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DISCUSSION

Sea-level changes in the southern North Sea region: a response to Bungenstock and Weerts (2010)

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Abstract The article highlights the difficulties connected with getting secure fixed-points for sea-level curve construction and emphasises the care that should be taken with data interpretation. As such, it is a welcome contribution to this important topic. On the other hand, the paper has, in my opinion, several weaknesses. It not only disregards a large body of reliable and highly relevant information on sea-level changes available from investigations carried out using a variety of methodologies, but also makes assumptions that seem to be based, to varying degrees, on misconceptions and misunderstandings. Many of these misunderstandings might have been avoided had the discussions, that are referred to in the Acknowledgements, actually taken place. I wish to take this opportunity to set the record straight by stating that no such discussions took place.

Keywords Sea-level curve · Southern North Sea · Holocene

Introduction

In a recent issue of this journal, a paper by Bungenstock and Weerts (2010) presented new sea-level curves for the southern part of the North Sea bordering Germany. The paper touches on the old discussion regarding 'smoothers' versus 'wigglers' and, in this context, it gives a critique of the sea-level curve for this part of the German coast presented by Behre (2003, 2007). The authors provide no new dates and suggest, *inter alia*, that the data given by Behre (2003, 2007) might be more appropriately considered and presented in the context of various coastal sectors (also referred to as sections) or basins, and that sediment compaction may not have been sufficiently taken into account in the construction of the sea-level curve referred to above. In addition the authors recommend that, rather than presenting a single sea-level curve for the whole area, curves for individual sectors be constructed, even if the number of secure data points was small and the curves in question spanned relatively short time intervals. The authors' suggestions, plausible as they may be, have to be challenged in the interests of balanced presentation of the available data and interpretation of same.

The article highlights the difficulties connected with getting secure fixed points for sea-level curve construction, and emphasises the care that should be taken with data interpretation. As such, it is a welcome contribution to this important topic. On the other hand, the paper has, in my opinion, several weaknesses. It not only disregards a large body of reliable and highly relevant information on sea-level changes available from investigations carried out using a variety of methodologies, it also makes assumptions that seem to be based, to varying degrees, on misconceptions and misunderstandings. Many of these misunderstandings might have been avoided had the discussions, that are referred to in the Acknowledgements, actually taken place. I wish to take this opportunity to set the record straight by stating that no such discussions took place.

The main points at issue are conveniently considered under three headings as follows.

The concept of tidal basins

Bungenstock and Weerts (2010) recommend that the German North Sea coast be divided into five tidal basins or

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coastal sections so as to better elucidate sea-level changes in the region as a whole, and understand the various processes that are involved. This contrasts with the approach taken by Behre (2003, 2007), who used all reliable data from the area to construct a single curve. In constructing the curve, tidal ranges—with emphasis on MHW—from the various points were corrected to a standard tide gauge, namely that at Wilhelmshaven.

With respect to the five areas selected, it is incorrect to state that 'the mean tidal high water does not differ more than 30–40 cm in height within each section' (Bungenstock and Weerts 2010, p. 1690). Differences of 70 and 50 cm are cited for sections V and III, respectively. Furthermore, it should be noted that the overall variation in MHW across these five areas is only 87 cm (based on data published in Gezeitenkalender 2010), which suggests that, at present at least, there are no major differences in sea-level patterns in the region as a whole.

It is questionable if there is any substantial advantage in subdividing the German North Sea coast into five tidal basins that, by and large, have boundaries that are not really sharp, except for section V (but only 3% of the data relate to this area). A consequence of this approach is that the number of sea-level data points relating to each section is rather small and, more importantly, there are often long time intervals for which few or no data are available. Although there is a considerable amount of reliable sea-level data available from the region as a whole, the data are too few to construct five separate curves as has been proposed. Furthermore, there is little prospect for greatly augmenting the dataset in the foreseeable future since geological mapping in the German coastal region has virtually ceased. Given this scenario, consideration of the data as a whole—after appropriate evaluation and adjustments—so as to construct a single curve that conveys the best available estimates of sea-level change in the region as a whole would seem to be the optimal approach. As a general observation, I suggest that insufficient attention has been paid to data adjustment/correction in the construction of many of the composite sea-level curves published to date.

