THE HEARTLAND INSTITUTE

ARTHUR B. ROBINSON CENTER ON CLIMATE AND ENVIRONMENTAL POLICY

MAY 2019

POLICY BRIEF

Summary

- Contrary to the IPCC's statement that it is "very likely" sea-level rise is accelerating, the highest quality coastal tide gauges from around the world show no evidence of acceleration since the 1920s.
- Local and regional sea levels continue to exhibit typical natural variability, unrelated to changes in the global average sea level.
- Local sea-level trends vary considerably because they depend not only on the average global trend, but also on tectonic movements of adjacent land.

Global Sea-Level Rise: An Evaluation of the Data*

By Craig D. Idso, David Legates, and S. Fred Singer

Sea-level Rise

According to the Working Group I contribution to the Intergovernmental Panel on Climate Change's (IPCC) Fifth Assessment Report (IPCC, 2013), "it is very likely that the global mean rate [of sea level rise] was 1.7 [1.5 to 1.9] mm yr^{-1} between 1901 and 2010 for a total sea level rise of 0.19 [0.17 to 0.21] m" (p. 1139) and "it is very likely that the rate of global mean sea level rise during the 21st century will exceed the rate observed during 1971–2010 for all Representative Concentration Pathway (RCP) scenarios due to increases in ocean warming and loss of mass from glaciers and ice sheets" (p. 1140).

Also according to the IPCC (2013), mass loss from the Greenland and Antarctic ice sheets over the period 1993–2010 expressed as sea-level equivalent was "about 5.9 mm (including 1.7 mm from glaciers around Greenland) and 4.8 mm, respectively," and ice loss from glaciers between 1993 and 2009 (excluding those peripheral to the ice sheets) was 13 mm (p. 368). The total is 23.7 mm (5.9 + 4.8 + 13), which is slightly less than 1 inch.

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* Excerpted from Idso, C.D., Legates, D. and Singer, S.F. 2019. Climate Science. In: *Climate Change Reconsidered II: Fossil Fuels*. Nongovernmental International Panel on Climate Change. Arlington Heights, IL: The Heartland Institute. The following individuals also contributed to this *Policy Brief*: Joseph L. Bast, Patrick Frank, Ph.D., Kenneth Haapala, Jay Lehr, Ph.D., Patrick Moore, Ph.D., and Willie Soon, Ph.D. For lead author bios, see page 15.

Like ice melting, sea-level rise is a research area that has recently come to be dominated by computer models. Whereas researchers working with datasets built from long-term coastal tide gauges typically report a slow linear rate of sea-level rise, computer modelers assume a significant anthropogenic forcing and tune their models to find or predict an acceleration of the rate of rise. This *Policy Brief* reviews recent research to determine if there is any evidence of such an acceleration and then examines claims that islands and coral atolls are being inundated by rising seas.

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Recent Sea-level Trends

The recent Pleistocene Ice Age slowly ended 20,000 years ago with an initially slow warming and a concomitant melting of ice sheets. As a result, sea level rose nearly 400 feet to approximately the present level. For the past thousand years it is generally believed that globally averaged sea-level change has been less than seven inches per century, a rate that is functionally negligible because it is frequently exceeded by coastal processes such as erosion and sedimentation. Local and regional sea levels continue to exhibit typical natural variability—in some places rising and in others falling—unrelated to changes in the global average sea level.

Measuring changes in sea level is difficult due to the roles and impacts of gravity variations, density of the water due to salinity differences, temperature of the water, wind, atmospheric pressure differences, changes in land level and land uses, and uncertainty regarding new meltwater from glaciers. The change in technologies used to measure sea level with the arrival of satellite altimetry created discontinuities in datasets resulting in conflicting estimates of sea levels and their rates of change (e.g., Chen *et al*., 2013; Cazenave *et al*., 2014). While some researchers infer from satellite data rates of sea-level rise of 3 mm yr^{-1} or even higher (Nerem *et al*., 2018), the accuracy of those claims have been severely criticized (Church *et al*., 2010; Zhang and Church, 2012; Parker, 2015; Parker and Ollier, 2016; Mörner, 2017; Roach *et al*., 2018). Others have spliced together measurements from different locations at different times (Church and White, 2006). In fact, all the (very slight) acceleration reported by Church and White (2006) occurred prior to 1930—when CO2 levels were under 310 parts per million (Burton, 2012).

Many researchers place the current rate of global sea-level rise at or below the IPCC's historic estimate for 1901–2020 of 1.7 mm/year. Parker and Ollier (2016) averaged all the tide gauges included in the Permanent Service for Mean Sea Level (PSMSL), a repository for tide gauge data used in the measurement of long-term sea-level change based at the National Oceanography Centre in Liverpool, England, and found a trend of about + 1.04 mm/year for 570 tide gauges of any length. When they selected tide gauges with more than 80 years of recording, they found the average trend was only + 0.25 mm/year. They also found no evidence of acceleration in either dataset.

Parker and Ollier (2017) described six datasets they characterized as especially high quality:

- The 301 stations of the PSMSL database having a range of years greater than or equal to 60 years, "PSMSL-301."
- Mitrovica's 23 gold standard tide stations with minimal vertical land motion suggested by Douglas, "Mitrovica-23."
- Holgate's nine excellent tide gauge records of sea-level measurements, "Holgate-9."
- The 199 stations of the NOAA database (global and the USA) having a range of years greater than or equal to 60 years, "NOAA-199."
- The 71 stations of the NOAA database (USA only), having a range of years greater than or equal to 60 years, "US 71."
- The eight tide gauges of California, USA of years range larger than 60 years, "California-8."

