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DISCUSSION

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Discussion of: Boon, J.D. and Mitchell, M., 2015. Nonlinear Change in Sea Level Observed at North American Tide Stations. *Journal of Coastal Research*, 31(6), 1295–1305.

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ABSTRACT

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Boon and Mitchell determined sea-level acceleration using monthly averaged relative mean sea-level data from 45 U.S. tide stations and 1 Canadian station for 1969–2014. Their methods of analyzing tide gauge data are interesting and useful. However, they then projected sea-level change for 58 years from 1992–2050 based on constant accelerations calculated from these 46-year records. Calculations of acceleration based on records as short as 40–50 years are well known to be heavily corrupted by decadal variations in sea level. For example, Boon and Mitchell showed that 3–6 year variations in record length or time period resulted in what they said were "dramatic change" in calculated acceleration. Therefore, the accelerations they calculated did not even remain constant for a few years, making long-term projections based on them untenable. Boon and Mitchell projected significant sea-level falls from 1992 to 2050 on the coasts of California, Oregon, and Washington, in stark contrast with projections of significant rises by the National Research Council. Similarly, their projections on the U.S. Atlantic and Pacific coasts differ remarkably from projections of the Intergovernmental Panel on Climate Change. Acceleration calculated from 46-year records varies significantly through time, and it is not valid to fix an acceleration value and project it into the future as if it were a constant.

INTRODUCTION

Sea-level change recorded by individual tide gauges has decadal-scale variability with quite large fluctuations of 5–15 cm or greater (Sturges, 1987). Douglas and Peltier (2002) note that these low-frequency fluctuations are coherent over large ocean regions for several decades or more. This decadal variability can significantly affect accelerations determined from tide gauge records, in particular for short record lengths. Douglas (1992, p. 12701) calculated accelerations for tide gauge records in the database of the Permanent Service for Mean Sea Level (PSMSL) and found that "low-frequency variations of sea level heavily corrupt the computation of an acceleration parameter for records less than about 50 years in length." Douglas (2001) recommended that tide gauge records of at least 50–60 years be used to determine acceleration and noted that Douglas (1997) found improved results using tide gauge records with lengths greater than 70 years. Houston and Dean (2013) performed the same analysis as Douglas (1992), but with 20 additional years of data, for 1123 tide gauge records in the PSMSL database, concluding that record lengths needed to be at least 75 years to determine acceleration that was not corrupted by decadal variations.

Boon and Mitchell determined sea-level trends and accelerations using monthly averaged relative mean sea-level data from 45 U.S. tide stations and 1 Canadian station for 1969–2014, centering their calculations in 1992. They were aware of Douglas (1997, 2001) and noted that Douglas argued that records longer than 70 years were required to reliably determine acceleration. However, they determined trends and accelerations based on the 46-year records, assumed they would remain constant for 58 years, and projected sea-level rise from 1992 to 2050. This discussion will focus on their 50-percentile projections.

PROBLEMS

The problems of using short records to project future sea-level change are apparent in Boon and Mitchell. They noted (p. 1299) that "results from numerous analyses show a dramatic change after moving the 1969–2014 window back only 6 years to 1963–2008." For example, a 6-year shift in the analysis period changed trends and accelerations for Sitka, Alaska (shown in Figure 6 of their article), from –2.06 mm/y and +0.096 mm/y^2, respectively, based on the period 1963–2008, to –2.72 mm/y and –0.085 mm/y^2, respectively, based on 1969–2014. Assuming, as they do, that these trends and accelerations

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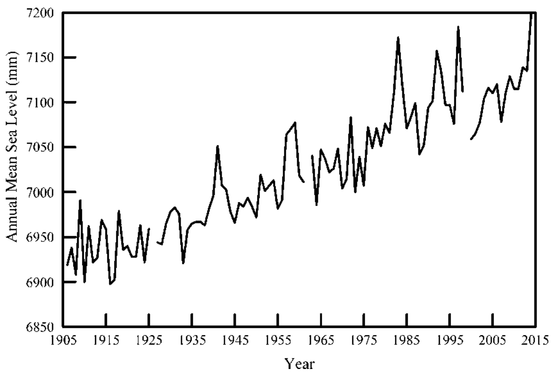

