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REPLY

Reply to: Rahmstorf, S. and Vermeer, M., 2011. 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.

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Rahmstorf and Vermeer (RV) argue that modeling sea level as a function of temperature using their semi-empirical approach as presented by Rahmstorf (2007) and Vermeer and Rahmstorf (2009) is superior to the standard approach of analyzing sea-level rise as a function of time used by Houston and Dean (2011). Their criticism applies not only to this paper, but also to the work of eminent sea-level experts such as Douglas, Holgate, Woodworth, and others who have used the same standard approach we use. In making this claim, RV present their Figure 1 as the key evidence supporting the efficacy of their model. Figure 1 purports to show good agreement between accelerations based on their modeling and accelerations based on the data of Church and White (2006). However, it is easily seen that the portion of Figure 1 where the agreement is "good" compares their modeling versus increasingly meaningless data, and they have been selective in showing only data that appear to match their modeling and not the data that strongly disagree.

Houston and Dean (2011) considered only tide-gauge records with lengths greater than 60 years, noting that shorter record lengths are "corrupted" by decadal fluctuations. Douglas (1992) shows that as a result of decadal fluctuations, as record lengths become increasingly shorter than approximately 50–60 years, about half of tide-gauge records display increasingly large positive accelerations, while the other half displays increasingly large negative accelerations. These positive and negative accelerations are uncorrelated to accelerations based on record lengths greater than approximately 50–60 years. Note in Figure 1 that as the record length becomes shorter, the 2-sigma range becomes increasingly large so that for most of the right-hand side of Figure 1 it is not possible to know whether the accelerations are positive or negative, making comparisons increasingly meaningless.

In Figure 1, RV show only the data that agree with their model. On the x axis of Figure 1, record lengths are shorter than 60 years for starting years after around 1940. It happens that at around 1940 the acceleration shown is approximately zero. Thus, as seen in Figure 2, the record from 1940 to 2001 has a strong linear trend with decadal fluctuations but approximately no acceleration. If the record from 1940 to 2001 has zero acceleration, how is it then possible that all shorter records (starting years after 1940) shown in Figure 1 have positive accelerations that increase as record lengths shorten? It is not possible. Again, RV only plot the data as long as they agree with their model. If the plot is extended, *e.g.,* to the starting year of 1985, the acceleration is -0.044 mm/y^2, more than twice the range shown for negative accelerations in Figure 1. If the plot is extended further, the folly of analyzing records shorter than approximately 60 years becomes increasingly obvious. The acceleration for a starting year of 1995 is -0.51 mm/y^2, about 25 times the range shown for negative accelerations in Figure 1. RV compare their model to data as long as there are positive accelerations and do not continue the plot when accelerations become negative, which must happen for the overall record from 1940 to 2001 to have an acceleration of approximately zero. Their rationale for stopping at a starting time of 1970 is that after 1970 "… short-term noise dominates the calculations and results oscillate strongly" (p. 789). But Douglas (1992) shows, *e.g.,* that 30–40-year record lengths (starting times 1960 and 1970 in Figure 1) show positive and negative accelerations 10–20 times larger than accelerations determined from 80-year records. Yet RV criticize our analysis of 80-year records from 1930 to 2010 as being too short. The fact is that decadal fluctuations begin to dominate records shorter

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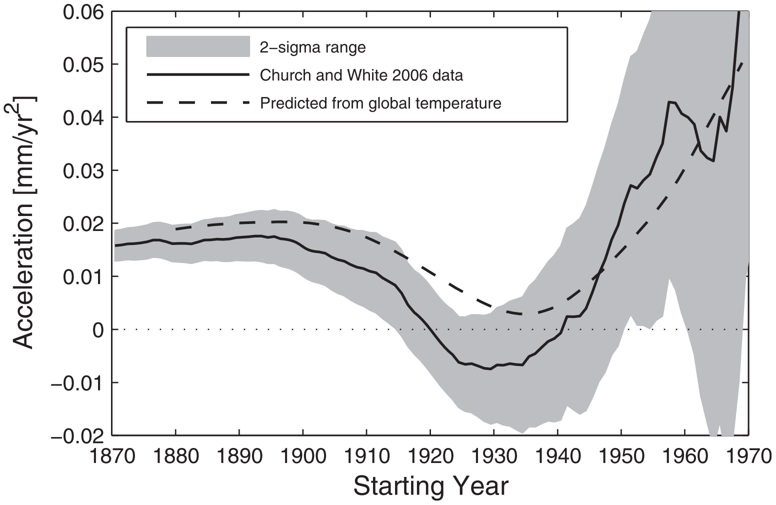

Figure 1. From Comment by Rahmstorf and Vermeer.

than about 60 years, and accelerations become increasingly meaningless for starting years in Figure 1 greater than about 1940. Moreover, positive accelerations peak some time after the starting time of 1970 and eventually plunge to very large negative values. In summary, RV compare their model results to meaningless data after the starting year of about 1940 and are selective in only showing data with positive accelerations after 1940.

Church *et al.* (2004) correctly analyze the same data set (their own) that RV incorrectly analyze and conclude that "Decadal variability in sea level is observed but to date there is no detectable secular increase in the rate of sea level rise over the period 1950–2000" (p. 2624). This conclusion is evident from Figure 2 and in stark contrast to the claims of RV and the acceleration they show in Figure 1 for a starting year of 1950.

RV link sea-level rise with temperature using a simple linear relationship with two free variables of opposite signs that allow them to "fit" any smooth data set. However, they are curve fitting, not modeling physics, so the approach cannot be used to predict future sea level. *Holgate et al.* (2007) criticized RV's assumption of a linear relationship between global mean surface temperature and the rate of global mean sea-level change and concluded, "We find no such linear relationship" (p. 1866b). Further they concluded, "… at the 50- to 100-year time scale, the linear relationship has little skill in predicting the observations not included in the original model formulation" (p. 1866b). A recent workshop of the Intergovernmental Panel on Climate Change (IPCC, 2010) considered the semi-empirical approaches of Rahmstorf (2007), Vermeer and Rahmstorf (2009), and others and concluded, "No physically-based information is contained in such models …" (p. 2) and "The physical basis for the large estimates from these semi-empirical models is therefore currently lacking" (p. 2).