According to Parker and Ollier (2017), "all consistently show a small sea-level rate of rise and a negligible acceleration." The average trends and accelerations for these datasets are:

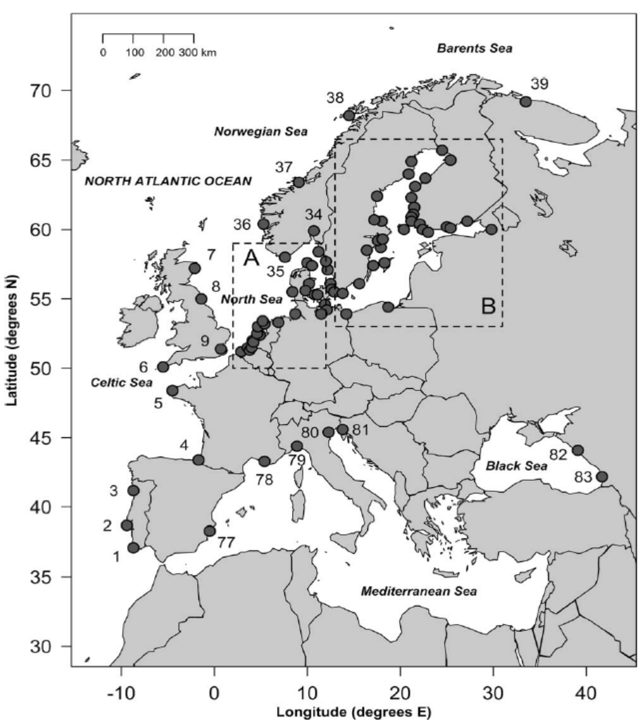
- $+0.86 \pm 0.49$ mm/year and $+0.0120 \pm 0.0460$ mm/year2 for the PSMSL-301 dataset.
- $+1.61 \pm 0.21$ mm/year and $+0.0020 \pm 0.0173$ mm/year2 for the Mitrovica-23 dataset.
- $+1.77 \pm 0.17$ mm/year and $+0.0029 \pm 0.0118$ mm/year2 for the Holgate-9 dataset.
- $+1.00 \pm 0.46$ mm/year and $+0.0052 \pm 0.0414$ mm/year2 for the NOAA-199 dataset.
- $+2.12 \pm 0.55$ mm/year and -0.0077 ± 0.0488 mm/year2 for the US 71 dataset.
- $+1.19 \pm 0.29$ mm/year and $+0.0014 \pm 0.0266$ mm/year2 for the California-8 dataset.

Bezdek (2017) notes "one region in the USA identified as being particularly susceptible to sea-level rise is the Chesapeake Bay region, and it has been estimated that by the end of the century Norfolk, Virginia could experience sea-level rise of 0.75 meters to more than 2.1 meters." The author's research revealed that water intrusion was in fact a "serious problem in much of the Chesapeake Bay region" but "due not to 'sea level rise' but primarily to land subsidence due to groundwater depletion and, to a lesser extent, subsidence from glacial isostatic adjustment. We conclude that water intrusion will thus continue even if sea levels decline." The author goes on to recommend water management policies that have been "used successfully elsewhere in the USA and other nations to solve water intrusion problems."

Wang and Zhou (2017) studied two tide gauge stations in the Pearl River Estuary on the coast of China (Macau and Hong Kong), applying a "peaks-over-threshold model of extreme value theory to statistically model and estimate secular parametric trends of extreme sea level records." Tide gauge data for Macau and Hong Kong spanned the period 1925–2010 and 1954–2014, respectively. In describing their findings, the two Chinese researchers note there are "evident decadal variations in the intensity and frequency of extremes in [the] sea level records," but "none of the parameters (intensity and frequency) of daily higher high-water height extremes in either Macau or Hong Kong has a significant increasing or decreasing trend." Similar results were obtained upon examination of trends of extremes in tidal residuals, where Wang and Zhou again report "none of the parameters presents a significant trend in recent decades."

Watson (2017) notes "some 28 of the 30 longest records in the Permanent Service for Mean Sea Level (PSMSL) global data holdings are European, extending as far back as 1807 (Brest, France). Such records provide the world's best time series data with which to examine how kinematic properties of the trend might be changing over time." He chose 83 tide gauge records with a minimum of 80 years reporting, at the locations shown in Figure 1, and used "a recently developed analytical package titled 'msltrend' specifically designed to enhance estimates of trend, real-time velocity, and acceleration in the relative mean sea-level signal derived from long annual average ocean water level time series."

Figure 1
Location of tide gauge records in Europe with at least 80 years of reporting



Source: Watson, 2017, Figure 1, p. 24.

Even though "the msltrend package has been specifically designed to enhance substantially estimates of trend, real-time velocity, and acceleration in relative mean sea level derived from contemporary ocean water level data sets," Watson (2017) reports (with apparent surprise), "Key findings are that at the 95% confidence level, no consistent or compelling evidence (yet) exists that recent rates of rise are higher or abnormal in the context of the historical records available across Europe, nor is there any evidence that geocentric rates of rise are above the global average. It is likely a further 20 years of data will distinguish whether recent increases are evidence of the onset of climate change–induced acceleration." Watson (2017), like many other researchers, observed "the quasi 60-year oscillation identified in all oceanic basins of the world (Chambers, Merrifield, and Nerem, 2012)."

