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## Oceanic versus continental influences over the last 7 kyrs from a mid-shelf record in the northern Bay of Biscay (NE Atlantic)

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1 **Oceanic versus continental influences over the last 7 kyrs from a mid-shelf**  
2 **record in the northern Bay of Biscay (NE Atlantic)**

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27

## 28 **Abstract**

29 We discuss paleoenvironments of north-western France over the last 7 kyrs in terms of: i)  
30 long-term changes (relative sea-level rise and boreal summer insolation), ii) rapid climate  
31 changes (millennial-scale Bond events and multi-decadal regimes of the North Atlantic  
32 Oscillation: NAO) and iii) growing human impacts in watersheds. Our study focuses on the  
33 CBT-CS11 core, retrieved in the northern Bay of Biscay, with new high-resolution (70 years)  
34 palynological data (dinoflagellate cysts and pollen), combined with sedimentological and  
35 oxygen stable isotopic records. This multiproxy approach enabled us to gain a better  
36 understanding of the influence of varying Middle to Late Holocene climate regimes on  
37 marine, coastal and terrestrial ecosystems as well as on human coastal societies. We  
38 especially show that the slowdown of the relative sea-level rise, starting at around 5.9 ka BP,  
39 led to the stabilization of tidal flats in estuarine environments. Subsequently, increasing river  
40 flows to the ocean resulted in a progressive seasonal stratification of the shelf under  
41 increasing winter precipitations and establishment of the modern winter thermohaline front at  
42 3.3 ka BP. In addition, within the 4–2 ka BP interval, palynological and sedimentological  
43 evidence suggests increasing river discharges in north-western France, in a context of a  
44 weakened Atlantic subpolar gyre and recurrent negative “NAO-like” conditions. Finally, we  
45 identified a major transition at around 1.2 ka BP (Early Middle-Ages) that appears to be  
46 linked to a period of maximal anthropogenic landscape opening and soil erosion, implying  
47 stronger primary productivity in coastal surface waters of the studied region.

48

49 *Keywords: Holocene; Vegetation dynamics; Stable isotopes; Atlantic subpolar gyre; Rapid*  
50 *climate changes; Precipitation regimes; Winter horizontal thermohaline front.*

51

52

## 53 1. Introduction

54 **Paleoenvironmental studies of the Holocene (i.e., the last 11.7 kyrs) raise questions about**  
55 **environmental changes under mixed natural and anthropogenic forcings.** However, in marine  
56 sediment archives, it **is difficult** to discriminate signals induced by natural modes of climate  
57 variability, integrating the complexity of atmosphere-ocean-biosphere-cryosphere-lithosphere  
58 interactions, from those produced by anthropogenic activities and their impacts on the  
59 surrounding watersheds. Studying Holocene sediment archives often requires interdisciplinary  
60 **studies (e.g., combining** geology, geography, geochemistry, paleoecology, archaeology) **to**  
61 unambiguously disentangle natural and human **signatures** of environmental changes recorded  
62 in sediments.

63 Over the long-term decrease in summer insolation at boreal latitudes that started **around 9**  
64 **kyrs ago** (Berger and Loutre, 1991), high-resolution Holocene studies mainly addressed the  
65 question of millennial time scale climate shifts (abrupt cooling events in the North Atlantic:  
66 Bond et al., 1997, 2001, also referred to as Rapid Climate Changes with a more global-scale  
67 perspective including cool poles and dry tropics: e.g., Mayewski et al., 2004). Previous  
68 **studies** suggested the existence of solar-induced cycles of 2,500 years throughout the  
69 Holocene (e.g., Debret et al., 2009). Superimposed on the latter, a 1,500-year (e.g., Bond et  
70 al., 1997, 2001; Debret et al., 2007, 2009; Wanner et al., 2008; Thornalley et al., 2009; Sorrel  
71 et al., 2012) or 1,250-year (Mojtahid et al., 2019) mode of periodicity was identified **as having**  
72 existed over the Middle to Late Holocene and attributed to internal forcings. Uncertainties  
73 nonetheless subsist **concerning** the main drivers of these latter modes and their different  
74 impacts according to the investigated area (e.g., Mayewski et al., 2004; Eynaud et al., 2018).

75 Another concern is the impact of human activities on landscapes (deforestation and land use  
76 for cultures, pastoralism, **living areas and** access to terrestrial and/or marine resources;  
77 Ruddiman et al., 2016) and, by **extension**, on near-continent sea-surface water characteristics  
78 **(e.g., sediment supply or** coastal biodiversity) that **have** increased over the last thousand years  
79 and more intensively for 4 **kyrs** in western France (e.g., Gaudin, 2004; David, 2014).  
80 However, producing representative records of local anthropogenic influences can be  
81 challenging depending upon where the sedimentary archive is retrieved. **For instance, local-**  
82 **scale or regional-scale paleo-reconstructions depend on the proximal or distal position of the**  
83 **sediment cores. Furthermore, the anthropogenic signal is less transmitted to offshore depths**  
84 **(hemipelagic sediments) than to proximal sedimentary sinks (e.g., continental lakes, coastal**  
85 **environments or estuarine bays).** Yet, as recently shown by the studies of Lambert et al.

86 (2017) and Ganne et al. (2016) on modern sediments from the Bay of Brest and Loire estuary  
87 (western France), respectively, anthropogenic pollen signals (*Cerealia* around 1%) suffer  
88 from an over-representation of arboreal pollen grains relative to the actual vegetation cover on  
89 the watersheds. Along the **western** European margin, it is therefore critical to select archives  
90 mitigating the proximity of continental sources with non-biased sedimentary records. **To that**  
91 **end**, the northern **shelf** of the Bay of Biscay (around 100 m water depth), located in a  
92 transitional domain, appears ideal for investigating Holocene rapid **and long-term**  
93 paleoenvironmental changes with a **combined** land-sea approach (Naughton et al., 2007;  
94 Mojtahid et al., 2019).

95 In this study, we investigate **the** CBT-CS11 **core**, retrieved in the northern part of the **Bay of**  
96 **Biscay (BoBy; northern part** of the *Grande Vasière* mid-shelf sediment patch). Mojtahid et al.  
97 (2019) recently **published their results on** benthic foraminiferal content, benthic oxygen and  
98 carbon stable isotopes on **epibenthic species** *Cibicides refulgens*, grain-size analyses and XRF  
99 data. **Their** stable oxygen isotope **measurements** on *C. refulgens* showed a significant shift  
100 around 3.5–2.5 ka BP, **which they** interpreted as resulting from the onset of the modern winter  
101 thermohaline front. Here, we present new **and complementary** high-resolution records of  
102 dinoflagellate cyst data, pollen assemblages and benthic foraminiferal stable isotopic data on  
103 *Ammonia falsobeccarii*. By **combining** our dataset with previously published geochemical and  
104 sedimentological data from the CBT-CS11 core, and other sediment archives from the BoBy  
105 and North Atlantic basin, our Holocene study aims to: i) document the hydrographical  
106 changes on the BoBy shelf **together with vegetation changes** in north-western France  
107 watersheds, and ii) **place** those changes in the complex paleoceanographic and paleoclimatic  
108 context of the North Atlantic basin. This **approach allows** us to suggest synoptic mechanisms  
109 explaining the main drivers for precipitation and flood regimes over the last 7 **kyrs** in the  
110 studied region. Ultimately, our results will help the archaeological community integrate  
111 climate forcings **into** the framework of settlements and withdrawals **from** ancient coastal sites  
112 in the region since the Neolithic period.

113

## 114 **2. Environmental context of the Bay of Biscay**

### 115 ***2.1. The hydrographic pattern***

116 The Bay of Biscay (BoBy) is an open oceanic basin in the north-eastern Atlantic Ocean,  
117 fringed by the Spanish and French coasts (Figure 1). **Today, seasonal** atmospheric dynamics  
118 (Isemerand Hasse, 1985; Pingree and Le Cann, 1989) and **high** river discharges (e.g., Lazure  
119 and Jégou, 1998; Lazure et al., 2008; Ferrer et al., 2009) **lead to** a complex system of coastal  
120 currents where residual shelf currents mainly depend on wind driven, tidally induced and  
121 density driven flows (e.g., Vincent and Kurc, 1969; Pingree and Le Cann, 1989;  
122 Koutsikopoulos and Le Cann, 1996; Castaing et al., 1999).

123 More precisely, the circulation of the BoBy shelf can be schematized as follows (Charria et  
124 al., 2013; Figure 1b): in winter (October to March), a SW-dominant wind regime forces a SE  
125 to NW shelf current (with more intense currents from October to December) while, in  
126 summer (April to September), dominant winds from the NW sector force a NW to SE shelf  
127 current (with **greater** shelf currents from July to September). From mid-autumn to early spring  
128 (thus including winter as a whole), intense river flows associated with sustained wind activity  
129 maintain this region under the influence of the northward plumes of the Gironde and Loire  
130 rivers along the coast, with relatively low salinities between the coast and the 100 m isobath,  
131 at around 20–40 km from the coast. Freshwater discharges from the main rivers (Loire,  
132 Gironde, Vilaine **and** Adour; annual mean flow around 4,200 m<sup>3</sup>/s) in surface layers thus  
133 induce **steep** density gradients driving a poleward circulation (about 10 cm/s) modulated by  
134 wind forcing (Lazure and Jégou, 1998; Lazure et al., 2008).

135 An along-slope seasonal current, occurring between the autumn and winter, is also  
136 characterized by cyclonic circulation (Pingree and Le Cann, 1989) and an intensified  
137 poleward surface flow (Iberian Poleward Current, IPC; Figure 1b). This warm and saline  
138 current (Frouin et al., 1990; Pingree and Le Cann, 1992a,b; Solabarrieta et al., 2014) can  
139 extend up to **the Armorican** upper slopes (**western France**; Le Cann and Serpette, 2009;  
140 Garcia-Soto and Pingree, 2012).

141

142

## 143 **2.2. Precipitation, river discharges, winter thermohaline front**

144 The coastal environments of north-western Europe are connected to the main Atlantic  
145 atmospheric regimes (e.g., North Atlantic Oscillation, NAO; East Atlantic pattern, EA). In  
146 Brittany, these weather regimes and North Atlantic Sea Surface Temperatures (SSTs), are the  
147 main mechanisms that drive the oceanic-rainfall regime, i.e., precipitation patterns and related  
148 river discharges (Tréguer et al., 2014), as well as storminess (van Vliet-Lanoë et al., 2014).

149 During positive NAO modes, northern Europe **generally has** milder and wetter conditions and  
150 has the opposite during negative modes (Hurrell, 1995; Hurrell et al., 2003). Present-day  
151 environmental conditions in northern Europe (i.e., continental climate, as well as sea-surface  
152 temperature and salinity changes) are thus strongly impacted by the NAO and associated  
153 changes in seasonal precipitation and fluvial discharge regimes (Castaing et al., 1999; Charria  
154 et al., 2013; Le Boyer et al., 2013; Tréguer et al., 2014). At the Holocene scale, previous  
155 studies **have** discussed the possible role of the “NAO-like” pattern in westerly storm activity  
156 within the north-eastern Atlantic **area** (van Vliet et al., 2014; Goslin et al., 2018, 2019; Pouzet  
157 et al., 2018) as well as in sea-surface and bottom hydrological conditions in the northern  
158 (Zumaque et al., 2017; Durand et al., 2018; Mojtahid et al., 2019) and southern BoBy (Garcia  
159 et al., 2013; Mojtahid et al., 2013; Mary et al., 2017).