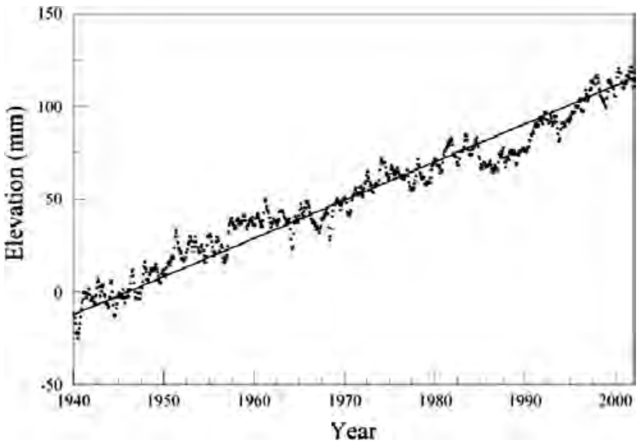

Figure 2. Church and White (2006) data from 1940–2001.

RV also present less fundamental criticisms of Houston and Dean (2010). For example, they note that data considered by Houston and Dean are biased to the northern hemisphere. This criticism would apply to any study of sea-level rise and is attributable to the lack of historical tide-gauge data in the southern hemisphere. In fact, it applies to the historical temperature that RV use in their analysis. However, we note that Watson (2011) published an analysis of sea level in Australia and obtained small decelerations very similar to those of our study.

RV argue that impoundment by dams decreased the rate of sea-level rise after around 1960. They say that our paper claims that groundwater mining would offset this impoundment, and they then argue that this mining is relatively small. They neglect to mention that groundwater mining is only one of the offsetting factors given in Houston and Dean. Houston and Dean (2011) state, "However, in the IPCC, Bindoff et al. (2007) note that the reservoir impoundment is largely offset by other anthropogenic activities that accelerated since 1930, such as groundwater extraction, shrinkage of large lakes, wetland loss, and deforestation" (p. 415). Houston and Dean further state that "Huntington (2008) showed ranges of the contribution of each term of the land–water interchange determined in several studies and concluded that the net effect of all the contributions was to increase the sea-level trend" (p. 415). This conclusion is in direct opposition to the claim of RV that impoundment by dams significantly decreased the rate of sea-level rise.

The important conclusion of our study is not that the data sets we analyze display small sea-level decelerations, but that accelerations, whether negative or positive (we reference studies that found small positive accelerations), are quite small. To reach the multimeter levels projected for 2100 by RV requires large positive accelerations that are one to two orders of magnitude greater than those yet observed in sea-level data.

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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.

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ABSTRACT

RAHMSTORF, S., and VERMEER, M., 2011. 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. *Journal of Coastal Research,* 27(4), 784–787. West Palm Beach (Florida), ISSN 0749-0208.

A recent article published in the *Journal of Coastal Research* analysed a number of different sea-level records and reported that they found no acceleration of sea-level rise. We show that this is due to their focusing on records that are either too short or only regional in character, and on their specific focus on acceleration since the year 1930, which represents a unique minimum in the acceleration curve. We find that global sea-level rise is accelerating in a way strongly correlated with global temperature. This correlation also explains the acceleration minimum for time periods starting around 1930; it is due to the mid-twentieth-century plateau in global temperature.

ADDITIONAL INDEX WORDS: *Ocean, sea level, climate change, global warming.*

INTRODUCTION

In a recent paper, (Houston and Dean, 2011) cast doubt on whether global sea-level rise has accelerated over the past century or so, and they questioned the link between global warming and an acceleration of sea-level rise shown in a number of recent studies (Grinsted, Moore, and Jevrejeva, 2009; Jevrejeva, Grinsted, and Moore, 2009; Rahmstorf, 2007; Vermeer and Rahmstorf, 2009). They conclude by asking "why this worldwide-temperature increase has not produced acceleration of global sea level over the past 100 years, and indeed why global sea level has possibly decelerated for at least the last 80 years" (p. 416).

However, the five main arguments presented by Houston and Dean in support of a lack of acceleration in global sea-level rise are all unconvincing:

(1) The global sea-level reconstruction of Church and White (2006) shows a small deceleration since 1930, but 1930 is a uniquely chosen start date in this respect, and this deceleration is neither statistically significant nor robust across different sea-level data sets.
(2) Many U.S. tide gauges show a deceleration; since 1930, most of them do. However, again, 1930 is a special choice, and U.S. tide gauges only provide a regional signal, not a global one.
(3) The authors' extension of the Douglas (1992) sea-level compilation shows a sea-level deceleration for 1905–2010, but this data set is not a global average but is instead highly biased to the Northern Hemisphere. It is known that the twentieth-century acceleration is largely found in the Southern Hemisphere (Merrifield, Merrifield, and Mitchum, 2009), and the only two Southern Hemisphere groups in the extended Douglas data set indeed show acceleration.
(4) Decadal trends in tide gauge compilations show large variations over the full record, and the most recent decadal trends are not unusual. However, these variations in decadal tide gauge trends are not a climate signal but rather are dominated by sampling noise due to the inadequate number of tide gauges.
(5) The satellite altimeter record shows a slight deceleration since 1993, but this time interval is far too short to draw any conclusions.

In the following we will discuss these issues in detail.

THE GLOBAL SEA-LEVEL RECORD AND ITS LINK TO TEMPERATURE

When fitting a quadratic equation to sea-level data, Houston and Dean ignore the fact that global warming has not been

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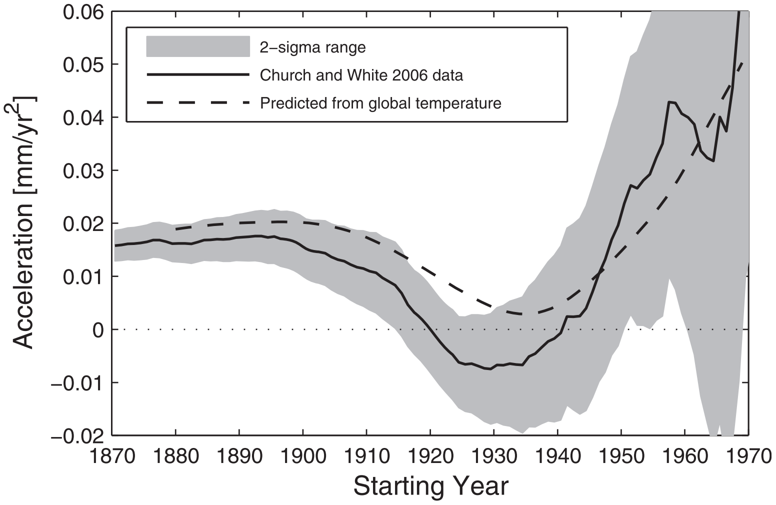

