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HAL Authorization

1 **Sedimentological and dendrochronological indicators of coastal storm risk in western**  
2 **France**

3

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10 **Abstract**

11 This paper compares results from two different environmental methods to observe past storm  
12 impacts: the back coastal barrier stratigraphical and dendrochronological archives. With a  
13 detailed historical database of the past 50 years storm observations, we discuss the  
14 combination of results from these two methods in a coastal study located in western France.  
15 The study shows that neither tree ring nor sedimentological results build a complete storm  
16 chronology by themselves. However, the combination of the two is sufficient to detect the  
17 strongest storms, which caused marine flooding. Comparing them with an accurate impact of  
18 storm chronology, extracted from written sources to test their robustness, we show that the  
19 combination of these two approaches offer a complete dataset. From this exhaustive historical  
20 sequence ranging from 1955 to 2016, three winters with major storms are highlighted in  
21 Traicts du Croisic: 1990, 1978 and 1972. Combining dendrochronology and sedimentology  
22 therefore enables a better understanding of extreme storm occurrences.

23

24 **Keywords:** Atlantic coast, extreme events, environmental indicators, ecological damages.

25

26 **Highlights**

27 Dendrochronology detects storm events using a tree-ring disturbance analysis.

28 Sedimentological indicators identify extreme events with marine flooding.

29 Coupling the two proxies is a powerful tool to characterize coastal extreme events.

## 30 **1. Introduction**

31 Documenting past storm impacts on coastal environments is a methodological challenge. This  
32 challenge must be based on the analysis of various indicators and their combination to ensure  
33 accuracy in reconstructing the extreme environmental parameters creating these disturbances.  
34 Several methods were used in scientific literature (reviews in Chaumillon et al., 2017; Goslin  
35 and Clemmensen, 2017). Many indicators, such as speleothems (e.g. Frappier et al., 2007;  
36 Zhu et al., 2017), cliff top deposits (e.g. Dewey and Ryan, 2017; Hall et al., 2006; Hansom  
37 and Hall, 2009), corral (e.g. Gardner et al., 2005; Hongo, 2018; Scoffin, 1993) and diatom  
38 (e.g. Nodine and Gaiser, 2015; Stager et al., 2017) survival or disappearance, detection of  
39 marine intrusions into a back-barrier sedimentary sequence with the buildup of washover fan  
40 (e.g. Feal-Pérez et al., 2014; Liu and Fearn, 2000; May et al., 2017; Naquin et al., 2014; Wang  
41 and Horwitz, 2007), have enabled the detection of past meteorological disturbances. Another  
42 biogeographical approach, dendrochronology, can be used to document past storms from the  
43 tree-ring disturbance it encounters during its lifespan (Schweingruber, 1996; Speer, 2012). To  
44 complete the results from the sedimentological and dendrochronological approaches,  
45 historical archives of storms were consulted, adding exhaustive and precise information on  
46 past storms (Garnier et al., 2017; Gottschalk, 1977; Hickey, 1997; Lamb and Frydendahl,  
47 1991; Lamb, 1995).

48 This study seeks to highlight the combination of results from washover detection into a  
49 sedimentary sequence and a dendrochronological approach. Stratigraphy in washover context  
50 has often been used to document and date past storms (e.g. Bregy et al., 2018; Donnelly et al.,  
51 2004; Kenney et al., 2016; Liu and Fearn, 1993; Sabatier et al., 2008); in the context of  
52 violent winds, dendrochronological studies are rare. Tree-ring approaches have seldom been  
53 used in coastal environments; sea-shore erosion quantification and survey is then the main  
54 interest, analyzing exposed roots (Rovera et al., 2013), as was done along mountain torrents  
55 (Gärtner, 2007; Gärtner et al., 2001; Hitz et al., 2008), gullies (Malik, 2008) or along rivers  
56 (Begin, 1990; Begin et al., 1991). Other tree-ring approaches were used recently to  
57 reconstruct past climatic variations, mostly with chemical indicators (Berkelhammer and  
58 Stott, 2011, 2008; Brienen et al., 2012). The disturbance of tree-ring patterns to reconstruct  
59 storms is seldom in international literature: one study identified past hailstorm marks using  
60 damage made in tree trunks (Hohl et al., 2002), and few others studied records of ice storms  
61 (Lafon and Speer, 2002; Olthof et al., 2003; Travis and Meentemeyer, 1991). Here, in the  
62 absence of coastal erosion and exposed roots, we focus on tree stems and adapt the tree-ring

63 method previously used for geomorphic processes on slopes (e.g. Decaulne et al., 2014, 2012;  
64 Martin and Germain, 2016). Based on reports of forest damage from strong winds, tree  
65 stability may be affected in a similar way to a snow avalanche over a short period of time  
66 (Everham and Brokaw, 1996).

67 We focus on the storm reconstruction of the last 50 years based on these two indicators;  
68 results are compared with historical data for each of the indicators used. We then discuss the  
69 relevance of dendrochronology and sedimentology using historical proxies, and finally  
70 question the relevance of the combination of the two methods.

## 71 **2. Study area**

72 The western coast of France is an important storm - crossed area (Chauveau et al., 2011;  
73 Feuillet et al., 2012). The selected study site is located in the central Pays-de-la-Loire region:  
74 Traicts du Croisic and the nearby Pen Bron forested dune. This area is characterized by its  
75 high morphogenic activity coastal marsh (Fig. 1), which is separated from the sea by a sandy  
76 barrier and is ideal for detecting recent storms (Baldock et al., 2008; Pierce, 1970; Switzer  
77 and Jones, 2008; Zecchetto et al., 1997). The highest tidal ranges are from 6 to 7 meters  
78 (Service Hydrographique et Océanographique de la Marine). With protecting dunes reaching  
79 nearly 10 m asl, only storms which were concomitant to the high tide can be observed (Le  
80 Roy et al., 2015). The selected study site is exposed to western winds (from SW to NW) and  
81 marine flooding. This specific area was selected as the back barrier coastal depositional  
82 environment has been preserved from anthropogenic activities over the last 300 years, as  
83 highlighted in a GIS chronological analysis based on IGN (French National Geographic  
84 Institute) data, together with an historical and topographical study map that identified the  
85 urban evolution and landscape changes (with the method extracted from Pouzet et al., 2015).  
86 A few kilometers northward, dendrochronological analyses were also carried out from the  
87 *Pinus pinaster* forest in the Pen Bron dunes (Fig. 1). Precise coordinates of each  
88 dendrochronological and sedimentological core can be found in Table 1.

89

## 90 **3. Material and methods**

### 91 **3.1. Historical data**

#### 92 **3.1.1. Meteorological archives: determining storm occurrence**

93 To rebuilt a chronology of storms that have crossed the study area, historical documents were  
94 consulted: (i) documents from libraries and archives, (ii) narrative sources (chronicles, diaries,  
95 memoires etc.), and (iii) old maps. These documents contain observational and descriptive  
96 data on past extreme weather occurrences, useful to estimate the intensity of each recent  
97 event. However, before being used to reconstruct the storms and sea flooding chronology over  
98 the last seven decades, this data was analyzed and evaluated. The reliability of a written  
99 document is evaluable on the basis of (i) the witness statement by the author and (ii) the  
100 institutional framework of the evidence record (Athimon et al., 2016; Athimon and Maanan,  
101 2018, submitted). Moreover, it was necessary to inspect testimonies with several sources. The  
102 aim was to have a more precise and exhaustive record of each event within a precise temporal  
103 and spatial frame.

104 We also considered records from instrumental installations such as meteorological data  
105 collected by Meteo France for the period (within the study area). On the Meteo France storm  
106 report website <http://tempetes.meteofrance.fr/>, numerous details about recent storms are  
107 available. However, this data is limited: the website provides accurate information about well-  
108 known storms only. Therefore, storms that have severely impacted the country, but that were  
109 not significant at a regional scale, are not documented there. Thus, we had to consult more  
110 accurate sources, such as local archives. The detailed historical investigation, bearing in mind  
111 the reliability of all documents, is needed in combination with other digital sources to obtain  
112 the most accurate chronology possible.

### 113 **3.1.2. Reanalysis data to accurately reconstruct recent wind conditions**

114 The HOMERE © database was analyzed (Boudiere et al., 2013) using the WAVEMATCH III  
115 (v. 4.09) model. This reanalysis enabled the reconstruction of windy conditions over recent  
116 years, complementing the wind data extracted from weather database (Meteo France). After  
117 selecting a mesh located a hundred meters offshore of the study area, we extracted all wind  
118 and wave data with MATLAB ©. The database provides hourly mean wind direction and  
119 speeds for the 1994 – 2012 period, calculated from *uwnd* (eastward wind) and *vwnd*  
120 (northward wind) raw data. It was used to statistically detect the windiest years, and to note  
121 the years where the most south-western winds were observed as standing trees are mostly  
122 tilted by south-western winds, and to extract the years where the highest number of hourly  
123 devastating winds are modeled.

### 124 **3.2. Sedimentological record of storms**

125 Extracting cores from Traicts du Croisic back barrier coastal marsh, as close as possible to the  
126 Pen Bron dune barrier, offers a sedimentological record of the coastal marshes' recent  
127 development (Pouzet et al., 2018, submitted). The morphology of lacustrine sediment layers  
128 differs from the ones received from marine conditions, seen as allochthonous layers within the  
129 cores (Baumann et al., 2017; Chaumillon et al., 2017; Das et al., 2013; Liu, 2004; Orme et al.,  
130 2015; Sabatier et al., 2010, 2008). A method enabling the characterization of sediment  
131 parameters was set. Three sediment cores, 50 mm in diameter and a maximum of 100 cm  
132 long were extracted with an Eijkelkamp © gravity corer in August 2016; the position of each  
133 core was localized with a Trimble Differential Global Positioning System (DGPS). All  
134 locations were tied to IGN benchmarks and levelled with respect to the NGF datum. Cores  
135 were first longitudinally sliced, photographed and described. Then, the Avaatech© XRF core  
136 scanner was used to carry out high-resolution elemental analyses of the split sediment cores.  
137 Element intensities, normalized by the total intensity (count per second of each spectrum:  
138 cps); and element ratios were calculated (Bouchard et al., 2011; Chagué-Goff, 2010; Martin et  
139 al., 2014; Sabatier et al., 2012). The Scopix© system was used to take X radiographs to  
140 precisely describe the sedimentology of the three cores (Migeon et al., 1998), commonly  
141 used to identify finer washovers, shells or pebbles within the invisible part of the core into  
142 several studies (e.g. Coor et al., 2009; Sabatier et al., 2012; Scott et al., 2003). Colorimetric  
143 analyses estimated the lightness of sediments with a Minolta© Cm-2600d spectrometer  
144 (Debret et al., 2011; Polonia et al., 2013) as Mix et al., 1995 demonstrated a positive  
145 correlation between lightness and carbonate content. A MS2E-1© Bartington-type measured  
146 the magnetic susceptibility (MS) of each centimeter for a magnetic oxide and clay detection  
147 (Bloemendal and deMenocal, 1989; Wassmer et al., 2010), a proxy previously used with  
148 success in some paleoclimatic studies (e.g. Begét et al., 1990; Buynevich et al., 2011; Roy et  
149 al., 2010). For a grain size analysis (mean grain size : MGS), the main proxy used in most of  
150 storminess reconstructions (e.g. Chaumillon et al., 2017; Eden and Page, 1998; Liu and Fearn,  
151 1993; Noren et al., 2002), measured by a Malvern Mastersizer 2000© laser beam grain sizer  
152 (Parsons, 1998; Yu et al., 2009), sediment cores were sampled every 1 cm, and every 0.5 cm  
153 for dating.

154 Once layers are characterized as marine, dating them is essential, in order to associate them  
155 with stormy conditions in the second step. Dating was established from a combination of two  
156 short-lived radionuclides: lead ( $^{210}\text{Pb}$ ) and cesium ( $^{137}\text{Cs}$ ) isotopes (Hippensteel and Martin,  
157 1999; Lima et al., 2005; Sabatier et al., 2008). The first is a naturally-occurring radionuclide

158 rapidly incorporated into the sediment from water column scavenging and atmospheric fallout  
159 ( $T_{1/2} = 22.3$  years).  $^{137}\text{Cs}$  ( $T_{1/2} = 30$  years) is an artificial radionuclide related to the  
160 atmospheric nuclear weapons tests in the early sixties (maximum near 1963 in the northern  
161 hemisphere) and to the Chernobyl accident in April 1986. Activities of  $^{210}\text{Pb}$  and  $^{137}\text{Cs}$  were  
162 determined at the University of Bordeaux on 3-4 g of dried sediment by gamma spectrometry,  
163 using a well-type, high efficiency low background  $\gamma$  detector equipped with a Cryo-cycle  
164 CANBERRA © (Pouzet et al., 2018, submitted).

### 165 **3.3. Dendrochronology**

166 In order to find the most appropriate trees, we first used reanalysis data to identify the areas  
167 with the highest winds (Fig. 2). During the 1994 – 2012 period, the wind direction was mainly  
168 from south and south west, with the strongest mean wind from the south west. This area is  
169 dominated by high south-westerly winds, corresponding with the visual observations made in  
170 the field, as most of disturbed trees are inclined in an SW-NE axis. From a historical map  
171 study, we then identified the location of the oldest trees in the area. In the selected site, we  
172 finally identified selected seventeen trees to core, including a high proportion of SW-NE  
173 disturbed trees.

174 Trees exposed to high winds develop specific tree-ring patterns (Schweingruber, 1996), as  
175 they do when impacted by other geomorphic processes: stormy years show a significantly  
176 wider tree-ring expressed as compression wood as the species investigated here is mostly  
177 composed of *Pinus pinaster* (Fig. 3B).

178 To identify the stormy years during the lifespan of the trees, twenty disturbed *Pinus pinasters*  
179 were sampled with a Mattson© corer following classical dendrochronological methods  
180 (Grissino-Mayer, 2003). Trees presenting tilting and located at the fringe, closer to the sea  
181 were selected and sampled at breast height. A standard Global Positioning System (GPS) was  
182 used to precisely position the selected trees. Sampling was made throughout the entire  
183 thickness of the trunk, in the disturbance direction (mostly from south-west, see Table 1) to  
184 encompass the axes where the largest dissymmetry is expected (full expression of  
185 compression wood). Following dendrochronological preparation guidelines (Speer, 2012),  
186 samples are dried at room temperature over two weeks inside the protective plastic pipes they  
187 were placed in at the sampling stage; then samples are mounted on wood supports and sanded.  
188 A fresh scalpel cut was also done before measuring ring widths on the Lintab Rinntech©

189 platform at LETG laboratory. TsapWin© software enabled measurements and gave a precise  
190 chronology of all tree sampled.

191 To fit the tree growth pattern, we considered successive vegetative and dormancy seasons as  
192 one year, i.e. March to October as the vegetative season, and November to February as the  
193 dormancy season. Any disturbance (e.g. tilting during an excessive wind event) experienced  
194 by a tree during its dormancy phase will be visible within the formation of the next tree ring  
195 during the following vegetative season : during the vegetative season, the tree-ring cells will  
196 organize to counterbalance the stress from the dormancy period, i.e. by producing  
197 compression wood, visible through an asymmetric growth (cells produced on the face  
198 exposed to the stress will be smaller than those on the opposite face, which will be much  
199 larger than during a normal growth). A complete tree season, called “tree year”, is from  
200 November of the calendar year n-1 to October of the calendar year n.

201 To detect wind disturbance axes, a precise comparison is made between tree-ring widths  
202 (TRW) of asymmetric radiuses C and D of all trees sampled (Fig. 3C). Before extracting  
203 growth disturbances and identifying years with increasing growth values in C, concomitant to  
204 a decrease in growth values in D visually, we first have to calculate an evolution rate between  
205 each tree year mathematically as follows:

$$206 \quad GE = (TRW_n - TRW_{n-1}) / TRW_{n-1} * 100$$

207 *Where GE is the growth evolution, TRW<sub>n</sub> is the tree-ring width at year n and TRW<sub>n-1</sub> is tree-*  
208 *ring width at year n-1.*

209 From a double visual and mathematical analysis, a disturbed year that experienced stress is  
210 considered when:

211 - The width of the tree-ring decreases in C by at least -25% from the previous year value,  
212 together with an increase of D radius (GE of C radius < -25, and GE of D radius > 0);

213 - The width of the tree ring increases in D radius by at least +25% from the previous year  
214 value, together with a decrease of the C radius (GE of D radius > 25, and GE of C radius < 0).

215 In cases of successive disturbed years, only the first year of disturbance is taken into account  
216 as the tree might react to a disturbance for several years (Schweingruber, 1996). A year is  
217 recognized as significant if at least two trees react, in a minimum of five living trees (25% of  
218 the number of trees sampled) i.e. from 1955. These criteria set the dendrochronological  
219 chronology into a temporal scale starting in November 1955 and ending at the last vegetative

220 year of the samples, i.e. October 2016. For each year of the chronology, an index of storm  
221 disturbance (ISD) is calculated to estimate the impact of one storm or a series of storms  
222 during a year, as follows:

$$223 \quad \text{ISD}_n = (DT_n * 100) / LT_n$$

224 *Where ISD<sub>n</sub> (as a percentage) is the Index of Storm Disturbance of the year n, DT<sub>n</sub> is the*  
225 *number of disturbed trees during the year n and LT<sub>n</sub> is the number of living trees during the*  
226 *year n.*

227

## 228 **4. Results**

### 229 **4.1. Marine occurrences from sedimentological archives**

#### 230 **4.1.1. Dating of Traicts du Croisic sequences**

231 <sup>210</sup>Pb profile of Traicts du Croisic (TC) core is classic, with decreasing activity reaching  
232 negligible levels below 20 cm (Fig. 4). A mean sediment accumulation rate of 0.24 cm yr<sup>-1</sup>  
233 was estimated, used to extrapolate ages by assuming that the mean sedimentation rate was  
234 constant for horizons beyond the timescale covered by <sup>210</sup>Pb. The sedimentary <sup>137</sup>Cs profile  
235 helped to estimate that the <sup>210</sup>Pb chronology ranges from 1916 AD (Anno Domini) ± 13 years  
236 to 2016 AD: <sup>137</sup>Cs activities disappear below the deep “nuclear weapons tests” peak at about  
237 12-13 cm, in 1963 according to <sup>210</sup>Pb dating. The 1986 Chernobyl accident can also be  
238 estimated with a small rebound of the <sup>137</sup>Cs curve at 7 cm depth from <sup>210</sup>Pb dating (Lomenick  
239 and Tamura, 1965; Ritchie and McHenry, 1990; Walling and He, 1999). To fit the  
240 dendrochronological chronology, which goes no further than 1955 AD ± 8 years, the  
241 sedimentological dating assessment goes no further than 15 cm depth in this study.

#### 242 **4.1.2 Allochthonous marine layers detection**

243 Cores, drilled in a coastal back barrier environment, present an original clayey-silty context,  
244 with small grain sizes, low values of lightness and a high magnetic susceptibility. Terrestrial  
245 elements such as Iron (Fe) or Titanium (Ti) are significantly more dominant than marine  
246 elements (Strontium: Sr or Calcium: Ca). Consequently, in a back barrier type sequence, low  
247 ratios of Sr/Fe and Ca/Ti must be identified. A marine intrusion into this environmental  
248 condition must leave evidence such as high values of mean grain size (with sands),  
249 geochemical ratios, lightness and a low magnetic susceptibility (Chagué-Goff et al., 2017;

250 Coor et al., 2009; Lu and An, 1998; Mix et al., 1995; Peng et al., 2005; Roy et al., 2010). The  
251 post-1955 layers are encompassed within the upper 15 centimeters of the three cores (Fig. 4).

252 We reported in core TC1 a unique marine intrusion at 9 cm depth with a high increase of  
253 MGS passing from 110 $\mu$ m to 180 $\mu$ m, two geochemical increases from 0.1 to 0.2 Sr/Fe and 8  
254 to 20 Ca/Ti, a (high starting of lightness increase) and a state of neutral to low MS. The  
255 Scopix image also shows the coarse sandy incursion. Dating assesses this layer to be 1977 AD  
256  $\pm$  3 years. A second marine incursion hypothesis was rejected at 11 cm depth because  
257 geochemical indicators are stable despite a high MGS increase, rendering the marine origin of  
258 these sediments uncertain. In TC2, one incursion is also reported at nearly 11 cm depth for a  
259 storm in 1972 AD  $\pm$  4 years. This layer marks the beginning of a high increase of MGS (from  
260 20 to 90 $\mu$ m), and a slight Sr/Fe increase from 0.2 to 0.3, an increase of lightness and a hollow  
261 in the MS curve. In TC3 core, sediments are less sorted, and a high variation in MGS is  
262 observed. Two certain marine intrusions are extracted at 6 and 11 cm depth, dated as 1990  
263 AD  $\pm$  2 year and 1972  $\pm$  4 years. The first layer shows a high MGS, Sr/Fe, and lightness  
264 increases respectively from 50 to 270 $\mu$ m, 0.05 to 0.1 and 47% to 48% with a low MS level.  
265 The second layer is identified at 11 cm depth: despite high MGS starting within the upper  
266 unit, the accurate geochemical and Scopix proxies respond with a double Sr/Fe and Ca/Ti low  
267 increase, and a fall of MS. We identify clearly in the Scopix image a *Venerupis decussata*  
268 shell, typical of a marine environment. At 13 cm depth, we observed a high MGS increase,  
269 which probably do not correspond to a marine occurrence as all other proxies do not follow  
270 MGS.

#### 271 **4.1.3 Correlation of stormy sedimentological signatures with historical written records**

272 From the analyses of sediments retrieved from the back barrier coastal marsh area, three main  
273 post-1955 dates point out potential overwashes in 1972, 1977 and 1990. Historical records  
274 show all three dates correspond either to one strong storm event (February 13, 1972) or to a  
275 series of storms (December 2, 1976 and January 11, 1978; January 25, 1990 February 2, 1990  
276 and February 26, 1990) crossing the area during the winter, causing severe damage. During  
277 the three recorded events a high tide coefficient was recorded, contributing to the deposition  
278 of the marine layer observed.

279 During the February 13, 1972 storm, maximum wind speed was recorded up to 172 km/h in  
280 western France; damage included uprooted trees, broken steeples, toppled cranes, destroyed  
281 dikes, damage to boats and roofs (<http://tempetes.meteofrance.fr/Tempete-du-13-fevrier->

1972.html; Municipal Archives, Nantes, 1038 W 327; Departmental Archives of Vendée, 78/31 1953-1975 – tempête du 13 février 1972). Starting on the 13 December of 1972, it mostly hit western France over three days, with a tide coefficient of 75 to 100 at Le Pouliguen harbor, located two kilometers south of Traicts du Croizic (according to the Service Hydrographique et Océanographique de la Marine). Many coastal floods and nearly 30 deaths and fatalities were recorded.

The second date derived from the sedimentological analyses is 1977. From historical archives, two different events correspond: December 2, 1976 and January 11, 1978. In the first case the tide coefficient was very low, ca. 50; in the second event it reached 109 (SHOM). The second date is therefore more likely. With ten deaths and fatalities reported, the early 1978 storm crossed a large part of the country as damage was reported from Dunkirk (500 kilometers northward) to the Gironde estuary (200 kilometers southward), with numerous shipwrecks and marine flooding (Le Marin 1595, MetMar 101). During the same storm “*numerous houses have been blown away by sea waves*” and several storm surges were reported in eastern England, where the storm was much more mediatized and wind records reached more than 130 km/h (Steers et al., 1979). While historical sources mentioned uprooted trees and devastated buildings in many parts of the country, no maximal wind speed is documented in France.

Finally, in 1990, three different storms crossed the study area causing widespread damage, including a high tide coefficient: in February 26-28, 1990, a 104 tide coefficient (SHOM) was recorded. The successive storms caused 100 fatalities over the whole country, with winds reaching 176 km/h maximum in western France; many flooded houses and broken dikes were reported (<http://tempetes.meteofrance.fr/Daria-le-25-janvier-1990.html>, <http://tempetes.meteofrance.fr/Herta-le-03-fevrier-1990.html>, and <http://tempetes.meteofrance.fr/Viviane-du-26-au-28-fevrier-1990.html>; Municipal Archives of Nantes, 23 Z 355; 24 PRES 152, 05/02/1990 and 24 PRES 152, 27 and 28/02/1990; Departmental Archives of Vendee, 1856 W 38).

## 4.2. Storm detection using dendrochronology

### 4.2.1 Tree Ring Width analysis

From the twenty trees sampled, seventeen present readable cores enabling the creation of a robust chronology. On the three eliminated cores, the latewood boundary and the next earlywood were not clearly separated, possibly due to the lack of harsh winter at the study site, which benefits from a pronounced temperate maritime climate. The TRW analysis

314 highlights a number of years with wood reaction formation (Fig. 3C). Several years were  
315 disregarded as they concern only one tree (Fig.6). From this chronology, the temporal  
316 distribution of growth disturbances, i.e. the onset of growth eccentricity (corresponding to the  
317 unequal growth of the tree along the main axis C-D, i.e. tilting of the tree), and strong growth  
318 disturbances in relation to the stated criteria is revealed (Fig. 5). Numerous tree years have  
319 been disturbed since 1955. Depending on their location within the stand, trees show a high  
320 variation of the response-year occurrence. For example, tree PB05 is located on the SW-NE  
321 edge of the stand (Fig. 1) and shows 13 response years over the 61 year period, providing a  
322 return period of impacts due to storms of 4.7 years. On the other hand, sample PB10, which  
323 was less exposed and located further inside the stand with a S-N orientation (Table 1, Fig. 1),  
324 recorded only one major disturbance at the sampling height. On the whole, the most exposed  
325 trees to southwestern, south-southwestern or west-southwestern high winds located at the  
326 edge of the stand are the most exposed, as shown by the strongly impacted samples. This  
327 observation is in accordance with the main trajectories of extratropical storms, coming from a  
328 south-western direction in southern France and from a western direction in north-west France  
329 (Lozano et al., 2004); in the study area, the highest winds mainly come from a SW direction  
330 (Fig. 2). Over the 61 years covered by dendrochronology, 19 years present strong evidence of  
331 growth disturbance in at least two trees. According to these results, a mean return period of  
332 strong winds, or storms, is assessed to be 15.6 years at the study site (Fig. 5).

333 With an ISD of 33%, the 1965 tree year (from November 1964 to October 1965) is the most  
334 impacted, with only 6 trees alive at this time (Fig. 5, Fig. 6). Another significantly impacted  
335 tree year is 1998, with nearly 30% of the 17 pines sampled showing clear signs of responses  
336 according to the identification criteria. Those showing more than 20%, 1977 (12 living trees),  
337 2002, 2007 and 2014 (17 living trees) are also strongly impacted. 2009, 2013 (17 living trees)  
338 and 1978 (13 living trees) are considered as significant stormy years too. Other years with a  
339 lesser impact on trees are 1983, 1986, 1987, 1989, 1990, 1996, 2004, 2006, 2012 and 2016.,  
340 Several years were disregarded as they did not fulfill the established criteria. Finally, since  
341 1955, data shows that as much as 83% of storms recorded in the chronology derived from  
342 tree-ring analyses occurred during the three winter months (December, January and  
343 February).

#### 344 **4.2.2 Correlation of dendrochronological results with historical data**

##### 345 *4.2.2.1 A clear correlation between tree disturbances and storm occurrence*

346 Dendrochronological results were compared with written storm records (Table 2). A clear  
347 correlation can be observed between impacted tree years and storm occurrences in the study  
348 area. Correlations were considered positive if an historical stormy year (year with at least one  
349 reliable historical storm record) corresponds to an impacted tree year, as described in the  
350 dendrochronological method. First of all, we observed that each impact tree year is correlated  
351 with at least one known storm passing through the study area, except in 2002. On the whole,  
352 during the 61 years of the dendrochronological study, 50 years (80%) show a good correlation  
353 with storm records. We also reported six years (10%) of uncertainties due to a lack of precise  
354 recorded information about the wind impacts reported in the study area. The six other tree  
355 years show no correlation between dendrochronological results and storm reports: 1967,  
356 1972, 1980, 1999 and 2000 are not revealed within the tree-ring patterns even though  
357 impacting storms were reported, and 2002 shows tree-ring patterns when no storm was  
358 reported.

359 Tree-ring results are compared with reanalysis data. The highest winds observed for eleven of  
360 the twelve years from 1994– 2012 (Table 2) correspond to storm records (Fig. 7). 2007 is the  
361 only year with high wind records not correlated to any storm. The main wind direction during  
362 these extreme records is SW-NE; which is also the main direction of tilting in trees sampled  
363 in the study area. Therefore, we consider it highly probable that growth disturbances observed  
364 in the trees sampled were produced by storms during the period 1994-2012. From these  
365 positive results, we can extrapolate that earlier growth-disturbance signals are also due to  
366 storm occurrences. We consider dendrochronology a good proxy to reveal past storm  
367 occurrences.

#### 368 *4.2.2.2 Understanding absences of correlations*

369 Reanalysis data was also used to understand the apparent absence of correlation between the  
370 tree-ring analyses and historical data of storm occurrences. The annual study of wind speed  
371 and direction (Fig. 8) and the study of the highest wind speed records (Fig. 9A and B) over  
372 the period 1994-2012 are combined with Meteo France data available for the period 1955-  
373 2016.

374 Tree-ring data reveal growth disturbances in 2001-2002 when no storm was recorded (Fig. 6,  
375 Table 2). Reanalysis data shows that this growth disturbance follows two years of strong  
376 winds (Fig. 8). Years 2001 and 2002 were the two windiest years without storms, with an  
377 annual mean wind speed of almost 20.5 to 21 km/h. Years 1998 and 2012 were very windy

378 also, recording high wind speeds and storms (Fig. 7, Fig. 9A and B), influencing the annual  
379 wind speed average. Altogether, the cumulative winds in 2001 and 2002, with a prevailing  
380 SW wind, may have impacted the trees and contributed to their tilting, creating a durable  
381 growth disturbance that also extended over the 2002 tree ring.

382 Another type of non-correlation appeared during the years 1999 and 2000: despite a series of  
383 impacting storms (especially in 2000), no major disturbances appear in tree-ring patterns (Fig.  
384 6, Table 2). These well documented events, including the Lothar and Martin severe storms are  
385 highlighted too in the reanalysis data: high values of extreme winds were oriented to be  
386 recorded in the study area (Fig. 7, Fig. 9B). In the winter of 1998, high annual mean wind  
387 speeds (Fig. 8) with intense and extreme wind speeds were encountered (Fig. 9A and B).  
388 Three devastating storms crossed the study area in 1998 (Table 2). The year 1998 is clearly  
389 recorded in the tree-ring patterns; the following years 1999 and 2000 might not have recorded  
390 the disturbances as tree-ring development was still suffering from the 1998 impacts that lasted  
391 over a few growth seasons, as described by Schweingruber (1996).

392 Three more years, 1967, 1972 and 1980, do not show correlations between tree-rings and  
393 written sources (Fig. 6, Table 2). The timing of these stormy seasons does not fit with the  
394 period covered by the reanalysis data. However, Meteo France storm database enabled the  
395 extraction of the maximum wind speed record maps (Fig. 10) for each known storm  
396 (<http://tempetes.meteo.fr/Tempete-du-12-mars-1967.html>, <http://tempetes.meteofrance.fr/Tempete-du-13-fevrier-1972.html>,  
397 <http://tempetes.meteo.fr/Tempete-du-15-decembre1979.html>). The storms of February 13, 1972 and December 15, 1979 present maximum instant  
398 wind from NW to SE; this is the opposite to the core extraction from trees, oriented SW-NE:  
399 these storms have not left disturbances in the core extracted, therefore are invisible from the  
400 dendrochronological approach. Regarding the March 13, 1967 event, its orientation was  
401 mainly W-E; despite the limited information available regarding this storm, only one tree  
402 showed changes. However, only a few of the tree samples go back to this period, and those  
403 living then were young and therefore more flexible and wind resistant.  
404

405

## 406 **5. Discussion: What is the value of combining sedimentological and dendrochronological** 407 **results?**

408 Independently, sedimentological and dendrochronological methods exhibit the dating of some  
409 very destructive storms and their impacts on a back barrier coastal marsh and on trees, in a

410 specified area. The sedimentological study shows some of the strongest marine flooding  
411 reported in Traicts du Croisic, and the tree-ring analysis offers an overview of the occurrence  
412 of the windiest storms at a forest scale. A high wind storm crossing at low tide or during a low  
413 tide coefficient day will not be recorded in the sedimentological archives but can be found in  
414 tree-ring patterns (this can be questioned for the 1998 stormy year). