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# DISCUSSION

# Discussion of: Houston, J.R. and Dean, R.G., 2011. Sea-level acceleration based on U.S. tide gauges and extensions of previous global-gauge analyses. *Journal of Coastal Research*, 27(3), 409–417

**Joseph F. Donoghue**[†] **and Randall W. Parkinson**[‡]

[†]Department of Earth
Ocean and Atmospheric Science
Florida State University
108 Carraway Building
Tallahassee, FL 32306, U.S.A.
jfdonoghue@fsu.edu

[‡]RWParkinson Consulting, Inc.
2018 Melbourne Court, Suite 205
Melbourne, FL 32901, U.S.A.
rwparkinson@cfl.rr.com

## INTRODUCTION

In a recent article, Houston and Dean (2011) attempted to quantify acceleration in the rate of historical sea-level rise (SLR) by analyzing monthly averaged, long-term, tide-gauge records for 57 U.S. tide stations. The data were extracted from the Permanent Service for Mean Sea Level (PSMSL) at the National Oceanography Centre in Liverpool, U.K. The investigation involved the calculation of accelerations for each station for the period of record, plus accelerations for the 25 stations whose records extended back to 1930. The authors calculated decelerations, *i.e.,* a slowing in the rate of SLR, for 16 of the 25 selected long-term gauge records. The authors stated that there is no evidence of acceleration in 20th century SLR, despite rising atmospheric temperatures. Therefore, they contended the accelerations forecasted to accompany continued warming are highly suspect. They concluded that researchers must now determine why global warming has not produced an acceleration in SLR. We believe the authors' conclusions are erroneous for a variety of reasons, including those argued in the accompanying rebuttals. We will focus our criticism on three issues in the sections that follow.

## GEOGRAPHIC AND TEMPORAL LIMITITATIONS OF THE TIDE-GAUGE DATA

There are approximately 1800 global tide stations with reasonably long records in the PSMSL database that the authors accessed. The authors initially selected just 57 stations, and later reduced the number analyzed to 25 stations. The gauge locations were only in the United States. Additionally, the authors used data collected between 1930 and 2009, despite the fact that many of the PSMSL data sets extend back well beyond 100 years. Jevrejeva *et al.* (2006) employed advanced statistical analyses to examine the PSMSL tide gauge database and found that determining the rate of SLR was highly dependent on the time period chosen. They further noted large decadal-scale and regional variability in the global tide-gauge record, a variability that has increased toward the present. They noted that some of the problems with analyzing tide-gauge data are inherent in the system: poor distribution of tide gauges, sparse data from the southern hemisphere, regional tectonic activity, and the ongoing glacial isostatic adjustment following the last ice age. Taking such a small geographic and temporal subset of the PSMSL tide gauge data makes any conclusions based on that subset suspect.

## UNIFORMITARIANISM AND THE INADEQUACY OF HISTORIC TIDE-GAUGE DATA TO REPRESENT FUTURE CONDITIONS

The Hutton (1788) dictum that the present is the key to the past has been a major tenet of the modern science of geology. For normal processes, the present is a useful analog for understanding past events. However, infrequent events that have occurred in the geologic past, such as major meteorite impacts or supervolcano eruptions, cannot be understood through study of present-day processes. Similarly, a study of processes of the recent past, such as long-term tide-gauge records, is not necessarily a good indicator of future circumstances. This is especially true in a future where models predict conditions that have not been experienced for many millennia.

Climate models project that the global ocean–atmosphere system is likely to behave differently in a warmer future than it has since human civilization began. If the ice sheet contribution to SLR becomes significantly larger than at present, then the response in sea level will be quite nonlinear. As a result, the recent past is a poor predictor of the near future, and analyses of small subsets of the historic tide-station database are of little prognostic value. We believe that it is inappropriate to relate sea-level history during the *past* century with projections for the *next* century. Global conditions during the past century

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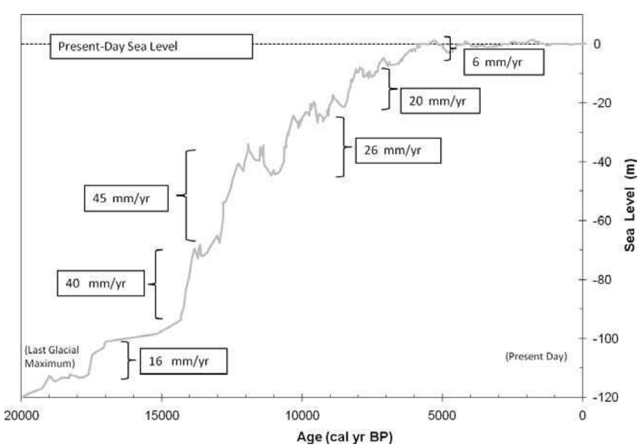

Figure 1. Gulf of Mexico sea-level change, 20,000 years ago to present, based on approximately 300 radiocarbon-dated paleoshoreline indicators. Several episodes of rapid sea-level rise are indicated. Figure adapted from Donoghue (2011).

