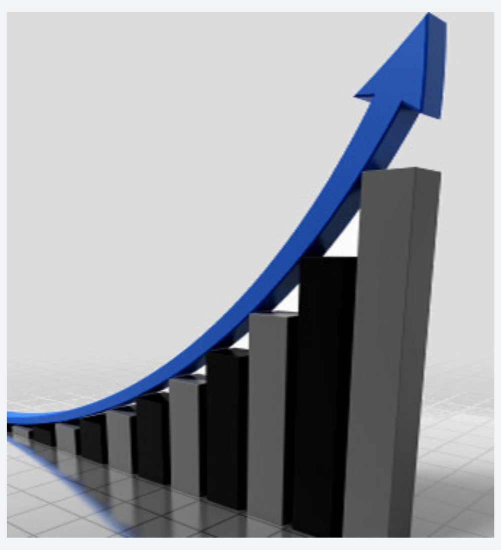
UNIVERSITY OF Southampton

National Oceanography Centre, Southampton
UNIVERSITY OF SOUTHAMPTON AND NATURAL ENVIRONMENT RESEARCH COUNCIL

THE UNIVERSITY OF WESTERN AUSTRALIA
Achieving International Excellence

Time scales for detecting a significant acceleration in sea-level rise



Ivan Haigh[1,2], Chari Pattiaratchi[2], Thomas Wahl[3], Rene Price[4]

1. Ocean and Earth Science, National Oceanography Centre, University of Southampton, UK. E-mail: I.D.Haigh@soton.ac.uk
2. The School of Environmental Systems Engineering and the UWA Oceans Institute, The University of Western Australia, Australia
3. Research Institute for Water and Environment, University of Siegen, Germany.
4. Department of Earth and Environment and SERC, Florida International University, USA

Introduction

There is observational evidence that global sea levels (SL) are rising and there is concern that the rate of rise will accelerate, significantly threatening growing coastal communities. However, a consensus has not yet been reached on whether SL has been rising more quickly in recent years, which would indicate we are following a high SL projection pathway. We believe this is because there is uncertainty regarding two related questions: (1) Has there been a significant acceleration in SL since early in the 20C or are changes since then essentially linear or even negative? (2) Are the high rates of rise measured since 1993 significantly larger than rates observed at other times in the past two centuries? Both questions relate to two methods that have tended to be used to detect accelerations, namely: (i) fitting quadratic equations to tide gauge (TG) records, with the acceleration defined as twice the quadratic coefficient; (ii) estimating linear trends for consecutive, overlapping time periods of different lengths. We briefly examine each question and then we apply these two methods, to synthesized datasets created by combining measured records with different projections of SLR from the present to 2100.

We ask:

1. If SL's were to rise by 0.5-2m by 2100 when might fitting quadratic trends to individual TG records or global reconstructions beginning in the late 19C to early 20C identify: (a) accelerations significantly different from zero? (b) Rates of SLR that would indicate we are following the upper end of the projected AR4 range or higher7?

2. When might fitting overlapping linear trends identify that SL are rising at a rate significantly higher, for the same period, than at any other time over the last two centuries, and which overlapping data length would identify this earliest?