160 Modelling work suggested that, in winter, the Loire estuarine plume completely covers the  
161 Armorican shelf in the BoBy (Lazure and Jégou, 1998). **Maximum** (/minimum) values of  
162 river flows are greater than 1,500 m<sup>3</sup>/s during winter-early spring (<300 m<sup>3</sup>/s during summer)  
163 (hydro.eaufrance.fr; Castaing and Allen, 1981). The confluence of marine and fluvial water  
164 bodies (turbid plumes; Jouanneau et al., 1999; Lazure and Jégou, 1998), then induces a winter  
165 thermohaline front **that** vertically separates bottom oceanic waters from surface freshwaters  
166 (Castaing et al., 1999; Yelekci et al., 2017), and takes over with increasing summer  
167 temperatures (Puillat et al., 2004). Consequently, a freshwater front also forms horizontally  
168 along the 100 m isobaths in the BoBy (dotted line in Figure 1b), which **will hereafter be**  
169 **referred to as the** “winter horizontal thermohaline front”.

170

171

### 172 **2.3. The “Grande Vasière” deposit**

173 The winter horizontal thermohaline front limits the offshore diffusion of continental  
174 sediments, inducing the concentration of **fine** fluvial sediments within a massive mud patch  
175 (225 km by 40 km long, ~100 m deep; Figure 1b) referred to as the *Grande Vasière* (GV;  
176 Dubrulle et al., 2007). The GV designates the upper part of the Holocene sediment  
177 accumulation that built up at a rate of 0.1 to 0.2 cm/year (Lesueur et al., 2001) from the  
178 sedimentary infilling of the Tertiary substratum during the last marine transgression (Bourillet  
179 et al., 2006). Today, the GV deposit represents a seasonal compromise between a winter  
180 period of sediment advection fed by fluvial supply, and a period of higher sediment settling  
181 under weakened remobilization through wave actions (storminess and distant swell) between  
182 April and September (Dubrulle et al., 2007).

183 Sediment grain size is **spatially** heterogeneous over the GV, with finer sediments brought **in**  
184 by fluvial turbid plumes (Jouanneau et al., 1999; Dubrulle et al., 2007). The Loire **River**  
185 represents the second largest fluvial **input volume** after the Gironde ( $0.5\text{--}0.6 \cdot 10^6$  t/yr) and  
186 contributes about 24% of the solid sediment charge **entering** the whole BoBy (Jouanneau et  
187 al., 1999). **In** the northern part of the bay, **the** Loire and Vilaine Rivers together represent 95%  
188 of **the** BoBy watersheds. Up to 90% of the nutrient contribution in the northern part of the  
189 Armorican shelf **comes from** the Loire **River**, Vilaine River and southern Brittany coastal  
190 river discharges **making** smaller secondary contributions (Guillaud et al., 2008).

191



## 192 **3. Material and methods**

### 193 **3.1. CBT-CS11 study core and benthic foraminiferal analyses**

194 The CBT-CS11 core (47°46.429'N; 4°25.308'W; 73m depth; 3.96 m long; Figure 1) was  
195 retrieved using a Calypso-Genavir corer during the CABTEX cruise (Ifremer) of the R/V  
196 *Pourquoi Pas?* in June 2010 (Dussud, 2010). The lithological log of the core, CaCO<sub>3</sub>-free  
197 grain-size analyses and XRF data (1 cm resolution) are fully described in Mojtahid et al.  
198 (2019), allowing the precise characterization of the deposits through time. Benthic  
199 foraminiferal assemblages have also been published in Mojtahid et al. (2019), with stable  
200 oxygen and carbon isotopes measured on the epibenthic species *Cibicides refulgens*, which  
201 was hand-picked from the 150–250 µm fraction (113 analyses, PSO, Plouzané, Table 2). In  
202 this study, we present a new isotopic dataset based on 101 analyses (~3–4 cm spacing; ~74 yr  
203 resolution) of *Ammonia falsobeccarii*, also hand-picked in the 150–250 µm and analysed at  
204 the PSO (Table 2). The external reproducibility (1σ) on repeated measurements of NBS19  
205 international standard is ±0.04‰ and 0.09‰ for δ<sup>13</sup>C and δ<sup>18</sup>O, respectively.  
206

### 207 **3.2. Palynological analyses**

208 A total of 114 samples (mean spacing of 3 cm between each) allowed us to reconstruct  
209 palynological assemblages with an optimal minimum (mean) resolution of 20 years (70  
210 years). The same palynological procedure was applied for dinocyst and pollen extraction so as  
211 to allow direct comparison between terrestrial (pollen, spores and freshwater microalgae) and  
212 marine (dinocysts, other marine microalgae and foraminiferal linings) microfossils on the  
213 same palynological slide, thus avoiding chrono-stratigraphical issues. Palynological  
214 treatments (EPOC laboratory, Bordeaux University) were conducted on the < 150 µm fraction  
215 following the protocol of de Vernal et al. (1999) (Data in Brief).

216 A minimum of 300 dinocysts and 200 pollen grains were counted per level. In case of over-  
217 representation of a taxon (here *Lingulodinium machaerophorum* for dinocyst assemblages),  
218 counts were prolonged until at least 100 other specimens were found, keeping in mind that the  
219 threshold of 100 individuals is required to identify 99% of major species (> 5%) (Fatela and  
220 Taborda, 2002). Palynomorph percentages (%) and concentrations (taxa/cm<sup>3</sup>) were then  
221 calculated (Table 2). Palynological taxonomical diversity was quantified by statistical  
222 analyses using the “Past version 1.75b” program (Hammer et al., 2001; indexes explained in  
223 Harper, 1999) (Table 2). In this study, we also established palynological ratios used for the

224 discussion of the main results (briefly detailed in Table 2) based on statistical analyses and  
225 described in **Data in Brief**.  
226

### 227 **3.3. Radiocarbon dates**

228 **By adding four more** AMS-<sup>14</sup>C dates (**three** on lamellibranches and **one** on *Turritella*  
229 *communis*) to **those from** the study of Mojtahid et al. (2019), **we were able to build** a robust  
230 chrono-stratigraphy based on 25 dates; six dates being excluded from the final age model  
231 (Table 1, Figure 2a). All dates were calibrated (Table 1) with Calib 7.1 software, using the  
232 calibration curve IntCal13 (Stuiver and Reimer, 1993; Reimer et al., 2013), considering a  
233 reservoir age of -324 years to radiocarbon dates (age reservoir for western Brittany, Sein  
234 Island, Mangerud et al., 2006). The age model was then established using the *Bchron* package  
235 in R version 3.5.1 (Figure 2b), **allowing the** reconstruction of the last 7 **kyrs** with mean  
236 sedimentation rates of 74 cm/kyr from the base of the core to 5.5 ka BP, 33 cm/kyr from 5 to  
237 1.8 ka BP, and 72 cm/kyr from 1.8 ka BP to the top of the core (Figure 2a). The top of the  
238 core is assumed to **have been** reworked because of chronological issues (Mojtahid et al., 2019;  
239 **Figure 2a**). Also, in this study, three pollen grains of *Zea mays* were observed at 44, 47 and 54  
240 cm. Around the BoBy, maize cultivation **began** in northern Spain and France in the 17<sup>th</sup>  
241 century (Tenaillon and Charcosset, 2011), before **really** taking off in 1950. Thus, the rare  
242 grains observed in marine cores **tend rather to be from the post-1950 period. Even though our**  
243 **numerous dates could support extrapolation to the top of the core, as a precaution, only data**  
244 **up to 60 cm (0.5 ka BP in age) will be discussed in this manuscript.**

245

246  
247

## 4. Palynological results and their associated interpretation

248 The description of palynological results led us to consider three main limits (A, B and C;  
249 introduced in Figure 3), as well as five palynozones (CBT 1 to CBT 5; shown in Figure 4  
250 only). These boundaries/zones were established based on pollen and dinocyst observations in  
251 terms of both concentrations and percentages. In the following discussion, only limits A to C  
252 will be placed on Figures 5 to 10 to maintain the same scope as in the result section of this  
253 manuscript. Raw data are available in [Data in Brief](#) with a full description of the multivariate  
254 analyses conducted on pollen and dinocyst communities with other environmental variables.

255

### 4.1. Dinoflagellate cysts

#### a. Diversity and concentrations

257 **Thirty-nine** different dinocyst taxa were identified **in the whole core**, with a mean species  
258 richness (Figure 3a) of 18 different taxa per slide. From the base of the core to limit A (296  
259 cm), species richness was higher than the **dataset average**, then diversity was lower than  
260 average up to limit C (110 cm) and then continuously increased towards the top of the core  
261 (Figure 3a). The evolution of the diversity (Margalef index; Figure 3a) was anti-correlated  
262 with the trend of *Lingulodinium machaerophorum* percentages, which were higher between  
263 limits A and C, with the lowest diversity being recorded on both sides of limit B (200 cm)  
264 between 217 and 163 cm (yellow band on Figure 3) when *L. machaerophorum* percentages  
265 (Figure 3a) as well as concentrations and fluxes (Figure 3b) were the highest.

267 Total dinocyst concentrations (Figure 3b; as well as the **dominance index**: Figure 3a) were  
268 mainly **influenced** by *L. machaerophorum* occurrences and ranged between 450 and 10,500  
269 cysts/cm<sup>3</sup>, with mean values of around 3,300 cysts/cm<sup>3</sup>. Therefore, we **plotted** the  
270 concentrations of *L. machaerophorum* against the concentrations of other dinocysts to  
271 discriminate the respective parts occupied by this species and by the rest of the community  
272 (Figure 3b). **Up to** limit A, total concentrations of the other dinocysts were higher than *L.*  
273 *machaerophorum* ones. **They, then followed** a similar pattern between limits A and C, except  
274 in the interval “217–163 cm”, **which was** characterized by the highest *L. machaerophorum*  
275 concentrations (~4,130 cysts/cm<sup>3</sup>) and fluxes (~140 cysts/cm<sup>2</sup>/yr), while the other cysts did  
276 not show any major variations. Finally, from limit C onwards, concentrations of the other  
277 dinocysts were highest (~5,000 cysts/cm<sup>3</sup> from 110 cm; Figure 3b).

278

## 279 b. Dinocyst assemblages and dinocyst-zones

280 Overall, dinocyst assemblages were dominated by 10 autotrophic taxa: *L. machaerophorum*,  
281 *Spiniferites ramosus* (group of *S. ramosus* and *Spiniferites bulloideus*), *Operculodinium*  
282 *centrocarpum*, *Spiniferites lazus*, cysts of *Pentapharsodinium dalei*, *Spiniferites elongatus*,  
283 *Spiniferites mirabilis*, *Spiniferites bentorii*, *Spiniferites delicatus*, *Spiniferites membranaceus*  
284 (group of *S. membranaceus* and *Spiniferites belearius*), and two heterotrophic taxa including  
285 *Echinidinium* spp. and *Selenopemphix quanta* (group of *S. quanta* and *Protopteridinium*  
286 *nudum*) (Figure 4a). The five dinocyst zones (labelled from CBT 1 to CBT 5; Figure 4a) were  
287 related to the fluctuations of major cyst taxa percentages. First zone CBT 1 was characterized  
288 by the dominance of *S. ramosus*, *O. centrocarpum*, and cysts of *P. dalei*, revealing decreasing  
289 trends in parallel with the progressive rise of *L. machaerophorum* percentages (Figure 4a).  
290 Second zone CBT 2 was marked by a strong increase of *L. machaerophorum* percentages  
291 from around 50 up to 90% at the top of the zone (Figure 4a). *S. ramosus*, *O. centrocarpum*  
292 and *S. elongatus* are still abundant and their percentages gradually decreased to the end of the  
293 zone. From limit B (CBT 2-CBT 3 transition), *L. machaerophorum* percentages decrease  
294 onwards. *S. lazus* increased during CBT 3, while oceanic taxa (association *O. centrocarpum* -  
295 *S. elongatus*) no longer reached values as high as before the *L. machaerophorum* peak. Zone  
296 CBT 4 was characterized by the highest percentages of cysts of *P. dalei* while CBT 5 was  
297 marked by maximal values of *S. ramosus*, although percentages of *L. machaerophorum* were  
298 still significant across both zones.

