the rate of sea-level rise could overtake the sediment build up" (New Scientist, 2 June 2010). Projected rates of sea level rise over the coming century appear to be well outside the range where atoll islands are known to be stable and well into the range where it is very likely they did not survive in the past.

[5] If this currently observed acceleration continues, the contribution from polar ice sheets would grow from less than 1 mm/yr in the period 2002-2006, to 17 mm/yr by the end of the 21st century.

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