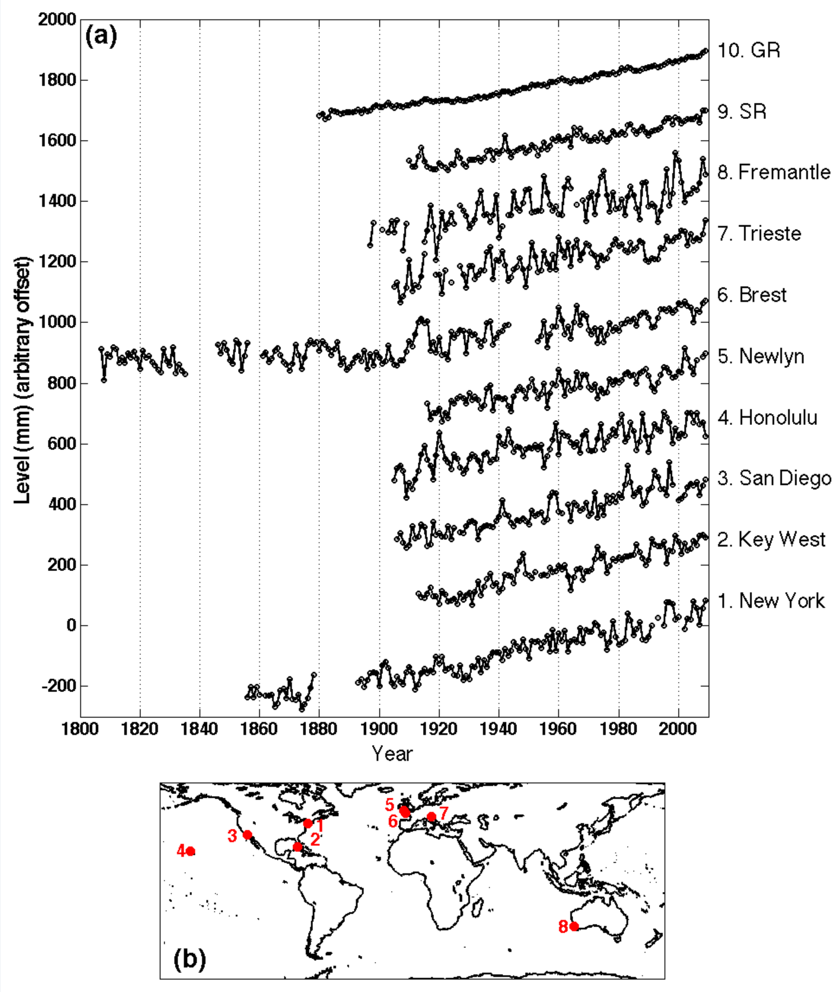


Figure 1: (a) Annual mean sea level time-series (corrected for GIA), offset for presentation purposes; (b) location of the eight TG sites.

Methods

We use eight TG records and two global reconstructions - one a simple average of these eight records and the other the reconstruction from Church and White (2011) (hereafter SR and GR, respectively) (Fig. 1). We consider four projections: ~0.5 and ~0.8m (i.e. mid and upper AR4 range), and 1.5 and 2.0m (i.e. around the upper end of the range suggested by semi-empirical studies) of SLR from 1990-2100 (hereafter P1, P2, P3, P4, respectively). For each record and projection, we created 10,000 artificial time-series; comprising the historic data for that record and the specific projection from present to 2100 superimposed with different random auto-correlated noise signals to account for year-to-year variability (Fig 2a).

To answer question 1, we fit quadratic trends to specific periods of these time-series, increasing the period, relative to a fixed start year, by one year into the future each time (Fig. 2b). To answer questions 2, we fit linear trends to overlapping periods of different lengths (Fig. 2c,d). We identify the end year of the period when: an acceleration statistically different from zero is first obtained; the acceleration exceeds 0.1mm/yr^2; the linear trends are significantly higher than the largest trends pre-2010.