Frederikse *et al*. (2018) comment on how "different sea level reconstructions show a spread in sea level rise over the last six decades," citing among the reasons for disagreement "vertical land motion at tide-gauge locations and the sparse sampling of the spatially variable ocean." The authors create a new reconstruction of sea level from 1958 to 2014 using tide-gauge records, observations of vertical land motion, and estimates of ice-mass loss, terrestrial water storage, and barotropic atmospheric forcing and find "a trend of 1.5 ± 0.2 mm yr^{-1} over 1958–2014 (1σ), compared to 1.3 ± 0.1 mm yr^{-1} for the sum of contributors," an acceleration of 0.07 ± 0.02 mm yr^{-2}.

Ahmed *et al*. (2018) used a geographic information system and remote sensing techniques to study land erosion (losses) and accretion (gains) for the entire coastal area of Bangladesh for the period 1985–2015. Because it is a low-lying river delta especially vulnerable to sea-level rise, concerns are often expressed that it could be a victim of global warming-induced sea-level rise (e.g., Cornwall, 2018). Ahmed *et al*. find "the rate of accretion in the study area is slightly higher than the rate of erosion. Overall land dynamics indicate a net gain of 237 km2 (7.9 km2 annual average) of land in the area for the whole period from 1985 to 2015." Rather than sinking beneath rising seas, Bangladesh is actually *growing into the sea*.

Contrary to the IPCC's statement that it is "very likely" sea-level rise is accelerating, Burton (2018) reports the highest quality coastal tide gauges from around the world show no evidence of acceleration since the 1920s or before, and therefore no evidence of being affected by rising atmospheric CO2 levels. Figure 2 shows three coastal sea-level measurement records (in blue), all more than a century long, in each case juxtaposed with atmospheric CO2 levels (in green).

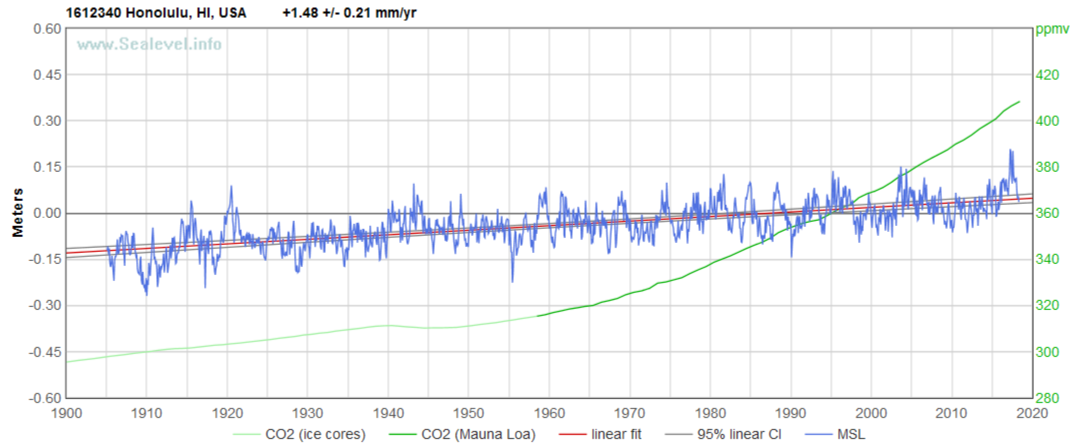
The mean sea-level (MSL) trend at Honolulu, Hawaii, USA is +1.48 mm/year; at Wismar, Germany is +1.42 mm/year; and at Stockholm, Sweden is -3.75 mm/year. The first two graphs are typical sea-level trends from especially high-quality measurement records located on opposite sides of the Earth at sites that are little affected by distortions like tectonic instability, vertical land motion, and ENSO. The trends are nearly identical, and perfectly typical: only about 6 inches per century, a rate that has not increased in more than nine decades. At Stockholm, sea-level rise is negative due to regional vertical land motion. To see how typical these trends are, as well as to observe natural variability for reasons already presented, see the entire 375 tide stations for which NOAA did long-term trend analysis at http://sealevel.info/MSL_global_thumbnails5.html.

Local sea-level trends vary considerably because they depend not only on the average global trend, but also on tectonic movements of adjacent land. In many places vertical land motion, either up or down, exceeds the very slow global sea-level trend. Consequently, at some locations sea level is rising much faster than the global rate, and at other locations sea level is falling. Figure 3 shows sea level since 1930 at Grand Isle, Louisiana, USA and Skagway, Alaska, USA.