Figure 1. Tide gauge recording at San Diego from 1906 to 2014 (PSMSL, 2015; retrieved 24 December 2015). Data record missing for 1926 and 1999.

remain constant for 58 years results in a projected rise in sea level of +4 cm based on 1963–2008 but a fall of –30 cm based on 1969–2014. A shift of only 6 years in the analysis period changes the projected rise by –34 cm, twice the magnitude and in the opposite direction of global sea–level rise in the 20th century, which was about +17 cm (Church *et al*., 2013). Similar large differences are shown for five other gauge locations in Figures 6 and 7 of Boon and Mitchell. If moving the 46-year window back 6 years leads to a "dramatic change" in projections, moving the window forward 6 years as the years unfold to 2020 would likely result in a similar dramatic change, making the projections completely unreliable. Accelerations based on short records simply do not remain constant for 58 years.

Boon (2012) performed the same basic analysis as Boon and Mitchell for 23 gauge locations on the U.S. Atlantic coast, but for the period 1969–2011 rather than 1969–2014. Both made projections to 2050. For example, Boon projected that Fernandina Beach, Florida, would have a fall in sea level by 2050 of –6 cm, whereas Boon and Mitchell project a rise of +11 cm using just 3 additional years of data from 2011 to 2014. A mere 3-year difference in the analysis period resulted in a sea-level rise rather than fall, with the magnitude of the difference equal to the global rise in sea level in the 20th century. Boon and Mitchell noted that adding 3 years to the analysis period analyzed by Boon changed projections along most of the U.S. Atlantic coast by 10–17 cm, sometimes lowering projected levels and sometimes raising them. Therefore, projections based on accelerations calculated from 1969 to 2017 will likely differ substantially from those based on 1969–2014, and the projections will change markedly every 3 years. Projections based on short record lengths of 40–50 years are of little value to communities, because they change significantly over short time periods.

The projection of sea-level change from 1992 to 2050 that Boon and Mitchell made for the San Francisco, California, gauge location powerfully illustrates that accelerations based on 46-year records cannot be used to validly project future sea-level change. They project a fall in sea level of –18 cm from 1992 to 2050, despite a measured rise of +18.9 cm from 1855 to 2014, including a rise of +1.6 cm from 1992 to 2014 (PSMSL, 2015). In

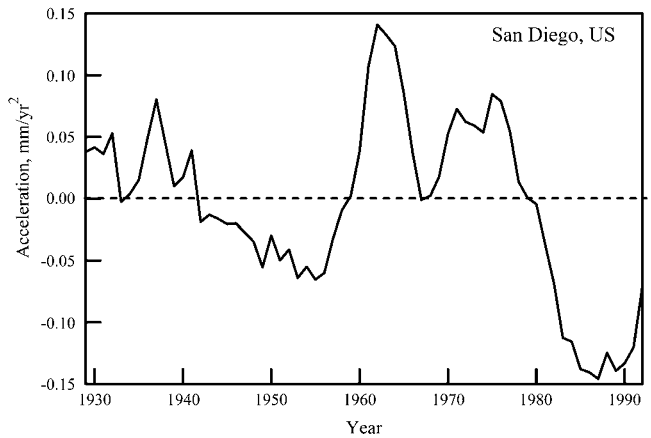

Figure 2. Sea-level acceleration at San Diego based on 46-year records centered in years 1929–1992 and representing the years 1906–2014.

stark contrast, the National Research Council (NRC, 2012) projected a rise in sea level at the San Francisco gauge of +28.0 ± 9.2 cm from 2000 to 2050. The average annual relative sea level at the San Francisco gauge rose +17.3 cm from 1855 to 1992 (PSMSL, 2015). Combining this actual rise to 1992 with the projection of –18 cm from 1992 to 2050 by Boon and Mitchell results in a projected net fall in relative sea level of –0.7 cm over 195 years from 1855 to 2050. Despite a rise in sea level of +18.9 cm at San Francisco from 1855 to 2014, global warming, and worldwide sea-level rise, the Boon and Mitchell projection leads to the absurd result that sea level will fall at San Francisco over 195 years from 1855 to 2050.

