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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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| 1        | A new Holocene relative sea-level curve for western Brittany (France): insights  |
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| 2        | on isostatic dynamics along the Atlantic coasts of north-western Europe  |
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| 17       | Abstract   |
| 18       | This study presents new Relative Sea Level (RSL) data that were obtained in the Finistère region   |
| 19       | (Western tip of Brittany, France) and the implications those data have for the understanding of the  |
| 20       | isostatic dynamics at the scale of north-western Europe, and more specifically along the Atlantic and  |
| 21       | Channel coasts. New stratigraphic sequences were obtained and analyzed to derive 24 new Sea-level  |
| 22       | Index Points, in which 6 are basal. These new data considerably increase the knowledge we have of  |
| 23       | the RSL evolution along the coasts of Western Brittany since the last 8 kyr B.P. From this new dataset,  |
| 24       | RSL was estimated to rise continuously over the last 8 kyr with a major inflection at ca. 6 kyr cal. BP.   |
| 25       | Our results show large vertical discrepancies between the RSL records of Brittany and South-western  |
| 26       | UK, with the latter plotting several meters below the new data. From this comparison we suggest that   |
| 27       | the two regions underwent a very different pattern/amplitude of subsidence during the last 8 kyr which   |

28 has implications for the spatial and temporal pattern of the peripheral bulge of the European ice 29 sheets. We compared our data against predictions of Glacio-Isostatic Adjustment models (GIA models). There are large misfits between RSL observations and the predictions of the global (ICE-5G 30 31 (VM2a) - Peltier et al., 2004, GLAC1-b - Tarasov & Peltier, 2002; Tarasov et al., 2012, Briggs et al., 2014) and regional UK models ("BIIS" -Bradley, 2009; Bradley et al., 2011-, model of "Kuchar"- Kuchar 32 33 et al., 2012), which can't be resolved through significant changes to the deglaciation history and size 34 of the British-Irish Ice sheet. Paleo-tidal modelling corrections indicate regional changes in the tidal 35 ranges played a negligible role in the data-model misfits. Hence, we propose that the misfits are due to 36 some combination of: (i) unaccounted mass-loss of far-field ice-sheets (Antarctic ice-Sheet or 37 Laurentide Ice-Sheet) or, more likely, (ii) significant lateral variations in the Earth's structure across the English Channel. 38

Key words: Relative sea-level; Holocene; isostasy; GIA models; Tidal-range modeling; Earth
structure; Brittany.

#### 41 Introduction

42 During the last decades, there has been extensive effort to reconstruct Holocene relative sea-level 43 (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 44 45 understanding present-day and possible near future sea-level variations (Bindoff et al., 2007; Church 46 and White, 2011; Church et al., 2008; Engelhart et al., 2009; Leorri et al., 2012; Gehrels and 47 Woodworth, 2013). This contributes to understanding the behaviour of coastal sedimentary systems 48 during periods of RSL rise and provides improved constraints of the vertical movements of the solid 49 Earth which have taken place since the Late Glacial Maximum (LGM). During the Holocene, the main processes driving regional RSL changes are (i) eustatic sea-level rise (ESL) (i.e. the increase of the 50 51 volume of the oceans induced by the retreat of the continental ice-sheets, regional glaciers and steric changes), (ii) isostatic dynamics (commonly referred to as GIA ; Glacio-Isostatic Adjustments), i.e. 52 53 changes in the topography of the solid Earth induced by the decrease of the ice load following the 54 retreat of the major land based ice-sheets ("glacio-isostasy") and from the increase of the water-55 loading of the continental shelves ("hydro-isostasy") and (iii) tectonic movements, the relative 56 importance of all these parameters in RSL evolution being variable during the Holocene. At mid- to 57 high-latitudes, the northern hemisphere was covered by large land-based ice-sheets (e.g. Laurentide, 58 British-Irish and Fennoscandian Ice-Sheets, noted LIS, BIIS and FIS, respectively, but also the 59 Innuitian, Cordilleran, Greenland and Kara-Barents ice-sheets) and as such glacio-isostatic dynamics 60 have been the predominant processes in RSL evolution since the middle Holocene.

61 Glacio-Isostatic Adjustment (GIA) resulting from the melting of these northern hemisphere icesheets is still ongoing, and will play a major role in present-day and near-future RSL changes along 62 63 the coasts of the northern hemisphere. The Holocene RSL signal across NW Europe is mainly driven by the GIA resulting from the regional ice sheets (i.e. the "Fennoscandian Ice-Sheet" and the "British 64 Irish Ice-sheet", respectively noted FIS and BIIS hereafter). Therefore, recent sea-level observations 65 66 from tide gauges and satellites contain remnant GIA signals that must be taken into account when 67 isolating eustatic and steric signals (e.g. Peltier, 2001; Tamisiea and Mitrovica, 2011, Wöppelmann & 68 Marcos, 2012). Understanding the regional GIA dynamics is hence crucial before reliable scenarios of 69 future regional RSL rise can be proposed. To address this problem, numerical geophysical models 70 (termed Glacio-Isostatic Adjustment models or "GIA models") have been developed since the early 71 seventies. These models provide RSL predictions for any particular location on the surface of the 72 Earth by solving a unified set of equations (the Sea-Level Equation, "SLE", Farrell and Clark, 1976) 73 that merges (i) an "Ice model", which defines the history of the major land-based ice sheets and (ii) a 74 rheological model ("Earth model") describing the behaviour of the Earth's surface in response to 75 surface load changes, and (iii) the changes in gravitational field induced by the redistribution of the 76 mass at the Earth's surface (melting of the ice-sheets) and within the Earth's interior (displacement of 77 mantle material due to isostatic adjustment) (e.g. Mitrovica and Peltier, 1991; Peltier, 1998; Mitrovica 78 and Milne, 2003; Spada et al., 2012). Significant regional misfits continue to exist between predicted 79 and observed RSL (e.g. Engelhart et al., 2012; Ostanciaux et al., 2012), which suggest errors and/or 80 simplifications 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. 81

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 to 0.8 mm/yr<sup>-1</sup> 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
propose to push the comparison between Holocene RSL and GIA model predictions a few hundred
kilometers south on the other side of the English Channel.

92 Within the framework of a coastal risk assessment research program (ANR COCORISCO, French 93 National Research Agency), extensive fieldwork has been conducted during the past four years 94 around the Finistère peninsula (Western Brittany, France). Along with the study of Holocene paleo-95 storminess, which was the prime objective of the research program (Van Vliet *et al.*, 2014a, 2014b), 96 many of the sampled sedimentary sequences could also be successfully analyzed to derive RSL data.

97 The first objective of this study is to obtain new precise and reliable sea-level index points (SLIPs) 98 for the Western Brittany region with a particular emphasis placed on recovering compaction-free basal 99 SLIPs. The second objective is to explore the implications of these new RSL data for the isostatic 100 dynamics of the coasts of Western Europe, following a two-step approach. First, we perform a regional 101 comparison of our data with the RSL history proposed for the closest region for which a well-102 constrained Holocene RSL record is available (Southwest UK). We thereby evaluate if isostatic 103 gradients can be identified on the basis of RSL data alone. Second, we compare our new data against 104 predicted RSL from both global and regional published GIA models. We also discuss the origin of the 105 misfits between our data and model predictions, with a particular emphasis on local- to regional-scale 106 factors which can potentially influence paleo-RSL.

107

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

108 Despite the several RSL studies that have been conducted since the seventies along the 109 French Channel and Atlantic coasts (Delibrias and Guillier, 1971; Ters, 1973; Morzadec-Kerfourn, 110 1974; Ters, 1986, Van de Plassche, 1991; Goslin et al., 2013; Stéphan et al., 2014), there remains a lack of reliable and high-quality Holocene basal SLIPs (Stéphan and Goslin, 2014). For the Finistère 111 112 region (western tip of Brittany), only two studies achieved a sufficient data density to derive Holocene 113 RSL reconstructions (Morzadec-Kerfourn, 1974; Stéphan et al., 2014). However, none of these studies 114 included data prior to 6000 yr B.P., nor sufficient basal data to provide reliable conclusions on the 115 Holocene RSL evolution in Western Brittany. Additionally, Goslin et al. (2013) showed that a re-

116 assessment of the oldest data from the region, extracted by state-of-the-art methods, leads to a further 117 reduction by up to two thirds of the number of SLIPs which can be considered reliable. At a larger 118 scale, the data from Delibrias and Guillier (1971), Ters (1973, 1986), Morzadec-Kerfourn (1974) and 119 Van de Plassche (1991) formed the main constraint for modeling work of Lambeck (1997) and Leorri 120 et al. (2012). These studies aimed to quantify the contributions of the glacio- and hydro-isostatic 121 components in the RSL histories of the Atlantic coasts of Europe. Both studies proposed that a North-122 South trending glacio-isostatic gradient could have influenced the European Atlantic coasts, due to the 123 influence of the north-western European peripheral bulge that formed in response to the combined 124 influence of the BIIS and FIS ice loads. This gradient would have extended from the southern coasts 125 of UK to the south of the Bay of Biscay (Lambeck, 1997) or even as far as South Portugal (Leorri et 126 al., 2012). However, as Goslin et al. (2013) recently suggested, the field-data used by Lambeck (1997) 127 and by Leorri et al. (2012) for the Brittany region should not be considered reliable enough to 128 conclusively validate the outputs of their GIA models. Hence, the proposed isostatic gradients along 129 the western Atlantic coasts of France and Spain are still to be ascertained. In northwest Europe, Vink 130 et al. (2007) evidenced for a continuous heightening of the RSL records when progressing from 131 northern France to southern Denmark that illustrated a progressive damping of the FIS peripheral 132 bulge isostatic subsidence towards its tail. Unfortunately, the lack of basal data along both sides of the 133 English Channel coasts has up to now prevented from following this trend further west, while the 134 signal becomes more and more complex as it sums up with the isostatic signal induced by the BIIS 135 loading and hydro-isostasy. Finally, offsets between tide-gauge records at Brest and Newlyn 136 (Cornwall, Southwestern UK) (ca. 1.41 mm/year and 1.74 mm/year, respectively) hint for different 137 recent RSL rise rates between the two locations (Woodworth et al., 1987; Douglas, 2001, Haigh et al., 138 2009). Considering the proximity of the two stations, located ca. 200 km apart, and the absence of any 139 tectonic active process which could account for such a ca. 0.3mm.yr<sup>-1</sup> differential in vertical land-140 movement, this difference is still unexplained (Douglas, 2008; Wöppelmann et al., 2008, Haigh et al., 141 2009).

In this context, obtaining new high-quality RSL data in the Finistère (Western Brittany) region was critical to improving the understanding of Holocene isostatic dynamics and the RSL history along the Atlantic coasts of Europe. Located ca. 200 kilometers directly south of Cornwall, Brittany also remained ice-free during the Late Pleistocene. It can be considered, together with Southwest UK 146 (Massey et al., 2008), as a key area to constrain the extent, amplitude and dynamics of the north-

147 western European peripheral bulge and the ESL signal over this period.

#### 148 2. Regional settings and study sites

149

2.1 Geological, geodynamic and physiographic settings

150 The Finistère region is situated at the western end of the Armorican massif, which is bounded on this northern termination by the North-Armorican scarp marking the entrance of the English Channel 151 152 geological system. The latter is characterized by a system of grabens, delimited by a dense network of 153 multi-kilometric deep crustal faults (up to 7 to 10 kilometers, Evans, 1990; Lericolais, 1997; Lagarde et 154 al., 2003). The northern and southern parts of the Finistère region are composed of granitic batholiths 155 domains that were emplaced during the Cadomian and Variscan orogenies. In those regions, the 156 basement is mainly composed of endogenous granites and metamorphic rocks (gneisses and 157 amphibolites). In between those plutons, a synclinal deformation hosts sandstones and shale 158 formations of Palaeozoic age. Brittany is considered to have undergone a long step-wise passive 159 margin subsidence since the opening of the Bay of Biscay between the Jurassic and the Late and 160 Early Cretaceous (Evans, 1990; Van Vliet et al., 1997; Bonnet et al., 2000). The Finistère region is 161 currently undergoing compression due to the ongoing northward motion of the Iberian plate (Wyns, 162 1991; Bonnet et al., 2000). This dynamic results into a low-intensity and diffuse seismicity that remains 163 concentrated along two majors faults (the North- and South-Armorican Shear Zones, Lagarde et al., 164 2003). Large earthquakes (of magnitudes equal to or greater than 5.5) are unusual (centennal) and 165 mainly concentrated within the Cotentin region, in the central part of the English Channel. Seismic 166 activity can be considered to have been of equal magnitude and frequency during the Holocene, and 167 thus to have had none or insensible impacts on the sedimentary sequences of this period.

#### 168 2.2 Rationale for study sites selection

169 The Finistère peninsula is exposed to macro- to meso-tidal conditions, with spring tidal ranges 170 decreasing from up to 7.5 m in the north to ca. 4 m in the south of our study area (table 1). Present-171 day local tide data were obtained either from the nearest tide station(s) (SHOM, 2012, French Navy 172 Oceanographic Agency) or by interpolation between the two nearest tide stations.

173 New stratigraphic data were collected from six sites (Guissény, Landéda, Porsmilin, Treffiagat, 174 Kermor-Tudy and Guidel) which covered the entire study area (Fig.1), and sampled a range of very 175 diverse morphological configurations: open embayments, inner rias, open coast and estuarine back-176 barrier sites (classification after Allen, 2000). The spatial spread of the study sites was chosen to 177 improve the regional representation of the reconstructed RSLs. Finally, the extended north-south 178 spread of the study sites allowed (i) the differences in tidal ranges to be assessed and (ii) investigation 179 of the RSL signal from sites located at variable distances from the former centres of the paleo-ice-180 sheets (and thus situated in different positions along the glacio-isostatic gradient).