299

## 300 **4.2. Pollen assemblages**

### 301 a. Diversity and concentrations

302 A total of 70 different pollen taxa were identified in the core as a whole, with a mean species  
303 richness (Figure 3c) of 18 different taxa per slide. Species richness was slightly lower than 20  
304 before limit C and reached 20 to 30 taxa per slide immediately after. This increase in diversity  
305 was associated with the opening of the landscape (*Quercus* drop; Figure 3c) and the  
306 diversification of herbaceous plants. Mean total pollen concentrations were around 2,800  
307 grains/cm<sup>3</sup> (ranging between 500 and 16,400 grains/cm<sup>3</sup>), the highest values being  
308 representative of major peaks found between limits A and B, as well as in the top 60 cm.  
309 Total pollen concentrations are mainly driven by trees (especially *Quercus*). In addition to the  
310 type of vegetation cover, pollen production and river transport are the main factors  
311 influencing the concentration of pollen grains. Thus, seasonal synchronization between these

312 two factors likely leads to much higher pollen fluxes. A disconnection between river inputs  
313 and the pollination period **should have led** to an increase of other palynomorph fluxes at the  
314 expense of pollen grains. It is interesting to note that until limit B, pollen concentrations were  
315 higher than dinocyst ones (Figure 3d), and after limit B, total percentages of tree pollen  
316 declined in parallel with increasing fluxes of *L. machaerophorum* and lower pollen grain  
317 fluxes to the **shelf**. From limit C, the major observations **were** higher pollen concentrations  
318 and fluxes, as well as a diversification driven by grassland taxa.

319

#### 320 b. Pollen assemblages and pollen-zones

321 Zone CBT 1 (Figure 4b) was characterized by the dominance of arboreal pollen, mainly  
322 *Quercus* and *Corylus*, *Ulmus*, *Tilia* and *Alnus* being already present. Zone CBT 2 (Figure 4b)  
323 was marked by **a slight** increase of riparian trees (especially *Alnus*), *Betula*, and *Corylus*, with  
324 maximal values of *Alnus* percentages being reached at the end of the zone **concomitantly** with  
325 atypically high percentages of *L. machaerophorum*. Zone CBT 2 also showed a slight  
326 increase of Poaceae as well as the first discrete occurrences of cultivated taxa (i.e., *Cerealia*,  
327 *Secale cereale*, *Fagopyrum* at 224–227–230cm). Zone CBT 3 (Figure 4b) was then  
328 characterized by a continuous and rather high occurrence of *Fagus*, while thermophilic trees  
329 *Ulmus* and *Tilia* progressively faded out. This classic subboreal signature (Morzadec-  
330 Kerfourn, 1974) is the expression of the mid-Holocene freshening and increasing winter  
331 precipitations induced by the general decreasing summer insolation at 65°N (Naughton et al.,  
332 2007). Across Zone CBT 3 (Figure 4b), *Corylus* and *Alnus* percentages decreased, with  
333 *Betula* staying stable. Zone CBT 4 (Figure 4b) was marked by the highest values of Poaceae,  
334 ruderal plants and *Cerealia*, while mixed oak forest declined and *Fagus* nearly disappeared  
335 from the record. *Pinus* significantly increased in zone CBT 5, potentially **indicating** the  
336 appearance of pine forests in the 16th century.

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## 5. Discussion

### 340 **5.1. Offshore-nearshore dinocyst communities and the freshwater** 341 **front in the northern Bay of Biscay**

#### 342 a. Comparing offshore-nearshore dinocyst communities in the northern Bay of Biscay

343 Dinocyst ecology **has been** thoroughly described **through** the progressive development and  
344 compilation of Atlases of modern cyst distribution (Rochon et al., 1999; Marret and  
345 Zonneveld, 2003; Zonneveld et al., 2013). **Nonetheless**, there **remains** a need to better  
346 understand the paleohydrological signature of this complex group along onshore-offshore  
347 gradients **and in the specific case of sediments from stratified, frontal and mixed-water**  
348 **regions (Marret et al., 2004)**. In order to discuss ecological changes within a marine **as**  
349 **opposed to a** continental context, we compared dinocyst data from three sediment cores  
350 strategically located along a marine (distal or offshore) to coastal (proximal or onshore)  
351 transect across the BoBy (Figure 5): i) the full-oceanic MD95-2002 core (2,174 m water  
352 depth; Zumaque et al., 2017; Figure 1b) was directly influenced by the North Atlantic  
353 Circulation (Frew et al., 2000); ii) the shelf CBT-CS11 core (73 m water depth; this study;  
354 Figure 1b) was under mixed oceanic and winter fluvial influences; iii) the coastal “A” core,  
355 collected within the Bay of Brest, **comes from a shallow** macro-estuarine environment (8 m  
356 water depth; Lambert et al., 2019; Figure 1b). By including different bathymetric ranges from  
357 the same temperate latitudes, we accounted for potential changes in hydrographical and/or  
358 stratification conditions that may have resulted from the Holocene relative sea level (RSL)  
359 rise under variable climate and/or anthropogenic forcings. **To account for the over-**  
360 **representation of *L. machaerophorum* in coastal mudflats, percentages of other cyst taxa were**  
361 **represented for the A and CBT-CS11 cores without considering *L. machaerophorum* counts**  
362 **in the main dinocyst sum (Figure 5).**

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#### 364 b. General observations

365 Along Brittany’s coasts, the understanding of the modern distribution of coastal-oceanic  
366 dinocyst communities was **initiated** by **studies such as those of** Rossignol (1964, 1969), Reid  
367 (1974), Morzadec-Kerfourn (1974, 1977), and Wall et al. (1977), **which have been** recently  
368 complemented by Ganne et al. (2016) and Lambert et al. (2017). Previous studies showed the  
369 dinocyst groups of the oceanic zone (>100–150 m water depth, outer-neritic or neritic-oceanic  
370 assemblages) to be characterized by *Impagidinium aculeatum*, *O. centrocarpum*, *S. mirabilis*,

371 and *S. elongatus* (with *S. ramosus* and *S. bulloideus* in addition), with *I. aculeatum* being  
372 restricted solely to full-oceanic waters. In the coastal zone (inner-neritic), the association *S.*  
373 *ramosus-S. bulloideus-S. bentorii* was shown to be predominant, with *S. ramosus-S. bulloideus*  
374 being more specifically characteristic of the whole Iroise Sea (Figure 1b). Finally, the  
375 estuarine zone was shown to be characterized by *L. machaerophorum* until the upper part of  
376 the tidal zone (Morzadec-Kerfourn, 1977), which corresponds to this species' tolerance of  
377 large drops in salinity and its proliferation in brackish environments (Reid, 1975; Morzadec-  
378 Kerfourn, 1977, 1992, 1997). The presence of these ecological groups is shown on Figure 5  
379 by the green colour (A core) to the purple colour (MD95-2002 core) for selected major cyst  
380 taxa, making it possible to reveal the main estuarine to full-oceanic taxa found in the studied  
381 area. Concerning CBT-CS11 cyst data (shown in pink in Figure 5), there is some evidence for  
382 stratified water conditions in a shelf environment subject to both continental and oceanic  
383 influences: i) estuarine to coastal quasi-monospecific assemblages of *L. machaerophorum*, ii)  
384 inner-neritic assemblages characterized by the association *S. ramosus-S. bulloideus*, iii) outer-  
385 neritic assemblages characterized by the association *O. centrocarpum - S. mirabilis - S.*  
386 *elongatus*, as well as iv) no full-oceanic *Impagidinium*-type observations. Offshore (MD95-  
387 2002), open-ocean taxa such as *I. aculeatum* (for temperate to subtropical environments) and  
388 *B. tepikiense* (for northern seasonally contrasted Atlantic environments; Rochon et al., 1999;  
389 Marret et al., 2004) are dominant while they are absent at mid-shelf depth (core CBT-CS11).

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#### 391 *c. L. machaerophorum*, tracer for freshwater plumes under phosphate deficiency?

392 At offshore locations (core MD95-2002), *L. machaerophorum* was almost absent during the  
393 Holocene (always lower or equal to 2%, except between 4.5 and 2.5 ka BP when it just  
394 reached 5% in some periods; Figure 5). This is consistent with the fact that offshore surface  
395 conditions are influenced by the general North Atlantic circulation, while the circulation on  
396 the continental shelf is influenced by mixed fluvial/tidal currents restricted to the coast. In  
397 modern sediments, this taxon formed up to 30% of total cyst assemblages by 100 m water  
398 depth but barely reached 5% directly after 150 m water depth in full-oceanic Atlantic  
399 associations (Andreieff et al., 1971; Williams, 1971). 90 to 96% of *Lingulodinium polyedrum*  
400 resting cysts, i.e., *L. machaerophorum*, were found in surface sediments from north-western  
401 France estuaries (Vilaine, Loire, and Bay of Brest; Ters et al., 1968; Morzadec-Kerfourn,  
402 1976, 1977; Ganne et al., 2016; Lambert et al., 2017). A front may thus prevent the offshore  
403 dispersion of *L. machaerophorum* outside the region under influence of freshwater plumes  
404 (Costoya et al., 2016). This freshwater front may act as a major hydrological barrier

405 preventing the transfer of fine river-borne material to the slope and the open sea near the 100  
406 m isobath (Yelekci et al., 2017). In shelf sediments (CBT-CS11), the prevalence of the  
407 species over neritic to oceanic cyst taxa thus suggests coastal stratified waters are subject to  
408 strong continental influence. Additionally, phosphate deficiency in aquatic systems is  
409 considered a major nutritional condition required to form *L. polyedrum* resting cysts, which  
410 was deduced from culture experiments dedicated to investigating the sexual reproduction of  
411 this bloom-forming and widely distributed dinoflagellate (Figueroa and Bravo, 2005).

412 Interestingly, *L. machaerophorum* percentages from the Bay of Brest (core A) and South  
413 Brittany shelf (core CBT-CS11) showed equivalent patterns with a clear shift at 5.9 ka BP  
414 (limit A; Figure 5), most likely corresponding to a marked slowdown in the rates of the RSL  
415 rise identified at a regional scale (Morzadec-Kerfourn, 1995; Goslin et al., 2015; Stéphan et  
416 al., 2015; Garcia-Artola et al., 2018; Figure 2a). This inflexion of RSL rise-rates likely  
417 facilitated the encroachment and development of tidal flats and subsequent saltmarshes along  
418 the coasts, thus fostering the development of terrestrial sedimentation (e.g., Joly and Visset,  
419 2009; Menier et al., 2010; Stéphan et al., 2019). The formation of brackish marshes along the  
420 estuaries may explain the proliferation of *L. machaerophorum* cysts. Major occurrences of  
421 this species were particularly seen within the 4–2 ka BP interval, both in terms of percentages  
422 and concentrations (yellow band on Figure 5). Massive encystments may be attributed to  
423 unfavourable conditions (e.g., drops in salinity) in a context of phosphorus deficiency. This  
424 hypothesis gains weight when we consider that concentrations of other dinocyst taxa and  
425 overall species richness remained low, between 4 and 2 ka BP (Figures 3b and 5).