Figure 1. Acceleration of sea-level rise (*i.e.*, twice the quadratic coefficient) from different starting years up to 2001 in the global tide gauge data set of Church and White (2006; solid line), as compared to the same quantity from the sea-level hindcast of Vermeer and Rahmstorf (2009; dashed line) based on global temperature data. Note that we followed Houston and Dean in not accounting for the time-varying error bars of the tide gauge data, which is why we get slightly different numbers than those reported in Church and White (2006). We also show a conservative estimate of 2σ uncertainty in the acceleration, which accounts for an autocorrelation of 40% at lag 1 y and uses uniformly weighted data.

linear in time, nor can the sea-level history be well described by a linear increase in the rate of rise, *i.e.*, a quadratic increase in sea level itself. Instead, both follow a more complex time evolution with a high correlation between temperature and the rate of sea-level rise. Hence, Houston and Dean's method of fitting a quadratic and discussing just one number, the acceleration factor, is inadequate.

Modelling sea level as a simple function of time, $H(t)$, is not physical, because time is not the direct cause of sea-level rise. The more physical approach used in the semi-empirical models cited previously is to model sea level as function of temperature, $H(T)$. These approaches would converge only if temperature were to increase linearly in time—then semi-empirical models would give a constant acceleration of sea-level rise (Rahmstorf, 2007; Vermeer and Rahmstorf, 2009). However, global temperature evolution over the twentieth century is not even close to that, and neither is global sea level close to parabolic behaviour.

Houston and Dean even seem to think that despite the much faster warming expected in the twenty-first century, the same acceleration value should apply to the twentieth and twenty-first centuries. They write that "it is not clear that the acceleration necessary to achieve these comparatively large projected rises in mean sea level over the course of the 21st century is evident in tide-gauge records" (p. 409). Why would tide gauge data of the twentieth century show the acceleration expected in the twenty-first century? What we may expect instead is for tide gauge data of the twentieth century to follow the temperature evolution of the twentieth century. That is indeed the case, as shown in detail below.

Houston and Dean (2011) focus mostly on acceleration for the period 1930 to today, both for their sample of U.S. tide gauges (their Table 1) and the global sea-level record of Church and White (2006) (their Figure 1), stressing the slight negative acceleration over this period. In our Figure 1, we show the acceleration for the Church and White (2006) data up to the present, but for all starting years between 1870 and 1970, not just for 1930. The figure shows a pronounced minimum in acceleration values for starting years around 1930. Houston and Dean (2011) admit that they deliberately selected this starting year because of this feature: "Since the worldwide data of Church and White (2006) … appear to have a linear rise since around 1930, we analyzed the period 1930 to 2010." Positive acceleration is found for both earlier and later starting years, as Figure 1 here shows.

Figure 1 also answers the concluding question posed by Houston and Dean, cited on the opening paragraph here. The semi-empirical models *predict* and thus explain the acceleration minimum around 1930 as a consequence of the plateau in the global temperature record in the middle of the twentieth century. Since global temperature did not rise from about 1940 to about 1980, one cannot expect any significant acceleration of sea-level rise over this period.

When correlating sea level with global temperature, nonclimatic influences on sea level can muddy the waters and are best removed to isolate the climatic effect on sea level. Glacial isostatic adjustment is routinely corrected for, and in Figure 2 we show the way in which correcting for water storage in artificial reservoirs (Chao, Wu, and Li, 2008) affects the results, following Vermeer and Rahmstorf (2009). This significantly improves the agreement between the sea-level acceleration predicted from global temperature and the acceleration actually found in the tide gauge data.

Houston and Dean rightly point out that one should likewise correct for the water mined from deep groundwater sources for irrigation purposes. However, no suitable time series of twentieth-century groundwater mining is available. Nevertheless, Vermeer and Rahmstorf (2009) performed a sensitivity

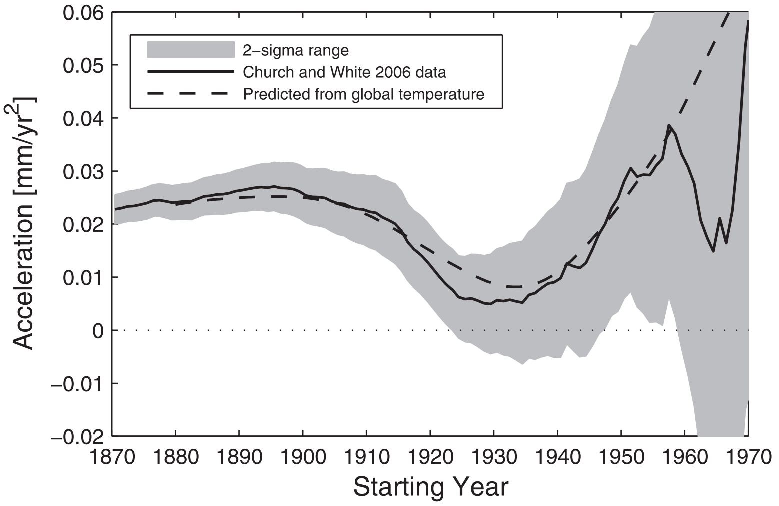

Figure 2. The same as Figure 1, but here the sea-level data are corrected for water storage in artificial reservoirs (Chao, Wu, and Li, 2008).

study of this effect, and Rahmstorf, Perrette, and Vermeer (personal communication) included the very high estimate of Wada *et al.* (2010) and assumed that water mining is proportional to global population (to extend it back in time before groundwater extraction data are available). The result is that groundwater mining only has a minor effect on semi-empirical sea-level projections: Inclusion of this effect only lowers projected future sea level by a few percent. A key strength of modelling sea level as a function of temperature is that the calibration with past data automatically tends to select for climatic effects. Nonclimatic sea-level changes do not correlate so well with temperature in the past and hence have a lesser influence on the model parameters that describe the correlation of sea level with temperature. Houston and Dean suggest that the sea-level data call into question the predictions of semi-empirical models. However, as Figures 1 and 2 show, the opposite is the case.