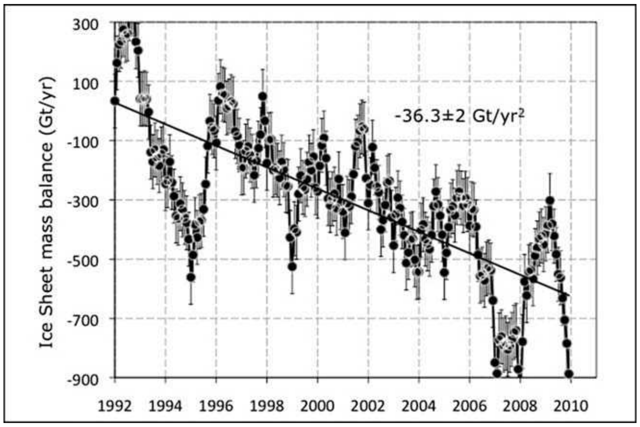

Figure 2. Total ice sheet mass balance and acceleration in the rate of loss between 1992 and 2010 for Greenland and Antarctica combined in gigatons per year with associated error bars. From Rignot *et al.,* 2011.

are geologically unique. They have little in common with the long-term geologic conditions of the past 20,000 years and potentially little in common with those projected for the next century.

The global long-term tide-gauge record for the past century has averaged about 1.7 mm/y (Church and White 2006; Church *et al.,* 2001; Douglas 2001; Peltier 2001). Satellite altimetry since 1993 has created an independent and more comprehensive database of global sea-level change. The TOPEX/Poseidon/Jason satellite data show an average rise of 3.0 mm/y since 1993 (NOAA, 2010). In contrast, the sea-level record of the past 20,000 years, since the last glacial maximum, has been quite different. Following the peak of the last glacial advance, the rate of SLR in the Gulf of Mexico, for example, was at times extremely rapid, as much as 45 mm/y (Figure 1) (Donoghue, 2011; Fairbanks, 1989; Wanless, Parkinson, and Tedesco, 1994), because the postglacial ice sheet retreated in pulses. These rates are in sharp contrast with those documented over the most recent few millennia. The geologic and instrumental record indicates that, within the limits of uncertainty, at no time in the past 2000 years has the rate of global SLR exceeded 50 cm/100 y (5 mm/y) (Church and White, 2006; Fairbanks, 1989; Stanford *et al.,* 2010; Toscano and Macintyre, 2003; Wanless, Parkinson, and Tedesco, 1994).

Model projections for SLR during the 21st century are equally unlike the observations of the past century. Projections of the rate of SLR for the next century far exceed the rate of rise associated with the past few millennia and are greater than, or equal to, any experienced since the last glacial maximum. A variety of recent modeling efforts, both empirical and physics-based, have projected that sea level during the current century will rise at rates as much as an order of magnitude or more greater than those of the past century, to levels of as much as 2 m above present by 2100 (Grinsted, Moore, and Jevrejeva, 2009; Horton *et al.,* 2008; IPCC, 2007; Jeverjeva, Moore, and Grinsted, 2010; Meehl *et al.,* 2007; Pfeffer, Harper, and O'Neel, 2008; Rahmstorf, 2007; Vermeer and Rahmstorf, 2009).

In summary, the behavior of sea level during the past century was quite unlike the past 20,000 years, and models project that the current century will be quite dissimilar from the last. As a result, the behavior of historical sea-level change as determined through a review of a limited number of North American tide-gauge records has little relevance to future sea-level change.

## MELTWATER VOLUME

It is curious Houston and Dean (2011) do not refer to glacial retreat and the resulting discharge of meltwater as a factor contributing to historical SLR. Time-series analysis of historical and recent photographs indicates mountain glaciers began an accelerated retreat no later than the early 20th century (USGS 2009). By the onset of the 21st century, a sophisticated array of satellites had been deployed with instrumentation designed specifically to quantify changing physical conditions of the world's mountain glaciers, ice caps, and ice sheets. Subsequently, a variety of published reports have attested to the widespread melting and associated sea-level change (*e.g.,* Chen *et al.,* 2009; Gardner *et al.,* 2001; Rignot *et al.,* 2011; van den Broeke *et al.,* 2009; Velicogna and Wahr, 2006; Wu *et al.*, 2010). The results of these and similar studies are perhaps best summed up by the nearly 2-decade-long study by Rignot *et al.* (2011). Those authors show that the Greenland and Antarctic ice sheets have been losing mass at a rate of approximately 300 Gt/y, adding meltwater to the world ocean at a rate of approximately 0.8 mm/y. This loss has accelerated at a combined average of 36.3 Gt/$y^2$ over the duration of their study (Figure 2). The loss of mountain glaciers and ice caps was equally significant and was shown also to have accelerated, albeit at a slower rate. If not contributing significantly to the magnitude and rate of SLR, as Houston and Dean (2011) would have us believe, where did all this meltwater go?

Most investigators caution that the observed historical and recent melting rates of ice sheets, mountain glaciers, and polar caps are expected to accelerate in the years and decades ahead as reflective ice and snow shrink and the darker areas of water and soil enlarge. These dark regions will retain ever more heat, in turn, accelerating the melting of the remaining ice and snow. Thus, we can expect the sea level to rise even faster than its present rate of approximately 3.0 mm/y in the coming years *if the "business as usual" response to climate change remains the default choice of industrialized nations.*

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