#### 181 3. Material and Methods

182 3.1 New data

#### 183 3.1.1 Sampling and surveying

184 Most of the sampling was from coring (using an Eijkelkamp 60-mm diam., hand-held motor-driven 185 percussion corer that extracts 1m sections in plastic tubes). For some sequences that comprised thick 186 layers of sand and a thick water table (Kermor and Guidel sites, see fig.1 and section 4.1), buoyancy 187 problems prevent us from using percussion corers. The BRGM's (French Research Agency for 188 Geology and Mines) sedidrill mounted-rig was then used. Extreme precautions were taken to identify 189 and sample undisturbed sediment and drillings were cross-checked in order to ensure the stratigraphic 190 continuity. This latter is also ensured by the high-resolution paleo-environmental studies that have 191 been made on the same sequences (Fernane et al., 2014, 2015). Finally, some short sequences were 192 retrieved from the foreshore using a hand-gouge prior to this study. All sites were positioned using a 193 Trimble 5800 DGPS and tied to IGN (French National Geographic Institute) benchmarks. Elevations 194 were determined with respect to the NGF datum (French levelling datum).

195 3.1.2 Sedimentary analyses and dating

All sedimentary sequences were described in the laboratory in terms of grain size, colour, organic and macrofossil contents. Particular attention was paid to identify possible reworked levels or erosional surfaces. Radiocarbon AMS dating was performed after the material was washed, dried and carefully selected under the microscope. Whenever possible, plant remains were preferred as their fragility reduces the risk of re-deposition (Gehrels *et al.*, 1996; Törnqvist *et al.*, 1998; Gehrels, 1999). Potentially reworked material such as drift wood or charcoal was dated only when no other material was sufficiently available. Marine shells were dated only if found complete and in living position within the deposits. AMS radiocarbon measurements were performed at the "*Laboratoire de Mesure du Carbone 14*" (Gif-S/Yvette) and at the Poznan Radiocarbon Laboratory (Poland). Dates were calibrated after correction for isotopic fractionation using Calib 7.0 with the IntCal13 and the Marine13 calibration curves for the terrestrial and marine material, respectively (Reimer *et al.*, 2013). Dates are reported with a  $2\sigma$  (95%) confidence interval.



#### 208

Figure 1 - Location map of the study area and of the study sites. A) Guissény -Tressény (inner dot) & Guisseny-Vougot (outer dot), B) Landéda, C) Porsmilin, D) Bay of Brest, E) Treffiagat, F) Kermor-Tudy, G) Guidel Loc'h. (H, I, J) are the locations of the SW England Holocene RSL records to which we compare our data to (section 4.4).

#### 213 3.1.3 Paleo-RSL elevation reconstruction

214 We follow the SLIP methodology (Shennan, 1986; Van de Plassche, 1986) to reconstruct RSL 215 changes. For a general view on RSL reconstruction methods and on the SLIP methodology, readers are referred to Shennan *et al.* (2015). In short, a valid index point requires the following information: (i)
the latitude and longitude of the site, (ii) the altitude (and associated uncertainties) of the surface, (iii)
an age and (iv) an Indicative Meaning (IM). The IM of a sample is the altitude of the original deposition
tied to a paleo-tidal reference level (e.g. Mean High Water Spring Tide MHWST or Mean tide Level
MTL). In this study, the elevation of each SLIP was calculated according to the following formula:

$$SLIP = H - D - I + T + A$$

where *H* is the elevation of the top of the core in meters relative to the reference water level; *D*, the depth of the sample in the core in meters; *I*, the Indicative Meaning in meters (in this study the IM was taken relative to the Mean High Water Spring Tide of each site), T the correction brought to I to include changes in paleo-tidal ranges and A the potential post depositional autocompaction undergone by the studied intercalated layer since deposition (uncorrected within this study).

SLIPs are then weighted with *Es* the sum of altitudinal error terms potentially introduced at each
stage of the reconstruction. For each index-point, *Es* can be calculated from the following expression
(Horton *et al.*, 2000):

$$E_{s} = \sqrt{E_{1}^{2} + E_{2}^{2} + E_{n}^{2}}$$

229 where  $E_1...E_n$  are the elevation uncertainties affecting the given sample. For example (i) the possible 230 deformation of the sequences during the coring (e.g., compaction induced by the percussion); (ii) the 231 non-verticality of the core that can lead to an under-estimation of the sample depth; (iii) the potential 232 flexure of the rods during hand-augurings; (iv) the potential "twirl" effect on the intercalated samples 233 retrieved with the screw-drilling rig; (v) the leveling uncertainties inherent to DGPS measurements; (vi) 234 the error in tying the station altitude to the IGN benchmark, and finally (vii) the uncertainty inherent to 235 the calculation of the IM, which is defined as the "Indicative Range" (IR). This later uncertainty 236 depends on the methodology used to determine the Indicative Meaning and on the specific tidal parameters of each site. The various terms used to calculate the elevation uncertainties are 237 238 summarized in table 2.

Changes in tidal regimes during the Holocene are an additional, and significant, source of error in
 RSL reconstructions. Indeed, paleo RSL positions are most often derived from indicators which were
 emplaced within the high-tide domains. Therefore, changes in the tidal ranges through time can result

242 in paleo-RSL positions that differ from the "true" Mean Sea Level (MSL) signal that represents "allogenic" RSL change (as termed by Gehrels, 1995). Estimating the paleo changes in local tidal 243 244 ranges is even more crucial when observational data are to be compared with RSL predictions produced by GIA models, which are defined relative to the MSL. In this study, the effects on RSL 245 246 reconstructions of possible changes in the tidal range in our study area have been obtained following 247 a modelling approach, described in section 3.3.2. This is one of the few studies to date where paleo-248 tidal corrections have been applied in the reconstruction of RSL histories in NW Europe (Shennan et 249 al., 2000; Shennan and Horton, 2002, Neill et al., 2010).

250 Indicative meanings are traditionally determined through the use of micro-fauna assemblages (e.g. 251 Horton et al., 2006; Massey et al., 2008; Kemp et al., 2009, Kemp et al., 2013, Stéphan et al., 2014). 252 Within most of our sedimentary sequences, foraminifera were scarce or totally absent while diatoms 253 were rare and limited to some particular layers. To overcome this difficulty, we determined indicative meanings using salt-marsh surface sediment stable carbon isotope ratios ( $\delta^{13}$ C) and bulk 254 255 geochemistry (TOC, TN, C/N ratio). The latter is an alternative RSL reconstruction approach whose 256 usability in micro-fauna poor saltmarsh environments has been recently highlighted (Engelhart et al., 257 2013; Goslin, 2014). We used the modern geochemical reference constructed for our study region by 258 Goslin (2014). Complete details on the development and use of this reference, along with the 259 protocols followed and the obtained results can be found in Supplementary Online Material (SOM, appendix S1). In short, δ<sup>13</sup>C, TOC and TN measurements were made on modern sediments sampled 260 261 at the surface of three saltmarshes located in Brittany. Samples were taken along transects running 262 from the low marsh to the high-marsh brackish to freshwater transitional domain. We combined the 263 results obtained from the surfaces of the three marshes to build a modern geochemical regional training set. Clustering statistical analyses (Partitionning Around Medoids, PAM) were then made on 264 the whole dataset to decipher whether groups of comparable  $\delta^{13}$ C, TOC and TN values could be 265 identified along the tidal frame. This way, we identified four elevational groups characterized by 266 267 specific values of  $\delta^{13}$ C, TOC and TN and altitudinally bounded. Palaeo salt marsh elevations (and *i.e.* 268 palaeo RSL positions) were then reconstructed from Holocene cores using Linear Discriminant 269 Functions, that allow to determine the probability for palaeo observations (core samples) to be 270 allocated to one of pre-specified classes (here, to one of the biozones obtained above by PAM from modern samples and characterized by specific values of  $\delta^{13}$ C, TOC, and TN). Palynological data were 271

also used when available (Morzadec-Kerfourn, 1974; Fernane *et al.*, 2014). Deposits that could not be
directly related to the reference water level were used to provide limiting points: terrestrial freshwater
deposits gave high-limiting points; and marine deposits, low-limiting points (Shennan *et al.*, 2015).
Indicative meanings that were used are summarized in table 3.

As proposed by Engelhart *et al.*, (2012), we classified our SLIPs into three categories (see Engelhart *et al.*, 2012 for a full description of these categories): (1) Base of Basal deposits (noted "BB"), considered to provide compaction-free index-points (thus of prime reliability for RSL reconstruction); (2) Basal deposits (noted "B", possible but limited autocompaction); finally (3) the SLIPs derived from Intercalated deposits (noted "I", prone to autocompaction, non-corrected within this study).

#### 282 3.2 Additional data

283 RSL data previously produced by Morzadec-Kerfourn (1974) in the North Finistère region were 284 thoroughly re-assessed (recalibration of the dates, new determination of the indicative meaning, 285 assignation of error terms) before they were incorporated into our dataset. The details of these re-286 assessments can be found in Goslin et al. (2013). This included reassessment of the salinity regime of 287 some of the basal peat from these previous studies using a mixed palynological and geochemical 288 approach (Goslin et al., 2013). When it could be ascertained that these basal peats were deposited 289 within a brackish environment, it was considered that they formed between the Mean High Water 290 Neap Tide (MHWNT) and the Highest Astronomical Tide (HAT) levels (Goslin et al., 2013). Recent 291 RSL data published by Stéphan et al. (2014), mostly obtained from salt-marshes of the Bay of Brest, 292 were incorporated as published. Data we retained from previously published studies of Goslin et al. 293 (2013) and Stéphan et al. (2014) are summarized in table 5, with their original error terms.

294 3.3 Modelling

#### 295

#### 3.3.1 Geophysical glacio-isostatic adjustment modelling

We compared the RSL predictions of five GIA models (five different ice and Earth models combinations) against the new RSL data obtained in this study. We utilised two global ice models. The "ICE-5G" model, developed by Peltier (2004) is a non-glaciological ice-loading model that has been hand-tuned to provide best-fit predictions to an extensive global database of RSL and GPS records. 300 The second global ("Glac1-b") model is a set of interim results for an ongoing large ensemble 301 Bayesian calibration of the Glacial Systems Model (GSM) which includes a 3D thermomechanically 302 coupled ice sheet component (Tarasov et al., 2012; Tarasov, 2013). The constraint data set for the 303 calibration includes most of the same data use to tune ICE-5G along with additional ice sheet specific 304 data such as strandline records of pro-glacial lake levels and marine limits for North America and the 305 dynamic model fit to present-day observed ice topography and thickness for Antarctica and 306 Greenland. Glac1-b contains components from Tarasov & Peltier, 2002 (Greenland); Tarasov et al., 307 2012 (North America), Briggs et al., 2014 (Antarctica), and a yet unpublished component for Europe 308 (that has been validated for the Barents/Kara region against GRACE observations in Root et al., 309 2015). We also utilized two regional models which were combined with the global ice model "Brad15", 310 an extension of the global model of Bassett et al. (2005) constrained with new Holocene RSL data 311 from China and Malay-Thaïland (Bradley, 2009; Bradley, 2011; Bradley et al., submit.). The "BIIS" 312 model was originally published in Bradley et al., (2011). It was developed by combining Brad15 with a 313 UK-Ireland ice sheet model (Brooks et al., 2008). The latter was developed to fit the UK geomorphological data and fine-tuned to fit the British-Irish RSL database and GPS data (Bradley et 314 315 al., 2009, Bradley, 2011). The second regional ("Kuchar") model (Kuchar et al., 2012) was derived 316 from output of a glaciological three-dimensional thermomechanical ice sheet model for the BIIS 317 (Hubbard et al., 2009). The ICE-5G and GLAC1-b models respectively use the VM2a and VM5a Earth-318 models for the European region. These Earth-models were tuned to provide the best-fit solution to 319 near-field Hudson Bay and Angerman River (Sweden) RSL records (Peltier, 2004). Conversely, we 320 ran the "BIIS" and the "Kuchar" models with Earth-models whose parameters were fine-tuned against 321 near- and intermediate-field RSL data from the British Isles and present-day GPS land vertical motion 322 data (Bradley, 2011; Bradley et al., 2011). All these GIA models are based on the self-consistent SLE 323 theory first introduced by Farrell and Clark (1976). The ICE-5G (VM2a) model of Peltier (2004) was originally developed with a lithosphere thickness of 90 km. We ran it with upper mantle viscosities of 324 0.5x10<sup>21</sup> Pa.s, and lower-mantle viscosities of 2.7x10<sup>21</sup> Pa.s. GLAC1-b uses Peltier's VM5a Earth 325 326 model. VM5a is a variant of VM2a, with lithospheric thickness reduced to 60 km and an additional 40 km thick low viscosity layer directly below the lithosphere (1.0x10<sup>21</sup> Pa.s). It has upper mantle 327 viscosities of 0.5x10<sup>21</sup> Pa.s and lower-mantle viscosities of 1.6x10<sup>21</sup> Pa.s (upper 500 kms) and 328 3.2x10<sup>21</sup> Pa.s (rest of lower mantle). "BIIS" (Bradley, 2009, Bradley et al., 2011, Bradley et al., submit.) 329

and Kuchar *et al.*'s (2012) regional models adopt a lithosphere thickness of 71 km, upper- and lowermantle viscosities of  $0.5 \times 10^{20}$  Pa.s and  $3 \times 10^{22}$  Pa.s for the former and of  $0.3 \times 10^{20}$  Pa.s and  $2 \times 10^{22}$ 

332 Pa.s for the latter, respectively.

#### 333 3.3.2 Paleo-tidal modelling

334 We computed changes in tidal ranges for our study sites using the 3D tidal model of Neill et al. 335 (2010). The reader is referred to Neil et al. (2010) for greater details about model parameters and 336 calculations. In summary, the evolution of the principal semi-diurnal  $(M_2)$  and solar  $(S_2)$  tidal constituents were simulated to describe "mean" spring and neap ranges and interpolated initially by 337 338 running the outer coarser global tidal model of Uehara et al. (2006), modified to account for the updated ICE-5G (VM2a) GIA model (Neill et al., 2010). A 1/24<sup>th</sup> degree resolution grid was used for 339 340 the tidal range computations (Neill et al., 2010). Due to negligible differences at the scale of the shelf 341 after 6ky B.P., we did not performed calculations after this date (Neill et al., 2010). Thus, we obtained 342 tidal ranges for 5 kyr, 4 kyr, 3 kyr, 2 kyr and 1 kyr B.P by linear interpolation between model output 343 values. We corrected and recalculated the Indicative Meanings and the Indicative Ranges of our 344 modern regional tidal zones to account for the tidal conditions that prevailed at each site at the time of 345 deposition of the various sedimentary layers. The output figures of the model runs are provided as 346 supplementary information in SOM (appendix S2), for each study site.