It should be noted that the updated global sea-level reconstruction by Church and White (2011) also shows a minimum in acceleration for starting years around 1930 (confirming this is a robust feature), but acceleration does not become negative there; it instead shows positive acceleration throughout, from any starting date up to AD 1970 (after which short-term noise dominates the calculations, and results oscillate strongly). Hence, not deceleration but acceleration is a robust feature of the global sea-level reconstructions, and sea level has responded to global warming just as suggested by semi-empirical models. Sea level in recent decades has risen *faster* than Intergovernmental Panel on Climate Change (IPCC) projections (Rahmstorf *et al.*, 2007), which are lower than those of semi-empirical models.

LOCAL VERSUS GLOBAL SEA-LEVEL DATA

In addition to the global sea-level record of Church and White (2006), Houston and Dean (2011) analyse (i) a group of U.S. tide gauge records and (ii) a small group of globally distributed long records used earlier by Douglas (1992). For the U.S. records, they find on average a deceleration since 1930 that is larger than that in the global record. For the full record lengths of each gauge, they find an average acceleration close to zero. However, the periods considered vary greatly (with starting years ranging from the 1850s to the 1940s), so simple averaging of the acceleration factors makes little sense. Also, use of only U.S. gauges does not allow any conclusions to be drawn about the acceleration of *global* sea-level rise.

It is well known that water motions between different parts of the world, *e.g.,* between Northern and Southern Hemisphere, cause regional sea-level changes unrelated to the mechanisms of global sea-level change. Houston and Dean note the analysis of Merrifield, Merrifield, and Mitchum (2009), which shows that the twentieth-century acceleration of sea-level rise is not evident in northern data but rather stems from tropical and Southern Hemisphere data.

This picture is consistent with the fact that their U.S. gauges show little acceleration, and it is also consistent with their extension of the analysis of Douglas (1992). As their Table 2 shows, the average "group acceleration" since 1905 of the eight Northern Hemisphere groups in this collection is −0.022 mm/yr^2, while for the two Southern Hemisphere groups it is +0.027 mm/yr^2. Averaging these two values, weighted by the respective ocean areas of both hemispheres, yields a positive acceleration of 0.0059 mm/yr^2. However, Houston and Dean report a *negative* acceleration for these data because they form a simple average over all groups, thus introducing a strong Northern Hemisphere bias. This illustrates that the excessive weighting of Northern Hemisphere records in the simple averaging used by Houston and Dean is sufficient to explain the deceleration they found in this data set.

SIGNAL VERSUS NOISE

In their Figure 6, Houston and Dean show decadal trends in sea-level rise over the past century that vary widely, oscillating from less than −1 to more than +5 mm/yr. What is the nature of these variations? When looking at an overlay of decadal trends from a range of different tide gauge reconstructions, it is clear that these variations are highly inconsistent between different data sets and thus cannot be considered true variability of global mean sea level (Rahmstorf, Perrette, and Vermeer, personal communication). Rather, they are evidently a noise problem. For example, coincident with the high 1970 peak in Figure 6 of Houston and Dean (2011), another global reconstruction (Jevrejeva *et al.*, 2008) shows a minimum with near-zero decadal rise. Also, the tide gauge reconstruction in Figure 6 of Houston and Dean (2011) shows a *negative* decadal rate centred on the year 2000, when the satellite altimeter record shows a decadal rate of rise of almost 4 mm/yr.

Christiansen, Schmith, and Theill (2010) have shown that the short-term noise in global tide gauge data compilations is almost fully attributable to inadequate spatial sampling by the limited number of coastal sites and their very uneven global distribution, getting poorer still going back in time. The principal components–based reconstruction technique of Church and White aims at, and partially succeeds in, mitigating this. It shows greatly reduced variability in decadal sea-level trends but still contains some sampling noise.

Rahmstorf, Perrette, and Vermeer (personal communication) have shown that even very little random noise in the sea-level data, with a standard deviation of only 5 mm and 40% autocorrelation for 1 y lag, is enough to cause fluctuations in decadal sea-level trends of the magnitude shown by Houston and Dean. Hence, their claim that the altimeter trend is not unusually high ("the altimeter measurements appear similar to several decadal oscillations over the past 100 years," p. 415) mistakes the sampling noise of the tide gauges for a meaningful signal. The altimeter data do not suffer from this sampling problem due to their near-global coverage.

Finally, Houston and Dean argue with the slight deceleration found in the altimeter data, a record that began only in 1993. Given the brevity of this record, it would be highly premature to draw conclusions about the sea-level response to global warming from such small short-term variations in the trend. The main feature of the altimeter data is that the trend is very linear and has much less short-term variability than seen in the tide gauge reconstructions.

CONCLUSION

In summary, we find that the deceleration in sea-level rise reported by Houston and Dean either applies to a far-too-brief time interval (since 1993), or to a unique and specially selected start date (1930), or only to regional, strongly Northern Hemisphere–biased records that are spatially or temporally averaged in an inappropriate manner. None of this supports a lack of acceleration in global sea-level rise, as compared to what is expected from global warming.

Outside a few starting years around 1930, global sea-level reconstructions robustly show a modern acceleration of sea-level rise in conjunction with global warming. A modern acceleration is also supported by data going back further in time, which show constant sea level preceding AD 1800. The tide gauge reconstruction of Jevrejeva *et al.* (2008) starting in AD 1700 finds a stable sea level from 1700 to 1800, with the largest rate of rise in the latter half of the twentieth century, and the proxy data of Kemp *et al.* (2011) show a period of stable sea level from AD 1400 to 1800, with the twentieth-century rate of rise unprecedented in at least the past 2000 y.

Moreover, when the rate of global sea-level rise is correlated to global temperature data, this correlation not only explains the lack of acceleration since 1930, it also is both highly statistically significant *and* points to a sea level that responds more strongly to global warming than predictions by climate models would indicate. This is why semi-empirical models, which use the observed sea-level data and their link to temperature, yield much higher sea-level projections than the model-based ones of the IPCC (2007).

