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A new Holocene relative sea-level curve for western Brittany (France): Insights on isostatic dynamics along the Atlantic coasts of north-western Europe

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ABSTRACT

This study presents new Relative Sea Level (RSL) data that were obtained in the Finistère region (Western tip of Brittany, France) and the implications those data have for the understanding of the isostatic dynamics across north-western Europe, and more specifically along the Atlantic and Channel coasts. New stratigraphic sequences were obtained and analyzed to derive 24 new Sea-level Index Points, in which 6 are basal. These new data considerably increase the knowledge we have of the RSL evolution along the coasts of Western Brittany since the last 8 kyr B.P. From this new dataset, RSL was estimated to rise continuously over the last 8 kyr with a major inflection at ca. 6 kyr cal. BP. Our results show large vertical discrepancies between the RSL records of Brittany and South-Western UK, with the latter plotting several meters below the new data. From this comparison we suggest that the two regions underwent a very different pattern and/or amplitude of subsidence during the last 8 kyr which has implications for the spatial and temporal pattern of the peripheral bulge of the European ice sheets. We compared our data against predictions from Glacio-Isostatic Adjustment models (GIA models). There are large misfits between RSL observations and the predictions of the global (ICE-5G (VM2a) – Peltier, 2004, GLAC1-b – Tarasov and Peltier, 2002; Tarasov et al., 2012, Briggs et al., 2014) and regional UK models ("BIIS" – Bradley et al., 2009; Bradley et al., 2011; "Kuchar"- Kuchar et al., 2012), which can't be resolved through significant changes to the deglaciation history and size of the British–Irish Ice sheet. Paleo-tidal modelling corrections indicate regional changes in the tidal ranges played a negligible role in the data-model misfits. Hence, we propose that the misfits are due to some combination of: (i) unaccounted mass-loss of far-field ice-sheets (Antarctic ice-Sheet or Laurentide Ice-Sheet), (ii) unresolved differences in the deglaciation history and size of the Fennoscandian Ice sheet or, more likely, (iii) significant lateral variations in the Earth's structure across the English Channel.

1. Introduction

During the last decades, there has been extensive effort to reconstruct Holocene relative sea-level (RSL) histories, with a clear revival of interest in more recent years, due to concerns relating to future global climate change. Reconstructions of past RSL have proved to be of prime interest to understanding present-day and possible near future sea-level variations (IPCC, 2007; Church and White, 2011; Church et al., 2008; Engelhart et al., 2009; Leorri et al., 2012; Gehrels and Woodworth, 2013). This contributes to understanding the behaviour of coastal sedimentary systems during periods of RSL rise and provides improved constraints on the vertical movements of the solid Earth which have taken place since the Late Glacial Maximum (LGM). During the Holocene, the main

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processes driving regional RSL changes are (i) eustatic sea-level rise (ESL) (i.e. the increase of the volume of the oceans induced by the retreat of the continental ice-sheets, regional glaciers and steric changes), (ii) isostatic dynamics (Glacio-Isostatic Adjustments, GIA), i.e. changes in the topography of the solid Earth induced by the decrease of the ice load following the retreat of the major land based ice-sheets ("glacio-isostasy") and from the increase of the water-loading of the continental shelves ("hydro-isostasy") and (iii) potential neo-tectonic movements in tectonically active areas, with variable importance of the influence of all these parameters on the RSL evolution during the Holocene. At mid-to high-latitudes, the northern hemisphere was covered by large land-based ice-sheets (e.g. Laurentide, British–Irish and Fennoscandian Ice-Sheets, noted LIS, BIIS and FIS hereafter, respectively, but also the Innuitian, Cordilleran, Greenland and Kara-Barents ice-sheets) and as such GIA have been the predominant processes in RSL evolution since the middle Holocene.

GIA resulting from the melting of these northern hemisphere ice-sheets is still ongoing, and will play a major role in present-day and near-future RSL changes along the coasts of the northern hemisphere. The Holocene RSL signal across NW Europe is mainly driven by regional ice sheets (FIS and BIIS) GIA contributions. Therefore, recent sea-level observations from tide gauges and satellites contain remnant GIA signals that must be taken into account when isolating eustatic and steric signals (e.g. Peltier, 2001; Tamisiea and Mitrovica, 2011; Wöppelmann and Marcos, 2012). Understanding the regional GIA dynamics is hence crucial before reliable scenarios of future regional RSL rise can be proposed. To address this problem, numerical geophysical models (termed GIA models) have been developed since the early seventies. These models provide RSL predictions for any particular location on the surface of the Earth by solving a unified set of equations (the Sea-Level Equation, "SLE", Farrell and Clark, 1976) that merges (i) an "Ice model", which defines the history of the major land-based ice sheets and (ii) a rheological model ("Earth model") describing the behaviour of the Earth's surface in response to surface load changes, and (iii) the changes in gravitational field induced by the redistribution of the mass at the Earth's surface (melting of the ice-sheets) and within the Earth's interior (displacement of mantle material due to isostatic adjustment) (e.g. Mitrovica and Peltier, 1991; Peltier, 1998; Mitrovica and Milne, 2002; Spada et al., 2012). Significant regional misfits continue to exist between predicted and observed RSL (e.g. Engelhart and Horton, 2012; Ostanciaux et al., 2012), which suggest errors in the ice history and/or earth rheology components of the GIA models. Hence, precise and reliable RSL observations are still needed in many places to better constraint GIA models.