#### 347 4. Results and discussion

348 4.1 Stratigraphies

Complete information regarding the data presented below (e.g. datings, depth, geochemical
measurements, IM, IR) is summarized in table 4.

- 351 Kerlouan Guissény (A. North Finistère)
- 352 Tressény marsh

Core GUIS-C2 was retrieved from the central part of the inner cove salt-marsh of Tressény (fig. 2-1). The sequence sampled by the GUIS-C2 core consists in 0.4 m of Pleistocene material, progressively topped with ~0.6 m of a highly organic stratified silty peat, containing rare foraminifera and *Phragmites australis* macroremains (fig.2-3), indicating its brackish character. The base of the basal peat layer yielded geochemical values characteristic of high-marsh deposits (index n° 17, table

- 358 4). This basal deposit evolves into a 0.15 m thick black-peat layer that denotes the onset of slightly
- 359 regressive conditions towards highest marsh deposit environments on the site around 5.1 kyr B.P. and
- 360 4.7 kyr B.P.



Figure 2 - 1) Map of the Tressény marsh (noted A on Fig.1) showing the location of the coring transects. The red
star locates the GUIS-C2 sampled core. 2) Detailed stratigraphy from coring transects taken through the marsh
(adapted from Stéphan *et al.*, 2014), (1\*) is an informative dating taken from Stéphan *et al.* (2014) and unused in
this study. 3) Complete stratigraphic log of the GUIS-C2 core.1- Weathered granite basement, 2- Angular gravels
and pebbles, 3- Coarse sand, 4- Fine sand, 5- Laminated silt dominated minerogenic deposit, 6- Silty Reed peat,
7- Black peat, 8- Humic soil horizon, 10- wood fragments, 11- fragmented shells, 12- Erosion surface.

Commentaire [BVVL1]: NEW FIGURE ADDED

368 The black peat layer is abruptly eroded at its top. A 0.6 m thick sand layer rests above the peat layer,

369 showing high energy granulometric characteristics and evolving upward from terrestrial material at its

370 base towards coarser shell-rich marine sand. The top of the sequence is composed of alternating 371 layers of organic silty layers and some sand enriched layers, progressively increasing in organic 372 content before reaching the contemporaneous salt-marsh soil (3.75 m NGF, Fig. 2). The silty layers in 373 the top of the sequence show evidence of deposition within a channel environment and contain signs 374 of allochtonous material embedded in the sediment (in particular, very low  $\delta^{13}C$  and C/N values). 375 Therefore these layers were not considered reliable for RSL reconstruction. The roof of the infill, dated 376 ca. 500 yr B.P., displays all the geochemical characteristics of middle to high marsh environment 377 (index n°1, table 3).

378 Vougot Beach

The sequence preserved at the bottom of the Vougot beach at Guisseny was investigated by one hand-auguring (see sequence Guis-S2, Fig.3). Within the Guis-S2 sequence, 0.65 m of brown peat was retrieved before reaching the underlying loess formation. The base of the basal peat layer (-1.15 m NGF) shows signs of brackish environment deposition (embedded reed fragments).



383

Figure 3 - 1) Map of the Vougot beach (noted A on Fig.1) showing the location of the cores. The red star locates
the GUIS-S2 sampled core. 2) Detailed stratigraphy from coring transects taken through the marsh. Dating in
brackets is given for informative purposes and in not used in this study. 1- Weathered granite basement, 2- Silt, 3Medium sand, 4- Reed peat, 5- Erosion surface.

388 Landéda – Tariec (B. North Finistère)

In core 'TAR-S1', an approximately 0.6 m-thick highly fibrous peat was reached at -3 m NGF (Fig.4), It is principally composed of embedded reed-leaves fragments and directly overlaid the Pleistocene loessy silt level. It is topped by a ca.1 m-thick sand layer. The blended *Phragmites australis* and *Juncus maritimus* macro-remains suggest a brackish highest high marsh environment. Commentaire [BVVL2]: NEW FIGURE ADDED





Figure 4 - 1) Map of the Tariec foreshore (noted B on Fig.1) showing the location of the coring transect. The red
 star locates the TAR-S1 sampled core. 2) Detailed stratigraphy from the coring transect taken through the site. 1 Granite basement, 2- Silt, 3- Medium sand, 4- Reed peat, 5- Erosion surface.

397 Porsmilin (C. West Finistère)

398 Five piston cores were retrieved from the foreshore to the bottom of the back-barrier swamp (Fig. 5). 399 Only core PorsC1, which was retrieved at the bottom of the beach, could successfully be interpreted 400 for RSL reconstruction purposes as the cores retrieved from the inner areas of the marsh only 401 contained freshwater deposits that delivered non informative limiting points (Fig.5). In PorsC1, the roof 402 of the weathered basement was reached at -5 m NGF. Over this basement lays ca. 0.3 m of gravel-403 rich clay, topped with around 2 m of slightly clayey sand of probable channel origin. Above this layer, 404 the upper half of the sequence is characterised by a shift towards organic and stratified silt deposits, 405 intercalated with woody peat layers (Fig.2). The base of the basal peat (-3.3 m NGF) was dated at 7 ky 406 cal. B.P. A high marsh depositional environment can be inferred from the geochemical values obtained 407 on this deposit. This is in accordance with the palynological assemblages described by Fernane et al. 408 (2014) that show dominating Poacea and Cyperacea pollen spores (which can correspond to plant 409 species adapted to a brackish environment, such as Spartina altinerflora, Phragmitus australis and 410 Juncus roemarianus). The upper half of the sequence shows constant signs of pyritisation embedded

Commentaire [BVVL3]: NEW FIGURE ADDED



413 Figure 4 - 1) Map of the Porsmilin site (noted C on Fig.1) showing the location of the coring transects and of the 414 sampled core. The red star locates the PORS-C1 sampled core. 2) Detailed stratigraphy from coring transects 415 taken through the marsh and the foreshore. Datings in brackets (Fernane et al., 2014) are given for informative 416 purposes and are not used in this study. 3) Complete stratigraphic log of the PORS-C1 core:1- Weathered granite 417 basement, 2- Angular gravels and pebbles, 3- Sand, 4- Stratified silt deposit, 5- Highly organic layer, 6- Peat, 7-418 Humic soil horizon, 8- wood fragments, 9- Tree stump, 10- Erosion surface.

Commentaire [BVVL4]: NEW FIGURE ADDED

420 Treffiagat (D. South Finistère)

421 Two cores were taken near the swamp in the back-barrier zone, respectively at 2.2 m NGF and 422 1.75 m NGF, that were merged to build a compound complete sequence (Fig.6). The observed sequence begins at -1.25 m NGF with a ~0.3-m thick Pleistocene silty-mud complex (traces of 423 oxidation and several roots remains attest of its aerial exposure) overlaying the weathered basement. 424 425 Over this first layer, a 30-cm thick organic silty peat layer is found, progressively turning into a wood-426 rich black peat above ca. -0.75 m NGF (Fig.6). This peat layer is capped by ~1.70 m medium to

427 coarse sand layer, of sand-barrier origin, whose onset was dated ca 1000 cal. B.P. 428 Micromorphological analyses revealed an extensive presence of pyrite within the matrix of the basal 429 Holocene silty peat layer, along with *Chrysophyceae* fragments (unspecified species). Geochemical 430 data from this basal deposit imply deposition in a mid- to low marsh environment. In contrast, no direct 431 evidence for brackish influences could be obtained from the overlying peat deposit.



432

Figure 6 - 1) Map of the Treffiagat site (noted E on Fig.1) showing the location of the TREF-1 and TREF-2
sampled cores (red stars). 2) Detailed stratigraphy from coring transects and trenches/outcrops observations. 3)
Compound stratigraphic log of back-barrier sedimentary sequence: 1- Weathered granite basement, 2- gravels
and pebbles, 3- Clayey/silt deposit, 4- Medium sand, 5- Coarse sand, 6- Highly organic layer, 7- Peat, 8-Humic
soil horizon, 9- wood fragments, 10- Erosion surface.

438 Kermor - Tudy (F. South Finistère)

439 Two cores were taken in the eastern part of the Kermor site, near the root of the barrier. Core K-IX

440 (3.8 m NF) passed through nine meters of sediments before encountering the weathered basement at

Commentaire [BVVL5]: NEW FIGURE ADDED

- 441 -5.6 m NGF (Fig.7). The base of the sequence consists of a ca. 0.2-m thick silty-peat layer, containing
- 442 several Phragmitus australis and Juncus sp. remains. The peat is truncated by a sharp erosive surface
- 443 on top of which lays ca. 0.5 m of sandy-silt.



Figure 7 - 1) Map of the Kermor-Tudy site (noted F on Fig.1) showing the location of the coring transects and of
the sampled cores (red stars). 2) Detailed stratigraphy from coring transects. 3) Stratigraphic log of the K-IX and
K-X sampled: 1- Weathered granite basement, 2- gravels and pebbles, 3- Medium sand, 4- Fine sand, 5- Fine
Aeolian dune sand, 6- Organic sandy clay, 7- Sandy clay, 8-Salt-marsh soil horizon, 9- Peat, 10- Humic soil
horizon, 11- Shell in living position / fragmented shells, 12- Erosion surface.

Commentaire [BVVL6]: NEW FIGURE ADDED

The top of this latter unit is itself eroded at -4 m NGF and is overlaid by ca. 2 m of slightly shelly coarse sand, topped with a 0.1 m sandy peat layer at -1.8 m NGF. The sequence continues with ca. 3m thick very-shelly (*Scrobicularia*) sandy-silt infilling.

453 Above 1-m NGF and up to 2.3m NGF, clay becomes dominant, where it is topped by a 1.5-m thick 454 sand upper layer. Foraminiferas were observed throughout the sequence, but were too scarce to 455 permit representative counting. Assemblages are dominated by Elphidium williamsoni, 456 Haplophragmoides wilberti and Haynesina germanica, which characterize a low-salt-marsh to mudflat 457 depositional environment (Perez-Belmonte, 2008; Stéphan et al., 2014). All dated layers gave 458 geochemical values that are characteristic of the low marsh environment, with populations dominated by Elphidium williamsoni and Haynesina germanica. Geochemical indicators yielded a heavy  $\delta^{13}C$ 459 value of -19.95‰ and very low TOC and TN values (1.17% and 0.11%, respectively) in accordance 460 461 with a low-marsh environment. Using these latter geochemical values, we obtained a RSL position of - $0.67 \pm 0.76$ m on the same layer (index n°3, Table 4). 462

463 Core K-X (1.3 m NGF) reached the weathered rocky substrate at -2.7 m NGF (Fig.7). The 464 sequence is composed of a ca. 0.1-m thick sandy silt layer at its base, progressively turning into a 465 black peat until ca. -2.45 m NGF (Fig.2). The basal peat was dated using organic content to give an 466 age of ca. 5.5ky cal. B.P. at a depth of -2.49 ± 0.22 m NGF (i.e. ~10 cm above the basal contact). 467 Over the peat lays 0.8 m of very organic stratified silt horizons (Fig.2) cut by a sharp erosion surface. 468 Above this rests a very shelly marine mud layer (Hydrobia ulvae), dated from ca. 5.1 kyr cal. B.P. This 469 layer becomes progressively more organic and looses its shell content towards the top, until ca. -1 m 470 NGF where a thin soil horizon is observed. The uppermost part of the core is composed of 1.3 m of 471 brown to green clay, on which rests a dune sand level. The basal peat layer provided geochemical 472 values characteristic of the high-marsh domain. Other samples yielded geochemical signatures 473 characteristic of the low-marsh-to mudflat environment, in accordance with the domination of 474 Elphidium williamsoni, Haplophragmoides wilberti and Haynesina germanica within the foraminifera 475 assemblages. No other indicator bears out a deposition within a brackish environment.

476 Guidel (E. South Finistère)

Two drillings were completed along a SW/NE transect across the Guidel-Loc'h pond (Fig.8): GLG-1
was drilled in the center of the pond, and GLG-2 was drilled about 500 m seaward of GLG-1.