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DISCUSSION

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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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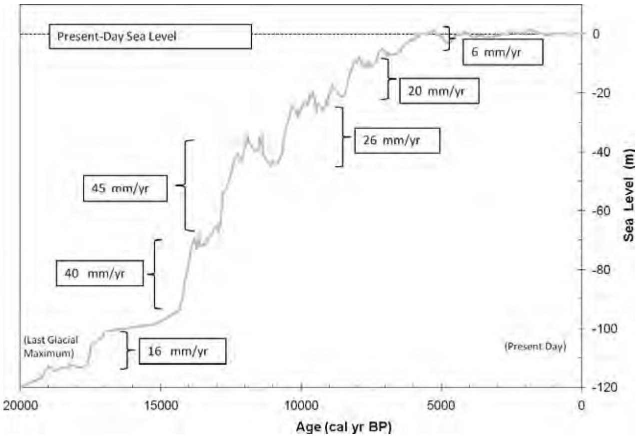

Figure 1. Gulf of Mexico sea-level change, 20,000 years ago to present, based on approximately 300 radiocarbon-dated paleoshoreline indicators. Several episodes of rapid sea-level rise are indicated. Figure adapted from Donoghue (2011).

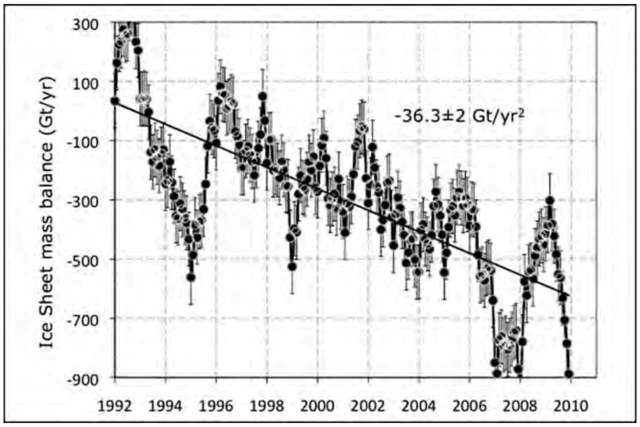

Figure 2. Total ice sheet mass balance and acceleration in the rate of loss between 1992 and 2010 for Greenland and Antarctica combined in gigatons per year with associated error bars. From Rignot *et al.,* 2011.

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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REPLY

Reply to: Donoghue, J.F. and Parkinson, R.W., 2011. 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

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INTRODUCTION

Donoghue and Parkinson present three concerns regarding our article: (1) the temporal and geographic limitations of the tide-gauge data, (2) the inadequacy of tide-gauge data to represent future conditions, and (3) ice-sheet meltwater volume.

Before responding to each of these issues, we note that our emphasis was to accurately characterize U.S. and global tide-gauge recordings during the 20th century, rather than to either project into the future or to speculate as to the causes.

LIMITATIONS OF TIDE-GAUGE DATA

Unfortunately, it appears that Donoghue and Parkinson (hereafter D&P) did not read our article sufficiently to grasp its scope or intent. For example, in discussing gauges selected for analysis, they state "The gauge locations were only in the United States." However, even as indicated in the title of our article, in addition to the U.S. data analysis, we analyzed global data sets, including those of Church and White (C&W; 2006) and a more recent set posted by C&W on Permanent Service for Mean Sea Level (PSMSL), and we presented an extended analysis of the gauges selected by Douglas (1992) to represent global sea level. All three analyses yielded small, negative accelerations. We are mystified that D&P did not recognize the global analysis, which occupied about three pages of our article, including the Table 2 listing the 23 gauges incorporated in the extended Douglas (1992) global analysis. Further, D&P state "Additionally, the authors used data collected between 1930 and 2009, despite the fact that many of the PSMSL data sets extend well back beyond 100 years." Table 1 shows the 57 U.S. gauges analyzed for their *full* records, one of which was 156 years (San Francisco). The extended analysis of Douglas (1992) included global records from 1905 to 2010 and, as noted, resulted in a small, negative acceleration.

INADEQUACY OF TIDE-GAUGE DATA TO REPRESENT FUTURE CONDITIONS

We agree that tide-gauge data, by themselves, do not provide a valid basis for predicting future sea levels and indeed that was not our emphasis. However, accurate characterizations of sea-level changes during the past century through analysis of tide-gauge records are critical to the development of improved models of sea-level change at the century-long scale.

ICE-SHEET MELTWATER VOLUME

As noted, we did not try to address the causes of sea level rise. However, in discussing the results of Rignot *et al.* (2011), D&P ask the question "…where did all this meltwater go?" If the rates and acceleration of 36.3 $\mathrm{Gt/y^2}$ found by Rignot *et al.* (2011) are adopted, and using the conversion factor that 100 Gt/y of meltwater volume = 0.28 mm/y rise (Section 5.5.6, Bindoff *et al.,* 2007), the average contribution to sea-level rise during the 18-year length of their study, is 0.91 mm/y. This may explain, in part, the increased rate of sea-level rise of approximately 3 mm/y documented by the satellite altimeters since 1992. Even considering this recent acceleration, the net over the 20th century was a small, negative acceleration. Moreover, we do not know yet whether the increased trend measured by the altimeters will be sustained or is a fluctuation. Church and White (2011) note that the rise measured by the altimeters is not statistically different than peaks in trend in the 1940s and 1970s.

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EDITORIAL

Trends in Sea-Level Trend Analysis

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ABSTRACT

BAART, F.; VAN KONINGSVELD, M., and STIVE, M., 2012. Trends in sea-level trend analysis. *Journal of Coastal Research,* 28(2), 311–315. West Palm Beach (Florida), ISSN 0749-0208.

Discussions on sea-level rise trend estimates as, for example, the one recently published in this *Journal of Coastal Research*, reveal different perspectives on proper methods of deriving sea-level trend estimates. This editorial discusses various methodological considerations and proposes a number of best practices for sea-level trend analysis.

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ADDITIONAL INDEX WORDS: *Sea level, subsidence, climate change, research methods.*

SEA-LEVEL DECELERATION

In their recent article in this journal, Houston and Dean (2011c) reported that the relative sea level along the U.S. coast and in a selection of global tide gauges is slightly decelerating. A relative sea-level deceleration was also reported recently by Watson (2011), based on tide gauges along the Australian coast. The conclusion that the sea-level rises, but that the rate of the rise is decreasing, does not conform to the general anticipation that the rate of sea-level rise should be accelerating, not decelerating, resulting in a fierce debate in the popular (Rintoul, 2011), as well as in the academic arena.