Boon and Mitchell projected that 9 of the 10 tide gauge locations they considered in California, Oregon, and Washington would have drops in sea level of –6 to –34 cm from 1992 to 2050. These projections completely disagree with projections by the NRC (2012) of rises of +18–48 cm on these coasts from 2000 to 2050. What is happening with sea-level change on these coasts is illustrated by the tide gauge recording at San Diego, California (Figure 1). Boon and Mitchell project 2.5- and 50-percentile drops in sea level at San Diego from 1992 to 2050 of –33 cm and –7 cm, respectively. Yet Figure 1 shows no apparent sign that sea level will drop from 1992 to 2050. Rather than just determining acceleration based on a single period of 1969–2014, centered in 1992, it is illustrative to consider the entire 109-year San Diego tide gauge record using a sliding 46-year window. First, the acceleration from 1906 to 1951, centered in 1929, is determined, then the acceleration from 1907 to 1952, centered in 1930, and so on thorough a record of 1969–2014, centered in 1992. Figure 2 shows that accelerations determined from 46-year portions of the San Diego gauge record oscillate as a result of decadal variations. Boone and Mitchell obtained a negative acceleration at San Diego for their analysis centered in 1992 because sea level is in a negative acceleration phase for this particular time period, as seen in Figure 2.

Bromirski *et al*. (2011) said that the negative-acceleration phase of sea-level change on the U.S. Pacific coast, including

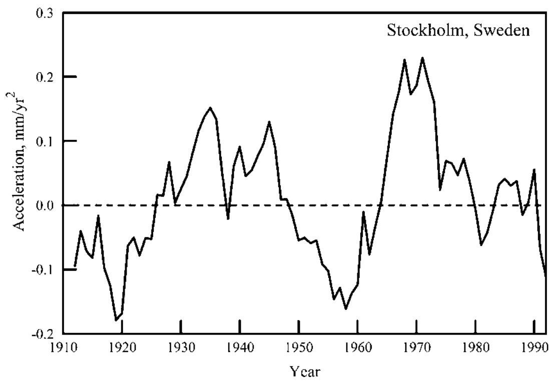

Figure 3. Sea-level acceleration at Stockholm based on 46-year records centered in years 1912–1992 and representing the years 1889–2014.

San Diego, would soon end and be followed by a positive acceleration phase in a long-term pattern of oscillations between positive and negative phases due to decadal variations, as seen in Figure 2. Boon and Mitchell acknowledged that Bromirski *et al*. might be correct, but they said that their 46-year records did not show a shift had started. Their records did not show a shift because they only considered records centered on a single year, 1992. As Figure 2 clearly shows, the negative acceleration phase reversed direction in a record from 1964 to 2009, centered in 1987, and is now rapidly moving toward a positive acceleration phase. Figure 2 supports Bromirski *et al*., and in a handful of years San Diego will move to a positive acceleration phase.

Projections by Boon and Mitchell also disagree remarkably with projections of the Intergovernmental Panel on Climate Change (IPCC, 2013). Annex II of IPCC shows a projected global sea-level rise from 1986–2005 to 2050 of +25.0 ± 7.0 cm to +27.0 ± 7.0 cm, depending on the scenario. Local ground motion at Boston, Massachusetts, is –0.84 ± 0.08 mm/y (Zervas, Gill, and Sweet, 2013). Subtracting ground motion of –3.8 ± 0.4 cm to –5.4 ± 0.5 cm (covering the range from 1986–2005 to 2050) gives a 2050 total range of projected relative sea-level rise at Boston of +28.8 ± 7.0 cm to +32.4 ± 7.0 cm. Boon and Mitchell have 2.5-, 50-, and 97.5-percentile projections of relative sea-level rise for Boston of +46 cm, +62 cm, and +80 cm. Their low projection and the IPCC high projection do not even overlap at 95% confidence intervals. Similarly, projections for San Francisco based on IPCC projections with ground motion added result in a 50-percentile global sea-level rise from 1986–2005 to 2050 of +25.0 ± 7.0 cm to +27.0 ± 7.0 cm, depending on the scenario. NRC (2012) used a different method and projected a similar rise of +28.0 ± 9.2 cm from 2000 to 2050. Both sets of projections contrast remarkably with the 50-percentile fall of –18 cm projected by Boon and Mitchell.