Figure 8 - 1) Map of the Guidel site (noted G on Fig.1) showing the location of the sampled cores (red stars). 2)
Stratigraphic log of the GLG-1 and GLG-2 cores: 1- Weathered granite basement, 2- gravels and pebbles, 3Medium sand, 4- Fine sand, 5- Fine Aeolian dune sand, 6- Organic sandy clay, 7- Sandy clay, 8-Salt-marsh soil
horizon, 9- Peat, 10- Humic soil horizon, 11- Shell in living position / fragmented shells, 12- Erosion surface.

484 GLG-1 is an 11-m deep drilling that reached the micaschist weathered basement at -8.3 m NGF. 485 The base of the sequence consists of ca. 0.2 m of lacustrine clay encroaching the basement on which 486 lays a 0.2m thick silty-peat layer. From -7.9 m NGF, the sequence is a 7-m thick succession of sand 487 and muddy-silty layers, interrupted by several salt-marsh soils. The top of the sequence consists of 488 clay-dominated deposits, the uppermost 1.4 m being coarse sand (Fig.8). Except for the basal peat 489 layers, the whole sequence contains foraminifera, the assemblages being dominated by Haynesina 490 gemanica, Amonia becarii and Elphidium williamsoni. At -2m NGF, Scrobicularia plana in living 491 position gave an age of 4.9 kyr cal. B.P. Geochemical values infer deposition within a low-marsh to 492 mudflat environment.

The GLG-2 sequence is somewhat equivalent to the GLG-1 sequence, only lacking the basal peat layer (Fig.8). As for GLG-1, the whole sequence is characterized by the extensive presence of shells (*Hydrobia ulvae* especially) within the deposits and by the domination of low-marsh to mudflat foraminifera species.

497 4.2 Holocene Relative Sea Level variations and responses of the coastal systems

Commentaire [BVVL7]: NEW FIGURE ADDED

498 This study has resulted in 24 new dates for the coastal Holocene sedimentary infillings in Western Brittany (table 4). This new RSL record, containing five new base-of-basal SLIPs, considerably 499 500 improves the precision of the regional RSL history between 8 kyr and 5 kyr cal. B.P. Specifically, (i) 501 this new dataset extends the previous available data by ca.1.5 kyr to 8 kyr cal. B.P.; and (ii) the basal 502 SLIPs provide new critical constraints on RSL inflections around 6 kyr cal. B.P. No reliable basal 503 indexes could be retrieved for dates younger than 4 kyr cal. B.P. so the RSL evolution for the Late 504 Holocene remains less precise (Fig.9). Our new data show an overall continuous 6.5 m RSL rise since 505 7 kyr cal. B.P. Following an initial rapid rise between 8-6kyr B.P. from ca. -8m to -5m below present-506 day level, there is a marked slowdown in the RSL rise around 6kyr cal. B.P., after which the rate of 507 RSL rise progressively decreases towards present day values.

508

4.2.1. RSL evolution from 8 kyr cal. B.P. to 6 kyr cal. B.P.

509 The two oldest samples (index n° 23 and 24) obtained are intercalated SLIPs and provide for the first 510 time an indication of the RSL history between 8 kyr and 7.5 kyr BP. However, the lack of base of basal 511 peats (Fig.9) limits the reliability of the RSL chronology over this period (Fig.9) These two samples 512 (index n°23 and 24) were obtained from deposits taken at the base of the sequences cored at the 513 Guidel sites but were not sampled directly at the contact with the underlying bedrock. Thus, a 514 compaction-induced artefact cannot be ruled out, and we suspect that true RSL positions may have 515 been slightly higher than drawn by these SLIPs. Therefore, we suggest that the RSL positions given 516 by these two indexes should be taken as indicative of minimum values.

Around 7000 cal. B.P., basal peats formations were emplaced along most of Western Brittany coasts. These basal deposits record a RSL situated between -6.74  $\pm$  1.22m (index n°22) and -6.95  $\pm$ 1.22m (index n°20) below present day between ca. 7 kyr and 6.8 kyr cal B.P (Fig.3). A limiting date, obtained from a basal freshwater peat deposit sampled in the Porsmilin sequence (index n°21) further constrains that the RSL was situated *at least* -6.47 m below present-day ca. 7 kyr cal. B.P.

Between 6.5 kyr and 6 kyr cal. B.P., where some SLIPs are derived from incompressible basal peat deposits, there is a continuous RSL rise reaching ca.  $-3.27 \pm 0.76$  m at around 5.9 kyr cal B.P. On top of these basal peat deposits, where an erosive hiatuses (wave ravinement surfaces) did not erode the previously-deposited sediments, a widespread onset of silty deposits mostly showing back-barrier lagoonal facies formed. These formations are, in turn, topped by humic layers (maximum- flood 527 surfaces) which suggest a widespread heightening of lagoonal marsh surfaces and evidence for 528 regressive conditions in the back barrier environments. They record the shift from the transgressive 529 system tract towards the mid-Holocene highstand system tract, where deposition most probably 530 occurred in the context of a deceleration of the RSL rise and with a large amount of sedimentary 531 material available within the foreshore domain.

The RSL rise rates we obtained in Brittany between 7ky B.P and 6ky B.P. are closely comparable to those observed for the same period in South-Western UK (Massey et al., 2008, Gehrels *et al.*, 2011; Gehrels and Anderson, 2014), in the North of France (Gandouin, 2003) and in the west of the Netherlands (Hijma and Cohen, 2010), suggesting the eustatic component still played the dominant role in RSL evolution during this period. However, as stated above, due to a lack of basal SLIPs, large uncertainties remain in the RSL rise rates observed in Western Brittany for the older periods.

538

#### 4.2.2. RSL evolution from 6 kyr cal. B.P. to 4 kyr cal. B.P

539 From 6 kyr cal. B.P., there is a pronounced slowdown in the rate of RSL rise in Finistère region (Fig.9). 540 Around 5000 yr cal. B.P., basal SLIP n°8 records the RSL at -2.6 ± 0.6 m below the present level, 541 while the high-limiting point n°38 constrains the RSL to lay at least 2 ± 0.55 m below its present position between 4.4 - 3.8 kyr cal. B.P. While the new basal SLIPs clearly suggest a decrease in the 542 RSL rise rate between 6 and 4 kyr cal. B.P., denser and more precise basal data are still necessary to 543 544 provide a detailed description of this RSL rise deceleration. From a more regional viewpoint, it is 545 interesting to note that, as the rate of RSL rise slowed down, some of our study sites (Porsmilin, 546 Kermor, Guidel) clearly returned to transgressive conditions, as shown by silty-sandy deposits. This 547 stratigraphic evidence implies the local creation of accommodation space between 6 kyr and 5 kyr cal. 548 B.P. driven by (i) the persistent and continuous, even if slow, RSL rise and probably (ii) the possible 549 compaction of the underlying sequences. Indeed, there is a clear spread (up to 3 meters for SLIPs of 550 approximately the same age) of the intercalated SLIPs between 6 kyr and 5 kyr cal. B.P. which is similar to what was observed by Massey et al. (2008) in Southwestern UK and by Gandouin (2003) in 551 552 the St Omer marsh (Northern France). This process may be caused by (i) the onset of coastal barriers 553 due to both a slowing-down in the rate of RSL rise and the large amount of available sediment (ca. 554 5000 yr cal. B.P.; Van-Vliet et al., 2014a), (ii) by the subsequent landward migration of these barriers, 555 as they rolled-over the back-barrier marsh sequences and (iii) by the shifting of tidal inlets, potentially



## 556 fostered by barrier breaching (Stéphan *et al.*, 2014).





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561 4.2.3. RSL evolution from 4 kyr cal. B.P. to present

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No basal index-point could be obtained younger than 4 kyr cal. B.P. This, when combined with the
lack of SLIPs between 4kyr and 2kyr cal. B.P. (Fig.9), prevents a precise constraint on the RSL
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564 evolution during the late Holocene. Several SLIPs that were dated around 3 kyr cal. B.P. (either during 565 this work or by Stéphan *et al.*, 2014) were rejected due to the anomalously low elevation which 566 resulted from a massive reorganization and disruption of the sedimentary system during formation 567 (Goslin *et al.*, 2013, Stéphan *et al.*, 2014), e.g. as illustrated by the widening of the river channel in the 568 Guisseny site.

569 From 2 kyr cal B.P. onwards, RSL reached a position very close to the present-day. Index n°3 570 which was obtained from the top of a thick sandy sequence (Kermor KIX) is likely to have undergone only a small amount of post-depositional compaction and hence can be considered as fairly reliable. 571 572 From this data point, the rate of RSL rise is estimated to have been reached a maximum of 0.71 mm.yr<sup>-1</sup> during the last ca. 2 kyr cal. B.P. Assuming that the ESL over the last 2 kyr was small, we 573 estimate that Western Brittany underwent a maximum subsidence of ca. 0.7 mm.yr<sup>-1</sup> for the last 2000 574 575 years, as a consequence of the post-glacial isostatic response of the lithosphere. Yet, this value is 576 calculated on the basis of only one point that carries some uncertainty due to its stratigraphical 577 position. Hence, this latter result must be considered as only indicative at this stage of the study and it 578 would require basal SLIPs for the Brittany region over the last two millenaries to be conclusive on this

579 latter point.

## 580 581

4.4 Comparison of Holocene RSL geological records along the English Channel: evidencing for a particular behavior of south-western UK (Devon, Cornwall and Scillies).

582 Vink et al. (2007) gave clear evidences for the glacio-isostatic subsidence induced by the collapsing of 583 the northern Europe peripheral bulge to progressively decrease along a NE - SW gradient running from 584 Germany to Belgium (as mainly driven by the loading of the FIS). In order to explore the glacio-585 isostatic gradients and subsidence patterns induced by the loading of the north-European ice-sheet complex and the collapse of associated peripheral bulge, we compared the RSL data from this study 586 587 to the high-quality RSL records available along the English Channel, either produced by the study of Holocene sedimentary successions in Southwest UK (Devon, Cornwall and Scillies, Healy, 1993; 588 589 Healy, 1995; Massey et al., 2008; Gehrels et al., 2011, Gehrels and Anderson, 2014), southern UK 590 (Hampshire region; Long and Tooley, 1995), Northern France (Seine Estuary, Huault, 1980; Frouin et 591 al., 2007; Stéphan and Goslin, 2014) and Belgium (Izjer valley, Denys and Baetman, 1995). The main Commentaire [BVVL8]: RSL RISE RATES FIGURE DELETED TO FREE SOME SPACE FOR THE FIGURES REQUESTED BY THE REVIEWERS IN THE MODELLING SECTION

**Commentaire [BVVL9]:** COMPLETELY REWRITTEN SECTION

sim of this comparison was to broadly evaluate if the glacio-isostatic subsidence gradient identified by
Vink *et al.* (2007) from northern Germany to Belgium could be followed further eastward.

594 As far as the data allowed it, only the basal SLIPs were compared. Before the data could be 595 compared, adjustments had to be made to fix vertical differences between the datums of the different 596 countries and/or the RSL datum used within the different studies. Indeed, the French data are 597 referenced to the NGF system (Nivellement Général de la France) at Marseilles (IGN69 datum), the 598 UK data we used are related to the Ordnance Datum of Newlyn (ODN) while the Belgium data is 599 related to the DNG system (Deuxième Nivellement Général) at Ukkle. Yet, the ODN is higher than the 600 NGF of ca. 40 ± 2 cm (Greaves et al., 2008), while the Belgian DNG lies 1.75m above the NGF 601 (Crastes de Paulet, 2013). Hence, before comparing the different RSL datasets, we applied a 602 consistent altitudinal correction to the depths of the samples to resolve this altitudinal discrepancy: a 603 ca. -40 cm shift was applied to the UK RSL data prior to their comparison with our RSL records, while 604 the Belgian data were lowered by 1.75m. However, as for the ODN correction it must be noted that 605 this offset is a somewhat crude estimate and is likely to slightly overestimate the real difference 606 between both datum's. Nonetheless, considering the fact that leveling errors are globally east-west 607 conservative both in UK and in France (Rebischung et al., 2009), this correction can be considered as 608 a sufficient first approach (P. Woodworth, comm. pers,). In some of the UK studies we took data from 609 (Massey et al., 2008), RSL positions were expressed relative to MTL, and not to ODN. In order to 610 relate these data to ODN and prior to the correction for the vertical difference between the ODN and 611 NGF datum, these were applied them a vertical shift corresponding to the local tidal heights relative to 612 ODN (Massey et al., 2008): -0.11m, -0.09m, -0.12, -0.11 for the SLIPs obtained at Bantham Sand, 613 North Sands, Slapton Sands and Blackpool Sands sites, respectively.

This comparison clearly shows that all studied regions undergone very comparable RSL histories during the 8.5 - 5 ky B.P. period, in great accordance with the one of Western Brittany. While all regions seem to have experienced slightly different RSL variations over the considered period (that is notably observable via slight differences in the RSL rise rates prior to 5 kyr cal. B.P.), a general synchronicity is clearly observable between the RSL trends estimated from the records. In all regions, there is an obvious inflection in the rate of RSL rise at ca. 6 kyr cal. B.P. (Fig.10) that most probably reflect a decrease in meltwater production from the melting of the global ice sheets (Vink et *al.*, 2007).

- 621 The synchronicity of the global RSL trends between Brittany and sites located eastward (Hampshire,
- 622 UK; Seine Estuary, Northern France) in the English Channel and at its eastern termination (Izjer
- 623 Valley, Belgium) suggests that all considered regions have been subjected to major synchronous RSL
- 624 forcing agents.