Donoghue and Parkinson (2011) concluded that the study had “little relevance to future sea-level change.” Rahmstorf and Vermeer (2011) argued that “the five main arguments presented by Houston and Dean in support of a lack of acceleration in global sea-level rise are all unconvincing” and propose Rahmstorf’s semi-empirical approach as a better alternative. Houston and Dean (2011a) replied to Donoghue and Parkinson by pointing out they had incorrectly assumed that only the U.S. tide gauges were studied. They rebutted Rahmstorf and Vermeer, indicating that the main point of their study was that projections of more than a meter per century sea-level rise are not in the same order of magnitude as the current observations (Houston and Dean, 2011b), referring to the global sea-level rise of between 0.5 and 1.4 m for the period 1990–2100 (Rahmstorf, 2007).

Several interesting methodological topics were argued throughout the discussion. Should we use numerical models or rely on observations? Which is the correct independent variable, time or temperature? What are appropriate time periods for determining trends? Which corrections should be applied? A common element underlying all these questions relates to a fundamental question in the scientific method (Popper, 1934): Can we falsify a theory? The theory, in this case, is that sea level will rise at an accelerating rate. The evidence presented, the tide gauge observations, show a rise but no acceleration. This contradicts the quite fundamental theory that sea level will rise and do so at an increased rate or, at least, that it has done so in past decades.

The debate is important because the acceleration theory is widely used for coastal protection planning and climate change–related measures. For coastal protection, the relative sea level is important. The eustatic change is only one of the contributing factors. Especially for larger cities, subsidence can be more influential on the relative sea level than the change in absolute sea level (Camuffo and Sturaro, 2003; Waltham, 2002). For climate change–related studies, absolute sea level is the most used quantity. The discussion here relates to both relative sea level, as measured by tide gauges, and absolute sea level, as measured by altimetry satellites.

Rahmstorf and Vermeer, as well as Donoghue and Parkinson, argue that the methods used by Houston and Dean were not valid and *vice versa*. But then, what *are* valid methods? Is the theory of acceleration in the rate of sea-level rise falsifiable? By creating an overview of best practices, we aim to facilitate the ongoing scientific debate on sea-level trend estimates. It is our belief that the arguments used to underline opposing views

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can often be combined to achieve a more-robust and neutral approach.

FORECAST *VS.* TREND, PHYSICAL *VS.* EMPIRICAL

Would it be bad practice to use the observed sea-level trend as a forecast method? According to Donoghue and Parkinson (2011) it is: It "is inappropriate to relate sea-level history during the past century with projections for the next century." One could argue that recent sea-level rise can be used as an estimate for future sea-level rise. Using a regression model to predict future sea-level rise is not uncommon. For example, Church and White (2006) state, based on a regression model that included an acceleration term, that "[i]f this acceleration remained constant, then the 1990 to 2100 rise would range from 280 to 340 mm." This estimate was based on a reconstruction in which tide gauge measurements before 1900 were included.

Given the "near" linear trend of the sea-level rise throughout the 20th century (Church and White, 2006), it is easy to conclude that, for estimates on the order of a few decades, the recent sea-level rise has been shown to be a good indicator for future sea-level rise. It is also a very parsimonious approach. A regression line is determined by only two parameters, one for the level and one for slope. Using a regression with an acceleration term may be good as a method for detecting trends, but extrapolating future rise using this approach would have to be considered a bad practice. Perhaps the easiest way to see this is to extrapolate backward rather than forward. This results in trends that indicate that historically sea-level rise has dropped; where the general picture is that sea level has been rising since the last ice age.

Using the current, linear trend in sea-level rise to predict future sea level implicitly assumes that the trend we have seen in the past is representative of the trend we will see in the near future. Of course, like Donoghue and Parkinson (2011) point out, if one anticipates conditions that have not been experienced for many millennia, using the existing trend makes little sense. The current trend-forecast method, if not assumed to be the best approach, could at least be used as a reference approach. Thus, when making a forecast about sea-level rise, the forecast skill (SS) can be computed with the current sea-level rise trend as a reference forecast.

The advantage of models that are based on physical-process knowledge over trend extrapolations is that the effects of changing conditions can be included in forecasts, assuming of course, that sufficient knowledge on the relevant acting processes and boundary conditions is available. Rahmstorf and Vermeer (2011) argued that "sea level as a simple function of time, $H(t)$, is not physical." Houston and Dean (2011b) pointed out that the same argument was used by Stocker *et al.* (2010) to disqualify the suggested alternative, semiempirical model by Rahmstorf (2007).

The methods available to forecast sea level cover a broad spectrum. On one end of the spectrum, we find the full physical approach, like that used to estimate the scenarios for the Intergovernmental Panel on Climate Change (IPCC). This approach is based on a chain of different numerical models (Meehl *et al.,* 2007). On the other end of the spectrum, there are the empirical models that are based on the observed relation between measured quantities. The most common approach is to estimate sea level as a function of time, where time is a proxy for other monotonic varying conditions, such as temperature, gravitation effects, ice melting, and subsidence. The aforementioned estimates of Church and White (2006) and Rahmstorf (2007) are examples of this method. Whichever approach is used, there are assumptions, weak and strong, about the representativeness of the formulas and the processes used to describe the parameters of interest.

The above discussion shows strong similarities to the recurring debate in geoscientific modeling, on whether to use a statistical (empirical) or a numerical (process-based) model. When choosing one model over another, there is a wide variety of arguments to choose from. Some of the arguments relate to the expected validity. Will the model predict future situations? Is the model representing the processes that it should describe? Was the model tested for this purpose? How many free parameters does the model have? Other arguments relate to practical aspects, such as run time and software quality. Is there enough time to run the model 1000 times to get a probabilistic answer? Is the source available? What is the test coverage of the model? See Merali (2010) for a relevant discussion on the quality of scientific software.

A challenge for any modeler is to find an appropriate balance between the relevant processes and proxies to include, on the one hand, and keeping the model as simple as possible, on the other. Examples of such discussions can be found in various scientific disciplines, such as river modeling (Booij, 2002).