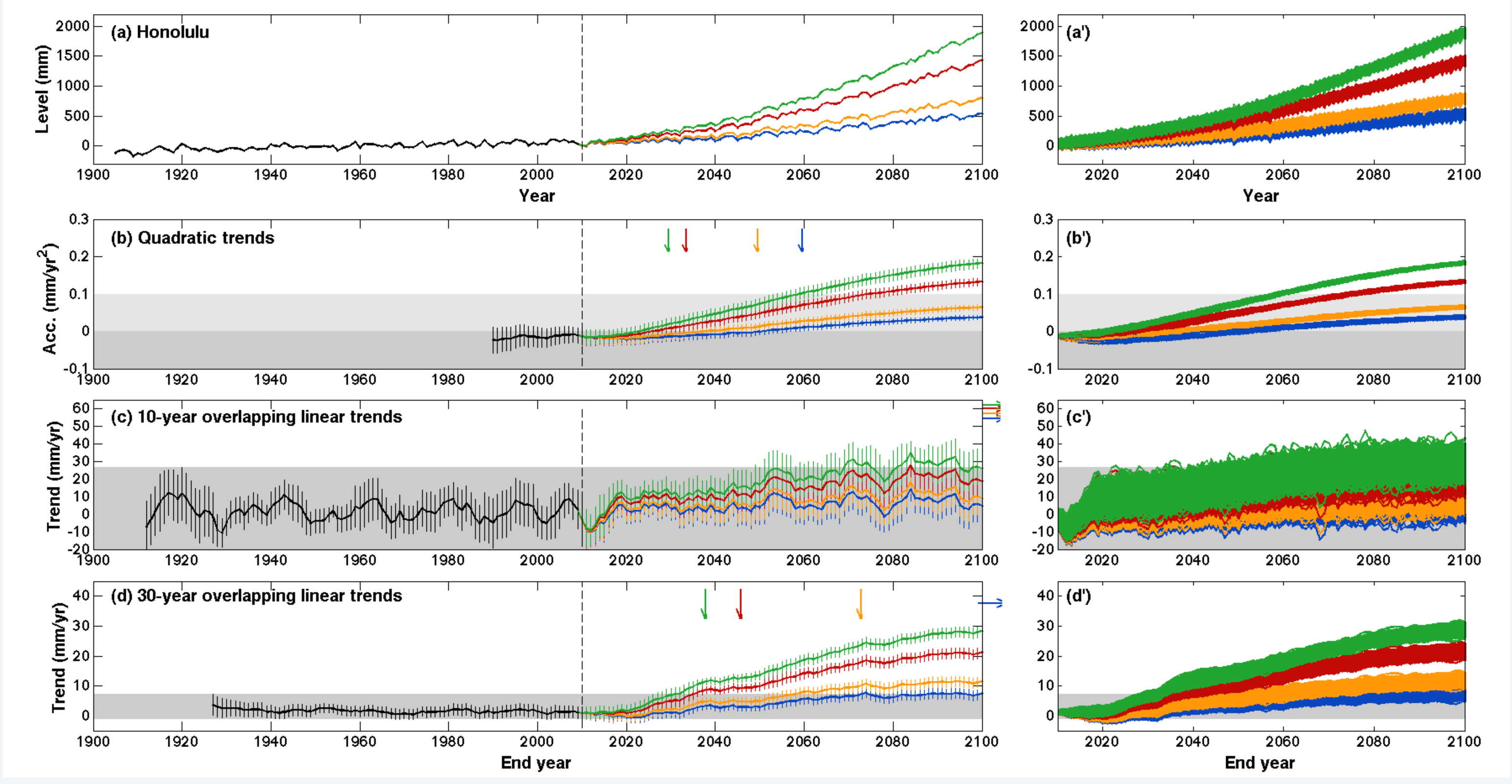


Figure 2: Left panels show the: (a) synthetic SL time-series (only 1 of the 10,000 randomly generated time-series is shown as an example) and associated; (b) quadratic trends; (c) overlapping 10-year linear trends; (d) overlapping 30-year quadratic trends; plotted against the end year of the period for which the trend was calculated at Honolulu. Right panels show the 10,000 synthetic time-series for each of the four SLR projections (a') and the associated quadratic (b') or linear (c',d') trends. Vertical bars indicate 95% confidence intervals associated with the trends. Down pointing arrows indicate when quadratic trends at statistically different from zero (b) or when lower 95% confidence limit of the linear trend is higher than the upper 95% confidence limit of the trends for the historic period (c,d). Arrows pointing to the right indicate that these criterion are not met until after 2100. In plot b, the darker and lighter grey areas indicate trends less than 0 and 0.1mm/yr2, respectively. In plots c and d the grey areas indicate trends less than the upper 95% confidence limit of the trends for the historic period.

Results 1

As anticipated, the GR gives the earliest indication of an acceleration significantly different from zero (Fig. 3) and distinct from past rates (Fig. 4), followed in most cases by the SR. Significant accelerations are detected years to decades later at individual sites - earlier at sites with less variability (i.e. Newlyn) and later for sites with large variability (i.e. Fremantle) (Fig. 1).