Another important consideration is the substantial differences in the palaeogeographical configuration of the coastline in former times compared with the modern coastline. Sea-level curves constructed within the context of modern tidal basins have validity only for those intervals during which the coastline configuration was comparable to that pertaining today. For instance, the Wadden Sea in present-day North Friesland came into existence only after AD 1362; in other words, there was no section V, as delineated by Bungenstock and Weerts (2010), prior to that date. The same is true for section III (Jade/Weser) and I (Ems/Dollart), where tidal conditions have been greatly influenced by the formation of the Dollart and Jade Bays, which dates to the thirteenth century (Behre 1999). In an earlier period—ca. 1500–1000 cal. BC—the so-called Upper Peat layer extended far into the North Sea from East Frisia as well as from Schleswig–Holstein. Indeed, the precise coastline of that period has yet to be established, but it was certainly situated far to the north and west, respectively, of the proposed tidal basins.

Given the considerations outlined above, construction of sea-level curves that extend back over many millennia for relatively small areas, defined in terms of present-day tidal basins, hardly makes sense. Compilation and correction of all reliable data to give a single curve is a more preferable approach, given the geomorphological characteristics of the region and the database available at present.

Intercalated peats as indicators of sea-level change and the role of compaction

Most researchers regard the presence of peat layers intercalated in marine or brackish deposits along an open coast as an indication of a temporary decline in sea level. This, however, may not always be the case, as is recognised by many authors. For instance, in lagoonal environments, separated from direct influence of the sea, peat formation may occasionally occur during rising sea level. Indeed, freshwater conditions may persist in such lagoons over several centuries even though conditions at the coast are undergoing considerable change. Nevertheless, such local or at least rather limited, developments must be distinguished from the widespread and more or less synchronous peat formation that occurred at least twice along the north German coast, which is an open coast in contrast to the barrier coast of the western Netherlands.

These peat layers were formed on top of marine or brackish deposits. This signifies that a *complete change from saline to freshwater conditions* took place, caused by a considerable drop in sea level. The Upper Peat, which formed in the late Subboreal, is of particular importance in that it extends over far more than a thousand square kilometres from North Frisia and across the Elbe River to East Frisia and continues also into the Netherlands. It is about a metre thick.

A conspicuous and interesting phenomenon in large areas of the Upper Peat is the change from reed to raised-bog peat. The cessation of fen-peat formation, which is dependant on the availability of groundwater, and the change to ombrotrophic conditions indicate another prolonged lowering of groundwater level that is indirectly related to lower MHW levels. Along East Frisia, the Upper Peat extends several kilometres in front of the modern dike in the Wadden Sea area. The development of such a widespread peat layer can only have come about as a result of a considerable sea-level decline that led to a far reaching regression.

These facts have been ignored in the paper that is critiqued here. The authors recognise a decline in sea level or ‘at least a stagnation of sea-level rise’ only between AD 700–1000 and suggest that this ‘may indicate a signal with a supra-regional meaning’ (Bungenstock and Weerts 2010, p. 1698). On the other hand, the obvious sea-level drop between ca. 1500–1000 cal. BC, that led to the formation of the Upper Peat, is questioned ‘because all sea-level index data for the time span lasting from 3000 to 1000 cal. BC are from coastal section III, the suggested sea-level fluctuations during this time span documented cannot be supported by the other curves’ (p. 1698). A quick inspection of the spatial distribution of the Upper Peat and the published ^{14}C data, of which there is a lot (though not included in the publications by Behre, i.e. the only data sources used by the authors), would have shown that this was a truly widespread phenomenon throughout the coastal areas as defined by the authors.

As regards the effects of compaction, it is hardly necessary here to review in detail the views of Jelgersma (first published in 1961) that proposed a continuous rise in sea level, an assumption commonly held, especially in the Dutch literature, for many years. As is well known, this author used only data from the basis peat for her sea-level curve, which led to a systematic error because declines in sea level cannot be detected using this methodology. This particular approach was adopted by the author in an attempt to avoid introducing errors, due to possible compaction, in the altitude of dated fix points.

Compaction of sediments, in particular of peat or clay, can often pose considerable problems and so should be given serious consideration. Due to problems associated with compaction, several hundred of the available data points from the German North Sea coast were not included by Behre (2003, 2007) in the dataset he used to construct his sea-level curve because the effects of compaction could not be reliably estimated. Data points regarded as prone to compaction were used in a careful way and appear below the sea-level curve and an arrow is used to indicate what is regarded as the appropriate altitudinal correction.

Quantitative estimation of compaction is always difficult so that corrected data can only be regarded as a best approximation. The degree of compaction in peat and clay is dependant on several factors, the most important being the length of time involved since formation of the deposit, thickness, nature and duration of overburden, and, as regards mineral deposits, grain size is of major importance.

Quantification of compaction by simply assuming a 50% reduction in thickness with respect to the original peat bed, as was done by Linke (1982), can give very misleading estimates. Equally, assuming a constant vertical error that is universally applicable, i.e. independent of varying local conditions can also be misleading. This is the approach adopted by Bungenstock and Weerts (2010), where a constant error of +0.5 m is assumed. This results in errors and it largely explains why the curves presented by these authors cannot be reconciled, in many instances, with the available geological and archaeological evidence. In parts of the German Clay District, for instance, compaction is greater than 2.5 m in soft clay and peat sediments (Streif 1971) while, in other parts, there is almost no compaction.

To identify and characterise periods of regression it is important that reliable dates from within the Holocene sequence, e.g. intercalated peats, are critically selected and appropriately used. There are many dates from the German coastal region that show the start and end of formation of intercalated peat layers, and, in particular, the very striking and widespread Upper Peat that indicates sea-level decline. The dates derived from these peats seldom indicate exact synchronous change, because peat formation started earlier and lasted longer at the landward, compared with the seaward, side. While these dates are very important for placing the peat layer within a temporal scale, they give only approximate information as regards altitude at the time of peat formation; altitude must therefore be derived from other sources.

Apart from the Upper Peat, well known from many excavations, there is another widespread intercalated peat layer, the so-called Middle Peat, in the German coastal region from Emden to Cuxhaven and with indirect evidence from Schleswig–Holstein. In all, 21 ^{14}C dates relating to this layer were presented in table 2 (Behre 2003, 2007), where what is referred to as Regression 1 is considered in detail. These dates, which roughly span 3050–2600 cal. BC, were used for the construction of the sea-level curve because they provided good temporal control though, in many instances, it was not possible to estimate compaction. The widespread occurrence of peat layers relating to this time interval demonstrates beyond doubt a decline in sea level. As usual, this peat was formed on top of marine deposits. It thus indicates a pronounced change that included a shift to freshwater conditions. Later on, this peat layer was again covered by clastic marine deposits. These facts are ignored by Bungenstock and Weerts (2010).

Interpretation of data and their presentation with respect to sea-level changes

Apart from the interpretation of intercalated peat layers as an indicator of sea-level decline, there are two further substantial differences between the scenarios proposed by Bungenstock and Weerts (2010) and the views of the present author (cf. Behre 2003, 2007).

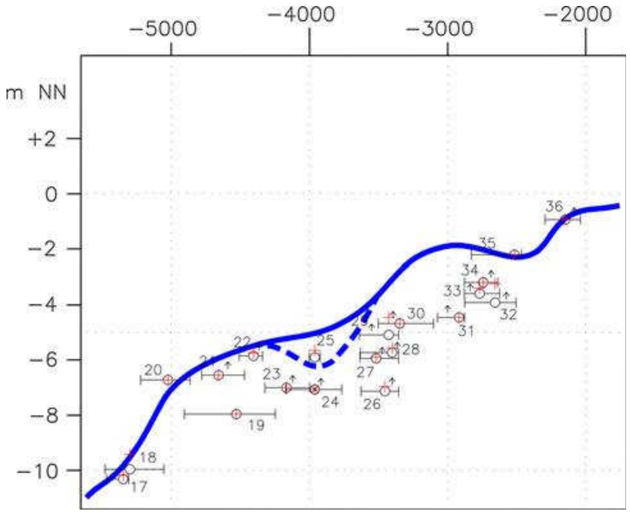

Fig. 1 Detail of the sea-level curve by Behre (2003, 2007) at ca. 4000 cal. BC. The broken line shows sea-level change as discussed in Bungenstock and Weerts (2010). For explanation see Fig. 2

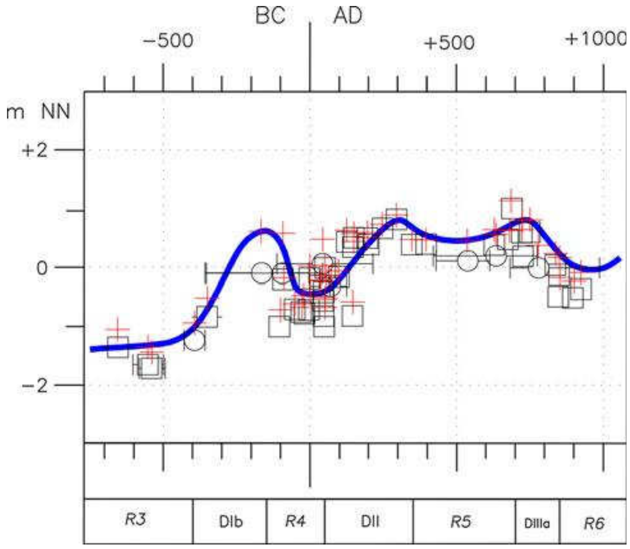

Fig. 2 Detail of the sea-level curve by Behre (2003, 2007) at about the BC/AD transition. *Circle* geological fixed point, ^{14}C dated (with 1 σ deviation is indicated); *square* archaeological fixed point; *arrow* compaction probable (direction of necessary correction is indicated); *cross* correction to the standard tide gauge in Wilhelmshaven

The first difference relates to the statement concerning a ‘sea-level drop of more than 1 m around 4000 cal. BC documented in curve III’ which Bungenstock and Weerts (2010, p. 1702) suggest and subsequently reject in their paper. The sea-level curve, as constructed by this author, in fact shows no decline at this time. Why this difference, particularly given that Bungenstock and Weerts (2010) have used the same dataset (see Fig. 1)? These authors schematically applied a correction of +0.5 m to all compaction-prone points, without consideration of important variables such as the thickness of the Holocene sequence or duration of deposition. It is not surprising that the schematic adjustments, as applied by them to the raw data, gave rise to this spurious decline, which again not surprisingly, is not replicated in curve I (note: only one ^{14}C date in a 3,000-year interval!). The authors rightly reject the decline, but hardly for the correct reasons.

In fact, critical estimation of compaction at points 23, 24 and 26 suggests no decline in sea level as indicated by the curve proposed by Behre (2003, 2007). The data relating to these points come from the top of a low-lying basis peat. The basis peat at these three points underwent strong compression over an interval of 5,000–6,000 years, under an overburden of minerogenic deposits that exceeded 8 m in thickness. In these conditions, the degree of compaction is much greater than in the case of intercalated peats where the overburden is less thick and compaction operated over much shorter duration. If the authors had taken this into account, then their curve would show no depression and they would not have to cite ‘data artefacts’ to justify rejection of their reconstruct.

In conclusion, if compaction-prone data points are used, they should be critically assessed, taking into account the specific conditions at each particular point. Furthermore, in the case of a sea-level decline of a metre or more, corroborating evidence from other sources should be sought. For example, the occurrence of an intercalated peat layer, even if of restricted distribution, would be most useful, but, not surprisingly, no such layer relating to ca. 4000 cal. BC has been recorded from the German North Sea coastal area.

The other period for which there are conflicting views is the interval 500 BC to AD 500. According to Bungenstock and Weerts (2010, p. 1702), ‘the sea-level drop of more than 1 m at AD 0 documented in the original curve of Behre (2003) cannot be confirmed in the newly constructed curves’. Instead, they propose a strong sea-level rise at this time. Initial inspection of their curves seems to support this, mainly because it is difficult to see short-term oscillations, the plotted points being so crowded on the graph. A clearer and different picture emerges if the data points are plotted on a scale with a higher temporal resolution (Behre 2003, figs. 12 and 13; Behre 2007, fig. 3; see Fig. 2, where the relevant part of the curve as proposed in these publications is reproduced).

