Mean sea level change at Cooktown, Great Barrier Reef, Queensland

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Abstract

The claim by the Great Barrier Reef Marine Park Authority that sea level is increasing rapidly in the northern sector of the Great Barrier Reef is not substantiated by trends in mean sea level (MSL) measured by the tide gauge at Cooktown since January 1996, or time-series of aerial photographs. Covariance analysis partitioned variation ***IN*** monthly MSL data attributable to influential covariables, from factors that impacted ***ON*** the data-stream.

The southern Oscillation Index (SOI), monthly and lag_2 antecedent rainfall were significant predictors but only explained 14.9% MSL variation ($R^2_{adj} = 0.149$). The combined effect of dredging following Tropical Cyclone Justin in 1997, wind and heavy seas associated with Tropical Cyclones Ellie (30 January to 4 February 2009) and Hamish (4 to 11 March 2009), further dredging in 2014 and refurbishment of the wharf in 2015 caused the tide gauge to settle 109 mm into the bed of the harbour thereby causing MSL to apparently increase. Additional tests verified that no residual trend or change is attributable to other factors.

There is no evidence that melting glaciers, increasing levels of atmospheric CO_2 or expansion of the oceans due to rising temperatures has caused sea levels to increase. Consequently, the likelihood that sea level will rise by 26 to 29 cm by 2030 as predicted by the IPCC is far-fetched. Furthermore, as trends measured by multiple tide gauges adjacent to the reef differ from satellite-based estimates, satellite data is biased and should not be used in critical studies. The El Niño Southern Oscillation exerts an overarching impact on fluctuations in sea level and other environmental variables.

1. Introduction

Rising sea level is frequently mentioned as likely to endanger the Great Barrier Reef (GBR). For instance, the Great Barrier Reef Marine Park Authority (GBRMPA) states “Our sea level is rising at an increased rate and the primary cause is higher temperatures”; that “Around Australia, and in the Great Barrier Reef, the fastest rates of sea level rise are in the north”, and that “Extreme sea level events (storm-driven waves and surge) also became about three times more frequent during the 20th century” [2].

GBRMPA say that according to the Intergovernmental Panel on Climate Change (IPCC), global sea levels will rise by around 26 to 29 centimetres over the next 9-years (i.e., by 2030), and by around 47 to 62 centimetres by 2080. Such rapid rates of change should be evident in mean sea level (MSL) measured by tide gauges relative to the land.

Sea level has been measured since at least December 1965 at the Port of Cooktown, which lies at the mouth of the Endeavour River in northern Queensland. Due its poor quality and lack of documentation the Permanent Service for Mean Sea Level advises against using their archived data for research purposes (https://www.psmsl.org/data/obtaining/stations/1131.php). Medium-term data for the Maritime Safety Queensland automated tide gauge is available from January 1996 from the Queensland Government Open Data portal (https://www.msq.qld.gov.au/Tides/Open-data). However, metadata describing changes to the gauge, sensors and data processing is unavailable. As such changes may affect raw-data trends it is important to assess the fitness of individual datasets using independent statistical methods.

2. Methods

Blocks of 10-minute interval raw data for the Cooktown gauge were combined into a single time-series, aggregated as monthly means using the statistical package R[3] and analysed for trend and change using the

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[2] https://www.gbrmpa.gov.au/our-work/threats-to-the-reef/climate-change/sea-level-rise

[3] R Core Team (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

same objective methods as outlined for Townsville Harbour and Cape Ferguson (https://www.bomwatch.com.au/bureau-of-meterology/sea-level-at-townsville-great-barrier-reef/). Covariate analysis was used to partition between variables (covariates) that caused variation **IN** monthly MSL from those that impacted **ON** the MSL data-stream. A suite of monthly environmental data including the seasonally-smoothed (3-point) BoM El Niño Southern Oscillation (SOI_{3pt}), average monthly discharge for the Endeavour River (ML/d), monthly rainfall and lags thereof (mm/month), average monthly solar radiation ($MJ/m^2/d$) and estimated pan evaporation (mm/month) were evaluated as potential MSL predictors using multiple linear regression and analysis of variance. Data were sourced from the Bureau of Meteorology (BoM), the Queensland Government Water Monitoring Information Portal and for the SILO grid-cell (https://www.longpaddock.qld.gov.au/) west of Cooktown centred on Latitude -15.45, Longitude 145.15.