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#### 427 d. Winter horizontal thermohaline front establishment

428 *O. centrocarpum* percentages reached around 40% offshore (core MD95-2002) before 3.3 ka  
429 BP (limit B, Figure 5; becoming inversely correlated with increasing *S. mirabilis* percentages  
430 at that time), and around 20% at mid-shelf depth (core CBT-CS11), suggesting a North  
431 Atlantic Current (NAC, Figure 1a) origin of this species (Turon, 1984; Rochon et al., 1999;  
432 Penaud et al., 2008). The decrease in *O. centrocarpum* at 3.3 ka BP in both cores may relate  
433 to a common hydrographic cause linked to a weaker NAC. Interestingly, while the oceanic *O.*  
434 *centrocarpum* pattern is similar in both shelf and hemipelagic cores, the oceanic *S. mirabilis*  
435 pattern (second major species in the MD95-2002 core) was not obvious beyond limit B on the  
436 shelf. CBT-CS11 was then characterized by rising percentages of *S. lazus*, followed after limit  
437 C by increasing values of cysts of *P. dalei*, both taxa rarely occurring within the deep-water  
438 core MD95-2002 at that time, while being found in the Central Celtic Sea at 118 m depth



439 (Marret et al., 2004). Along with the influence of the Iroise Sea (especially *S. ramosus*,  
440 Morzadec-Kerfourn, 1977), increasing presence of heterotrophic *S. quanta* with cysts of *P.*  
441 *dalei* from 1.2 ka BP (limit C) may indicate the existence of stratified high productivity  
442 conditions (Howe et al., 2010). In summary, the winter horizontal thermohaline front may  
443 thus be identified at 3.3 ka BP based on the pronounced disconnection of oceanic and shelf  
444 waters, the mid-shelf being characterized by enhanced stratification under increasing winter  
445 fluvial discharges, with a trophic change at 1.2 ka BP resulting from increasing nutrient  
446 bioavailability in surface waters.

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## 448 **5.2. Atlantic Meridional Overturning Circulation and subpolar gyre** 449 **dynamics through the Holocene**

### 450 a. The 5.9 ka BP limit: evidence of strong oceanic re-organization

451 The north-eastern Atlantic is a key climatic area requiring careful attention, particularly with  
452 regard to NAC vigour. This branch of the North Atlantic Sub-Polar Gyre (SPG; Sutton and  
453 Allen, 1997) affects the Atlantic Meridional Overturning Circulation (AMOC) by varying  
454 poleward heat transport intensity over time (Carton and Hakkinen, 2011). Some recently  
455 published data made it possible to synthesize the long-term Holocene trend considering  
456 AMOC dynamics (Figure 6). AMOC strength and SST south of Iceland were maximal until 6  
457 ka BP (e.g., Eynaud et al., 2018; Ayache et al., 2018) before slowly decreasing (as shown by  
458 the general decline in bottom flow strength: Kissel et al., 2013). This breakdown in North  
459 Atlantic dynamics associated with hydrological reorganization occurred synchronously with  
460 the 5.9 ka BP limit previously discussed for the CBT-CS11 core and resulting from the  
461 slowdown of the RSL rise and the stabilization of estuarine banks. The final collapse of the  
462 Laurentide Ice Sheet (Dyke, 2004; Kaplan and Wolfe, 2006; de Vernal and Hillaire-Marcel,  
463 2006) implies the start of the Labrador Sea convection (minimum of sea-ice concentrations in  
464 the eastern Fram Strait, northern Baffin Bay and Labrador Sea at  $6 \pm 0.5$  ka BP, de Vernal et  
465 al., 2013), thus impacting the AMOC through reduced poleward heat transport to the Nordic  
466 Seas, and then contributing to the establishment of the modern AMOC (Hoogakker et al.,  
467 2011; Ayache et al., 2018). Simultaneously, reduced summer SSTs in the north-eastern  
468 Atlantic (MD95-2002 core; Zumaque et al., 2017; Figure 6) reflect the half-cycle of the  
469 precessional signal implying decreasing summer insolation at 65°N for 9 kyrs (e.g., Berger  
470 and Loutre, 1991; Ayache et al., 2018).

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b. Eastern North Atlantic Central Water signature

Superimposed on this long-term RSL rise, AMOC, and insolation trends, North Atlantic SPG dynamics can be reconstructed at a sub-orbital timescale from marine sediment archives in the northern Atlantic Ocean (e.g., Giraudeau et al., 2010; Solignac et al., 2006, 2008; Zumaque et al., 2017; Ayache et al., 2018; Mojtahid et al., 2019). Millennial timescale events (Bond et al., 1997, 2001), as well as multi-decadal variability, related to internal modes of atmosphere-ocean teleconnection such as the “NAO-like” mechanism have exerted a control on the latitudinal position of westerly storm tracks (Sorrel et al., 2012; van Vliet et al., 2014; Goslin et al., 2018, 2019) and may have strongly impacted Atlantic gyre dynamics throughout the Holocene (Thornalley et al., 2009; Figure 6). Since the CBT-CS11 core was influenced by Eastern North Atlantic Central Waters (ENACW), which were themselves influenced by the NAC, Mojtahid et al. (2019) discussed the benthic  $\delta^{18}\text{O}$  signal of *Cibicides refulgens* as a proxy for ENACW waters mainly responding to subpolar rather than subtropical gyre influences. To complement these interpretations and go further, we produced another series of  $\delta^{18}\text{O}$  measures on the benthic foraminifera *Ammonia falsobeccarii* (Figure 6). Higher isotopic values on both species, here highlighting mainly higher salinities (such as tropical ENACW today; Voelker et al., 2015; Figure 6), match the density anomalies at sub-thermocline depths recorded in the southern Iceland basin (Thornalley et al., 2009; Figure 6). However, the two benthic isotopic records diverge at 3.3 ka BP (limit B; Figure 6), with the *C. refulgens* signature being characterized by a shift towards a new oscillating salinity state with heavier values after 3.3 ka BP. Mojtahid et al. (2019) interpreted this shift as an overall cooling state that occurred under the establishment of the winter thermohaline front (Figure 6). Since *C. refulgens* is an epibenthic/epiphyte species, we hypothesize that it may reflect an isotopic signature more characteristic of the surface (being transported by currents after first becoming attached to littoral plants) and thus a cooling related to fluvial water advectations being plated to the coast up to the 100 m isobath. *A. falsobeccarii*, which is part of the surficial infauna, would calcify in equilibrium with poral waters, being less influenced by seasonal surface conditions related to river plumes and more by polar (ENACWP) than tropical (ENACWT) oceanic signatures (cf. Figure 1a). The *C. refulgens* isotopic record confirms the 3.3 ka BP limit as the main time when the modern winter thermohaline front was established (Mojtahid et al., 2019). *A. falsobeccarii* will be used as a SPG dynamic index in the following discussion (Figure 7).

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### c. Subpolar gyre dynamics and Bond events

As a second step, we compared the *A. falsobeccarii* record with Ice-Rafted Debris (IRD) data in the North Atlantic (Bond et al., 2001; Figure 7). From the mean value of both datasets, we established an anomaly scale: red (less IRD–weaker SPG, with a more pronounced ENACWT signature) and blue (more IRD under stronger EGC–stronger SPG, with a greater influence of ENACWP at our studied site and of the NAC in the Nordic Seas). The two signals show a good **concordance**, with enhanced SPG strength at times of peaks in IRD, especially across Bond events 4, 2 and 1 (Figure 7). These three major intervals (6.4–5.1, 3.3–2.7, and 1.6–1.2 ka BP) **were** coded with blue bands for the following discussion and the red/blue scale (SPG dynamics) based on the *A. falsobeccarii*  $\delta^{18}\text{O}$  oscillating signal (cf. Figure 7) **was** placed in parallel with other proxies **to improve the** mechanistic understanding of climatic and hydrographic changes and related environmental impacts over the last 7 **kyrs** (Figures 8 to 10).

### **5.3. Oceanic versus continental influences on the Bay of Biscay shelf**

The BoBy exhibits three **kinds** of hydrographic regime depending on the bathymetry: the abyssal plain, the continental slope and the northward widening continental shelf reaching 160 km on the Armorican shelf. The BoBy is thus influenced by large-scale oceanic circulation (**which** we will refer to as “oceanic influence”) and local forcing implying seasonal wind regimes as well as river discharges and run-off (**which** we will refer to as “continental influence”). It is worth keeping in mind that our observations filter the mesoscale and interannual variability to depict **multi-decadal scenarios** of environmental forcing and related impacts.

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#### a. From 7 to 5.9 ka BP (~Early–Middle Neolithic)

**During this period, pollen concentrations were higher than dinocyst ones and seasonal synchronization between pollen production and river transport is assumed because of high pollen fluxes (Figures 3d and 9). These** may correspond to high arboreal pollination (higher summer insolation at 65°N) having been synchronous **with** fluvial discharges of the main rivers, thus implying higher precipitations during spring. In terms of sediment facies, we suggest that the generally coarser sedimentation (Zr/Al ratio, D50 CaCO<sub>3</sub> free; Mojtahid et

538 al., 2019), resulting from spring fluvial currents, took over the winter supply of fine material  
539 by fluvial turbid plumes. This hypothesis appears to be supported by the overall coherence we  
540 observe between grain-size tracers and summer SSTs reconstructed in the Bay of Biscay (core  
541 MD95-2002; Figure 8). Until 5.9 ka BP, stronger occurrences of the cosmopolitan-oceanic *O.*  
542 *centrocarpum* species, **suggested here** as a potential tracer for the NAC (Rochon et al., 1999),  
543 than occurrences of *L. machaerophorum* (ratio “*O. centrocarpum* / *L. machaerophorum*” on  
544 Figure 9), would reflect an increasing strength of the NAC at a time of stronger AMOC (e.g.,  
545 Ayache et al., 2018). We **further** suggest that stronger humidity through the NAC may have  
546 amplified seasonal continental humidity in Western France during the hypsithermal.  
547 Therefore, in a high boreal summer insolation context (Holocene Thermal Maximum; e.g.,  
548 Renssen et al., 2012), strong pollination of trees coupled **with** spring precipitations would be  
549 responsible for higher arboreal pollen fluxes to the **shelf**. We entitled this configuration  
550 “summer-prevailing mode” and suggest that a north-west to south-east shelf residual  
551 circulation was prevalent within the BoBy (Figures 8 and 11). At that time of still rapid RSL  
552 rise (Garcia-Artola et al., 2018), southward residual shelf currents may have dominated sea-  
553 surface circulation in the **BoBy**.