In Northwestern Europe, sea-level reconstructions have been produced since the seventies. The most intensive research efforts were conducted around the British Isles, especially along the northern and eastern coasts of the UK. The dense RSL dataset obtained in Great Britain served as a basis for the development and the fine-tuning of regional GIA models (Shennan et al., 2006; Bradley et al., 2011; Kuchar et al., 2012). Results recently published by Bradley et al. (2011) and by Shennan et al. (2012) agree for present-day land subsidence rates of ca. 0.5–0.8 mm/year in Devon and Cornwall. However, Bradley et al. (2011) and Kuchar et al. (2012) note misfits of several meters between geological reconstructions and regional model predictions for the Southwest UK. In this study, we expand this comparison to include Holocene RSL and GIA model predictions a few hundred kilometers south along the North French coasts.

Within the framework of a coastal risk assessment research program (ANR COCORISCO, French National Research Agency), extensive fieldwork has been conducted during the past four years around the Finistère peninsula (Western Brittany, France). Along with the study of Holocene paleo-storminess, which was the prime objective of the research program (Van Vliet-Lanoë et al., 2014a, b), many of the sampled sedimentary sequences could also be successfully analyzed to derive RSL data.

The first objective of this study is to obtain new precise and reliable sea-level index points (SLIPs) for the Western Brittany region with a particular emphasis placed on recovering compaction-free basal SLIPs. The second objective is to explore the implications of these new RSL data for the isostatic dynamics of the coasts of Western Europe, following a two-step approach. First, we perform a regional comparison of our data with the RSL history proposed for the closest region for which a well-constrained Holocene RSL record is available (Southwest UK). We thereby evaluate if isostatic gradients can be identified on the basis of RSL data alone. Second, we compare our new data against predicted RSL from both global and regional published GIA models. We also discuss the origin of the misfits between our data and model predictions, with a particular emphasis on local-to regional-scale factors which can potentially influence paleo-RSL.

1.1. Relative sea-level histories of the French Atlantic and Channel coasts: previous studies

Despite the several RSL studies that have been conducted since the seventies along the French Channel and Atlantic coasts (Delibrias and Guillier, 1971; Ters, 1973; Morzadec-Kerfourn, 1974; Ters, 1986; Van de Plassche, 1991; Goslin et al., 2013; Stéphan and Goslin, 2014), there remains a lack of reliable and high-quality Holocene basal SLIPs (Stéphan and Goslin, 2014). For the Finistère region (western tip of Brittany), only two studies achieved a sufficient data density to derive Holocene RSL reconstructions (Morzadec-Kerfourn, 1974; Stéphan et al., 2015). However, none of these studies included data prior to 6000 yr B.P., nor sufficient basal data to provide reliable conclusions on the Holocene RSL evolution in Western Brittany. Additionally, Goslin et al. (2013) showed that a re-assessment of the oldest data from the region, extracted by state-of-the-art methods, leads to a further reduction by up to two thirds of the number of SLIPs which can be considered reliable. At a larger scale, the data from Delibrias and Guillier (1971), Ters (1973, 1986), Morzadec-Kerfourn (1974) and Van de Plassche (1991) formed the main constraint for modelling work of Lambeck (1997) and Leorri et al. (2012). These studies aimed to quantify the contributions of the glacio- and hydro-isostatic components in the RSL histories of the Atlantic coasts of Europe. Both studies proposed that a North-South trending glacio-isostatic gradient could have influenced the European Atlantic coasts, due to the influence of the north-western European peripheral bulge that formed in response to the combined influence of the BIIS and FIS ice loads. This gradient would have extended from the southern coasts of UK to the south of the Bay of Biscay (Lambeck, 1997) or even as far as South Portugal (Leorri et al., 2012). However, as Goslin et al. (2013) recently suggested, the field-data used by Lambeck (1997) and by Leorri et al. (2012) for the Brittany region should not be considered reliable enough to conclusively validate the outputs of their GIA models. Hence, the proposed isostatic gradients along the western Atlantic coasts of France and Spain are still to be ascertained. In northwest Europe, Vink et al. (2007) documented evidence for a continuous shallowing of the RSL records when progressing from northern France to southern Denmark. This likely indicates a progressive reduction in the FIS peripheral bulge isostatic subsidence towards its western limit. Unfortunately, the lack of basal data along both sides of the English Channel coasts has up to now prevented extraction of this trend further west, where the signal becomes more complex due to the interplays between