This challenge is further complicated by the tension between pursuit of scientific interest, often driving scientists toward including ever more detail, and the need for practical spin-off, requiring scientists to provide answers to practical questions with imperfect tools (van Koningsveld *et al.,* 2003). Best practice for both the cautious and the opportunistic researcher is to ensure complete transparency in the methods used and to facilitate, as much as possible, detailed scrutiny by peers. Where possible, it is wise to make use of approaches from opposing schools of thought at the same time. Approaching the problem from different perspectives will help to keep an open mind to the strengths and limitations that are inevitably involved in any approach.

THE FORBIDDEN YEARS AND WHERE DID THE WATER GO?

What is the best time window to compute a trend in sea-level rise? This question lingers after Rahmstorf and Vermeer (2011) noted that Houston picked "a unique and specially selected start date (1930)." In reaction, Houston and Dean point out that Rahmstorf and Vermeer "do not continue the plot when accelerations become negative." Because of the decadal variations in tide gauges records (because of the nodal cycle and ocean oscillations) trend estimates are indeed quite sensitive to the start and end period of the time window. By including the decadal variation by known decadal cycles, such as the 18.6-year nodal cycle, some of these sensitivities can be avoided (Baart *et al.,* 2012).

The origin of the sensitivity of the trend, however, is not only in the start and end period. The sensitivity to the starting period is extra large because both Rahmstorf and Vermeer (2011) as well as Houston and Dean (2011c) focus on only one of the three parameters of the regression equation, *viz.* acceleration, while leaving their assumptions on rate and level implicit. Equation (1) provides the complete description of the ordinary least-square equation, with a denoting sea-level rise rate, b denoting sea-level acceleration, c denoting sea level at $t = 0$, and t denoting the time in years (often since 1970).

$$H(t) = at + bt^2 + c \tag{1}$$

Part of the sensitivity is in the free c parameter. Comparing models over different periods with a free intercept can easily result in an artificial gain or loss of cubic kilometers of ocean volume: $\Delta_c \times oceansurface$. Such discontinuities in water volume can be avoided by using a volume-conserving regression approach. This can be achieved by fixating the constant parameter at the start of a subsequent regression window to the final value of the trend of the preceding period. Equation (2) provides the ordinary least-squares equation with a fixed constant, based on the assumption of volume conservation at t_0.

$$H(t - t_0) = at + bt^2 + h(t_0) \tag{2}$$

There are also other statistical problems in applying ordinary linear regression to estimate an autocorrelated time series (see Granger and Newbold [1974] and the comments from Schmith, Johansen, and Thejll [2007]), but these points are left for future discussion.

THE FALSIFIABILITY OF SEA-LEVEL FORECASTS AND STATISTICAL POWER

The most fundamental scientific point touched by the recent discussions relates to the falsifiability of the theory of accelerating sea-level rise. The essence is summarized by Houston and Dean (2011b): "To reach the multimeter levels projected for 2100 by Rahmstorf requires large positive accelerations that are one to two orders of magnitude greater than those yet observed in sea-level data." Both Rahmstorf and Vermeer and Houston and Dean appear to agree that a recent acceleration is what would be expected from the theory that global warming causes recent and future sea-level rise. The definitions of *recent* vary a bit. Rahmstorf and Vermeer (2011) argue that there is, in fact, a recent acceleration, referring to the changes after the period 1700–1800, and do not expect an increased sea-level rise for the 20th century, in hindsight. Houston and Dean (2011c) were expecting an increased sea-level rise in the past few decades. Donoghue and Parkinson (2011) point to the rate of the absolute sea level as measured by altimetry satellites as the already-increased rate.

An obvious way to test the theory of acceleration is to look at the old forecasts. Although describing relative sea-level states has been a common activity over the past centuries, forecasting the change in sea level on a decadal scale is an activity that became popular in the past decades.

An early publication of a forecast was provided by van Dantzig (1956), who made a rough estimate of 70 cm, local, relative sea-level rise in the coming century because of, among other reasons, the melting of ice on Greenland. This relation between ice melting and sea level is a theory that was examined by, for example, Thorarinsson (1940). Van Dantzig chose a high estimate of expected sea-level rise. This was mainly due to the coastal engineering considerations that were needed by the first Deltacommissie to reconsider the safety of the Dutch coast after the devastating 1953 flood. For engineering purposes, one often takes into account a high, but not totally unlikely, scenario (see Kabat *et al.* [2009] for a similar approach applied by the second Deltacommissie). A series of forecasts were made from the 1980s onward, when the ice cap melting theory got a new impulse through the study of the anthropogenic origin. Since then, new sea-level measurements have become available, enabling many of these forecasts to be subjected to falsification.

Two issues that make the falsification of sea-level forecasts difficult. Sea-level forecasts generally cover periods of several decades, which means one has to be patient before new measurements for model testing become available. This issue can partially be handled by starting the forecast before the current date. For example, when a forecast is made in this year (2011), the forecasting period should start in 1981 at the latest, allowing the last 30 years of measurements to be used as a verification period. Douglas (1992) even suggests using 50 years of data as a good practice, but, for the higher estimates, a shorter verification period of 20 years may be enough (Baart *et al.,* 2012). If the proper verification data are not yet available, one has to wait to enable the falsification of the forecast with enough statistical power. Because many sea-level forecasts were made in the 1980s, sufficient observation data are now available to compare the forecasts made at that time with the trends observed now. For example, the first forecast presented by the IPCC (Warrick and Oerlemans, 1990) expected a sea-level rise of 18 cm in the period 1990–2030. We could now state that was an overestimate if we could assume that the rise over the period was constant.

This brings us to the second issue in the falsifiability of sea-level forecasts: Sea-level rates during the forecast period are not always well defined. In the first IPCC forecast (Warrick and Oerlemans, 1990) and in the forecast made by van Dantzig (1956), only the total rise was given. No details were provided about how that rise was expected to take shape during the forecast period. This makes the falsification of the forecast almost impossible before its final due date. This issue can partly be handled by assuming a trend, *e.g.,* a linear one. However, the forecaster may claim a nonlinear trend should be used. Omitting this kind of detailed information from sea-level forecasts allows the intermediate falsification of the hypothesis to be deferred with the claim that "the acceleration may start tomorrow."

An alternative, empirical result that could falsify the theory of *global warming–induced* acceleration in the rate of sea-level, as Rahmstorf and Vermeer propose, could be made by using historical tide gauge data. If it could be shown that current sea-level rise started before the onset of temperature change, the temporal ordering required for a causal relation would not exist, enabling falsification of the theory.