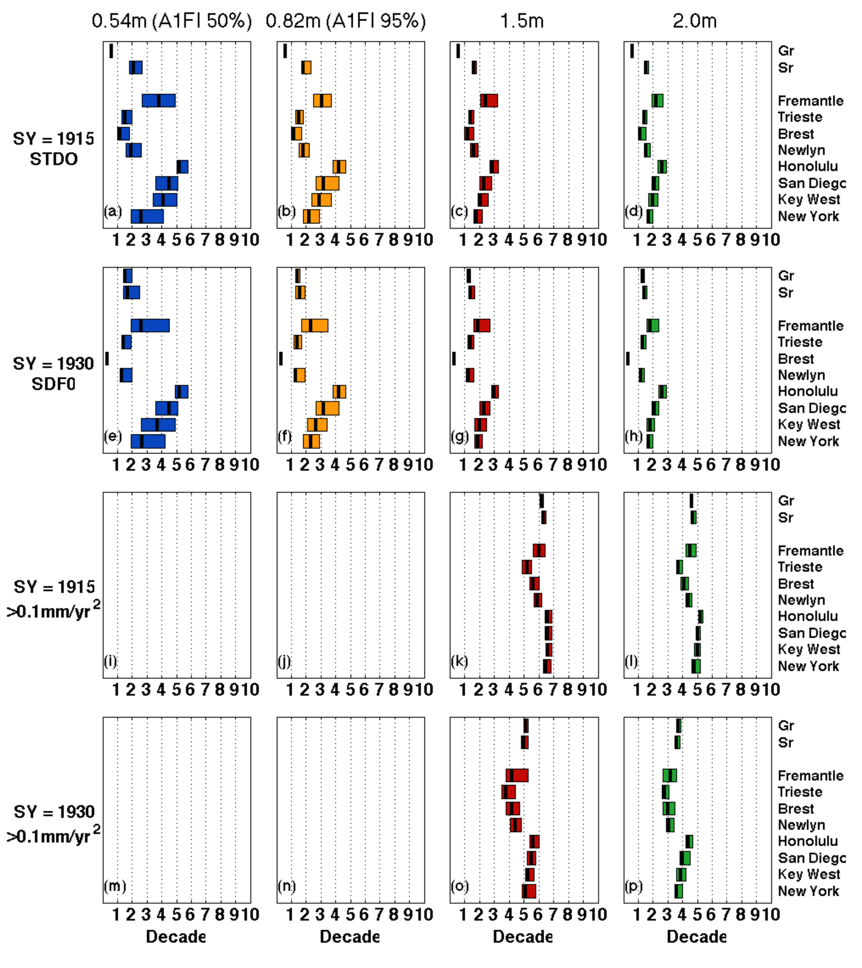


Figure 3: Quadratic trends (mm/yr2) calculated for increasing data periods relative to different start years (1915 of 1930) for SLR projections corresponding to a 0.54, 0.82, 1.5 and 2m total rise in SL between 1990-2100 (columns). Bars show the range of years in the 21st century for each of the 10,000 synthetic time-series when quadratic trends are statistically different from zero (SDF0) (top two sets of panels) or >0.1mm/yr2 (bottom two sets of panels). The solid line within each bar indicates the 50th percentile year. The x-axis show the decade (1 is 2010, 2 is 2020, etc).

In regard to question 1a; quadratic trends are very sensitivity to the chosen start year (Fig. 3). We focus on two start years: 1915, 1930. An acceleration significantly different from zero is apparent in the GR for 1915-2009 but not for 1930-2009; whereas trends are not significantly in the other nine records for periods starting from 1880. Considering data only from 1930 onwards, an acceleration significantly different from zero is identified in the GR between 2014-2019, 2013-2017, 2013-2015 and 2013-2014 for projections P1-4, respectively (Fig. 3e-h). For the SR the corresponding years, considering data only from 1930 (1915) onwards, are: 2014-2024 (2018-2028), 2014-2020 (2016-2023), 2013-2017 (2015-2018) and 2013-2015 (2014-2017). For the individual locations results are much more variable.

Regarding question 1b; quadratic trends are not, somewhat surprisingly, likely to exceed 0.1mm/yr2 by 2100 for P1 and P2 in the 10 records (Fig. 3i,j,m,n). This is partly because the quadratic equation does not tend to provide a good fit to the data for P1-P2. However, accelerations are likely to exceed this threshold for P3 and P4, but not until 2050-2070 and 2035-2053, respectively (Fig. 3k,l,o,p).

Results 2

In regard to question 2; the earliest detection of a rate of SLR that is distinct from past rates observed over the same period is typically obtained when linear trends are fitted to 30- or 40-year overlapping periods (Fig. 4m-p). Previous authors tended to fit linear trends to 10-, 15- or 20-year periods, to match the length of altimetry data available at the time. If SLR follows P1 (P2), a distinct rate of rise is unlikely to be detected using 10-year periods until after 2100 (2060-85) for the GR (Fig. 4a,b,e,f). Using 40-year periods, a significant acceleration is likely to be detected in the GR about 2025-2029, 2023-2026, 2021-2023 and 2021-2022 for projections P1-4, respectively. For individual locations a significant acceleration is only likely to be identified up to as much as 50-, 30-, 25- and 20-years after these dates for the four projections.