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#### 555 b. From 5.9 to 3.3 ka BP

556 At 5.9 ka BP, the reduced accommodation space on the **shelf**, as well as the stabilization of  
557 fluvial environments, favoured the development of alluvial plains and allowed the ripisylve to  
558 progressively colonize riverbanks (limit at 5.7 ka BP identified by Cyprien, 2002). This  
559 period of valley alluviation (increasing *Alnus* and *L. machaerophorum* percentages; Figure 9)  
560 corresponds to a still active poleward heat transport to the Nordic Seas via the NAC (as  
561 shown by the **persistent** high percentages of *O. centrocarpum*; Figure 8) and the rise of  
562 *Corylus* and *Betula* under **increasingly** fresher and wetter climate conditions. Thanks to the  
563 development of riparian hydrophilous shrublands along freshwater bodies, the stabilization of  
564 fluvial systems (i.e., **development of vegetation on riverbanks and their fixation**) may have  
565 implied: i) reduced sedimentation rates to the **shelf** by retaining solid and dissolved river  
566 inputs (Figure 9), and ii) increased brackish waters in coastal waters (major drops in salinity)  
567 as observed through *L. machaerophorum* cyst proliferation (Figure 9).

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569 Two sub-periods can be identified within this time interval:

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- 571 • 5.9 to 4 ka BP (~Recent–Late Neolithic): The sustained elevated abundances of *O.*  
572 *centrocarpum* and **relatively** coarse sedimentation may suggest mixed oceanic-  
573 continental influences with a non-oriented shelf residual circulation, **referred to here as**  
574 “autumn-prevailing mode” (Figures 8 and 11). This mode would have especially  
575 prevailed until 4 ka BP (equivalent values of neritic-oceanic and *L. machaerophorum*  
576 concentrations and fluxes, high tree pollen grain percentages; Figure 9). This period  
577 would correspond to the settlement and evolution of Recent and Late Neolithic coastal  
578 societies on the fringes of coastal zones (e.g., Molène archipelago; Pailler and Nicolas,  
579 2019).
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- 581 • 4 to 3.3 ka BP (~Early–Middle Bronze Age): This interval **fits** within the larger 4–2 ka  
582 BP interval identified in Figure 5 (yellow band). This latter also corresponds to a  
583 peculiar interval of generally higher winter SST and SSS (2 to 3 psu higher-than-  
584 average) within the MD95-2002 slope core (yellow band on Figure 6), **which was**  
585 synchronous with the strongest *L. machaerophorum* occurrences (Figure 9) and  
586 generally weaker SPG dynamics (Thornalley et al., 2009; Figures 6 and 9).  
587 **Additionally**, a shift at 4 ka BP from **prevalently** positive to **prevalently** negative  
588 NAO-like conditions until 2 ka BP was suggested from the study of a lake sediment  
589 record from south-western Greenland (Olsen et al., 2012; Figure 9). The long-term  
590 phase of recurrent negative NAO-like conditions may have resulted in an enhanced  
591 East Greenland Current and/or in some melting of the Greenland Ice Sheet according  
592 to Orme et al. (2018) who identified a major long-term SST cooling south of the  
593 Iceland Basin over the 4–2 ka BP interval. Our data **tell** a more complex story for this  
594 latter 4–2 ka BP interval and **make it possible** to divide it in three sub-periods. The 4–  
595 3.3 ka BP period constitutes its first phase and is characterized by negative NAO-like  
596 recurrent modes. Poleward flows have been thoroughly studied (Pingree and Le Cann,  
597 1989; Koutsikopoulos and Le Cann, 1996) and are known to occur frequently within  
598 the BoBy, pulsing during the autumn and winter seasons (Charria et al., 2013). This  
599 along-slope circulation (IPC; top 350 m of the water column; Figure 1b) implies  
600 seasonal warmer conditions extending up to the Armorican slope, and it has been  
601 suggested that, **today**, southerly winds represent the **main** contribution to the IPC  
602 intensification over the upper slope and outer shelf, generating anomalously high  
603 winter SSTs (e.g., Pingree and Le Cann, 1992a,b; Le Cann and Serpette, 2009; Garcia-  
604 Soto and Pingree, 2012). Here, we thus suggest that, between 4 and 3.3 ka BP,

605 prevalent southerly winds may have promoted a northward IPC, resulting in higher  
606 winter SSTs in the north-eastern Atlantic Ocean (MD95-2002; Figure 9). The highest  
607 *I. aculeatum* percentages recorded within core MD95-2002 during this time interval  
608 (Zumaque et al., 2017; Figure 5) reinforce the hypothesis of a major advection of  
609 subtropical waters during this interval. This context may have promoted major winter  
610 precipitation and thus major repeated flood events **over the** Loire riverbanks during the  
611 winter seasons. It is **noteworthy** that Delaine et al. (2015), who studied the Loire  
612 valley infilling near Nantes during the Holocene, reported a period of high erosional  
613 regime and/or intense reworking denoting high hydrodynamics of the Loire **River**  
614 **from ~ 5.8 to 2.1 ka BP. In addition**, a synthesis on the Loire **showed** a peak frequency  
615 and/or magnitude of floods between 4.4 and 3.5 ka BP (Val d'Orléan; Arnaud-Fassetta  
616 et al., 2010), **concomitant** with our observation.

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#### 619 c. From 3.3 to 1.2 ka BP

620 This **period was** characterized by a strong drop **in** Greenland air temperatures (Vinther et al.,  
621 2006; Figure 8), large global temperature anomalies (Marcott et al., 2013; Figure 8), as well  
622 as increasing annual precipitation and decreasing atmospheric temperature seasonality as  
623 shown by pollen-based climate reconstructions conducted in north-western France (Core  
624 VK03-58bis; Naughton et al., 2007; Figure 1b). At 3.3 ka BP, this change in precipitation  
625 resulted in major winter river discharges (Stéphan et al., 2015) and **a large decrease in** oceanic  
626 influence (major decline of *O. centrocarpum* percentages) in BoBy shelf waters. Finer  
627 sediments (Figure 8) thus correspond to winter advection of fine sediments and spring  
628 deposition under hypopycnal currents (similar to the present-day configuration: Charria et al.,  
629 2013). The establishment of the winter horizontal thermohaline front is obvious here at 3.3 ka  
630 BP and this configuration was **named** the “winter-prevailing mode” (Figures 8 and 11).

631 The 4–2 ka BP interval of prevalent negative NAO-like conditions is **interrupted** by the 3.3–  
632 2.8 ka BP interval (Bond event 2; Figures 8 and 9) during which persistent positive NAO-like  
633 conditions occurred, accompanied **by** enhanced SPG strength, decreased influence of the  
634 warm and salty poleward current (lower winter SST/SSS offshore), and strengthened northern  
635 Atlantic westerly storminess (Goslin et al., 2018; Figure 9). Regionally, this latter period  
636 (Middle to Late Bronze Age) was characterized by a **scarcity of** coastal archaeological  
637 remains. Indeed, it is generally accepted that the harsh meteorological conditions caused by  
638 this period of climatic deterioration, accompanied with widespread dune-sand invasions of

639 coastal areas (e.g., Tisdall et al., 2013; van Vliet et al., 2016), may have caused the  
640 withdrawal of coastal societies from the shores during the winter season or even permanently  
641 (Stéphan et al., 2013, 2018). Among other adaptive possibilities, this may have encouraged  
642 some populations to turn more towards land cultivation rather than exploitation of marine  
643 resources (although salt producers were probably also farmers or herders). This is suggested  
644 by the decreasing occurrences of *Alnus* and *Corylus* pollen grains in our data (and further  
645 emphasized by the ratio of *Corylus* to *Quercus* (explained in Table 2) in Figure 9), which may  
646 reflect major phases of upland clearance (Figure 9). The anthropogenic origin of this pollinic  
647 observation is also indicated by the fact that no comparable shifts appeared during either  
648 Bond event 4 or 1 while, on the contrary, both pollinic tracers (*Alnus*, *Corylus*) tended to  
649 increase (Figure 9). Accounting for the synchronous trend of increasing sedimentation rates  
650 (Figure 9), the drops in *Alnus* and *Corylus* percentages around 3.3–2.8 ka BP, while *Betula*  
651 percentages remain stable, could indicate an anthropogenic impact on the landscape, with  
652 preferential human selection of alluvial taxa in a context of landscape opening (a continuing  
653 decreasing trend of arboreal pollen percentages following the increase of Poaceae as well as  
654 of *Plantago lanceolata*; Figure 4b).

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#### 656 d. From 1.2 ka BP onwards

657 From 1.2 ka BP, which also corresponds to the end of Bond event 1, a sharp shift was  
658 observed in both pollen and dinocyst communities (Figure 10). Cultivated, ruderal and  
659 adventive plants clearly indicate massive landscape opening after this point (Figure 10). The  
660 increase in the area under cultivation and pasture was thus established from the Middle Ages,  
661 as previously noted (Barbier and Visset, 1997; Cyprien, 2002; Joly and Visset, 2009; David,  
662 2014). At this time, the increase in sedimentation rates may thus have resulted from rainwater  
663 runoff over bare watersheds. The human imprint on coastal wetlands also became strong,  
664 especially for drainage or water intakes (Joly and Visset, 2009).

665 Increasing concentrations of *S. quanta*, a heterotrophic taxon, and of cysts of *P. dalei* (Figure  
666 10) could be explained by an increase in the supply of nutrients to the shelf, most likely  
667 provoked by the reduction of the forest cover and the subsequent increase of soil erosion and  
668 continentally derived organic matter. This may indicate the existence of stratified high  
669 productivity conditions (Howe et al., 2010). Indeed, cysts of *P. dalei* increase when upper  
670 water salinities are reduced throughout the year as a result of increasing: i) freshwater riverine  
671 inputs (Zonneveld et al., 2013) and ii) phosphate concentrations within the upper water  
672 column (Zonneveld et al., 2012). Because *Lingulodinium polyedrum* cyst formations are

673 favoured in cultures in a media replete in phosphate levels (Figuroa and Bravo, 2005), the  
674 massive nutrient, and especially phosphate, influx from 1.2 ka BP would contribute to  
675 explaining the sharp drop in *Lingulodinium machaerophorum* occurrences. At that time, it  
676 should also be noted that the highest concentrations of diversified dinocysts (without *L.*  
677 *machaerophorum*: ~5,000 cysts/cm<sup>3</sup>; Figure 3b and 5) are recorded. The same trophic re-  
678 organization of coastal water bodies has recently been described in the Bay of Brest, though  
679 in much higher proportions, with sharp drops of *L. machaerophorum* percentages related to  
680 intensive agriculture practices after World War II (Lambert et al., 2018).

681

## 682 **5.4. Understanding western European river floods**

### 683 a. Effects of climate-driven factors on anthropogenic palynological evidence

684 As a first general observation, the first clear retreat of mixed temperate forest was recorded  
685 between 4.5 and 4 ka BP, indicating the beginning of the landscape opening and onset of  
686 inland agro-pastoral practices (as shown by the presence of ruderal plants such as *Rumex* and  
687 *P. lanceolata* accompanied by first low *Cerealia* occurrences, Figure 10). This is consistent  
688 with other pollinic studies carried out in north-western France (e.g., Gaudin, 2004; David,  
689 2014; Fernane et al., 2014, 2015), i.e., with the transition from the Neolithic to the Bronze  
690 Age cultural periods (Figure 10). The next major step in landscape opening dynamics  
691 occurred at the Bronze to Iron Age transition, shown well by the increase of ruderal and  
692 cultivated plants, as well as by a higher “dinocyst (without *L. machaerophorum*) to pollen”  
693 ratio (Figure 10). The rise of this ratio is probably based on two non-exclusive factors: i) a  
694 higher dinocyst productivity induced by nutrient enrichment of coastal waters, and ii) a  
695 smaller contribution of the strongest tree pollinators to the pollen assemblages induced by the  
696 clearing of regional woodlands.