There are a wide variety of studies on how the sea level varied over the past millennia. Thanks to the collection of tide-gauge data sets by PSMSL (Woodworth and Player, 2003), we have a good overview of how the sea level changed near the coast during the past century. With the help of altimetry satellites, we know how the sea level varied in the past two decades across the globe (Beckley *et al.,* 2007). How the sea level varied in the centuries before 1900 is less known. Tide gauges before 1900, at least the Dutch ones, are not well suited for estimating trends, as discussed already by Van Veen (1945). Therefore, estimates of trends before 1900, such as by Jevrejeva *et al.* (2008), should be confirmed before used. Confirmation can be provided by using other sources, such as historic records, paintings (Camuffo and Sturaro, 2003), and vegetation (Woodworth, Menéndez, and Gehrels, 2011).

BEST PRACTICES

The recent discussions on trend estimates and forecasts in sea-level rise have revealed that this research field could benefit from a constructive debate on appropriate research methods and reporting approaches. The fact that we are entering an era where decades worth of verification data are now available exacerbates the crucial need for a clear framework to facilitate the imminent scientific progress on this topic.

Although we realize its incompleteness, this article has attempted to take a first step toward that framework by discussing, in as neutral a manner as possible, various methodological considerations raised in the contemporary literature, and to derive from them a number of best practices for sea-level trend analysis. The most important ones are reiterated briefly in this final section:

(1) **Aim for falsifiability.**—A crucial ingredient of the scientific method is the proposition of clear hypotheses that may be subjected to falsification by peers. Previous publications in the field of sea-level research have involved obstacles that make it hard, and in some cases, nearly impossible to test the hypotheses proposed. Examples include a lack of information on the methods, the corrections and assumptions applied, the trend periods used, the trend evolution predicted, *etc*. Good practice would be to aim for falsifiable claims as much as possible, *e.g.,* by providing so-called crucial tests that any peer could perform to refute the proposed theory when sufficient data are available. *Nota bene:* It is important to realize that the falsification of a single hypothesis does not inevitably prove that an entire theory is false, merely, that the theory needs to be reformulated to accommodate the new evidence.

(2) **Take care of transparency and reproducibility.**—Another crucial element of the scientific method is that results should be reproducible by peers. In some publications, authors have not made all data, models, and tools available, thus making it difficult for peers to establish exactly what analytic methods were used, to reproduce the results based on the same data, and to apply the same approach to new or other data. Good practice would make all data, models, and tools available, as much as possible, with the report or article in which a particular claim is made.

(3) **Include perspectives from opposing schools of thought.**—A recurring element in the current debate on sea-level trends is the discrediting of one method while placing full belief in another, *e.g.,* relying on models *vs.* relying on data. Although an important function of the scientific debate is to identify and point out flaws and errors in the methods applied, different approaches can have merit in specific cases, and approaching one problem from different points of view can be a powerful way to gain a better understanding. Good practice would be to use a broad range of methods rather than to rely on a single method only.

(4) **Avoid unnecessary controversy related to jargon.**—The field of sea-level research is complex and involves researchers from various disciplines. This means that unnecessary conceptual confusion is a realistic threat to the already-emotional debate. Someone with a background in statistics may have a different association with the term *linear model*, for example, than someone with a background in hydraulic engineering. Furthermore, short formulations intended to facilitate the reader's comprehension may, in fact, turn out to promote confusion. An example would be the use of a term like *sea-level rise*, leaving the reader unclear about whether absolute or relative sea-level rise is intended. Another example would be to speak of "x m" of sea-level rise without indicating the interval over which that rise is supposed to materialize. Good practice would be to formulate carefully, using clear terminology consistently throughout a publication, while avoiding as much as practicably possible the use of jargon.

(5) **Make appropriate use of statistical methods.**—When using linear regression or any other generalized linear model, assumptions like independence of errors should be verified, and the full, fitted model should be reported. The linear trend estimated by the linear regression is a good reference model for forecasts. If a model does not provide a forecast significantly better than that reference forecast, the simple line is probably the best choice. Most estimation methods are quite sensitive to the selections made in time and space. At least one aspect that can reduce those sensitivities is to make sure that the trend estimates for connecting periods also have a connecting sea level.

(6) **Use available data to test old as well as new predictions.**—The time is ripe to compare old forecasts to current, observed trends. Several forecasts from the 1980s can already be tested to acquire a first indication of our skill in forecasting sea-level rise. For new forecasts, longer verification periods should be allowed for than is the current practice. Forecasts should be reported with well-defined time windows and rates over the forecast period.

As mentioned before, the best practices listed above are by no means complete. Inevitably, readers of this article may feel that important items have been overlooked. In fact, some of the best practices suggested here, although logical to the authors, may trigger fierce debate in their own right. Adding to these and the other ongoing debates, a reflective component that promotes productive discussion would be a big step forward in sea-level research.

It is the hope of the authors that the current article delivers a constructive contribution to the ongoing debates. With the best practices suggested in this article and the development and subsequent application of other best practices, we hope that the scientific debate may again focus on delivering the best estimates, rather than on providing the best counterarguments.

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DISCUSSION & REPLY

Discussion of: Baart, F.; van Koningsveld, M., and Stive, M., 2012. Trends in Sea-Level Trend Analysis. *Journal of Coastal Research*, 28(2), 311–315.

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Baart, van Koningsveld, and M. Stive (2012) are commended for a stimulating discussion of sea-level trend analysis.

We were surprised by the reaction to Houston and Dean (2011) because we reached conclusions in agreement with several earlier studies and made no attempt to project sea-level rise into the 21st century. The issue is not whether data show a small acceleration (as found by Church and White, 2011) or deceleration (as we and others found) of sea level in the 20th century. In either case, the values are so close to zero that the trend is essentially linear. Woodworth *et al* (2009) note, "However, little evidence has been found in individual tide gauge records for an ongoing positive acceleration of the sort suggested for the 20th century itself by climate models." This mirrors the conclusion in the seminal article by Douglas (1992) that said, "There is no evidence for an apparent acceleration in the past 100+ years that is significant either statistically, or in comparison to values associated with global warming." Houston and Dean (2011) highlight the lack of understanding of 20th century sea-level rise and the challenge this offers to projecting into the 21st century.

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