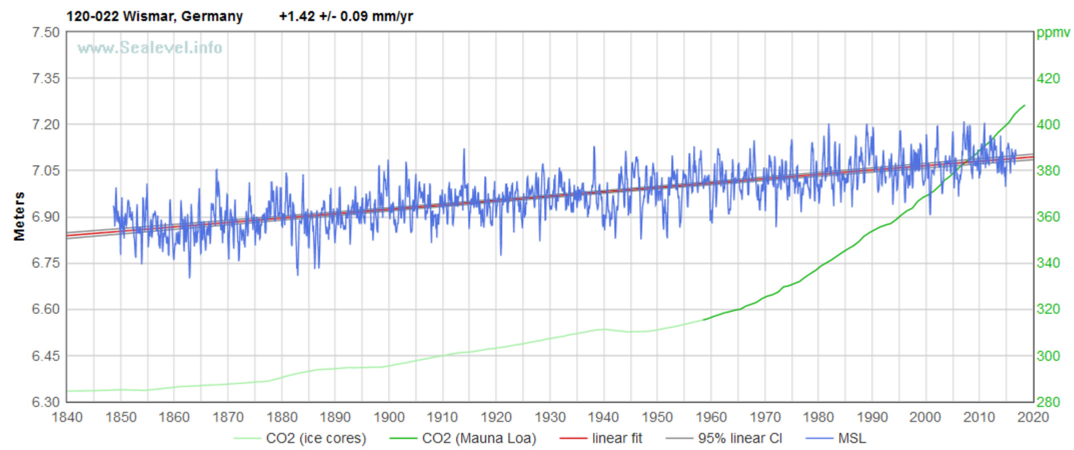
The best available data show dynamic variations in Pacific sea level in accord with El Niño-La Niña cycles, superimposed on a natural long-term rise in the volume of water in Earth's oceans (called the *eustatic* rise) (Australian Bureau of Meteorology, 2011; Scafetta, 2013). Though the range of natural variation has yet to be fully described, evidence is lacking for any recent changes in global sea level that lie outside natural variation.

Figure 2
Coastal measurement of sea-level rise (blue) in three cities vs. aerial CO2 concentration (green)