Houston and Dean (2013) applied 40-, 50-, and 60-year moving windows described for San Diego to every long tide record in the world and found the same significant positive and negative phases of calculated acceleration that would make projections based on short records nonsensical. Figures 3–8 show examples using the moving 46-year window approach described for San Diego. Calculated accelerations do not continue at the same rate for even a year, and on a decadal scale there are large oscillations between calculated positive and negative accelerations. For example, Figures 3 and 4 for

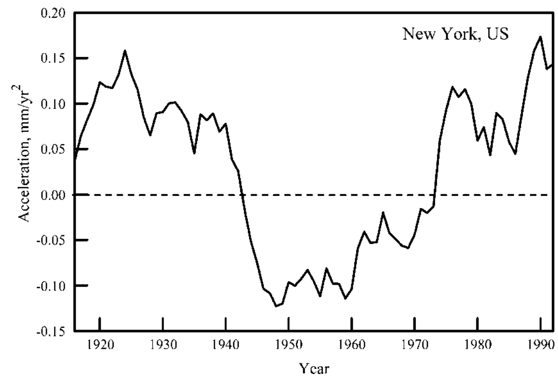

Figure 5. Sea-level acceleration at New York based on 46-year records centered in years 1916–1992 and representing the years 1893–2014.

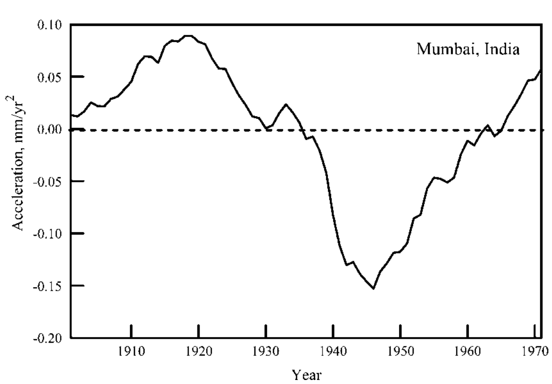

Figure 4. Sea-level acceleration at Mumbai based on 46-year records centered in years 1901–1971 and representing the years 1878–1993.

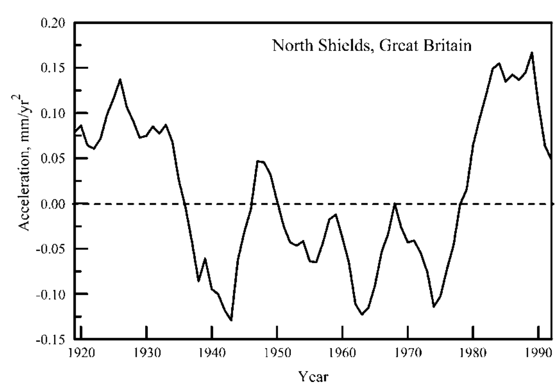

Figure 6. Sea-level acceleration at North Shields based on 46-year records centered in years 1919–1992 and representing the years 1896–2014.

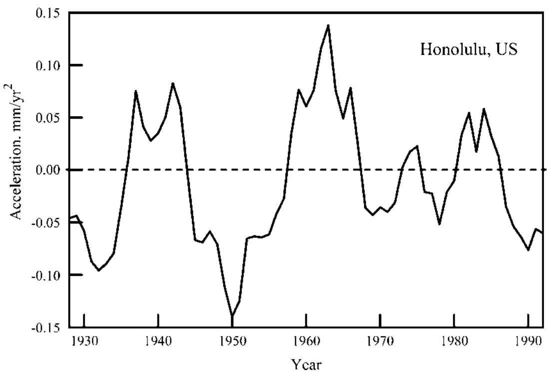

Figure 7. Sea-level acceleration at Honolulu, Hawaii, based on 46-year records centered in years 1928–1992 and representing the years 1905–2014.