The study aimed to verify if predictions of rapid sea level rise in the northern sector of the GBR are consistent with MSL measured by the Cooktown tide gauge.

3. Results

Tide gauge data and other meteorological elements are dominated by repeating monthly (seasonal) cycles that explain >50% of variation in raw data. As cycles are non-trending, result in autocorrelation, inflate variation explained and potentially mask other signals, data except for the SOI (which was seasonally stationary) were de-seasoned by deducting monthly averages from respective monthly data prior to analysis. De-seasoned data are referred to as anomalies (Figure 1).

While MSL appears to be increasing at a rate of 0.036 m/decade, removal of the seasonal cycle which peaks in March and April, shows anomalies clustered into irregular sequences above and below the rescaled mean (=0). Thus, anomalies exhibit step-like behaviour. Intense El Niño and La Niña episodes cause MSL to vary by *c*. 100 mm from the rescaled mean and would impact on naïve linear trend.

Rainfall is strongly summer-dominant with highest falls and highest variability occurring in February and March. Rainfall anomalies show drought from March 2001 ended with Tropical Cyclone Fritz in March 2004. Also, heavy rainfall due to an intense tropical low in late December 2018 (681 mm between 24 and 31 December). Although not presented here, average annual rainfall from 1900 to 1947 was 1455 mm/year verses 1692 mm from 1948 to 2020; thus, despite the Millennium drought, there is no evidence that the climate is becoming drier or more extreme.

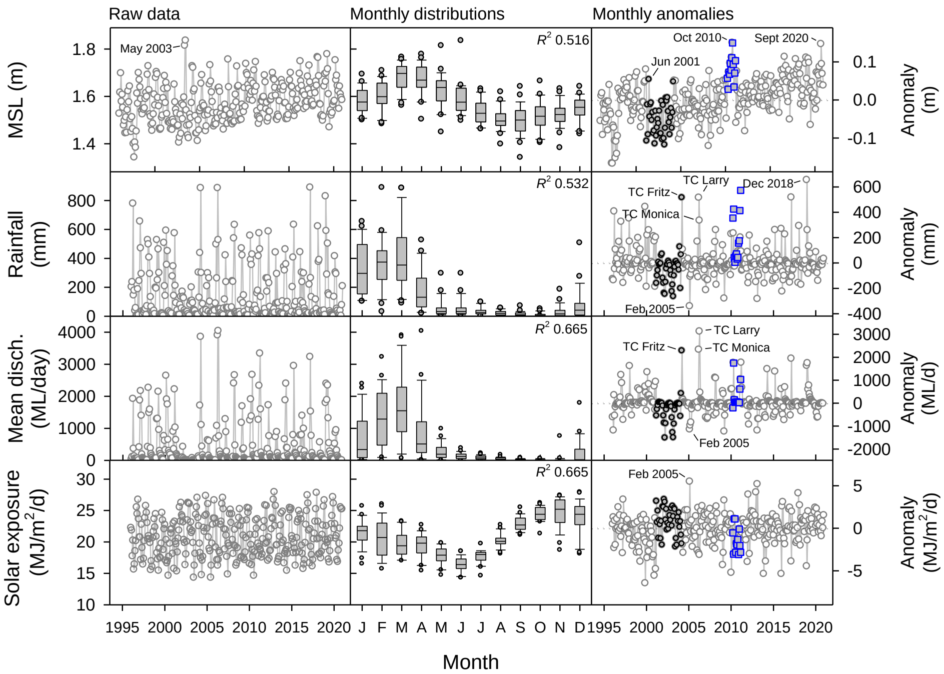
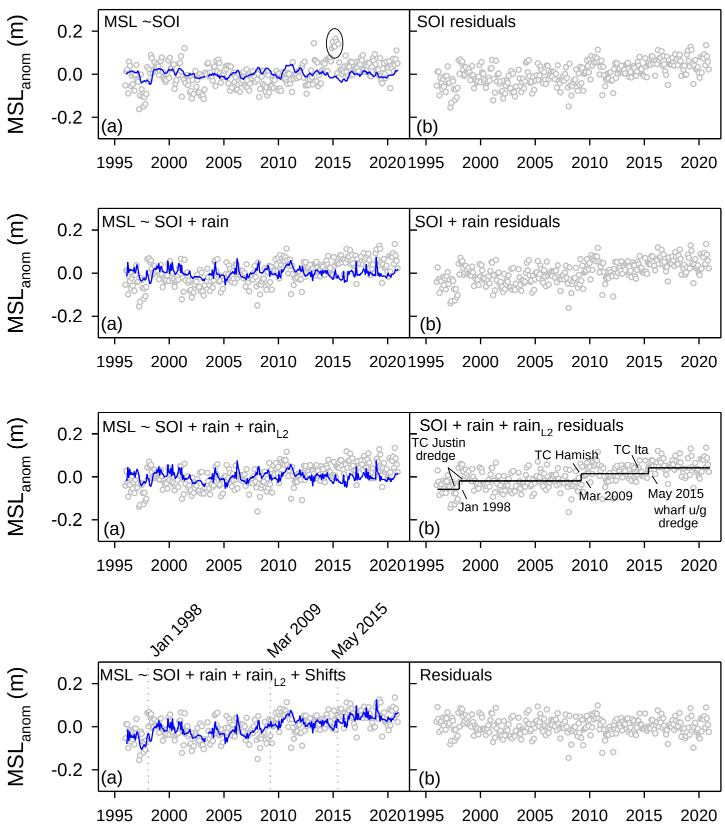


Figure 1. Raw monthly MSL, rainfall, mean discharge and solar exposure data (left panels) embed a repeating seasonal signal (shown as box-plots in the middle panel), which explains >50% (R^2_{adj} >0.50) of the variation in raw data. Removing the cycle exposes patterns in the data that are otherwise obscure including clustering of MSL anomalies due to ENSO, cyclones etc. that may affect naïve trend. The March 2001 to March 2004 El Niño and the March 2010 to March 2011 La Niña are highlighted.

Of the climate covariables evaluated for their potential impact on MSL anomalies, only SOI_{3pt}, and rainfall and $Rain_{Lag2}$ anomalies were significant (P <0.05). SOI_{3pt} explained the highest proportion (9.62%) of the total sum of squares, which estimates variation in MSL, followed by rainfall (5.15%) and $Rain_{Lag2}$ (0.99%). However, as the multiple linear regression (MLR) relationship explained only 14.1% of variation in MSL anomalies, tide-gauge data were possibly erratic and unpredictable. Step-changes were detected in MLR-residuals in January 1998, March 2009 and May 2015, which showed the data-stream was impacted by underlying inhomogeneities. Covariance analysis evaluates the significance and magnitude of step-changes holding other variables (SOI and rainfall) constant. Values in the following paragraph are covariate adjusted.

Following siltation of the harbour by Tropical Cyclone Justin in March 1997, a major dredging campaign was implemented[1](with follow-up dredging in 1999[2] following TC Rona (incorrectly named in that document as TC Justine)). Removal of 108,000 m^3 of overburden in 1997 (but not the 26,000 m^3 in 1999) caused the wharf supporting the tide-gauge to settle about 40 mm into the bed of the river. The cause of the highly significant step-change in March 2009 is less clear. However, following TC Ellie from 30 January to 4 February, severe TC Hamish lashed the Queensland coast with high winds and storm-surges from 4 to 14 March resulting in extensive damage to coastal communities and the Reef. Although rainfall at Cooktown was relatively light (73 mm from 5 March), total rainfall for the previous three months was around 1000 mm. Presumably as a result of wind and storm surges in February and March, the gauge settled a further 37 mm. The harbour was again dredged following TC Ita in 2014 (60,000 m^3), then in January 2015, the former wooden wharf that supported the tide gauge was strengthened and re-decked with a new composite material capable of allowing small trucks to load and unload supplies[3]. The combined effect of dredging and re-decking the wharf caused the tide-gauge to settle a further 32 mm.

Table 1. Sequential analysis of significant (*P* <0.05) climate covariables that impacted on MSL anomaly data for the Port of Cooktown tide gauge. For each case, graph (a) represents the statistically fitted signal (blue line) overlaid on the preceding residual dataset shown in (b). The background series for Case 1 is the anomaly data from Figure 1.



Case 1
MSL ~ SOI;
P <0.001; R^2_{adj} = 0.093
Residual trend = 0.039 m/decade;
P <0.001

Case 2
MSL ~ SOI + $rain_{anom}$;
P <0.001; R^2_{adj} = 0.142
Residual trend = 0.040 m/decade;
P <0.001

Case 3
MSL ~ SOI + $rain_{anom}$ + $rain_{L2,\,anom}$
P <0.001; R^2_{adj} = 0.149
Residual trend = 0.040 m/decade;
P <0.001

Case 4
MSL ~ Sh_{MSL} + SOI + $rain_{anom}$ + $rain_{L2,\,anom}$
P <0.001; R^2_{adj} = 0.495
Residual trend = <0.00 m/decade;
P = 0.476 (n.s.)

Residuals were random and untrending. The three highly significant step-changes (*P* <0.001) totalling 109 mm (SEM 9.4 mm) accounted for all the apparent raw data trend (Table 1). Segmented analysis verified

[1] P. 218 in: Ryle, P.A. (2000). *Decline and recovery of a rural coastal town: Cooktown 1873-1999*. PhD thesis, James Cook University.
[2] P. 10 in: file:///C:/Users/johns/AppData/Local/Temp/empcooktown-3.pdf
[3] https://www.wagner.com.au/main/our-projects/cooktown-wharf/

that due to underlying inhomogeneities the step-change model was more appropriate for the data than a naïve trend model.

Figure 1 shows that prolonged El Niño events were accompanied by reduced MSL, rainfall and stream discharge and increased solar exposure due to less cloud. Conversely, La Niña causes MSL, rainfall and discharge to increase, and solar exposure to be reduced. Due to its overarching impact on the general climate, ENSO cycling is the dominant cause of both longer and short-term fluctuations in MSL.

The BoM SOI is a non-trending stochastic, episodic impulse variable calculated as the standardised anomaly of the Mean Sea Level Pressure difference between Tahiti and Darwin. As factors are additive, adjusting for covariates related to rainfall and inhomogeneities caused by dredging, TC Hamish and the wharf and port upgrade, but not SOI, Figure 2 shows that residuals closely mirror positive and negative phases of ENSO.

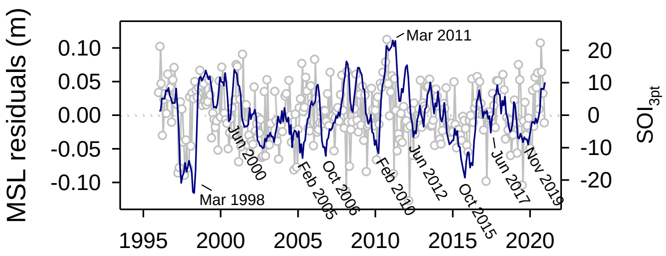


Figure 2. MSL residuals overlaid by the BoM Southern Oscillation Index. Residuals (circles) consist of deseasoned anomalies minus the effect of covariables and inhomogeneities, but not the effect of SOI. Note that the MSL range is about 200 mm overall.

ENSO varies continuously and unpredictably and, in the background, despite occasional cyclones, cycles and other perturbations that act independently, MSL excursions follow the SOI trajectory. Relative to the rescaled mean (which is zero), abrupt SOI excursions result in synchronous movements in MSL of up to ±0.1 m (100 mm), the most prominent events having been the 1997/1998 El Niño and the 2010/2011 La Niña. Other notable El Niño episodes occurred around October 2015 and November 2019.