631

Figure 10 - Inter-regional comparison of RSL records from Western Brittany (brown boxes), Southwestern UK (Devon, Cornwall - black boxes), Central UK (Hampshire - green boxes), Seine estuary (Blue boxes) and Western Belgium (red boxes) during the last 8 ky B.P. Mind that all represented data basal SLIPs, excepted thin contoured brown boxes and SLIPs from Hampshire. These latter may thus have been lowered by some post-depositional compaction and hence potentially underestimate RSL position.

Commentaire [BVVL10]: NEW FIGURE ADDED

The RSL record from Belgium plots several meters under the ones from the Seine, Hampshire and Brittany regions (Fig.10). This undoubtedly illustrates the greater subsidence undergone by the Belgium coastal plain, in relation to the collapse of the peripheral bulge situated at the south of the North Sea (Vink et al., 2007). Indeed, this latter region has most probably been subjected to the conjunction of two subsiding dynamics, coming both from the north (glacio-isostatic gradient linked to 637 the collapse of the peripheral bulge south of the BIIS, as evidenced by Horton and Shennan, 2009) 638 and from the north east, induced by the deflation of the peripheral bulge southwest of the FIS (Vink et 639 al., 2007). Progressing westward, we note that the Hampshire and Seine regions show very lookalike 640 RSL records. Being located both in the middle part of the English Channel and in very comparable in 641 regard to the North Sea and Atlantic basins, these two regions must have been subjected to a 642 somewhat equivalent hydro-isostatic component, yet difficult to evaluate at this stage of the study. This 643 high variability in the hydro-isostatic component associated with the relatively large error margins the 644 SLIPs are weighted with makes it difficult to precisely identify a glacio-isostatic gradient that potentially 645 progressively damps westward along the English Channel.

646 However, a spectacular result emerges from the visual comparison of the RSL records that shows the 647 RSL data from SW UK to plot consistently several meters below the data of all studied regions during 648 the last 8 kyr B.P. Indeed, before 5 kyr cal. B.P the basal SLIPs retrieved from SW UK sedimentary 649 sequences SLIPs plot ca. 4 meters below the ones we obtained in Brittany (Fig. 10). It is interesting to note that the offset seems to reach a maximum ca. 6-5 ky B.P., while it appears to decrease towards 650 651 the older and younger times. To the first order, and assuming a constant decrease of the isostatic component, Brittany would have subsided at an average rate between 0.42 and 0.67 mm.yr<sup>-1,</sup> since 6 652 kyr cal. B.P., while the subsidence over the same period reached 1.3 to 1.5 mm.yr<sup>-1</sup> in Devon (a lack of 653 654 basal data for Brittany after 6 kyr cal. B.P. precludes a similar comparison for the late Holocene 655 period). This result is especially revealing if we consider that Brittany and SW UK have subsided partly 656 in response to the loading of the continental platform: the hydro-isostatic component accounts for ca. -657 2 to -3 m since ca. 7 kyr cal. B.P. and is considered commensurate between the two regions (e.g. 658 Leorri et al., 2012) as these latter share comparable peninsula configurations and almost identical 659 geological histories and features. Investigations on the gravitational and solid Earth changes from 10 660 kyr cal. B.P. show the geoid being less than 0.5m higher for Brittany than for Devon/Cornwall at 8 ky 661 cal. B.P. Therefore, the influence of differing hydro-isostatic components seems unlikely to explain the 662 large vertical discrepancies observed between UK and Brittany RSL levels.

In spite of the larger uncertainties concerning the most ancient and the most recent periods, this result nonetheless confirm that a time-dependent north-south subsidence gradient seems well to exist along the Atlantic coasts of Europe. This gradient would result from the collapse of the peripheral bulge of the European ice complex (British-Irish and Fennoscandian Ice-Sheets). SW UK and Brittany being 667 located at equivalent distances from the centers of glaciations, it could be awaited from glacio-isostatic 668 component to be broadly equivalent in the two regions and RSL histories to be quite close. As it is not 669 the case, we believe that two main hypotheses can be put forward. One hand, our new findings may 670 challenge the inferences previously made on the amplitude and extent of the peripheral bulge of the 671 north-European Ice-sheet complex south of the BIIS. The amplitude of the vertical offsets observed 672 between Western Brittany and Southwest UK RSL records could imply that Devon was much closer to 673 the apex of the bulge than Western Brittany was. If this is the case, our new findings challenge the 674 inferences previously made on the amplitude and extent of this bulge. The offset amplitude in the 675 isostatic subsidence between Brittany and Devon, regions which are close to one another, would 676 suggest some combination of (i) a shorter wavelength of the bulge than was previously inferred by 677 Lambeck (1997) and Leorri et al. (2012) and of (ii) a more northern position of the bulge apex than 678 was previously considered. One another hand, differences in the Earth response are also likely to be 679 invoked to explain such an offset. These results are in favor of a geological origin for the still 680 unexplained differences in the land-subsidence rates obtained from tide-gauges records between 681 Brest and Newlyn, as already suggested by Woodworth (1987). Indeed, recent tide-gauge based modern RSL studies (Wöppelmann et al., 2006, Douglas et al., 2008, Haigh et al., 2009) suggest that 682 RSL rises at a rate of 1.74 mm.yr<sup>-1</sup> at Newlyn against 1.41 mm.yr<sup>-1</sup> at Brest, thus advocating for a 683 684 greater subsidence in SW UK.

685

## 686 687

#### Brittany.

688 To investigate more in depth the origins of the vertical discrepancies we identified between 689 Brittany's and south-western's UK RSL records, we compared the new RSL data obtained in Western 690 Brittany (this work) and GIA model RSL predictions. As no significant differences could be identified 691 between the data records from the northern and southern part of our study area, we chose the location 692 of Guisseny (the northernmost site of our study area; 48°65' lat, -4°45' long.) as the reference location 693 for data-model comparison. This choice pertains to the fact that most of the basal SLIPs we obtained 694 come from the northern coast of Brittany. It is also justified by the fact that all sites that produced basal 695 SLIPs are seen to have been concerned by an equivalent hydro-isostatic component during the last 696 millenaries.

4.5 Comparison between predictions from GIA Models and RSL observations in Western

Commentaire [BVVL11]: RE WRITTEN SECTION WITH SUPPLEMENTARY FIGURES : 1) RSL SPATIAL PLOTS



- From the data-model comparison there are some key points (Fig.11):
- The patterns of the RSL predictions from the various models are, in general, consistent with our
- observations. The predicted RSL trends approximately capture the inflections in the observed rate of
- 706 RSL rise at ca. 7, 6, 5-4 and 2 kyr cal. B.P. (Fig.11)
- 707 This synchronism validates a posteriori the global pertinence of both the ICE-5G, BRAD15 and GLAC-
- 1b multiple ice models chronologies used as inputs for GIA models.

**Commentaire [BVVL12]:** NEW FIGURE : RSL Spataila plots to illustrates the spatial differences between the different models' predictions

<sup>Figure 11 – A) Data-model comparison between Holocene RSL observational data for western Brittany
(this study - grey boxes) and RSL predictions produced by GIA models of global and regional significance
(color lines), B) Spatial plots of the RSL evolution as predicted by the BRAD15, GLAC-1B and ICE-5G
VM2a GIA models, respectively. Here is shown only the RSL plot at 6 ky B.P. Plots for 7, 5 and 4 ky B.P.
periods can be found in the SOM (Appendix 3).</sup> 

709 - However, none of the models, whether "global" or "regional", was able to fit accurately our new RSL 710 observations in Brittany. All models under-estimate observed RSLs by up to several meters for the last 711 8 kyr and thus either (i) infer inaccuracies in the timing and amount of melt from the global ice sheets 712 or (ii) over-estimate the peripheral bulge subsidence. For example, the predictions of the ICE-5G 713 (VM2a) and GLAC1-b models lay up to 3 m below the mean RSL position obtained from our basal 714 SLIPs at 7 kyr cal. B.P. (Fig.11). When the "regional" "BIIS" and Kuchar et al. (2012) models are 715 compared to our new data, the misfits are even larger, ca. 6 m around 7 kyr cal. B.P. and more than ca. 2 meters around 4 kyr cal. B.P. (Fig.11). The global ICE-5G (VM2a) model, which is the most 716 717 highly tuned (of the models sampled) to fit global RSL data, is the one that produced the best fit to our 718 observations. Conversely, the best-fit UK regional models fail to fit our new RSL data. These latter 719 models produce RSLs for Brittany which plot slightly below those they produce for Devon. It was 720 previously proposed (Lambeck et al., 1997; Leorri et al., 2012) that the two regions would have 721 undergone comparable amounts of glacio- and hydro-isostatic subsidence, with Devon subject to a 722 slightly stronger glacio-isostatic signal. Our new data reinforce this idea but suggests a more abrupt 723 damping of this component across the Channel.

724

#### 4.6. Evaluating the influence of local process: changes in the paleo-tidal ranges

725 As stated before, we investigated changes in regional tidal ranges so that our RSL data, 726 constructed from high-tide indicators, could be directly compared to the RSL predictions from the GIA 727 models. For each of our sites, changes in the neap, spring and maximum annual tidal ranges are 728 shown in appendix S2 as height values and percentages of the present-day ranges. Graphical 729 representations of the results are presented in figure 7. The results of the paleo-tidal modeling indicate 730 that there were only very slight changes in the tidal range at our study sites during the last 8 kyr. The 731 maximum changes occurred between 8 and 6 kyr cal. B.P. and are mainly driven by changes in the 732 neap tidal ranges. For these latter, maximum changes were observed for the southern sites of our 733 study area (Treffiagat, Guidel), where neap tidal ranges increased by up to 30% of the present-day 734 value between 8 and 6 kyr cal. B.P. before reaching their present day values ca. 6 kyr cal. B.P.

However, considering the reduced amplitude of the tidal ranges at these sites, these tidal increases
only represent ca. 50 cm changes in height values (25 cm in half tidal ranges). Different evolutions
were observed for the spring tidal ranges. Indeed, for most of the sites situated on the outer coasts of

738 our study region (i.e. Bay of Brest and entrance excluded), model runs suggest that spring ranges 739 reached a maximum at 6 kyr cal. B.P., with values greater than present-day by to up to 3 to 6%. This 740 only translates into minor changes in the height values (max. 0.3 m). More importantly, the 741 relationships between neap, spring and astronomical tidal ranges have remained very constant 742 through time on all our study sites (see SOM, appendix S2). As a consequence, only minor changes in 743 indicative ranges are applied to most of the extracted SLIPs (Figure 14). Additionally, the model 744 results show differences between neap and maximum tidal ranges to have continuously increased 745 since 8 kyr cal. B.P., the most important rise being observed for Guisseny (0.7m). These changes 746 required the indicative ranges of SLIPs derived from undifferentiated high-marsh brackish peat 747 deposits (see section 3.1.3, indexes n°20, 22 and 39) to be slightly adjusted (reduced by 0.09m). As a 748 main result, we can state that our HWST-related indicators lead to only slightly over-estimate the MSL 749 evolution. Yet, it must be noted that the paleo tidal models we used were developed at a regional 750 scale (continental shelf) and thus are most probably unable to catch the changes in tidal ranges that 751 may have occurred at site-scales due e.g. to reorganizations of the foreshore sedimentary wedges. 752 These local changes in tidal ranges may have potentially been higher than those we modelled at the 753 shelf-scale.





Figure 13 - Paleo tidal model outputs of the maximum annual tidal range (maps 1 & 2) and Spring tidal ranges (maps 3 & 4) for the study region for 8 ky and 6 ky cal. B.P. Stars show the locations of the Guisseny-Tressény (A), Porsmilin (B) and Treffiagat (C) sites. Example plots of the 8ky to present-day evolution of the local max. annual, spring and neap tidal ranges are shown. Plots for the other sites are given in SOM (appendix S2). Complete model outputs values can be found as supplementary material in SOM (appendix S2).



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Figure 14 - Sea-level index points uncorrected (plain boxes) and corrected (doted boxes) for paleo tidal
 range changes through the last 8 ky cal. B.P.

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4.7. Regional to global causes of the data-models misfits: North-western Europe Icesheet complex history, lateral variations in the earth structure and meltwater

As demonstrated above (section 4.4), the effects of regional changes in the tidal-ranges remained negligible during the Holocene in our study region and are largely insufficient to explain the plurimetric offsets observed between our observational RSL data and GIA models RSL predictions (Fig.11, Fig.14). As such, hypotheses other than local to regional changes in the tidal ranges are required to explain the large data-models misfits we observe. In this section, we explore several agents that may play a role in the data-models misfits we observe between the RSL predictions of the GIA models and our RSL reconstruction based on geological indicators.

We propose that the misfits could mainly be due to an over-estimation of the glacio-isostatic
component, which can be explained by an over-estimation of the spatial extent and amplitude of the
European peripheral bulge and/or to temporal inaccuracies. This is partially corroborated by the

Commentaire [BVVL13]: RE WRITTEN SECTION WITH SUPPLEMENTARY FIGURES : 1) PLOT OF SPLIT RSL SIGNALS BETWEEN REGIONAL AND FAR-FIELD ICE-SHEETS ADDED TO FIG.9, 2) PLOTS OF SENSITIVITY ANALYSES TO EARTH-MODEL PARAMETERS 780 increases in model/data misfits with time. The easiest solution to resolve such under-predictions could 781 be to lower the vertical amplitude of the peripheral bulge, e.g. by reducing the ice-thicknesses - and 782 hence ice-loads - over the British Isles. Yet, a thinner BIIS would considerably increase the model-data 783 discrepancies in near-field areas (such as Scotland) and would be contrary to the recent reevaluations 784 of Scottish trimline data. Indeed, these latter studies suggest that BIIS ice-thickness would have 785 conversely been thicker than what is accounted in the models we used (e.g. Ballantyne et al., 2008, 786 Ballantyne, 2010; Ballantyne and Stone, 2015). To investigate the sensitivity of the RSL predictions to 787 the size of the BIIS, we generated RSL predictions for the Brittany region with bounding variants of 788 BIIS ice models (i.e., various ice-thicknesses for the BIIS, figure 9a and 9b). For example, the revised 789 ice-model used by Kuchar et al. (2012) which is up to two-three times thicker than the BRAD15 ice 790 model (Bradley et al., 2011) only results in a maximum 0.5 m vertical difference in the RSL predictions 791 produced by the two models (Figure 9a). This statement is also supported by figure 9b, where RSL 792 predictions generated by the GLAC1-b model with extremal bounding BIIS variants (bounding with 793 respect to regional Holocene RSL). These results illustrate that diverging scenarios of the BIIS and 794 ice-thicknesses over the British-Isles would only be responsible for slight changes in the RSL 795 predictions for ice-distal locations such as the Brittany region. As we illustrated in figure 9 and already 796 suggested by Bradley et al. (2011) and Kuchar et al. (2012), the RSL signal at these distal southern 797 sites is primarily driven by eustasy and the collapse of the peripheral bulges from all the major 798 Northern Hemispheric ice-sheets, and most prominently that of the Fennoscandian ice sheet that 799 accounts for much of the loading within our study region (about 50% at 6 ky cal. B.P., Fig.9 and 800 Fig.10). This advocates for the data-model misfits observed for Brittany, if such misfits are well driven 801 by problems at the level of the architecture and deglaciation histories of the ice-sheets, to be rather 802 linked to FIS than to BIIS. GIA response being non-linear, in must be noted that the separation 803 between ice-sheets would be fully appropriate only neglecting the migration of shorelines. The results 804 of such a separation are only approximations. Yet, uncertainties linked to this phenomenon are likely 805 to be very small, causing changes in the RSL trends of an order of 2x10<sup>-6</sup> mm.yr<sup>-1</sup> (G.Spada, comm. 806 pers.) Finally, the complex trade-of between regional and global signals must be accounted that 807 makes that straightforward relationships between ice-thicknesses and RSL history of distal regions 808 remain hard to establish (Kuchar et al., 2012).

On the basis of such statements, we suggest that the possible origin for the data-model discrepancies are related to some combination of: (i) errors in the regional earth structure in the adopted Earth model, (ii) inaccuracies in the pattern of ESL due to potential issues related to the amplitude, provenance and timing of farfield meltwater contributions and (iii) issues relating to the spatial and temporal pattern of deglaciation of the FIS and LIS and the resultant peripheral bulges.



814

815 Figure 9 - (A), (B) Plots showing the effects of varying the British Irish Ice-Sheet on the RSL predictions 816 from the regional and global GIA models, respectively (refer to the text for further explanation). (C) Plot of 817 the RSL signal induced by the different ice-sheet loadings as predicted by the "BIIS" model, showing the 818 relative responsibility of far-field ice-sheets, BIIS and FIS within the total Holocene RSL signal for the 819 Brittany region. (A) Predictions from the regional models fine-tuned for the British-Isles. "BIIS" and Kuchar 820 models ran with a unique earth model (lithosphere thickness of 71 km, upper- and lower-mantle viscosity of 821 0.3x10<sup>20</sup> and of 2x10<sup>20</sup> Pa.s, respectively). Note that the BIIS in the Kuchar model is 2-3 times than in the "BIIS" 822 model (B) Predictions of the Glac1-b model for BIIS bounding variants (after 9087 full model runs): Inner curves 823 (red and green lines, respectively) do have weakly acceptable European Ice-sheets. Conversely, outer curves 824 (black and blue lines, respectively) show max/min UK fits across the ensemble and do not have acceptable fits to 825 the European constraint data.

With regards to rheological issues, the data-model discrepancies we observe may originate from the fact that most GIA models use radially-varying one dimensional Earth models that assume a spherically symmetric Earth rheology. Yet, such earth models have been shown to be inaccurate (e.g. Spada *et al.*, 2006; Whitehouse *et al.*, 2006) as they disregard lateral variations in the Earth structure. The VM2 and VM5a earth models, which were combined with the ICE-5G and Glac-1b global models were developed on the basis of the fit to RSL data from old-cratons regions of north-American
(Hudson Bay, Canada) and Northern-Europe (Angerman River, Sweden). Hence, these models do not
consider the large-scale variations in the earth structure that were identified at the scale of Western
Europe (Spada *et al.*, 2006; Whitehouse *et al.*, 2006) and also may not be appropriate to use at
locations distant from the reference regions to which they were tuned.



836

837 Figure 10 - Plots of "BIIS" model RSL predictions for a range of (a) varying lithosphere thicknesses, (b) 838 varying upper mantle viscosities and (c) varying lower mantle viscosities. In (a), 120p530, 96p530 and 71p530 are model predictions for lithosphere thicknesses of 120 km, 90 km and 71 km, respectively and fixed 839 upper- and lower-mantle viscosities of 5x10<sup>20</sup> Pa.s and 3x10<sup>22</sup> Pa.s (parameters of the best fit model for the 840 British Isles, Bradley et al., 2011), In (b) 71p0530, 71p130, 71p530, 71130 and 71530 are predictions for fixed 841 842 lithosphere thickness and lower mantle viscosity values of 71 km and 3\*10<sup>22</sup> Pas, and upper-mantle viscosities values of 5x10<sup>19</sup> Pa.s, 1x10<sup>20</sup> Pa.s, 5x10<sup>20</sup> Pa.s, 1x10<sup>21</sup> Pa.s and 5x10<sup>21</sup> Pas, respectively. In (c) 71p51, 71p510, 843 71p530, 71p550 and 71p5100 are predictions for fixed lithosphere thickness and upper- mantle viscosity values of 844 71 km and 5x10<sup>20</sup> Pa.s, and lower-mantle viscosities values of 1x10<sup>21</sup> Pa.s, 1x10<sup>22</sup> Pa.s, 3x10<sup>22</sup> Pa.s, 5x10<sup>22</sup> Pa.s 845 846 and 10x10<sup>22</sup> Pa.s, respectively.

Commentaire [BVVL14]: NEW FIGURE

The best-fit UK regional models ("BIIS" and Kuchar) were also combined with Earth-models that adopt only a spherically symmetric Earth rheology (Bradley *et al.*, 2011, Kuchar *et al.*, 2012). However, these Earth model parameters were fine-tuned to provide adequate regional solutions fitting UK RSL data and UK GPS data. In this context, the very large misfits we observe in Brittany between the data and the UK regional models are even more surprising and we propose three possible explanations.

852 First, regional models were tuned to an older, relatively poorly constrained FIS component (modified 853 from ICE-3G model, see Shennan et al., 2006), which would in turn affect the amplitude and/or 854 position of the European peripheral bulges. Yet, as stated before, FIS would drive most of the RSL 855 signal for the NW Europe sites. Another explanation could be that adopted regional earth model 856 parameters are biased towards the RSL data from the northern rather than southern site (see Fig.7c 857 and Fig.4c in Bradley et al, 2011 and Kuchar 2012). Indeed, these studies showed a clear distinction 858 in the sensitivity of the RSL data to the adopted Earth model parameters between the northern and 859 southern UK RSL data. Finally, an explanation could be related to the lateral heterogeneities in the 860 lithospheric structure and mantle viscosity profile across the English Channel that are not included 861 within the earth models. We made some tests to evaluate the dependency of the data-model misfits to 862 changes in the Earth parameters (Fig.10). Several combinations of lithosphere thicknesses and upper-863 / lower-mantle viscosities were ran within the BRAD15 model. Slight variations in the RSL predictions 864 are with the different lithosphere thicknesses, in accordance with the suggestions of Watts (2001) and 865 Whitehouse et al. (2006). One another hand, our results show RSL predictions from BRAD15 model to be particularly sensitive to changes upper- and lower-mantle viscosities. The best fits with RSL data 866 from Brittany are obtained with low upper- and lower-mantle viscosities of 5x10<sup>19</sup> Pa.s and 1x10<sup>21</sup> 867 Pa.s, respectively. Those viscosities are significantly lower than those of the best-fit model for the 868 869 British Isles (Bradley et al., 2011; Kuchar et al., 2012), thus possibly highlighting for large lateral 870 variations in the Earth structure across the Western termination of the English Channel. Such 871 variations seem supported by seismic tomography studies which find evidence for differences in the 872 lower upper-mantle shear wave velocities between France and south-western UK at 410 and 585 km 873 depths (Legendre et al., 2012; Zhu et al., 2012). Particularly, contrasts in the S-wave speeds of up to 874 4% are observed in the Western and Irish Sea regions, which can be converted into variations in the 875 upper mantle viscosity of up to four orders of magnitude (Wu et al.; 1998) between Cornwall-Devon 876 and Brittany. This evidence supports the theory that significant variations exist in the near-field lateral 877 structure of the shallow earth below the study regions, which are not resolved by the GIA earth
878 models. This said, a caveat must be that such low upper-mantle viscosities values are inconsistent
879 with Angerman river decay time constraints (Nordman *et al.*, 2015) (Can you develop, LEV??).
880 Finally, the presence of a deep relic crustal suture zone (Rheic suture) along the southern coast of
881 England (Legendre *et al.*, 2012) also raises the question of the likelihood for the elastic response of
882 the lithosphere to get mitigated in the vicinity of deep faulted suture zones.

883 Also, As all GIA models considered under-estimate the RSL during the older Holocene (pre 8 kyr 884 cal. BP), this would be consistent with an under-estimation of the ESL resulting from the far-fields ice 885 sheets, such as Antarctic, Iceland, Patagonia and Eastern Siberia / Artic sea during this period (Clark & Tarasov, 2012; Niessen et al., 2013). As originally proposed by Milne and Peros (2013) from 886 887 comparisons with RSL data from circum-Caribbean far-field regions, the fact that the predictions of 888 Bradley's and Kuchar's models fall far below our observational data may imply that the EUST3 global model (part of the BRAD15 model; Bradley, 2011, Bradley et al., submit.) used by these models 889 890 involves too much melting after 8 kyr B.P., in turn causing the "eustatic" component to be over-891 deepened during Mid- to Late-Holocene. However, an increase in the melt from 8 kyr BP was required 892 in the EUST3 model to reduce the over prediction in the height of the Holocene high stand at the UK 893 and Ireland RSL data.

#### 894 Conclusion

895 This new RSL dataset developed for the Finistère region (Western Brittany, France) significantly 896 improves our knowledge of the Holocene RSL history in this region. We observe a general ca. 7-m 897 RSL rise over the last seven thousand years. The six new basal SLIPs, free from possible vertical 898 displacement induced by post-depositional compaction, now enable the extraction of reliable RSL 899 trends for the 8 kyr to 4 kyr B.P. interval. These new SLIPs points more precisely constrain the 900 decrease in the rates of RSL rise during the Mid-Holocene, with inflections centered around 7 kyr, 6 901 kyr and ca. 5-4 kyr cal. B.P. During Late Holocene (post 4 kyr cal. B.P. period), the lack of basal data 902 still precludes the reconstruction of a precise reliable RSL history. This study, for the first time applies 903 paleo-tidal modeling corrections to SLIP reconstructions for data sites from France. The results of our 904 paleo-tidal modelling confirm those previously published by Uheara et al. (2006) and Neill et al. (2010), 905 showing (i) that tidal ranges only underwent slight changes since 8 kyr cal. B.P. (max. 0.7m increase)

**Commentaire [BVVL15]:** NEED SOME HELP HERE TO WRITE SOMETHING SUBTLE AND PRECISE. 906 and (ii) that the relationships between neap, spring and astronomical tidal ranges remained very 907 constant through time.

This revisited Holocene RSL evolution for Western Brittany has significant implications for the understanding of isostatic dynamics along the Atlantic coasts of Western Europe and, particularly, of its glacio-isostatic component, linked to the collapse of the European peripheral bulge south of the British Isles. A large time-dependent vertical offset between the RSL records of the two regions suggests that Southwestern UK experienced a greater subsidence than Western Brittany during the last thousand years. We propose, that this offset probably indicates that Southwestern UK was located closer to the apex of the bulge than Brittany was.

915 At a larger scale, our results challenge the hypotheses that were previously proposed on the 916 amplitude and the extent of the glacio-isostatic peripheral bulge subsidence along the Atlantic coasts 917 of Northwestern Europe. Comparisons of our data with RSL predictions from both global ICE-5G (VM2a) and GLAC1-b (Tarasov & Peltier, 2002; Tarasov et al., 2012; Briggs et al., 2014) and regional 918 919 ("BIIS" model of Bradley et al., 2011, model of Kuchar et al., 2012) GIA models show that none of the 920 models fit our observations satisfactorily. The regional models under-estimate the observed RSLs by 921 several meters and thus probably over-estimate the subsidence that Brittany underwent during the 922 Holocene. This misfit could not be resolved with significant changes to the size and deglaciation 923 histories of the BIIS, suggesting the source of the misfit may be related to (i) errors in the pattern and 924 amounts of meltwater production from the far-field ice sheets, (Antarctic, Iceland, Patagonia and Arctic 925 sea) which are predominately driving the RSL rise across the study region and to (ii) lateral variations 926 in the Earth's structure across the English Channel, especially in the upper-mantle viscosity, which 927 occur over relatively short-scale lateral distances and (iii) potential misfits in the adopted FIS history. 928 More generally, this work highlights the importance for future work to consider the potential role played 929 by such lateral heterogeneities in the RSL signal across this region. Generally, this work again 930 identifies the importance of developing three-dimensional earth models and of further considering the 931 potential roles played by tectonic features in isostatic adjustment dynamics.

Several questions, pertaining to the isostatic dynamics at the scale of Northwestern Europe are still
to be resolved. Providing reliable answers to these questions will allow a better prediction of future
regional RSL variations. Our work emphasizes the need for more new reliable index points along the

coasts of Eastern North Atlantic and of the English Channel, in order to estimate more precisely the relative contribution of the hydro- and glacio-isostatic components of the RSL rise, as well as to better constraint three-dimensional lateral and vertical variations in the Earth structure across the English Channel. Such work is already underway. Furthermore, as such distal regions can be shown to the highly sensitive to changes in the far-field eustatic signal, such new data could provide new information for the rates of ESL rise over the Holocene.

The results of this study insist on the fact that GIA models are still unable to provide a reliable evaluation of the subsidence history for the Brittany region. Yet, recent RSL rise rates are calculated from modern tide-gauge records corrected from land-movements by using GIA predictions. Considering the inconsistence of the GIA prediction with the geological RSL records, it is likely that modern RSL rise rates obtained from Brest tide-gauge record are under-evaluated.

#### 946 Supporting information (Supplementary Online Material)

- 948 Additional supporting information can be found as Supplementary Online Material in the online version
- 949 of this article:

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- 950 S1- Building of the salt-marsh surface sediments geochemical modern referential and application to
- 951 Holocene cores
- 952 S2- Numerical outputs of the paleo tidal modelling at our study sites.
- 953 S3- RSL spatial plots from "BIIS", Glac-1B and ICE-5G (VM2a) GIA model predictions for the 7 ky,
- 954 6ky, 5ky and 4ky B.P periods.

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| Site        | Reference               | Spring      | HAT     | MHWST   | MHWNT   | MTL     | MLWNT   | MLWST   | LAT     |
|-------------|-------------------------|-------------|---------|---------|---------|---------|---------|---------|---------|
| Sile        | tide-gauge(s) location  | Tidal range | (m NGF) |
| Guissény    | Brignogan / Aber Wrac'h | 7.52        | 4.74    | 4.06    | 2.36    | 0.62    | -1.07   | -3.46   | -4.37   |
| Landéda     | Aber Wrac'h             | 7.52        | 4.45    | 3.73    | 2.08    | 0.39    | -1.17   | -3      | -3.95   |
| Porsmilin   | Le Trez-Hir             | 5.55        | 4       | 3.17    | 1.67    | 0.39    | -0.93   | -2.38   | -3.21   |
| Treffiagat  | Le Guilvinec            | 4.2         | 3.16    | 2.66    | 1.56    | 0.50    | -0.44   | -1.54   | -2.38   |
| Kermor-Tudy | Loctudy                 | 4.20        | 3.09    | 2.45    | 1.35    | 0.41    | -0.65   | -1.75   | -2.40   |
| Guidel      | Le Pouldu               | 4.15        | 2.78    | 2.23    | 1.18    | 0.17    | -0.82   | -1.92   | -2.65   |

1241Table 1 - Present-day tidal levels on the studied sites (from SHOM, 2013). Levels are given related to the French ordnance datum (m NGF). HAT (Highest1242Astronomical Tide), MHWST (Mean High Water Spring Tides), MHWNT (Mean High Water Neap Tides), MTL (Mean Tide Level), MLWNT (Mean Low Water1243Neap Tides) MLWST (Mean Low Water Spring Tides), LAT (Lowest Astronomical Tide)

| Source of vertical uncertainties | Amplitude   |
|----------------------------------|---|
| Coring process                   | Hand-auguring : - 0.02m / meter depth<br>Percussion-coring: null<br>Screw-drilling: ± 0.5 m |
| Levelling                        | DGPS measurement : $\pm$ 0.02m<br>Geodetic benchmark accuracy : $\pm$ 0.1 m                 |
| Sampling                         | ± 0.02 m  |
| Tidal levels                     | $\pm 0.05$ m when estimated from distant stations   |

Table 2 - Errors terms used in RSL reconstruction.

| Deposit<br>environment                      | δ <sup>13</sup> C (‰) | TOC (%) | TN (%)     | Pollen                             | Plant macro-remains  | Foraminifera<br>(if present) | Pyrite                                    | Indicative<br>meaning       |
|---|-----------------------|---------|------------|------------------------------------|--|------------------------------|---|-----------------------------|
| Biozone 2                                   | -28 / -26.4           | 1 - 8   | 0.1 - 0.85 | Presence of<br>halophilous species | E.g. Halimione sp.,<br>Triglochin sp.,<br>Limonium vulgare                 | Mid to low<br>marsh species  | Embedded within the<br>sedimentary matrix | (SWLI 179 –<br>SWLI 129) /2 |
| Biozone 3                                   | -28 / - 25.5          | >4.95   | >0.9       | Presence of halophilous species    | E.g. Juncus<br>maritimus, Scirpus<br>maritimus, Halimione<br>portulacoides | high marsh<br>species        | Embedded within the sedimentary matrix    | (SWLI 212 –<br>SWLI 183) /2 |
| Undifferentiatd<br>brackish peat<br>deposit | n/a                   | n/a     | n/a        | Presence of halophilous species    | E.g. Phragmites<br>australis, Juncus<br>roemerianus, Juncus<br>maritimus   | Present                      | Embedded within the sedimentary matrix    | (HAT –<br>MHWNT) /2         |
| Freshwater peat deposit                     | n/a                   | n/a     | n/a        | Absence of<br>halophilous species  | Freshwater reed<br>species   | absent                       | absent                                    | High limiting<br>(> MHWST)  |

**Table 3 – Indicative meanings used to reconstruct RSL from foraminifera poor sedimentary sequences.** Reader is invited to refer to Supplementary

Online Material S1 for further explanations on the building of the modern geochemical reference.

| Index<br>n° | Cara    | 14C Lab        | Age B.P.   | Cal. a BP (2o)          | BP (2σ) Elevati |                              | Desition | $\delta^{13}C$ | тос   | TO<br>N | C/N   | Indicative | Vertical uncertainties (m) |        |          |           |                             |       | RSL (m<br>relative to  | RSL corrected for regional<br>changes in paleo tidal<br>ranges |                      |
|-------------|---------|----------------|------------|-------------------------|-----------------|------------------------------|----------|----------------|-------|---------|-------|------------|----------------------------|--------|----------|-----------|-----------------------------|-------|------------------------|--|----------------------|
|             | Core    | code           | conv.      | min (med. Prob.)<br>max | (m NGF)         | Relative to<br>local<br>HWST | Position | ‰              | %     | % %     |       | (m)        | Indicative range           | Coring | Sampling | Levelling | Distant<br>tidal<br>station | Total | present-day<br>MHWST)) | RSL position<br>(m relative to<br>present-day<br>MHWST)        | Indicative range (m) |
| 1           | GUIS-C2 | UBA-15681      | 431 ± 28   | 527 (500) 338           | 3.2             | -0.8                         | I        | -27.63         | 4.35  | 0.33    | 13.09 | -1.65      | 0.94                       | 0      | 0.02     | 0.12      | 0.05                        | 0.94  | 0.85 ± 0.94            | 0  | 0                    |
| 2           | GL2     | Poz-48807      | 970 ± 30   | 933 (860) 796           | 1               | -1.226                       | I        | -26.40         | 4.74  | 0.36    | 13.30 | -0.99      | 0.56                       | 0.5    | 0.02     | 0.12      | 0.05                        | 0.76  | -0.23 ± 0.76           | -0.04  | 0                    |
| 3           | KIX-1   | SacA-<br>23976 | 2305 ± 30  | 2084 (1964) 1864        | 0.8             | -1.65                        | I        | -19.95         | 1.17  | 0.11    | 11.09 | -0.98      | 0.56                       | 0.5    | 0.02     | 0.12      | 0                           | 0.76  | -0.67 ± 0.76           | -0.07  | 0                    |
| 4           | KIX-3   | SacA-<br>23978 | 2875 ± 30  | 2774 (2703) 2565        | -1.4            | -3.85                        | I        | -22.40         | 3.03  | 0.28    | 10.70 | -0.98      | 0.56                       | 0.5    | 0.02     | 0.12      | 0                           | 0.76  | -2.87±0.76 (*)         | n/d  | n/d                  |
| 5           | GUIS-C2 | UBA-15685      | 2 666 ± 25 | 2844 (2770) 2746        | 0.05            | -3.63                        | I        | -27.76         | 2.35  | 0.18    | 12.86 | -1.65      | 0.94                       | 0      | 0.02     | 0.12      | 0.05                        | 0.95  | -1.98 ± 0.94           | -0.20  | 0.02                 |
| 6           | KX1     | Poz-42852      | 3425 ± 35  | 3825 (3676) 3581        | -1              | -3.45                        | I        | -20.82         | 5.60  | 0.46    | 12.27 | -0.98      | 0.56                       | 0.5    | 0.02     | 0.12      | 0                           | 0.76  | -2.47 ± 0.76           | -0.12  | 0                    |
| 7           | GUIS-C2 | Poz-49796      | 4165+/-35  | 4830 (4709) 4580        | -0.8            | -4.48                        | I        | -28.01         | 36.92 | 1.50    | 24.60 | -0.07      | 0.48                       | 0      | 0.02     | 0.12      | 0.05                        | 0.50  | -4.41 ± 0.50           | -0.19  | 0.02                 |
| 8           | TREF    | Poz-45390      | 4340 ± 40  | 5035 (4913) 4839        | -0.95           | -3.61                        | BB       | -25.27         | 5.56  | 0.44    | 12.66 | -1.035     | 0.59                       | 0.09   | 0.02     | 0.12      | 0.05                        | 0.61  | -2.58 ± 0.61           | -0.28  | 0.01                 |
| 9           | GL1     | Poz-49806      | 4395 ± 35  | 5212 (4957) 4859        | -2              | -4.226                       | I        | -25.24         | 0.20  | 0.02    | 10.24 | -0.99      | 0.56                       | 0.5    | 0.02     | 0.12      | 0.05                        | 0.76  | -3.23 ± 0.76           | -0.26  | 0.04                 |
| 10          | KX-3    | Poz-36731      | 4530 ± 30  | 5309 (5156) 5053        | -2.2            | -4.65                        | I        | -23.67         | 12.15 | 0.64    | 19.02 | -0.98      | 0.56                       | 0.5    | 0.02     | 0.12      | 0                           | 0.76  | -3.67±0.61             | -0.17  | 0                    |
| 11          | GUIS-C2 | Poz-49798      | 4530+/-35  | 5311 (5159) 5050        | -0.95           | -4.63                        | I        | -27.90         | 16.89 | 1.04    | 16.22 | -0.07      | 0.48                       | 0      | 0.02     | 0.12      | 0.05                        | 0.50  | -4.56 ± 0.5            | -0.20  | 0.02                 |
| 12          | KX-2    | Poz-42853      | 4480 ± 35  | 5292 (5167) 4978        | -1.8            | -4.25                        | I        | -22.07         | 3.60  | 0.32    | 11.38 | -0.98      | 0.56                       | 0.5    | 0.02     | 0.12      | 0                           | 0.76  | -3.27± 0.61            | -0.17  | 0                    |
| 13          | KX-4    | Poz-42854      | 4800 ± 40  | 5606 (5520) 5334        | -2.49           | -4.94                        | I        | -26.62         | 23.51 | 1.21    | 19.51 | -0.04      | 0.3                        | 0.5    | 0.02     | 0.12      | 0                           | 0.60  | -4.9 ± 0.60            | -0.19  | 0                    |
| 14          | PM1     | Poz-42858      | 5000 ± 35  | 5891 (5728) 5645        | -1.5            | -4.67                        | I        | -28.61         | 23.92 | 1.26    | 19.00 | -0.1       | 0.4                        | 0      | 0.02     | 0.12      | 0.05                        | 0.42  | -4.57 ± 0.42           | 0.09   | 0                    |
| 15          | KIX-4   | Poz-42850      | 5215 ± 35  | 6129 (5965) 5908        | -1.8            | -4.25                        | BB       | -21.96         | 0.28  | 0.04    | 8.07  | -0.98      | 0.56                       | 0.5    | 0.02     | 0.12      | 0                           | 0.76  | -3.27±0.76             | -0.21  | 0                    |
| 16          | PM1     | Poz-42860      | 5365 ± 35  | 6277 (6170) 6006        | -2.27           | -5.44                        | I        | -28.00         | 13.56 | 0.65    | 20.82 | -1.3       | 0.76                       | 0      | 0.02     | 0.12      | 0.05                        | 0.77  | -4.1 ± 0.77            | 0.10   | -0.01                |
| 17          | GUIS-C2 | UBA-15686      | 5 563 ± 31 | 6403 (6351) 6299        | -1.52           | -5.2                         | BB       | -27.52         | 9.66  | 0.64    | 15.13 | -0.07      | 0.48                       | 0      | 0.02     | 0.12      | 0.05                        | 0.50  | -5.13 ± 0.5            | -0.13  | 0.02                 |
| 18          | GL2     | Poz-48773      | 5910 ± 40  | 6846 (6730) 6651        | -5.59           | -7.816                       | I        | -24.59         | 1.16  | 0.10    | 11.25 | -0.99      | 0.56                       | 0.5    | 0.02     | 0.12      | 0.05                        | 0.76  | -6.81 ± 0.76           | -0.13  | 0                    |
| 19          | KIX-5   | Poz-42851      | 5990 ± 40  | 6939 (6829) 6736        | -4.6            | -7.05                        | в        | -22.31         | 3.22  | 0.21    | 15.51 | -0.98      | 0.56                       | 0.5    | 0.02     | 0.12      | 0                           | 0.76  | -6.07 ± 0.76           | n/a  | n/a                  |
| 20          | TAR-S2  | UBA-15458      | 6 001 ± 28 | 6927 (6845) 6750        | -3.6            | -7.38                        | BB       | -26.9          | -     | -       | -     | -0.44      | 1.21                       | 0.06   | 0.02     | 0.12      | 0.05                        | 1.22  | -6.95 ± 1.22           | 0.13   | 0.03                 |
| 21          | PM1     | Poz-42861      | 6150 ± 40  | 7164 (7060) 6943        | -3.3            | -6.47                        | BB / HL  | -              | -     | -       | -     | -          | -                          |        | -        | -         | -                           | -     | < - 6.47               | n/a  | n/a                  |
| 22          | GUIS-S2 | UBA-15460      | 6 033 ± 29 | 6951 (6880) 6791        | -3.5            | -7.18                        | BB       | -              | -     | -       | -     | -0.44      | 1.21                       | 0.02   | 0.02     | 0.12      | 0.05                        | 1.22  | -6.74 ± 1.22           | 0.13   | 0.03                 |
| 23          | GL1     | Poz-47039      | 6650 ± 40  | 7587 (7530) 7444        | -8              | -10.226                      | в        | -26.38         | 15.51 | 0.77    | 20.08 | -0.04      | 0.30                       | 0.5    | 0.02     | 0.12      | 0.05                        | 0.60  | -10.18 ± 0.60          | -0.04  | 0                    |
| 24          | GL2     | Poz-49808      | 7090 ± 40  | 7996 (7923) 7840        | -8.39           | -10.616                      | В        | -24.84         | 1.40  | 0.13    | 10.61 | -0.98      | 0.56                       | 0.5    | 0.02     | 0.12      | 0.05                        | 0.76  | -9.63±0.76             | 0.05   | 0                    |

1250Table 4 - Details of the new Holocene RSL data obtained in this study. (\*) indicates rejected dates (see text). The last two columns on the right show the1251correction applied to raw RSL data for changes in paleo tidal ranges. "I" stands for "intercalated" deposits" (uncorrected for compaction), "B" for "basal"1252deposits and "BB" for "base-of-basal" deposits, "HL" stands for "High Limiting" indexes.

| Index<br>n° | Location     | Core  | 14C Lab<br>code | Age B.P.<br>conv. | Cal. a BP (2ơ)       | Position | Туре | RSL (m relative to present-day | Source  | Correction for<br>regional changes in<br>paleo tidal ranges<br>(This study) |
|-------------|--------------|-------|-----------------|-------------------|----------------------|----------|------|--------------------------------|---|---|
|             |              |       |                 |                   | min (med. Prob.) max |          |      | WHW31))                        |   | (m)   |
| 25          | Bay of Brest | P-C2  | Erl-10678       | 3500±60           | 3957 (3773) 3615     | Ι        | SLIP | $-3.49 \pm 0.67$               | Stéphan et al. (2014)                                   | 0.17  |
| 26          | Bay of Brest | P-C2  | Erl-10679       | 4280±60           | 5036 (4852) 4625     | I        | SLIP | -4.17 ± 0.67                   | Stéphan et al. (2014)                                   | 0.21  |
| 27          | Bay of Brest | P-C2  | Erl-10680       | 4640±60           | 5581 (5394) 5071     | I        | SLIP | $-5.32 \pm 0.67$               | Stéphan et al. (2014)                                   | 0.21  |
| 28          | Bay of Brest | T-C2  | Erl-10682       | 940±56            | 952 (850) 734        | Т        | SLIP | -0.48 ± 0.67                   | Stéphan et al. (2014)                                   | 0.04  |
| 29          | Bay of Brest | T-C2  | Erl-10683       | 3690±70           | 4235 (4031) 3843     | I        | SLIP | -3.35 ± 0.67                   | Stéphan et al. (2014)                                   | 0.17  |
| 30          | Bay of Brest | T-C2  | Erl-10686       | 5450±70           | 6399 (6242) 6015     | I        | SLIP | -5.32 ± 0.67                   | Stéphan et al. (2014)                                   | 0.25  |
| 31          | Bay of Brest | A-C10 | Erl-11753       | 1081±56           | 1174 (999) 916       | I        | SLIP | -0.61 ± 0.67                   | Stéphan et al. (2014)                                   | 0.04  |
| 32          | Bay of Brest | A-C14 | Erl-11749       | 436±55            | 546 (483) 316        | I        | SLIP | $-0.30 \pm 0.67$               | Stéphan et al. (2014)                                   | 0.02  |
| 33          | Bay of Brest | A-C14 | Erl-11750       | 1686±56           | 1720 (1597) 1415     | I        | SLIP | -0.97 ± 0.67                   | Stéphan et al. (2014)                                   | 0.06  |
| 34          | Bay of Brest | A-C14 | Erl-11751       | 2340±54           | 2691 (2372) 2159     | I        | SLIP | -2.26 ± 0.67 (*)               | Stéphan et al. (2014)                                   | 0.08  |
| 35          | Bay of Brest | A-C14 | Erl-11752       | 2716±55           | 2941 (2822) 2748     | В        | SLIP | -2.96 ± 0.67 (*)               | Stéphan et al. (2014)                                   | 0.13  |
| 36          | Tresseny     | G-C2  | UBA 15681       | 431±28            | 527 (500) 338        | I        | SLIP | -0.28 ± 0.55                   | Stéphan et al. (2014)                                   | -0.02   |
| 37          | Tresseny     | G-C3  | UBA 15459       | 4054±32           | 4785 (4530) 4426     | В        | SLIP | -3.75 ±1.35                    | Stéphan et al. (2014)                                   | -0.09   |
| 38          | Trezien      | /     | GIF-714         | 3660 ±<br>115     | 4385(3994) 3648      | BB / HL  | SLIP | <2 ± 0,55                      | Goslin <i>et al.</i> (2013)<br>Morzadec-Kerfourn (1974) | n/a   |
| 39          | Arg Gwen.    | /     | GIF-816         | 3970 ± 35         | 4525 (4453) 4297     | BB       | HL   | -3,61 ± 1,75                   | Goslin <i>et al.</i> (2013)<br>Morzadec-Kerfourn (1974  | n/a   |
| 40          | PlouPors.    | /     | GIF-711         | 4120 ±<br>140     | 5031 (4605) 4184     | BB       | SLIP | < -1,86 ± 0,55                 | Goslin <i>et al.</i> (2013)<br>Morzadec-Kerfourn (1974  | n/a   |

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**Table 5 - Holocene RSL data from previous studies** (Morzadec-Kerfourn, 1974; Goslin *et al.*, 2013; Stéphan *et al.*, 2014) incorporated to our dataset. (\*) indicates rejected dates (see text). The last column on the right show the correction applied to raw RSL data for changes in regional paleo tidal ranges. "I" stands for "intercalated" deposits" (uncorrected for compaction), "B" for "basal" deposits and "BB" for "base-of-basal" deposits, "HL" stands for "High Limiting" indexes.

|                         |           |       |           |         |           |         |           |       |             |         |           |       | _ |
|-------------------------|-----------|-------|-----------|---------|-----------|---------|-----------|-------|-------------|---------|-----------|-------|---|
| Sita                    | Guiss     | ény   | Porsmilin |         | Bay of    | Brest   | Treffi    | agat  | Kermor-Tudy |         | Guidel    |       |   |
| Time                    | Range (m) | %     | Range (m) | %       | Range (m) | %       | Range (m) | %     | Range (m)   | %       | Range (m) | %     |   |
| NEAP TIDAL RANGES       | <b>`</b>  |       |           |         |           |         |           |       |             |         |           |       | - |
| 0 (control)             | 3,50      | 100   | 2,6       | 100,0   | 2,79      | 100,0   | 2         | 100   | 2           | 100     | 2         | 100   | • |
| 1 Ky B.P                | 3,50      | 100   | 2,59      | 99,6    | 2,74      | 98,2    | 2         | 100   | 2           | 100     | 2         | 100   |   |
| 2 Ky B.P                | 3,50      | 100   | 2,57      | 98,8    | 2,69      | 96,4    | 2         | 100   | 2           | 100     | 2,01      | 100,5 |   |
| 3 Ky B.P                | 3,50      | 100   | 2,56      | 98,5    | 2,64      | 94,6    | 2,01      | 100,5 | 2           | 100     | 2,01      | 100,5 |   |
| 4 Ky B.P                | 3,50      | 100   | 2,55      | 98,1    | 2,6       | 93,2    | 2,01      | 100,5 | 1,99        | 99,5    | 2,01      | 100,5 |   |
| 5 Ky B.P                | 3,50      | 100   | 2,53      | 97,3    | 2,55      | 91,4    | 2,01      | 100,5 | 1,99        | 99,5    | 2,02      | 101   |   |
| 6 Ky B.P                | 3,50      | 100   | 2,52      | 96,9    | 2,5       | 89,6    | 2,01      | 100,5 | 1,99        | 99,5    | 2,02      | 101   |   |
| 7 Ky B.P                | 3,16      | 90,3  | no data   | no data | no data   | no data | 1,77      | 88,36 | no data     | no data | 1,78      | 89    |   |
| 8 Ky B.P                | 2,82      | 80,6  | no data   | no data | no data   | no data | 1,52      | 76,02 | no data     | no data | 1,54      | 77    |   |
| SPRING TIDAL RANGES     |           |       |           |         |           |         |           |       |             |         |           |       | • |
| 0 (control)             | 6,97      | 100   | 5,55      | 100     | 5,9       | 100     | 4,15      | 100   | 4,2         | 100     | 4,15      | 100   |   |
| 1 Ky B.P                | 7,01      | 100,6 | 5,53      | 99,6    | 5,82      | 98,6    | 4,2       | 101,2 | 4,23        | 100,7   | 4,2       | 101,2 |   |
| 2 Ky B.P                | 7,05      | 101,1 | 5,52      | 99,5    | 5,74      | 97,3    | 4,24      | 102,2 | 4,27        | 101,7   | 4,26      | 102,7 |   |
| 3 Ky B.P                | 7,09      | 101,7 | 5,5       | 99,1    | 5,65      | 95,8    | 4,29      | 103,4 | 4,3         | 102,4   | 4,31      | 103,9 |   |
| 4 Ky B.P                | 7,13      | 102,3 | 5,48      | 98,7    | 5,57      | 94,4    | 4,34      | 104,6 | 4,34        | 103,3   | 4,36      | 105,1 |   |
| 5 Ky B.P                | 7,17      | 102,9 | 5,46      | 98,4    | 5,49      | 93,1    | 4,39      | 105,8 | 4,37        | 104,0   | 4,41      | 106,3 |   |
| 6 Ky B.P                | 7,21      | 103,4 | 5,45      | 98,2    | 5,41      | 91,7    | 4,43      | 106,7 | 4,41        | 105,0   | 4,47      | 107,7 |   |
| 7 Ky B.P                | 6,84      | 98,1  | no data   | no data | no data   | no data | 4,22      | 101,7 | no data     | no data | 4,28      | 103,1 |   |
| 8 Ky B.P                | 6,48      | 93,0  | no data   | no data | no data   | no data | 4,01      | 96,6  | no data     | no data | 4,1       | 98,8  |   |
| MAX ANNUAL TIDAL RANGES |           |       |           |         |           |         |           |       |             |         |           |       |   |
| 0 (control)             | 8,73      | 100   | 7,2       | 100     | 7,68      | 100     | 5,54      | 100   | 5,49        | 100     | 5,43      | 100,0 |   |
| 1 Ky B.P                | 8,73      | 100   | 7,19      | 99,9    | 7,63      | 99,3    | 5,54      | 100   | 5,49        | 100     | 5,43      | 100,0 |   |
| 2 Ky B.P                | 8,64      | 98,9  | 7,17      | 99,6    | 7,58      | 98,7    | 5,54      | 100   | 5,49        | 100     | 5,44      | 100,2 |   |
| 3 Ky B.P                | 8,54      | 97,8  | 7,16      | 99,4    | 7,53      | 98,0    | 5,55      | 100,2 | 5,49        | 100     | 5,44      | 100,2 |   |
| 4 Ky B.P                | 8,45      | 96,7  | 7,15      | 99,3    | 7,49      | 97,5    | 5,55      | 100,2 | 5,48        | 99,82   | 5,44      | 100,2 |   |
| 5 Ky B.P                | 8,35      | 95,6  | 7,13      | 99,0    | 7,44      | 96,9    | 5,55      | 100,2 | 5,48        | 99,82   | 5,45      | 100,4 |   |
| 6 Ky B.P                | 8,26      | 94,6  | 6,57      | 91,3    | 6,53      | 85,0    | 5,43      | 98,0  | 5,41        | 98,54   | 5,49      | 101,1 |   |
| 7 Ky B.P                | 8,16      | 93,5  | no data   | no data | no data   | no data | 5,22      | 94,2  | no data     | no data | 5,31      | 97,8  |   |
| 8 Ky B.P                | 7,77      | 89,0  | no data   | no data | no data   | no data | 5,01      | 90,4  | no data     | no data | 5,13      | 94,5  |   |

Supplementary Online Material 2 (Appendix S2): Numerical outputs of the paleo tidal modelling at our study sites.