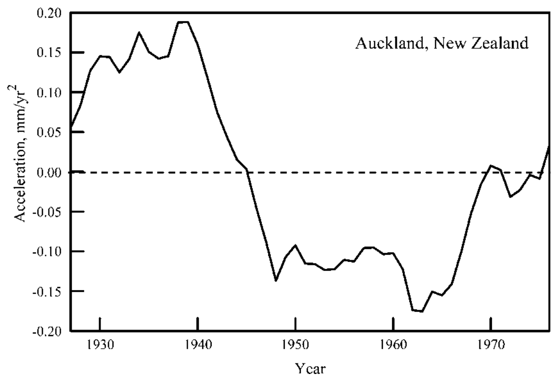

Figure 8. Sea-level acceleration at Auckland, New Zealand, based on 46-year records centered in years 1927–1976 and representing the years 1904–1998.

Stockholm, Sweden, and Mumbai, India, show that a shift in the analysis period of 1 year can change acceleration by more than ± 0.1 mm/y^2, which, when projected for 58 years, would change sea level by about ± 34 cm. The plot for New York, New York, in Figure 5 is typical of accelerations on the U.S. NE coast. Just as a negative acceleration phase has bottomed out in San Diego, a positive acceleration phase appears to be topping out in New York and heading toward a negative phase, the most recent of which lasted for about 30 years at New York. Note from Figure 6 that North Shields, Great Britain, which is in the north Atlantic, as is New York, has phase oscillations similar to New York, and it is already moving from a positive acceleration phase toward a negative. Douglas (1992) and Houston and Dean (2013) showed that about half the gauges in the world at any given time are in a positive acceleration phase and the other half in a negative acceleration phase, as seen in Figures 3–8. Phases always reverse eventually on time scales less than 58 years.

CONCLUSIONS

Houston and Dean (2013, 1071–1072) wrote, "It is not valid to project future sea-level rise based on acceleration or trend difference determined using tide gauge record lengths of only about 40 to 60 years." This conclusion holds for projections by Boon and Mitchell. They assumed accelerations they determined from 46-year records would be stationary in time from 1992 to 2050. However, they demonstrated accelerations were not stationary even for short periods when they noted that 6-year shifts in the periods they analyzed resulted in "dramatic" changes in accelerations and that adding 3 years to records caused similar large changes. Projections to 2050 are of little value to a community when they change greatly with the passage of a few years.

The Boon and Mitchell projections of falling sea level from 1992 to 2050 on the coasts of California, Oregon, and Washington are not valid, and they are troublesome because they support inaction in addressing sea-level rise on the U.S. Pacific coast. Why prepare for sea-level rise in San Francisco from 2014 to 2050 if Boon and Mitchell project sea level at the 50-percentile level will fall –20 cm (there was a rise of about +2 cm from 1992 to 2014) and there would be a rise of only +2 cm at the 97.5-percentile? Climate change skeptics would say that even in the worst-case scenario, sea-level rise would be negligible at San Francisco from 2014 to 2050. The same argument could be made for most of the U.S. Pacific coast and Hawaii, based on Boon and Mitchell projections.

It is best not to use acceleration determined from tide gauge records to project future sea-level change. Decadal variations heavily corrupt the computation of acceleration for short records, and accelerations computed from long records do not account for effects of increasing global temperatures on sea-level change. Instead, IPCC (2013) projections should be used to determine the global sea-level rise component of relative sea-level rise. Annex II of IPCC has global sea-level rise projections for every decade to 2100. Local ground motion should then be subtracted from IPCC projections (ground subsidence is negative and when subtracted adds to the rise). Some tide stations have GPS measurements that can be used to determine ground motion, but if not available, the approach in Zervas, Gill, and Sweet (2013) for estimating local ground motion can be used.

Boon and Mitchell present a valuable approach to analyzing tide gauge records, but it is overshadowed by their invalid projections based on 46-year records. In reply to this discussion, they should be explicit that the sea-level projections in their paper, which undercut the credibility of projections by the NRC (2012) and the IPCC (2013), should not be used.

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