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Correspondence

Reply to the comment by M.P. Hijma & K.M. Cohen on the paper by Van de Plassche et al. (2010)

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First of all, we want to stress that this reply to the comment by Hijma & Cohen on the paper by Van de Plassche et al. (2010) reflects our personal view and not necessarily the opinion of the first author of the paper under discussion, Orson van de Plassche. After a long career dedicated to sea-level research, Orson passed away on May 4, 2009, and left us with the Vlaardingen data set and his explicit wish to publish this material, which ultimately led to the Van de Plassche et al. (2010) paper. In the present paper we will: (1) give some background information on the Vlaardingen data set and the special circumstances under which the Van de Plassche et al. (2010) paper was written; (2) reply to the comment on the construction of our revised mean sea-level curve (MSL-R2); (3) reply to the comment on our suggestion that the palaeoriver-gradient might influence sea-level jump magnitude calculations.

Background

The paper by Van de Plassche et al. (2010) is primarily based on the Vlaardingen data set that was collected by Orson van de Plassche in the mid-1980s, in a sequel to his PhD project (Van de Plassche, 1982). Soon after the start of the Vlaardingen project Orson became busily occupied with sea-level research in North America, leaving the Vlaardingen data set virtually unpublished (some data were published in Van de Plassche (1995)).

The prime motive for setting up the Vlaardingen project was the ambition to reduce, as much as possible, the influence of river gradients in the process of mean sea-level reconstruction. Previous research in the Rhine-Meuse delta (Van de Plassche, 1982) had clearly demonstrated the considerable effects or river gradients, causing local water-level rise curves from inland sites to run above those from near the coastline (see also Van Dijk et al., 1991). The Vlaardingen dune, being the site nearest to the sea where sea-level index data covering a long time period could be collected, offered the opportunity to test the mean sea-level curve for the Netherlands published by Van de Plassche (1982).

By the end of 2008, Orson invited us as co-authors of a paper to be written on the Vlaardingen data set. At that time he anticipated that, despite his serious illness, enough time would be available to write the paper together. We decided to include data from the archaeological excavation pits of Polderweg and De Bruin (samples collected by WZH in the late 1990s), in order to place the Vlaardingen data in a broader context. In the first months of 2009, Orson's condition rapidly deteriorated, putting pressure on the writing process. When he, much earlier than expected, passed away, the full discussion section of the paper still had to be written. We completed the paper incorporating Orson's ideas about the interpretation of the data set, as expressed by him in discussions in the last few months before his death. Orson advocated the approach of comparison of water-level curves, to infer river-gradient and floodbasin effects.

After Orson's death, Hijma & Cohen (2010) published new sea-level index data from the Rotterdam area. We never discussed these data with Orson, but felt that the paper would benefit from including a brief discussion of the new data in relation to the Vlaardingen data. Moreover, Hijma & Cohen (2010) used data collected by Van de Plassche (1982) in the Rotterdam area to complete their sea-level curve. The Vlaardingen data provide a context for evaluating the significance of these earlier data, especially as to river-gradient and floodbasin effects.

Construction of the revised mean sea-level curve (MSL-R2)

Van de Plassche et al. (2010) presented a revised mean sea-level curve (MSL-R2 in their Fig. 9), which runs below a mean sea-level curve proposed by Hijma & Cohen (2010) (MSL-R1 in Fig. 9). Hijma & Cohen (their comment) have objections against MSL-R2, stating that Van de Plassche et al. (2010): (1) used wrong assumptions on river gradients, and (2) insufficiently appreciated the error margins involved in intracoastal tidal amplitude reconstruction. Their criticism strongly focuses on the use of Fig. 10 (in Van de Plassche et al., 2010), in which

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elevation differences between an inland water-level curve from the fluvial area and both alternative MSL curves, respectively, are compared as a validity test. However, in their comment Hijma & Cohen totally ignore the prime arguments underlying the MSL-R2 curve (Van de Plassche et al., 2010, pp. 16-17). The difference between MSL-R1 and MSL-R2 almost entirely relies on the valuation of index point H23 (a base-of-peat radiocarbon date from the Hillegersberg site and first published by Van de Plassche (1982); referred to as point 22 by Hijma & Cohen (2010)), which involves an assessment of various factors influencing the relationship between H23 and mean sea level. The factors under discussion for H23 are: (1) the local palaeotidal amplitude, (2) the river gradient, and (3) the accuracy of the radiocarbon date.

With peat formation in an inland tidal area occurring around the high tide level, the palaeotidal amplitude must be estimated to infer mean sea level from an index point such as H23. Hijma & Cohen (2010) supposed a tidal amplitude of 0.25 m, which we find rather conservative given the coastal tidal range of ~1.9 m for 7800 cal yr BP, resulting from modelling by Van der Molen & De Swart (2001, their Fig. 6). We, therefore, prefer a tidal amplitude of ~0.5 m, implying 50% intracoastal tidal damping. Both our palaeotidal amplitude assessment and that of Hijma & Cohen (2010) are arbitrary judgements, with indeed large error margins involved as illustrated by Hijma & Cohen (Fig. 1 in their comment), and may or may not be true and in our opinion are not worth an extensive debate.

A second difference of opinion as to index point H23 concerns the influence of river gradients, causing inland peat formation at some elevation above mean sea level. Hijma & Cohen (2010) suppose a negligible river gradient in the freshwater tidal environment of H23, whereas we suppose a significant river gradient of 2.5 cm/km as inferred from the average elevation difference between the Hillegersberg and Vlaardingen index points for the period 6650-5300 cal yr BP. We admit that extrapolating this river gradient backward in time goes with increasing uncertainty, but consider a zero-gradient situation for H23 very unlikely. It is hard to imagine that the freshwater tidal environment that developed by transgression over a significantly sloping fluvial plain did not inherit some slight gradient. The claim made by Hijma & Cohen (their comment) that "… during the open estuarine situation that ended shortly after 7500 cal yr BP, one can exclude the river gradient to have remained an influence in the Polderweg / De Bruin and Hillegersberg area …" is not substantiated by them and as such remains just another assumption based on theoretical notions of environments, not on field data.

A third argument for the relatively low position of our MSL-R2 curve is that H23 may be 'too old' because of dating errors. H23 represents a conventional bulk peat date, which may show some ageing (~100-200 years), because of peat sample contamination with old soil carbon from the underlying palaeosol in the sandy substrate. Berendsen et al. (2007) assessed the reliability of previously published water-level index data sets from the Rotterdam area and concluded that some age determinations seem up to 150 years too old, although there are no systematic ageing effects. We investigated potential ageing effects for the Vlaardingen samples by dating paired samples from slightly different depths in the same core and by using pollen data to assess the position of each sample relative to the underlying palaeosol (Van de Plassche, 2010, pp. 7-11). Such an analysis was not carried out on the H23 sample and therefore some ageing cannot be excluded.

The three arguments given above determine the low position of MSL-R2 relative to H23. After construction of MSL-R2 we analysed the development of the river-gradient effect in time by plotting the elevation difference between a water-level curve for the fluvial area (the De Bruin-Polderweg (BP) curve) and MSL-R2 against time (Fig. 10 in Van de Plassche, 2010). This yielded a so-called 'gradient-effect reduction curve', a type of graph that was introduced much earlier by Van de Plassche (1982, his Fig. 66). Fig. 10 shows a gradual decrease of the river-gradient effect forward in time. A comparable plot of the difference between the BP and MSL-R1 curves yielded a different trend that suggests a short phase of steepening river gradients (7700-7300 cal yr BP). We conclude that MSL-R2 better fits with the theory of the river-gradient effect (Van de Plassche, 1982, his Fig. 33) than MSL-R1. We stress that this analysis was carried out afterwards, and was not a basis for the construction of MSL-R2, as was suggested by Hijma & Cohen (their comment). We admit, and clearly stated in our paper (Van de Plassche et al., 2010, p. 17), that caution must be used in this interpretation of Fig. 10, because the observed difference concerns a limited time interval of 400 years and strongly relies on the interpretation of the lowest De Bruin-Polderweg index point.

The potential role of the river gradient in sea-level jump magnitude calculations

Hijma & Cohen (2010) inferred a sea-level jump to have occurred around 8400 cal yr BP from new sea-level index data collected in the Rotterdam area. This sea-level jump and the underlying age-depth data are well outside the data range discussed by us in Van de Plassche et al. (2010). One of the main findings of Van de Plassche et al. (2010) was a longitudinally fairly uniform river gradient of 2.5 to 3.0 cm/km in the lower Rhine-Meuse delta during the period 6650-5600 cal yr BP. Discussing the implications of this finding, we suggested that a significant river gradient in the western Rhine-Meuse delta, might have consequences for estimating the magnitude of the sea-level jump described by Hijma & Cohen (2010). This suggestion is disputed by Hijma & Cohen (their comment). We appreciate the additional clarifications in the comment by Hijma & Cohen on the methodology used in their paper of 2010.

Hijma & Cohen (2010) collected the sea-level index data indicative of a sea-level jump in a large area. The data bracketing the timing of the sea-level jump were collected 32 km apart, with the post-jump data stemming from the most inland site. In their comment Hijma & Cohen describe that a river gradient of ~0.12 m/km existed in the area prior to the jump, assuming that: "The valley-inherited gradient was to be completely overcome by the sea-level rise that would follow, including that of the sea-level jump." This is exactly what we question, because Van de Plassche et al. (2010) suggested significant river gradients in the freshwater tidal zone for a later time period. The radiocarbon-dated peat samples bracketing the sea-level jump were taken by Hijma & Cohen (2010) in the interpreted former freshwater tidal zone. Although our data on the river gradient cover a later time interval, we believe that it cannot be excluded that during rapid sea-level rise a gradient on the order of 2 to 3 cm/km existed in the freshwater tidal zone, due to hydraulic and morphodynamic backwater effects on the river entering the estuary. We agree with Hijma & Cohen (their comment) that if river-gradient effects for the upper and lower index points bracketing the sea-level jump are the same, the magnitude calculation would not be influenced. However, river-gradient effects may also differ for the pre- and post-jump index points, as will be explained below.

The Hijma & Cohen (2010) mean sea-level curve showing the sea-level jump is based on three local water-level curves each reflecting: (1) an initial phase of river-controlled groundwater levels (the gently rising part of the curve), (2) a next phase of gradual establishment of sea-level control (the gradually steepening part of the curve), and (3) an eventual phase of full control by mean sea-level rise (the steeply rising part of the curve). The index point marking the beginning of the sea-level jump (point 18 in their Fig. 1) is obviously in the steep fully sea-level-controlled part of the local water-level curve from their most downstream site (Maasvlakte), and therefore could be argued to almost represent mean sea level. The index point marking the end of the sea-level jump (point 10 in their Fig. 1) is interpreted by them to represent full sea-level control, but could also be interpreted to represent the transition phase of the local water-level curve for their upstream site (Rotterdam), in which fluvial gradients are strongly influenced, but still not completely overcome by sea-level rise. This would mean that mean sea level is significantly below index point 10 and therefore the sea-level jump would reduce in magnitude. Part of this interpretation could also be a slightly lower/younger post-jump sea-level curve connecting up with our curve MSL-R2 (see previous section). In our opinion this alternative interpretation of index point 10 is ruled out too easily by Hijma & Cohen (2010), by supposing a zero-gradient situation for both the lower and upper index points bracketing the sea-level jump.

The sea-level jump described by Hijma & Cohen (2010) is well outside the Vlaardingen data range and an extensive discussion of it in Van de Plassche et al. (2010) would have been out of place. Therefore, in that paper we limited ourselves to a remark as to the potential implication of river gradients on the sea-level jump magnitude calculation, a statement that we have clarified above. We do not claim that the option discussed above is more plausible than the interpretation by Hijma & Cohen (2010). With this paper we just want to contribute to the ongoing discussion about Holocene sea-level evolution in the Netherlands by offering an alternative interpretation that may have been overlooked. After all, when interpreting sea-level index data from a large river-influenced area, regardless of which Holocene timeframe is studied, the full range of possible effects influencing the relationship between the local water level and sea level needs systematic evaluation (e.g. Van de Plassche, 1982, pp. 11-16).

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