697 It is interesting to observe, however, that the most representative indices of anthropogenic  
698 impacts increase during periods of weakened SPG dynamics (or higher subtropical influence,  
699 red/blue scale on Figure 10). In other terms, palynological tracers of anthropic activity appear  
700 closely associated with more favourable climate conditions that allowed their transport and  
701 record to be left in marine sediments. This hypothesis is further confirmed by the fact that  
702 *Echinidinium* spp. percentages follow a pattern equivalent to the one followed by ruderal  
703 plants or Poaceae (Figures 4a and 10). The fluvial (or river-plume) sensitive nature of  
704 *Echinidinium* spp. (Zonneveld et al., 2013) confirms that strengthened nutrient-enriched river  
705 discharges occurred during time intervals characterized by weakened SPG activity. This



706 illustrates the difficulty of **accurately tracing past** human dynamics using pollen indicators of  
707 anthropisation within marine sediments. Indeed, their occurrences may first be the expression  
708 of higher precipitation capable of transporting heavy pollen grains to the sea. These indices  
709 nonetheless seem to adequately depict the main trends of anthropogenic impacts in regional  
710 watersheds from the start of the Bronze Age and later, as illustrated by **the regular Poaceae**  
711 **profile (dotted line in Figure 10: theoretical Poaceae trend).**

712

#### 713 b. An atypical signal of arboreal expansion during the 1.8–1.2 ka BP interval

714 When looking at **the general Poaceae trend** since the start of the Bronze Age (Figure 10), it is  
715 tempting to connect the arboreal rise between 1.8 and 1.2 ka BP with a major human decline  
716 **that coincided** with the Roman period and transition to the start of the Middle-Ages (Lambert  
717 et al., **pers. comm.**, for the Bay of Brest). For instance, working on a coastal sedimentary  
718 archive (southern edge of the Armorican Massif), Joly and Visset (2009) observed the  
719 reappearance of the oak during the Gallo-Roman period (as also observed in the Mayenne and  
720 Loire valleys, Barbier and Visset, 1997; Ouguerram and Visset, 2001; Cyprien, 2002), and  
721 suggested a link with possible strategies of forest management in reaction to forest over-  
722 exploitation during the Iron Age. However, the sharp increase in sedimentation rates at 1.8 ka  
723 BP (Figure 10) that we attributed to human-induced soil erosion, **suggests** hydrographic  
724 changes could be responsible for this atypical arboreal re-increase.

725 Several phases of SPG strengthening took place within the 1.8–1.2 ka BP interval (major  
726 climate deterioration of Bond event 1; Figure 10). This climatic context probably also had  
727 **consequences for** the arboreal *versus* Poaceae signatures; tree pollen grains being better  
728 preserved in marine sediments while, as previously discussed, **the Poaceae signature is**  
729 **enhanced by stronger fluvial discharges.** The impact of oceanic *versus* river processes on tree  
730 *versus* Poaceae occurrences and preservation **would also be clearer** in the context of an  
731 already opened landscape. This may explain the strong Poaceae decline observed during Bond  
732 event 1, but also the weaker ruderal signature observed during Bond event 2, while Bond  
733 event 4 occurred in a period during the **Neolithic, when major forest clearings were not yet**  
734 **observed.**

735 Interestingly, during the 1.8–1.2 ka BP interval, percentages of fluviate-sensitive  
736 *Echinidinium* spp. taxa as well as **the dinocyst to pollen ratio were** characterized by sharp  
737 drops, suggesting a small impact of river discharges to our study site. Also, a recent study  
738 from Durand et al. (2018), carried out at the mouth of the Loire **River** for the Late Holocene,  
739 discussed the influence of positive NAO-like configurations responsible for lower terrigenous

740 inputs to the sea **in a period known for** increased storminess. However, even if the absence of  
741 anthropogenic indices and the peak in arboreal pollen grains may not result from human  
742 causes (i.e., forest management, land abandonment in a context of wars or invasions), we  
743 cannot exclude that this climate event could have had serious consequences for coastal and  
744 inland societies because of storms and stronger humidity under recurrent positive NAO-like  
745 conditions.

746

#### 747 c. Factors required for major Holocene Loire **discharges**

748 Interestingly, major peaks of palynomorph fluxes (/drops of anthropogenic indexes), **make it**  
749 **possible** to understand the environmental conditions required for increasing (/decreasing)  
750 **fluvial discharges** from major north-western French rivers (Figure 9). During Bond events,  
751 strong positive NAO-like configurations are known to favour increased precipitation and  
752 storminess, then fostering fluvial discharges in north-western Europe (as **observed by Tréguer**  
753 **et al., 2014, for the 1998–2013**-time interval in the Bay of Brest). The opposite is true during  
754 negative NAO modes. Here, palynomorph fluxes (Figure 9) generally increased during  
755 periods characterized by weakened SPG dynamics and prevalent negative NAO-like  
756 conditions (Figure 9). This would imply that, at the location of the studied site (south  
757 Brittany), sediment supply is more influenced by river systems **with** watersheds extending  
758 southwards. The Loire **River**, and probably the Gironde, may thus largely explain our  
759 palynological concentration/flux records. Higher palynomorph fluxes (dates **given** in red in  
760 Figure 9) generally coincide with subtropical gyre strengthening and negative NAO-like  
761 conditions. On the general “summer-prevailing”, “autumn-prevailing” and “winter-  
762 prevailing” modes (Figure 8) linked with the long-term insolation trend (Berger and Loutre,  
763 1991), **we can therefore superimpose** a millennial-scale mechanism implying SPG strength  
764 coupled with natural atmospheric oscillations (Figure 11). Indeed, it has been demonstrated  
765 that North Atlantic SPG response is strongly related to persistent NAO configurations even  
766 though a large non-linearity exists regarding the NAO response to atmospheric forcing  
767 (Lohmann et al., 2009). A steady weakening of the SPG was however found throughout the  
768 integration of negative NAO modes in **a modelling study by** Lohmann et al. (2009), while  
769 positive phases of the NAO strengthened the SPG with poleward advection of NAC waters.  
770 This is notably due to the wind-stress implied by northern-located mean westerly storm tracks  
771 (e.g., Giraudeau et al., 2010; Goslin et al., 2018). Stronger Loire **River discharges** from the  
772 start of the Late Holocene would therefore represent a conjectural phenomenon of stronger  
773 subtropical gyre influence under negative NAO-like modes. This latter scenario may have

774 been amplified by periods of solar minima (reduced solar activity or solar irradiance under  
775 lower magnetic waves; Steinhilber et al., 2009; Figure 8). Indeed, during solar minima,  
776 several observational **revealed** southward shifts of North Atlantic storm tracks towards central  
777 to southern Europe (south of the 50°N) as well as an increase of associated precipitation and  
778 flood frequency (e.g., de Jong et al., 2006, 2007; Costas et al., 2012; Laurenz et al., 2019). As  
779 far as our data is concerned, **with** the exception of some events (**at** 5.9, 3.4 and 1.3 ka BP), the  
780 correlation between solar forcing and palynomorph fluxes at a multi-decadal timescale is  
781 **insufficiently** significant, but was convincingly discussed for the mouth of the Loire **River in**  
782 **a previous study** (Durand et al., 2018).

783

## 784 **6. Conclusion**

785 Ecosystem resilience to natural hazards, as well as to human occupation or withdrawal from  
786 the coast, **is a compelling issue** across the Holocene. In the present study, we took advantage  
787 of the complex sedimentation context of the northern Bay of Biscay (BoBy) shelf, especially  
788 marked by the dual influence of both oceanic currents derived from the North Atlantic  
789 Current and winter fluvial discharges, to address several issues regarding the links between  
790 natural climate modes (including Atlantic subpolar gyre and North Atlantic Oscillation  
791 dynamics, storminess and floods) and the dynamics of terrestrial and marine ecosystems. Our  
792 study may therefore help the archaeology community to understand major phases of  
793 occupation or desertion of coastal sites on the **western French** coastal fringe, but also the  
794 climate community to place the Loire floods as observed today in a broader spatio-temporal  
795 context.

796 **The high-time resolution (~70 years on average) multi-proxy analysis on the CBT-CS11 mid-**  
797 **shelf core revealed the complexity of the palaeohydrological and palaeoclimatic signals**  
798 **recorded over the last 7 kyrs. At 5.9 ka BP, we identified major reorganizations of the**  
799 **hydrological systems accompanying the stabilization of the sea-level rise and the slowdown**  
800 **of the Atlantic Meridional Overturning Circulation. We also revealed repetitive**  
801 **intensifications of the fluvial discharges, here mainly connected to the hydrological regimes**  
802 **of the Loire River, and showed the links between these latter events and increased winter**  
803 **precipitations during periods of enhanced subtropical gyre dynamics coupled with negative**  
804 **NAO-like modes. Among these events, major ones occurred within the 4–2 ka BP interval**  
805 **with probable repercussions for coastal societies from the Early Bronze and Iron Ages (access**  
806 **to marine food resources in spring, flooding risks during winter). In addition, within the 4–2**  
807 **ka BP interval, the 3.3 ka BP appeared as the establishment of the winter horizontal**  
808 **thermohaline front in the BoBy shelf. Finally, we revealed major soil erosion and primary**  
809 **productivity increase since 1.8 ka BP (Roman Period) and more specifically since 1.2 ka BP**  
810 **(Early Middle Ages).**

811

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823 **data (sedimentological and palynological data) are available as online supplementary material**  
824 **(Data in Brief) or by contacting the first author (aurelie.penaud@univ-brest.fr).**

825

## 826 **8. Table caption**

827 **Table 1:** CBT-CS11 AMS-<sup>14</sup>C dates. In black, dates previously published in Mojtahid et al.  
828 (2018). In bold and red: new dates from ARTEMIS received in March 2019. Grey cells  
829 represent levels averaged for the final age model. Dates in italic (with the annotation « \* »)  
830 were rejected for the final age model (Figure 2).

831

832 **Table 2:** This table gathers CBT-CS11 data discussed in this study and describes the way data  
833 were obtained (methodology) and can be interpreted. It is worth noting that a **Data in Brief**  
834 paper complementary to this study describes multivariate analysis on which some taxa groups  
835 or ratios here listed were established.

836

## 837 **9. Figure captions**

838 **Figure 1: a)** Geographical map of the “HAMOC” database subdivisions (provinces) with the  
839 location of the selected sedimentary records for the HAMOC synthesis (Eynaud et al., 2018;  
840 Ayache et al., 2018) and the additional superimposed studied site CBT-CS11. **b)** Map  
841 illustrating the general surface circulation of the Bay of Biscay (Koutsikopoulos and Le Cann,  
842 1996) and the extent of the Loire and Gironde catchment areas. Are indicated the locations of  
843 the CBT-CS11 core (studied site) and of the other cited cores in the text: VK03-58bis core  
844 (Naughton et al., 2007); A core (Lambert et al., 2019); MD95-2002 core (Zumaque et al.,  
845 2017). Map performed using the online EMODnet Portal for Bathymetry  
846 (<http://www.emodnet-bathymetry.eu/>) and adapted from Mojtahid et al. (2019).