For shallow corals, increased solar exposure and negative MSL-excursions are likely to be more damaging and widespread and more visible to observers undertaking aerial surveys than positive excursions. While La Niña episodes impact on freshwater discharge from rivers, nutrient washoff and dilution of seawater by rainfall, which also may also damage reefs, unpredictable El Niño and La Niña events are opposite phases of the same natural phenomenon, with El Niño more likely to damage shallow reefs.

4. Discussion

Although many claims have been aired and scores of scientific papers have blamed climate warming for perceived 'catastrophic' declines in the 'health' of coral-reef ecosystems, relationships between MSL and other climate covariables and the overarching role of ENSO-cycling has not been comprehensively considered. Nevertheless, an understanding of the interrelatedness of climate processes that affect the Reef (MSL, rainfall, runoff, nutrient washoff, solar exposure and sea surface temperature) is fundamental to evaluating and understanding ecosystem responses.

While Cooktown tide gauge data has been used naïvely to evidence sea-level rise, it has not been rigorously analysed before. Similarly for gauges run by the Australian Baseline Sea Level Monitoring Project at Rosslyn Harbour near Yeppoon and Cape Ferguson near Townsville, and the Townsville Harbour storm surge gauge. Tide gauge measurements are affected by gauge changes (transition from chart-recorders to encoders to digital loggers), dredging, data processing, harbour developments and changes within contributing catchments including groundwater discharge. As metadata is scant and unreliable, it cannot be presumed that raw data are useful for determining trend and change and in all cases when analysed and cross referenced to press releases, reports and aerial photographs etc. no trend in data is attributable to loss of glaciers, global warming or the amount of CO_2 in the atmosphere. At Cooktown and elsewhere, evidence is lacking that sea levels are rising, accelerating or that rates of increase are greater towards the equator than in the south. Quoting the IPCC, the claim the GBRMPA that sea levels will increase globally by 26 to 29 cm by 2030 is clearly ridiculous. Further, as trends measured by multiple gauges adjacent to the reef differ from data derived from satellites, satellite data is faulty and should not be used in critical studies or to inform government policy.

Similar to the situation at Townsville Harbour where covariables and step-changes related to construction and enlargement of the Ross River Dam explained only 49.2% of MSL variation and residuals were random, factors such as cycles, currents, waves, wind and possibly vessels using the wharf also affect the Cooktown gauge (R^2_{adj} = 0.476). Step-changes due to dredging and storm surges shows the gauge is not secured to the harbour floor. In comparison, 65.6% and 64.5% variation in MSL was explained by covariables and step-changes at Rosslyn Bay and Cape Ferguson. Although further individual site analysis is required, longer-term and storm-surge gauges located on piers and wharfs may be less precise or more prone to random fluctuations than gauges located on more solid, concrete-decked structures such as at Rosslyn Bay and Cape Ferguson.

5. Conclusions

Claims that anthropogenic global warming is causing sea level to rise, particularly in the norther sector of the Great Barrier Reef are unfounded. Since records commenced in January 1996, the Cooktown storm-surge tide gauge was impacted on by a major dredging campaign 1997 following TC Justin (108,000 m^3), TCs Ellie and Hamish which lashed the Queensland coast in February and March 2009, dredging following TC Ita in 2014 (40,000 m^3) and refurbishment of the wharf in January 2015. The tide gauge is not securely fixed to the bed of the harbour thus data are subject to random impacts and fluctuations.

Without taking account of local impacts, use of naïve linear regression or more complex schemes to calculate changes in sea level is fraught with inaccuracies and underlying inhomogeneities and therefore likely to find spurious trends. Valid trend analysis requires that residuals (tide gauge data minus trend) to be time-random, independent, with equal variance otherwise latent factors have not been accounted for.

As tide gauge data show no valid trend, satellite-derived MSL estimates that show sea level rise or acceleration should not be used for critical studies without independent verification. The possibility that trends is embedded by the process of estimating MSL from satellites cannot be ruled out.

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Author's note: Although this draft Report has been carefully researched and uses statistical tools, data and other evidence that is available in the public domain, no responsibility is accepted for errors of fact arising from the scarcity of corroborating information.

Data used in the study is provided separately.

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