Because the sea-level highstand during the Dunkirk Ib (D Ib) phase is quickly followed by a strong decline, both extremes have to be tightly fixed. The highstands can be difficult to pin down as conditions did not favour deposition of organic matter, which, in turn, might be used for ^{14}C dating. Fortunately, however, there are reliable dates for this period from the dune-island Borkum based on mollusc shell (2,120 ± 115 and 2,090 ± 115 BP; 351–349 and 358–352 years cal. BC, Freund and Streif 2000). The point in question indicates a corrected MHW of +0.60 m NN. The underlying material consists of sand so that compaction is hardly important (and if there were compaction, the original surface would have been even more elevated!). During this period, elevated levees formed all along the coast, which are securely dated by the prehistoric settlements erected shortly afterwards. These levees point to similar or even higher stands for MHW (details in Behre 2003, 33). Indeed, there are numerous other features that support the D Ib highstand: a strong southward (in Schleswig–Holstein eastward) advance of the sea, peat layers were eroded and covered with clay and sand, and a new coastline further inland was formed with newly created bays that carved deep and wide gullies into the peat (e.g. Bay of Sielmönken, Crildum Bay, Maade Bay). The top of the D Ib deposits are often characterised by storm-surge laminations typical of salt marshes.

The pronounced sea-level decline of Regression 4 at about the BC/AD transition is fixed by numerous ^{14}C and archaeological dates. Apart from these dates, there are also important features that indicate a strong decline in MHW and also a decline in height and frequency of storm surges. In summary, the top of the D Ib marine deposits shows widespread soil formation and re-establishment of a freshwater environment. Starting mostly around 50 BC, large-scale occupation of the former salt marshes took place. At the settlement of Feddersen Wierde, over the course of four generations, successive villages exposed to the open coast were erected on level ground. This suggests that there was no need for mound construction, i.e. sea levels were static. The available evidence clearly shows that there was all-year-round settlement which, in turn, suggests that storm floods did not pose a threat to habitation. Indeed, flood heights declined together with the decline in MHW.

As happened in the case of the Upper Peat during Regression 2, in much of the backswamp areas, fen peat gave way to raised bogs during Regression 4 which suggests a considerable decrease of groundwater level that was a consequence of lower MHW.

Even if the dated altitudinal points presented by Behre (2003, 2007) are disregarded, the weight of other evidence, such as discussed above, is such that *it alone* justifies the assumption that sea level declined by about a metre.

Starting at about AD 50 and persisting for some centuries, there is general agreement that there was considerable increase in MHW as well as storm surges. These changes resulted in salt marsh development and forced people to construct dwelling mounds (*Wurten*) to enable settlements to continue in the flat coastal areas.

Conclusion

The paper by Bungenstock and Weerts (2010) advocates new approaches to the question of sea-level reconstruction in the German coastal region of the North Sea but it should be kept in mind that no new data are presented. Rather, already published data are re-evaluated and conclusions are drawn regarding sea-level change in the study region that, in many instances, differ substantially from the up-to-now widely accepted views.

Rather than presenting a single, well-constrained sea-level curve based on all reliable data, the authors opt for five separate curves with the result that the number of points available to construct the individual curves is greatly reduced. The temporal resolution and the accuracy of the curves are thus greatly diminished. Fewer fix points mean fewer oscillations which is a feature of many other sea-level curves with few data points.

As well as many gaps in the curves as presented, there are also instances where short-lived oscillations are largely 'hidden' because of inadequate resolution of the graphs over those intervals where there are many fixed points.

Distinguishing several tidal basins along the German Bight, based on the modern coastal configuration, does not make sense because the former coastline was very different from that of today.

Schematic application of a standardised compaction rate, taking no cognizance of the nature or thicknesses of the organic and minerogenic deposits, and disregarding the material of overburden and the length of time during which the compaction took place, is inappropriate. It can give rise to a false impression of the true situation, as for instance the possibility raised by the authors that sea level fell by about a metre at ca. 4000 cal. BC, the result merely of a data artefact.

Decline in sea level can often only be observed in, and is best expressed by, *the formation of widespread intercalated peat layers which requires a change from salt to freshwater conditions*. There is often, however, uncertainty attaching to the original altitudinal position of these layers in the Holocene sequence due to compaction. On the other hand, the many ^{14}C dates that are available for peat layers give a good time-fix for their formation and this helps pinpoint particular periods during which lower sea levels prevailed for several centuries. The proposed declines in sea level are strongly supported by a great wealth of archaeological data.

The disregard of a large body of information derived from a variety of disciplines, and especially archaeology, is a serious shortcoming. While many of these data in themselves may not be suitable for construction of sea-level curves, they nevertheless provide important supporting evidence, the disregarding of which, especially in the present instance, where so many reliable data are available, can only be regarded as inadequate.

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