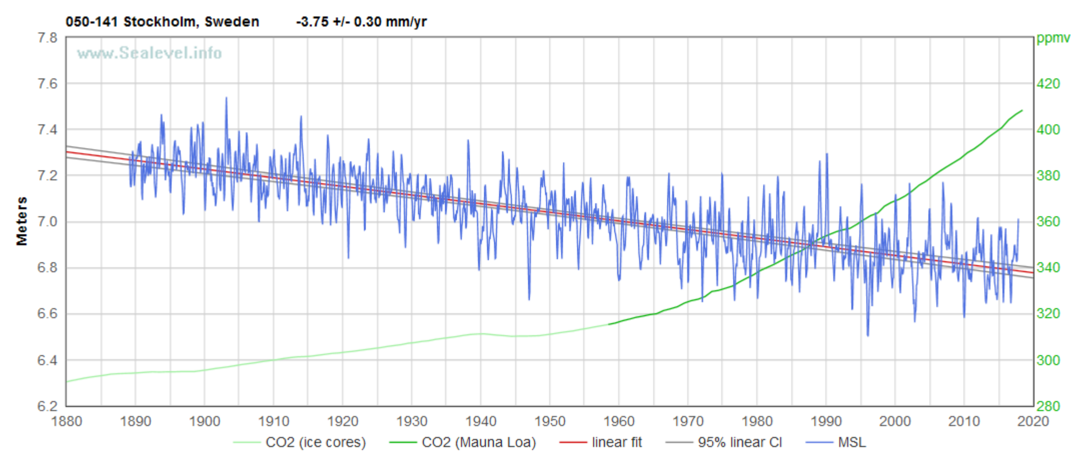
A. Honolulu, Hawaii, USA



B. Wismar, Germany



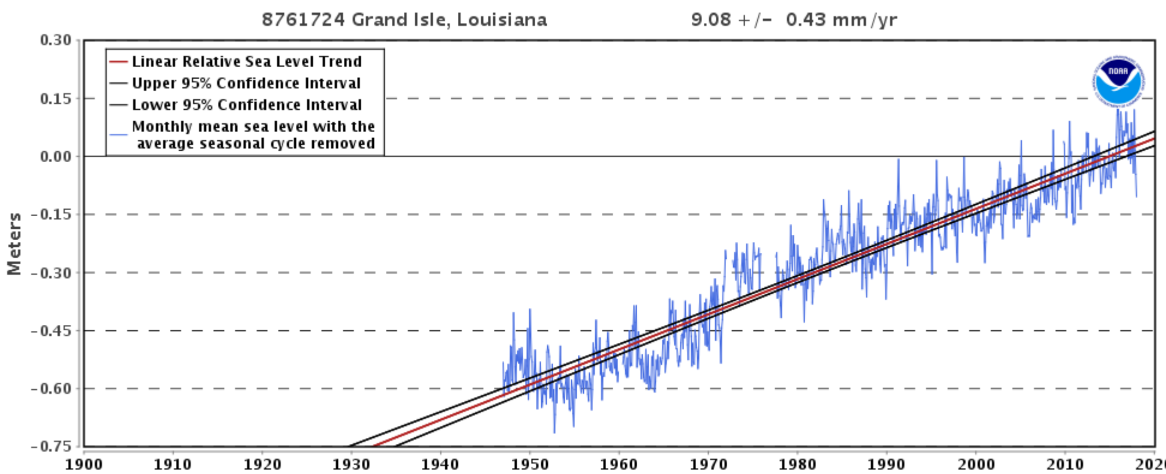
C. Stockholm, Sweden



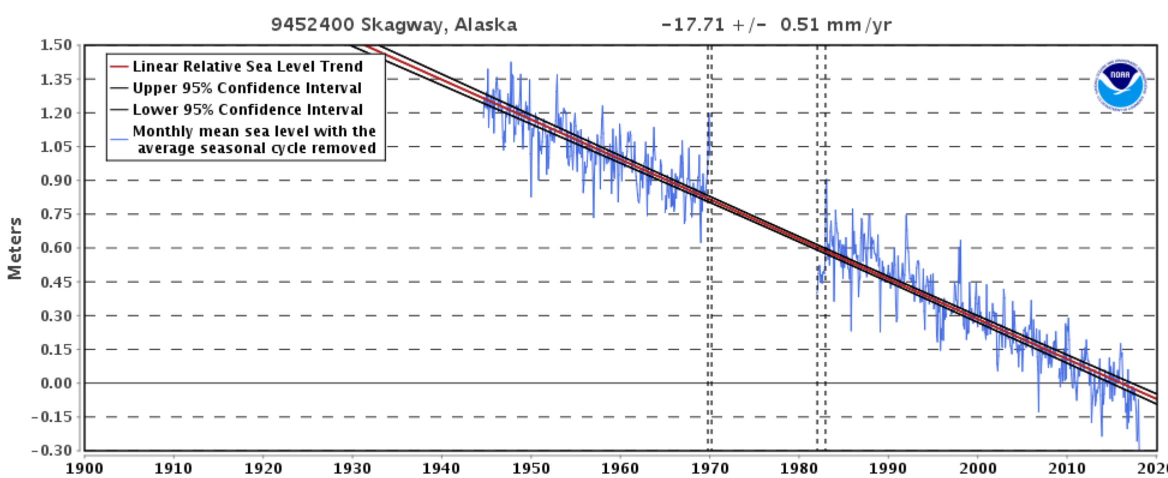
Mean sea level at Honolulu, HI, USA (NOAA 1612340, 760-031, PSMSL 155), Wismar, Germany (NOAA 120-022, PSMSL 8), and Stockholm, Sweden (NOAA 050-141, PSMSL 78). Monthly mean sea level in meters (blue, left axis) without the regular seasonal fluctuations due to coastal ocean temperatures, salinities, winds, atmospheric pressures, and ocean currents. CO2 concentrations in ppmv (green, right axis). The long-term linear trend (red) and its 95% confidence interval (grey). The plotted values are relative to the most recent mean sea-level data established by NOAA CO-OPS. *Source*: Burton, 2018.

Figure 3
Sea level from 1930, for Grand Isle, Louisiana, USA and Skagway, Alaska, USA

A. Grand Isle, Louisiana, USA



B. Skagway, Alaska, USA



See previous figure for notes. *Source*: Burton, 2018, using NOAA data.

Islands and Coral Atolls

Small islands and Pacific coral atolls (an *island made of coral* that encircles a lagoon partially or completely) are thought to be particularly at risk of harm from sea-level rise due to their low elevation and fragile shorelines. Since global sea levels have risen slowly but steadily since 1900, and that rise is alleged to have accelerated since 1990, its negative effects should be visible as a loss of surface area, but repeated studies have found this is not the case.

Island researchers generally have found that atoll shorelines are most affected by direct weather and infrequent high tide events due to El Niño-Southern Oscillation events and the impacts of increasing human populations. Pacific island ecologies are very resilient to hurricanes and floods since they happen so frequently, and plants and animals have learned to adapt and recover (Smithers and Hoeke, 2014; Mann and Westphal, 2016). Most flooding results not from sea-level rise, but from spring tides or storm surges in combination with development pressures such as borrow pit digging (a hole where soil, gravel, or sand has been dug for use at another location) or groundwater withdrawal. Persons emigrating from the islands generally do so for social and economic reasons rather than in response to environmental threats.

Biribo and Woodroffe (2013) write, "low-lying reef islands on atolls appear to be threatened by impacts of observed and anticipated sea-level rise," noting that "widespread flooding in the interior of Fongafale on Funafuti Atoll, in Tuvalu, is often cited as confirmation that 'islands are sinking' (Patel, 2006)." To see if this was true, the two scientists examined changes in shoreline position on most of the reef islands on Tarawa Atoll, the capital of the Republic of Kiribati, by analyzing "reef-island area and shoreline change over 30 years determined by comparing 1968 and 1998 aerial photography using geographical information systems."

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Biribo and Woodroffe (2013) determined that the reef islands of Tarawa Atoll "substantially increased in size, gaining about 450 ha, driven largely by reclamations on urban South Tarawa, accounting for 360 ha (~80% of the net change)." Of the 40 islands of North Tarawa, where population is absent or sparse, they report that "25 of the reef islands in this area showed no change at the level of detection, 13 showed net accretion and only two displayed net erosion." In addition, they indicate that "similar reports of reef island area increase have been observed on urban Majuro, in the Marshall Islands, again mainly related to human activity," citing Ford (2012). And they say "a recent analysis of changes in area of 27 reef islands from several Pacific atolls for periods of 35 or 61 years concluded that they were growing (Webb and Kench, 2010)," likely "as a result of more prolific coral growth and enhanced sediment transport on reef flats when the sea is higher," under which conditions they note that "shorelines will actually experience accretion, thus increasing reef island size (Kinsey and Hopley, 1991)."

Introducing their study, Kench *et al*. (2015) write, "low-lying coral reef islands are coherent accumulations of sand and gravel deposited on coral reef surfaces that provide the only habitable land in atoll nations such as Kiribati, Tuvalu, and the Marshall Islands in the Pacific Ocean, and the Maldives in the Indian Ocean." And they write that in extreme cases, "rising sea level is expected to erode island coastlines," forcing "remobilization of sediment reservoirs and promoting island destabilization," thereby making them "unable to support human habitation and rendering their populations among the first environmental refugees," citing Khan *et al*. (2002) and Dickinson (2009). But will this ever really happen?

One phenomenon that suggests it could occur is the high rate of sea-level rise (5.1 ± 0.7mm/yr^{-1}) and the consequent changes in shoreline position that have occurred over the past 118 years at 29 islands of Funafuti Atoll in the tropical Pacific Ocean. However, Kench *et al*. (2015) write, "despite the magnitude of this rise, no islands have been lost," noting, in fact, that "the majority have enlarged, and there has been a 7.3% increase in net island area over the past century (AD 1897–2013)." They add "there is no evidence of heightened erosion over the past half-century as sea-level rise accelerated," noting that "reef islands in Funafuti continually adjust their size, shape, and position in response to variations in boundary conditions, including storms, sediment supply, as well as sea level." The scientists conclude that "islands can persist on reefs under rates of sea-level rise on the order of 5 mm/year," which is a far greater rate-of-rise than what has been observed over the past half-century of significant atmospheric CO2 enrichment.

"In light of these findings, Ford and Kench conclude that 'governments of small island nations need to acknowledge that island shorelines are highly dynamic and islands have persisted and in many cases grown in tandem with sea level rise.'"

Ford and Kench (2015) used historic aerial photographs and recent high-resolution satellite imagery to determine "shoreline changes on six atolls and two mid-ocean reef islands in the Republic of the Marshall Islands." This work revealed, "since the middle of the 20th century more shoreline has accreted than eroded, with 17.23% showing erosion, compared to 39.74% accretion and 43.03% showing no change." Consequently, they determine "the net result of these changes was the growth of the islands examined from 9.09 km2 to 9.46 km2 between World War Two (WWII) and 2010." In light of these findings, Ford and Kench conclude that "governments of small island nations need to acknowledge that island shorelines are highly dynamic and islands have persisted and in many cases grown in tandem with sea level rise."

Purkis *et al*. (2016) observed that "being low and flat, atoll islands are often used as case studies against which to gauge the likely impacts of future sea-level rise on coastline stability." The authors examined remotely sensed images from Diego Garcia, an atoll island situated in the remote equatorial Indian Ocean, to determine how its shoreline has changed over the past five decades (1963–2013), during which time sea level in the region has been rising more than 5 mm per year, over at least the last 30 years, based on data they obtained from the National Oceanographic Data Center. According to the four scientists, "the amount of erosion on Diego Garcia over the last 50 years is almost exactly balanced by the amount of accretion, suggesting the island to be in a state of equilibrium." Commenting on the significance of this finding, Purkis *et al*. write their study "constitutes one of the few that have documented island shoreline dynamics at timescales relevant to inform projections of future change."

> "According to the four scientists, 'the amount of erosion on Diego Garcia over the last 50 years is almost exactly balanced by the amount of accretion, suggesting the island to be in a state of equilibrium.'"

Testut *et al*. (2016) acquired baseline data on both absolute and relative sea-level variations and shoreline changes in the Scattered Islands region of the Indian Ocean, based on aerial image analysis, satellite altimetry, field observations, and *in situ* measurements derived from the 2009 and 2011 Terres Australes et Antarctiques Francaises scientific expeditions. They discovered "Grande Glorieuse Island has increased in area by 7.5 ha between 1989 and 2003, predominantly as a result of shoreline accretion," which "occurred over 47% of shoreline length." They also note "topographic transects and field observations show that the accretion is due to sediment transfer from the reef outer slopes to the reef flat and then to the beach."

Duvat *et al*. (2017) studied shoreline change in atoll reef islands of the Tuamotu Archipelago in French Polynesia by examining aerial photographs and satellite images of 111 atoll reef islands from the area taken over the past 50 years. According to the researchers, their findings bring "new irrefutable evidences on the persistence of reef islands over the last decades." Over the past three to five decades, the total net land area of the studied atolls "was found to be stable, with 77% of the sample islands maintaining their area, while 15% expanded and 8% contracted." Furthermore, they note that seven out of the eight islands that decreased in area were very small in area (less than 3 hectares), whereas "all of the 16 islands larger than 50 hectares were stable in area."

McAneney *et al*. (2017) created a 122-year record of major flooding depths at the Rarawai Sugar Mill on the Ba River in the northwest of the Fijian Island of Viti Levu. "Reconstructed largely from archived correspondence of the Colonial Sugar Refining Company, the time series comprises simple measurements of height above the Mill floor." The authors report their findings as follows: "It exhibits no statistically significant trends in either frequency or flood heights, once the latter have been adjusted for average relative sea-level rise. This is despite persistent warming of air temperatures as characterized in other studies. There is a strong dependence of frequency (but not magnitude) upon El Niño-Southern Oscillation (ENSO) phase, with many more floods in La Niña phases. The analysis of this long-term data series illustrates the difficulty of detecting a global climate change signal from hazard data….”

Summarizing her own review of the scientific literature on sea-level rise, Curry (2018) writes, “Tide gauges show that sea levels began to rise during the 19th century, after several centuries associated with cooling and sea level decline. Tide gauges also show that rates of global mean sea level rise between 1920 and 1950 were comparable to recent rates. Recent research has concluded that there is no consistent or compelling evidence that recent rates of sea level rise are abnormal in the context of the historical records back to the 19th century that are available across Europe.”

“Summarizing her own review of the scientific literature on sea-level rise, Curry (2018) writes, ‘Tide gauges show that sea levels began to rise during the 19th century, after several centuries associated with cooling and sea level decline. Tide gauges also show that rates of global mean sea level rise between 1920 and 1950 were comparable to recent rates.’”

Kench *et al*. (2018) recount the “dispiriting and forlorn consensus” that rising sea levels will inundate atoll islands and argue there is “a more nuanced set of options to be explored to support adaptation in atoll states. Existing paradigms are based on flawed assumptions that islands are static landforms, which will simply drown as the sea level rises. There is growing evidence that islands are geologically dynamic features that will adjust to changing sea level and climatic conditions,” citing Webb and Kench (2010), Ford (2013), McLean and Kench (2015), and Duvat and Pillet (2017). The authors test the theory that rising sea levels were inundating atoll islands by analyzing “shoreline change in all 101 islands in the Pacific atoll nation of Tuvalu.” “Surprisingly,” they write, “we show that all islands have changed and that the dominant mode of change has been island expansion, which has increased the land area of the nation.” The nation saw a net increase in land area of 73.5 ha (2.9%) despite sea-level rise. While 74% of the islands gained land area, 27% decreased in size. “Expansion of islands on reef surfaces indicates a net addition of sediment,” the researchers write. “Implications of increased sediment volumes are profound as they suggest positive sediment generation balances for these islands and maintenance of an active linkage between the reef sediment production regime and transfer to islands, which is critical for ongoing physical resilience of islands.”

Finally, Kench *et al*. (2018) report “direct anthropogenic transformation of islands through reclamation or associated coastal protection works/development has been shown to be a dominant control on island change in other atoll nations. However, in Tuvalu direct physical interventions that modify coastal processes are small in scale because of much lower population densities. Only 11 of the study islands have permanent habitation and, of these, only two islands sustain populations greater than 600. Notably, there have been no large-scale reclamations on Tuvaluan islands within the analysis window of this study (the past four decades)." These results, Kench *et al*. write, "challenge perceptions of island loss, showing islands are dynamic features that will persist as sites for habitation over the next century, presenting alternate opportunities for adaptation that embrace the heterogeneity of island types and their dynamics."

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Small islands and Pacific coral atolls are not being inundated by rising seas due to anthropogenic climate change. Direct evidence reveals many islands and atolls are increasing, not decreasing, in area as natural process lead to more prolific coral growth and enhanced sediment transport on reef flats. Combined with evidence that sea levels are not rising at unusual or unprecedented rates around the world, this means the IPCC's concern over rising sea levels is without merit.

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References

Ahmed, A., Drake, F., Nawaz, R., and Woulds, C. 2018. Where is the coast? Monitoring coastal land dynamics in Bangladesh: an integrated management approach using GIS and remote sensing techniques. *Ocean & Coastal Management* 151: 10–24.

Australian Bureau of Meteorology. 2011. The South Pacific sea-level and climate monitoring program. Sea-level summary data report, July 2010–June 2011.

Bezdek, R.H. 2017. Water intrusion in the Chesapeake Bay region: is it caused by climate-induced sea level rise? *Journal of Geoscience and Environment Protection* 5: 252–63.

Biribo, N. and Woodroffe, C.D. 2013. Historical area and shoreline change of reef islands around Tarawa Atoll, Kiribati. *Sustainability Science* 8: 345–62.

Burton, D. 2012. Comments on 'Assessing future risk: quantifying the effects of sea level rise on storm surge risk for the southern shores of Long Island, New York. *Natural Hazards* 63: 1219.

Burton, D. 2018. Mean sea level at Honolulu, HI, USA (NOAA 1612340, 760-031, PSMSL 155, mean sea level at Wismar, Germany (NOAA 120-022, PSMSL 8, and mean sea level at Stockholm, Sweden (NOAA 050-141, PSMSL 78. Sea Level Info (website). Accessed December 11, 2018.

Cazenave, A., *et al*. 2014. The rate of sea-level rise. *Nature Climate Change* 4: 358–61.

Chambers, D.P., Merrifield, M.A., and Nerem, R.S. 2012 Is there a 60-year oscillation in global mean sea level? *Geophysical Research Letters* 39 (18).

Chen, J.L., Wilson, C.R., and Tapley, B.D. 2013. *Contribution of ice sheet and mountain glacier melt to recent sea level rise. Nature Geoscience* 6: 549–52.

Church, J.A. and White, N.J. 2006. A 20th century acceleration in global sea-level rise. *Geophysical Research Letters* 33: L01602.

Church, J.A., et al. 2010. Sea-level rise and variability: synthesis and outlook for the future. In: Church, J.A., Woodworth, P.L, Aarup, T., and Wilson, W.S. (Eds.) *Understanding Sea-Level Rise and Variability*. Chichester, UK: Wiley-Blackwell, pp. 402–19.

Cornwall, W. 2018. As sea levels rise, Bangladeshi islanders must decide between keeping the water out—or letting it in. *Science Social Sciences*: doi:10.1126/ science.aat4495, March 1.

Curry, J. 2018. Special report on sea level rise. Climate Etc. (website). Accessed November 27, 2018.

Dickinson, W.R. 2009. Pacific atoll living: how long already and until when? *GSA Today* 19: 124–32.

Duvat, V.K.E. and Pillet, V. 2017. Shoreline changes in reef islands of the Central Pacific: Takapoto Atoll, Norther Tuamotu, French Polynesia. *Geomorphology* 282: 96–118.

Ford, M. 2012. Shoreline changes on an urban atoll in the central Pacific Ocean: Majuro Atoll, Marshall Islands. *Journal of Coastal Research* 28: 11–22.

Ford, M. 2013. Shoreline changes interpreted from multi-temporal aerial photographs and high resolution satellite images: Wotje Atoll, Marshall Islands. *Remote Sensing of the Environment* 135: 130–40.

Ford, M.R. and Kench, P.S. 2015. Multi-decadal shoreline changes in response to sea level rise in the Marshall Islands. *Anthropocene* 11: 14–24.

Frederikse, T., Jevrejeva, S., Riva, R.E.M., and Dangendorf, S. 2018. A consistent sea-level reconstruction and its budget on basin and global scales over 1958–2014. *Journal of Climate* 31 (3): 1267–80.

IPCC. 2013. Intergovernmental Panel on Climate Change. *Climate Change 2013: The Physical Science Basis*. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. New York, NY: Cambridge University Press.

Kench, P.S., Ford, M.R., and Owen, S.D. 2018. Patterns of island change and persistence offer alternate adaptation pathways for atoll nations. *Nature Communications* 9: Article 605.

Kench, P.S., Thompson, D., Ford, M.R., Ogawa, H., and McLean, R.F. 2015. Coral islands defy sea-level rise over the past century: records from a central Pacific atoll. *Geology* 43: 515–8.

Khan, T.M.A., Quadir, D.A., Murty, T.S., Kabir, A., Aktar, F., and Sarker, M.A. 2002. Relative sea level changes in Maldives and vulnerability of land due to abnormal coastal inundation. *Marine Geodesy* 25: 133–43.

Kinsey, D.W. and Hopley, D. 1991. The significance of coral reefs as global carbon sinks–response to Greenhouse. *Palaeogeography, Palaeoclimatology, Palaeoecology* 89: 363–77.

Mann, T. and Westphal, H. 2016. Multi-decadal shoreline changes on Taku Atoll, Papua New Guinea: observational evidence of early reef island recovery after the impact of storm waves. *Geomorphology* 257: 75–84.

McAneney, J., van den Honert, R., and Yeo, S. 2017. Stationarity of major flood frequencies and heights on the Ba River, Fiji, over a 122-year record. *International Journal of Climatology* 37 (S1): 171–8.

McLean, R.F. and Kench, P.S. 2015. Destruction or persistence of coral atoll islands in the face of 20th and 21st century sea-level rise? *WIREs Climate Change* 6: 445–63.

Mörner. N.-A. 2017. Sea level manipulation. *International Journal of Engineering Science Invention* 6 (8): 48–51.

Nerem, R.S., et al. 2018. Climate-change–driven accelerated sea-level rise detected in the altimeter era. *Proceedings of the National Academy of Sciences USA* 115 (9): 2022–5.

Parker, A. 2015. Accuracy and reliability issues in the use of global positioning system and satellite altimetry to infer the absolute sea level rise. *Journal of Satellite Oceanography and Meteorology* 1 (1): 13–23.

Parker, A. and Ollier, C.D. 2016. Coastal planning should be based on proven sea level data. *Ocean & Coastal Management* 124: 1–9.

Parker A. and Ollier, C.D. 2017. California sea level rise: evidence based forecasts vs. model predictions. *Ocean & Coastal Management* 149: 198–209.

Patel, S.S. 2006. Climate science: a sinking feeling. *Nature* 440: 734–6.

Purkis, S.J., Gardiner, R., Johnston, M.W., and Sheppard, C.R.C. 2016. A half-century of coastline change in Diego Garcia, the largest atoll island in the Chagos. *Geomorphology* 261: 282–98.

Roach, L.A., Dean, S.M., and Renwick, J.A. 2018. Consistent biases in Antarctic sea ice concentration simulated by climate models. *The Cryosphere* 12: 365–83.

Scafetta, N. 2013. Multi-scale dynamical analysis (MSDA) of sea level records versus PDO, AMO, and NAO indexes. *Climate Dynamics*: 10.1007/s00382-013-1771-3.

Smithers, S.G. and Hoeke, R.K. 2014. Geomorphological impacts of high-latitude storm waves on low-latitude reef islands–observations of the December 2008 event on Nukutoa, Takuu, Papua New Guinea. *Geomorphology* 222: 106–21.

Testut, L., Duvat, V., Ballu, V., Fernandes, R.M.S., Pouget, F., Salmon, C., and Dyment, J. 2016. Shoreline changes in a rising sea level context: the example of Grande Glorieuse, Scattered Islands, Western Indian Ocean. *Acta Oecologica* 72: 110–9.

Wang, W. and Zhou, W. 2017. Statistical modeling and trend detection of extreme sea level records in the Pear River Estuary. *Advances in Atmospheric Sciences* 34: 383–96.

Watson, P.J. 2017. Acceleration in European mean sea level? A new insight using improved tools. *Journal of Coastal Research* 33 (1): 23–38.

Webb, A.P. and Kench, P.S. 2010. The dynamic response of reef islands to sea-level rise: evidence from multi-decadal analysis of island change in the Central Pacific. *Global and Planetary Change* 72: 234–46.

Zhang, X. and Church, J.A. 2012. Sea level trends, interannual and decadal variability in the Pacific Ocean. *Geophysical Research Letters* 39: 10.1029/2012GL053240.

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