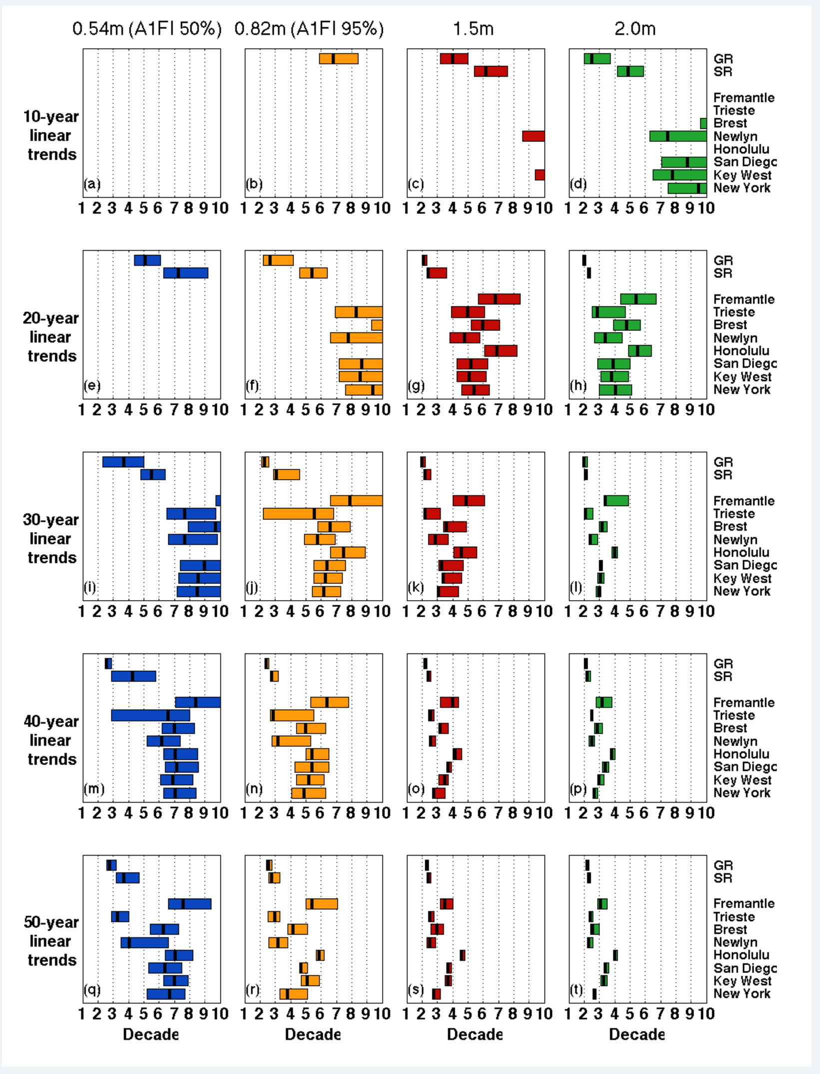


Figure 4: Linear trends (mm/yr) calculated for 10-, 20-, 30-, 40- and 50-year consecutive overlapping periods (rows) for SLR projections corresponding to a 0.54, 0.82, 1.5 and 2m total rise in SL between 1990-2100 (columns). Bars show the range of years in the 21C for each of the 10,000 synthetic time-series when the lower 95% confidence limit of the trends is higher for at least 1 years than the upper 95% confidence limit of the trends for the historic period (i.e. pre-2011). The solid line within each bar indicates the 50th percentile year. The x-axis show the decade (1 is 2010, 2 is 2020, etc).

Conclusions

Early detection of a significant increase in the rate of rise is crucial to enable adequate adaption, particularly if it is at the postulated higher rates of rise. By creating artificial future time-series we have shown that it could still be some time before we detect SLR accelerations that match model projections and are distinct from past rates. For SLR >0.5m, accelerations significantly different from zero are likely to be detected in this decade using global datasets, but trends are sensitive to the start year of the dataset. Results highlight the importance of focusing on global datasets and not records from individual locations.