847

848 **Figure 2:** Age model for the CBT-CS11 core. **a)** Age-Depth plot of all dates obtained on the  
849 core allowing to address three main trends in sedimentation rates. The plot is represented in  
850 parallel with: relative sea level (RSL) heights for southern Brittany from García-Artola et al.  
851 (2018), northern Europe (western Denmark) paleo-temperatures as reconstructed by the  
852 Aeolian Sand Influx (ASI) (Goslin et al., 2018), Bond Events as reconstructed through  
853 hematite-stained quartz percentages with stacked North Atlantic Ocean cores (Bond et al.,  
854 2001) and Total Solar Irradiance (TSI; Steinhilber et al., 2009). Blue horizontal bands  
855 represent stacked Eastern European Atlantic Storm Events (Pouzet et al., 2018) while dark  
856 blue vertical lines to the right only point to the southern Brittany paleostorminess record (Yeu  
857 island; Pouzet et al., 2008). The superimposition of both information allows to establish the

858 vertical storm scale also shown in Figures 8 and 9. **b)** Final age model established using the  
859 *Bchron* package in R version 3.5.1. **c)** Cultural subdivisions for western Brittany.

860

861 **Figure 3:** CBT-CS11 palynological data against depth (cm): Diversity indexes (Table 2) are  
862 drawn in blue for dinoflagellate cysts (**a**, in parallel with percentages of the major species  
863 *Lingulodinium machaerophorum*) and in green for pollen assemblages (**c**, in parallel with  
864 percentages of *Quercus* and Total Trees); Concentrations (in linear scale) and fluxes (in  
865 logarithmic scale) for dinocysts (**b**) and pollen grains (**d**). The yellow horizontal band  
866 underlines the atypical elevated signatures (percentages, concentrations, fluxes) of *L.*  
867 *machaerophorum*. A to C horizontal dotted lines consist in the main limits between the four  
868 palynozones discussed in the manuscript. **To the left, all radiocarbon dates are represented in**  
869 **Cal BP with rejected dates in italic-grey and selected dates for age model in bold-red.**

870

871 **Figure 4:** CBT-CS11 palynological data against depth (cm): major taxa occurring with values  
872 higher than 2% in palynological assemblages. **a)** dinoflagellate cyst (dinocyst) and **b)** pollen  
873 assemblages. Palynozones CBT 1 to CBT 5 are shown with CBT 5 being included in the  
874 probably reworked part of the top 60 cm of the studied core (grey band). A to C horizontal  
875 dotted lines consist in the main limits between the four palynozones discussed in the  
876 manuscript. To the left, all radiocarbon dates are represented in Cal BP with rejected dates in  
877 italic-grey and selected dates for age model in bold-red.

878

879 **Figure 5:** Nearshore-offshore dinocyst communities plotted in age (Cal years BP) from  
880 coastal (A core; Lambert et al., 2019; green code: line or full color), shelf (CBT-CS11 studied  
881 core; pink code: line or full color) to full-oceanic (MD95-2002 core; Zumaque et al., 2017;  
882 purple full color) waters in the northern Bay of Biscay. Data are expressed in percentages  
883 considering all dinocyst taxa for *Lingulodinium machaerophorum* percentages **only, and**  
884 **without considering this latter species in the main dinocyst sum for all other taxa percentages.**  
885 Yellow horizontal band underlines the atypical elevated signatures (percentages,  
886 concentrations) of *L. machaerophorum*. A to C horizontal dotted lines consist in the main  
887 limits between the four palynozones discussed in the manuscript.

888

889 **Figure 6:** Long-term Holocene insolation trends at 65°N (Berger and Loutre, 1991) in parallel  
890 with seasonal Sea-Surface Temperature (SST) and Sea-Surface Salinity (SSS) reconstructions  
891 in the north-eastern Atlantic Ocean (MD95-2002 core; Zumaque et al., 2017), as well as

892 qualitative estimates of summer SST South of Iceland (Orme et al., 2018; Eynaud et al.,  
893 2018). North Atlantic SubPolar Gyre (SPG) millennial-scale dynamics (density anomalies at  
894 sub-thermocline depths recorded in the southern Iceland Basin) are based on temperature and  
895 salinity reconstructions of the surface subpolar North Atlantic (Thornalley et al., 2009) and  
896 are compared with  $\delta^{18}\text{O}$  signatures of *Cibicides refulgens* and *Ammonia falsobeccarii* benthic  
897 foraminifera.  $\delta^{18}\text{O}$  SW (Sea Water) for isotope signatures of Northeast Atlantic water masses  
898 (Voelker et al., 2015). ENACW: Eastern North Atlantic Central Waters (P for Polar and T for  
899 Tropical). Yellow horizontal band underlines the atypical elevated occurrences of *L.*  
900 *machaerophorum* (cf. Figure 5). A to C horizontal dotted lines consist in the main limits  
901 between the four palynozones discussed in the manuscript.

902

903 **Figure 7:** Bond Event (BE) curve (Hematite-stained quartz grain percentages; Bond et al.,  
904 2001) in parallel with  $\delta^{18}\text{O}$  acquired on *Ammonia falsobeccarii* benthic foraminifera. From  
905 mean values of both datasets (i.e. locations of the coloured scale), a code based on  
906 positive/negative anomalies has been established in reference with the average of the  
907 considered dataset: Red (less Ice-Rafted Debris: IRD or weaker Sup-Polar Gyre: SPG) *versus*  
908 blue (more IRD or stronger SPG). Grey horizontal bands underline main common periods of  
909 stronger SPG–IRD between both proxies, and blue inserts to the right point to the selected  
910 intervals that will be drawn on Figures 8 to 10, especially representative of the A.  
911 *falsobeccarii*  $\delta^{18}\text{O}$  stronger negative anomalies (Bond events 4, 2 and 1). ENACW: Eastern  
912 North Atlantic Central Waters (P for Polar and T for Tropical). A to C horizontal dotted lines  
913 consist in the main limits between the four palynozones discussed in the manuscript.

914

915 **Figure 8:** Sedimentological (grain-size analyses and Zr/Al XRF ratio) as well as selected full-  
916 oceanic dinocyst data (percentages without *L. machaerophorum* in the main sum, and  
917 concentrations) plotted in age for the CBT-CS11 core, in parallel with NGRIP oxygen  
918 isotopes (Vinther et al., 2006) to the left as well as Bond events (Bond et al., 2001) and Total  
919 Solar Irradiance (TSI; Steinhilber et al., 2009) to the right of the diagram. Note also  
920 additional data from the MD95-2002 slope core (Zumaque et al., 2017): dinocyst-based  
921 summer Sea-Surface Temperature (SST) as well as qualitative major occurrences of *O.*  
922 *centrocarpum* and *S. mirabilis* (depicted in percentages in Figure 5). Blue horizontal bands  
923 are representative of Bond events 4, 2 and 1 from the base to the top of the core. Yellow  
924 horizontal band underlines the atypical elevated occurrences of *L. machaerophorum* (cf.



925 Figure 5). A to C horizontal dotted lines consist in the main limits between the four  
926 palynozones discussed in the manuscript.

927

928 **Figure 9:** CBT-CS11 sedimentation rates and selected palynological data (cf. Table 2), in  
929 parallel with North Atlantic Oscillation (NAO) data as interpreted from the NAO index  
930 (Trouet et al., 2009; Olsen et al., 2012), northern Europe storminess (Goslin et al., 2018; ASI:  
931 Aeolian Sand Influx), and winter Sea-Surface Temperature (SST) in the northern Bay of  
932 Biscay (Zumaque et al., 2017). Blue horizontal bands are representative of Bond events 4, 2  
933 and 1 from the base to the top of the core. Yellow horizontal band underlines the atypical  
934 elevated occurrences of *L. machaerophorum* (cf. Figure 5). A to C horizontal dotted lines  
935 consist in the main limits between the four palynozones discussed in the manuscript. IPC:  
936 Iberian Poleward Current. NAC: North Atlantic Current.

937

938 **Figure 10:** Selected palynological information from the continent (pollen) and marine  
939 (dinocyst) compartments from the CBT-CS11 core exclusively, addressed in parallel with  
940 sedimentation rates and Dinocyst *versus* Pollen ratios (cf. Table 2). Blue horizontal bands are  
941 representative of Bond events 4, 2 and 1 from the base to the top of the core. Yellow  
942 horizontal band underlines the atypical elevated occurrences of *L. machaerophorum* (cf.  
943 Figure 5). A to C horizontal dotted lines consist in the main limits between the four  
944 palynozones discussed in the manuscript. Cf. Figure 2 for cultural subdivisions in full text.

945

946 **Figure 11:** Synoptic approach of main hydrographic and climatic influences that prevailed at  
947 the western French coast scale. Superimposed on the “winter”, “autumn” and “winter” modes  
948 linked with the long-term insolation trend, millennial and infra-millennial mechanisms imply  
949 SubPolar Gyre (SPG) strength coupled or forced by natural atmospheric oscillations such as  
950 the North Atlantic Oscillation (NAO) and solar activity. IPC: Iberian Poleward Current;  
951 ENACW: Eastern North Atlantic Central Water; NAC: North Atlantic Current; SST: Sea-  
952 Surface Temperature.

953

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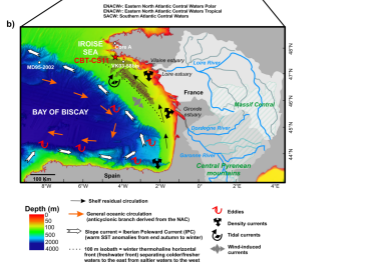
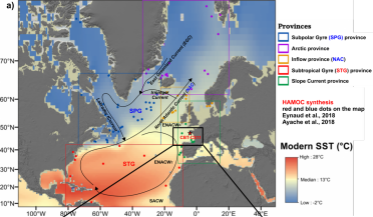
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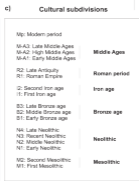
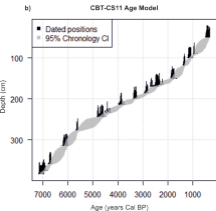
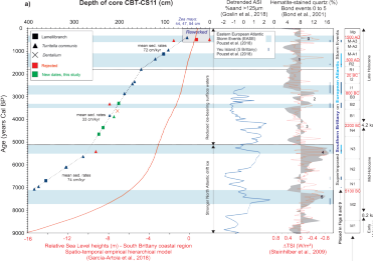
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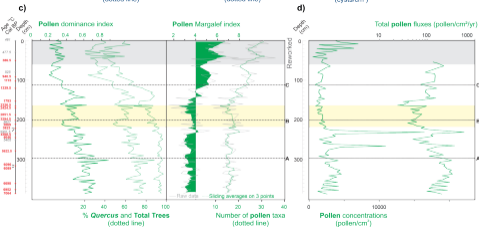
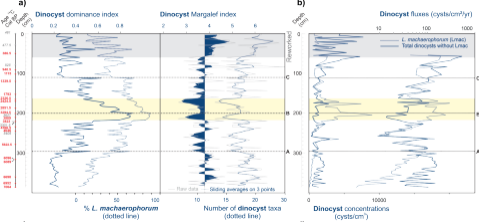
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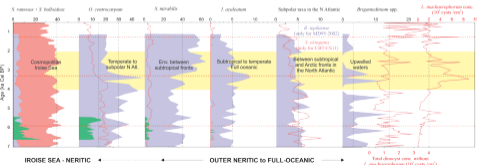
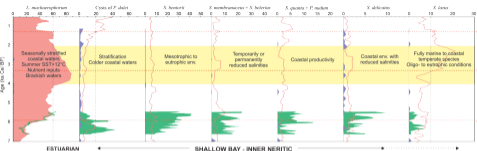








Percentages of dinocyst taxa on a proximal-distal gradient : percentages of taxa represented without *L. machaerophorum* counts in the main sum for A and CBT-CS11 cores



Slope, MD95-2002  
2174m water depth

Shelf, CBT-CS11  
73m water depth

Bay of Brest, Core A  
8.2 m water depth

0 1 2 3 4  
Total dinocyst conc. without  
*L. machaerophorum* (10<sup>7</sup> cysts/cm<sup>3</sup>)

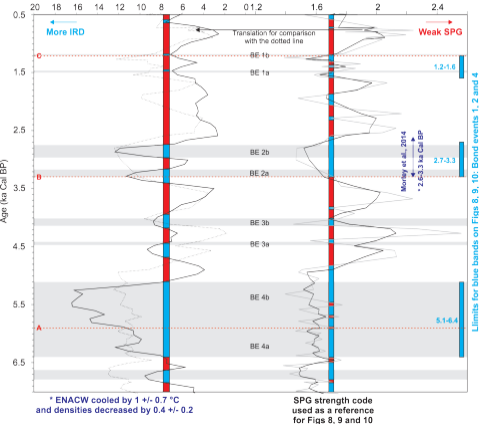


Hematite-stained quartz (%) (Bond et al., 2001)

(black solid line)

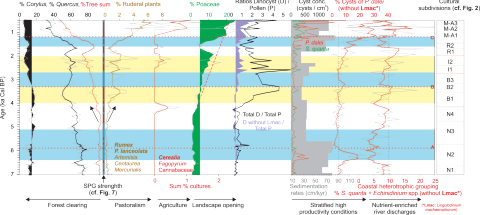
$\delta^{18}O$  (‰) *A. falsobeccarii* (This study)

(black: mobile average on 3 points / grey: all data)





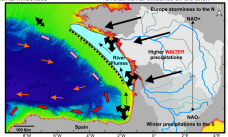
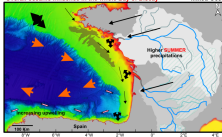




**A) = Summer prevailing mode = (until 5.9 ka BP)**  
**Overall oceanic influence in the whole Bay of Biscay**

**• Autumn mode = (especially 5.9 to 4 ka BP)**  
**Mixed Oceanic-Fluvial Influences**

**B) = Winter prevailing mode = (from 3.3 ka BP)**  
**Overall fluvial influence on the shelf**



#### Orbitally-driven hydrographic changes

**A)**

- Shelf residual circulation : stronger **summer SW-SE** direction and weaker winter SE-NW direction
- Slope current : **less intense IPC** influence to the southern and northern Bay of Biscay

**B)**

- Shelf residual circulation : stronger **winter SE-NW** direction and weaker summer SW-SE direction
- Slope current : **more intense IPC** influence to the southern and northern Bay of Biscay

Oceanic-driven millennial climate changes (superimposed on A) or B) : example with strong SPO on A) (and weak SPO on B) above)



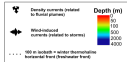
#### Strengthened Subpolar Gyre :

Increased BMACM = Polar = signature in the Boll  
 Intensified northward heat transport through the NAO  
 until the Nordic seas  
 Increased SST South of Iceland (Iringer Current)  
 Northern European storminess (Goslin et al., 2018)  
**NAO+ prevailing configuration**



#### Weakened Subpolar Gyre :

Increased BMACM = Tropical = signature in the Boll  
 Decreased North Atlantic oceanic influence through  
 the NAO recirculation in the Boll  
 Increased winter SST in the NE Atlantic Ocean : stronger IPC (MDS-2002)  
 Decreased SST South of Iceland (Dima et al., 2016 - etc 4-2 ka interval)  
**NAO- prevailing configuration**



Code	Depth (cm)	Sample nature	Age 14C BP	Error	Age min (mean) max Cal BP
<i>SacA41576</i>	0*	<i>Turritella communis</i>	720	30	457( <b>481</b> )505
<i>SacA 32019</i>	29*	Bivalve	715	35	451( <b>477.5</b> )504
<i>SacA 32020</i>	50	<i>Turritella communis</i>	645	30	305( <b>386.5</b> )468
<i>Poz-71200</i>	79*	<i>Turritella communis</i>	820	30	501( <b>525</b> )549
<i>SacA 32021</i>	91	<i>Turritella communis</i>	1340	30	923( <b>940.5</b> )958
<i>SacA38446</i>	101	Bivalve	1505	30	1049( <b>1115</b> )1181
<i>SacA39684</i>	120	<i>Turritella communis</i>	1765	30	1297( <b>1339.5</b> )1382
<i>SacA39683</i>	151	<i>Turritella communis</i>	2180	35	1713( <b>1793</b> )1873
<i>SacA 32022</i>	165	<i>Turritella communis</i>	2600	30	2307( <b>2326.5</b> )2346
<i>SacA38447</i>	170	<i>Turritella communis</i>	2750	30	2360( <b>2424.5</b> )2489
<i>SacA 32023</i>	187	<i>Turritella communis</i>	3080	30	2777( <b>2851.5</b> )2926
<b>SacA55615</b>	<b>200</b>	Bivalve	3410	30	3219( <b>3294.5</b> )3370
<i>SacA 32024</i>	203*	<i>Dentalium</i>	3695	30	3560( <b>3627</b> )3694
<b>SacA55616</b>	<b>210</b>	<i>Turritella communis</i>	3895	30	3834( <b>3869</b> )3904
<i>Poz-71201</i>	220	<i>Turritella communis</i>	3875	35	3720( <b>3823</b> )3926
<i>SacA39682</i>	220*	<i>Turritella communis</i>	3425	35	3218( <b>3301.5</b> )3385
<b>SacA55617</b>	<b>234</b>	Bivalve	4265	30	4288( <b>4366.5</b> )4445
<b>SacA55618</b>	<b>244</b>	Bivalve	4450	30	4565( <b>4646</b> )4727
<i>SacA39681</i>	250*	<i>Turritella communis</i>	4940	35	5345( <b>5405</b> )5465
<i>SacA39680</i>	278	<i>Turritella communis</i>	5205	35	5583( <b>5622.5</b> )5662
<i>SacA 32025</i>	315	<i>Turritella communis</i>	5650	30	5997( <b>6096</b> )6195
<i>SacA38448</i>	316	<i>Turritella communis</i>	5630	30	5995( <b>6089</b> )6183
<i>SacA 32026</i>	360	Bivalve	6200	30	6667( <b>6698</b> )6729
<i>SacA 32027</i>	376	<i>Turritella communis</i>	6415	30	6910( <b>6952</b> )6994
<i>SacA38449</i>	385	<i>Turritella communis</i>	6480	30	6967( <b>7064</b> )7161

**Table 1**



CBT-CS11 data	Figures with data (D for Dinocyst and P for Pollen)	Methodology and/or Interpretation of the signal
<b>Radiocarbon dates</b>	Table 1, Figure 1a	Calibration with the Calib 7.1 software using the calibration curve IntCal13 (Stuiver and Reimer, 1993; Reimer et al., 2013), with a reservoir age of -324 years (Mangerud et al., 2006)
<b>Age model</b>	Figure 2b	Bchron package under the R program version 3.5.1
<b>Palynomorph concentrations Pollen (P) – Dinocysts (D)</b>	Figures 3b (D), 3d (P), 5 (D)	Marker grain method with <i>Lycopodium</i> spores (de Vernal et al., 1999; Mertens et al., 2009): calibrated tablets of known numbers of <i>Lycopodium</i> spores are added to each sample before chemical treatments (Stockmarr, 1971)
<b>Palynomorph fluxes</b>	Figures 3b (D), 3d (P), 9 (P and D)	Multiplication of concentrations (taxa/cm <sup>3</sup> ) by sedimentation rates (cm/kyr), fluxes expressed in taxa/cm <sup>2</sup> /kyr
<b>Dominance index</b>	Figures 3a (D), 3c (P)	Dominance ranges from 0 (all taxa are equally present) to 1 (one taxon dominates the community completely)
<b>Diversity (Margalef) index</b>	Figures 3a (D), 3c (P)	Number of taxa per sample (S) and Margalef's richness index: $(S - 1) / \ln(n)$ , where n is the number of individuals counted in each sample
<b>Major pollen taxa in assemblages</b>	Figure 4b	Pollen percentages are calculated using a main sum excluding <i>Pinus</i> , spores, and indeterminate pollen grains
<b>Major dinocyst taxa in assemblages</b>	Figures 4a (in depth), 5 (in age)	Dinocyst assemblages are described by the percentages of each species calculated on the basis of the total dinocyst sum including unidentified taxa and excluding pre-Quaternary specimens.
<b>Sum <i>O. centrocarpum</i> and <i>S. elongatus</i></b>	Figure 8	Grouping of "North Atlantic subpolar gyre influence" taxa according to Detrended Correspondence Analysis analysis performed on dinocyst communities and other environmental variables (Data in Brief). Percentages calculated without Lmac in the main cyst sum.
<b>Ratio <i>O. centrocarpum</i> over <i>L. machaerophorum</i></b>	Figure 9	Ratio between North Atlantic Current (NAC) tracer and estuarine (Loire) tracer so as to discuss oceanic versus continental influences at the mid-shelf core location
<b>Ratio <i>Corylus</i> over <i>Quercus</i></b>	Figure 9	As trees in general suffer deforestation in parallel with the increase in Poaceae, the ratio <i>Corylus</i> over <i>Quercus</i> makes it possible to highlight the more pronounced/rapid decline of the corylaie
<b>Ratio Dinocyst / Pollen</b>	Figure 10	Marine versus strict continental tracer allowing to address the influence of both compartments (aquatic and terrestrial realms) in the fine sediment deposits of the mid-shelf
<b>Sum <i>S. quanta</i> and <i>Echinidinium</i> spp.</b>	Figure 10	Grouping of "Coastal heterotrophic" taxa according to Detrended Correspondence Analysis analysis performed on dinocyst communities and other environmental variables (Data in Brief). Percentages calculated without Lmac in the main cyst sum.

<b><math>\delta^{13}\text{C}</math> and <math>\delta^{18}\text{O}</math> (‰VPDB) <i>A. falsobeccarii</i></b>	Figures 6, 7	Foraminifera cleaned in a methanol ultrasonic bath for a few seconds, then roasted under vacuum at 380°C for 45 min to remove organic matter. Measurements at the IRMS platform: MAT253 mass spectrometer coupled with a KIEL IV preparation line for benthic species (PSO, Plouzané)
<b><math>\delta^{13}\text{C}</math> and <math>\delta^{18}\text{O}</math> (‰VPDB) <i>C. refulgens</i></b>	Figure 6	Mojtahid et al., 2019. Measurements on the GasBenchII platform (PSO, Plouzané)
<b>D50 CaCO<sub>3</sub>-free grain-size</b>	Figure 8	Mojtahid et al., 2019. Sediment decarbonation with 1 M hydrochloric acid. Laser diffraction particle size analyzer (Malvern™ Mastersizer 3000; LPG-BIAF, Angers)
<b>XRF data : Log (Zr/Al)</b>	Figure 8	Proxy for coarser sediments quartz-sand according to Canonical Correspondence Analysis conducted on XRF data

**Table 2**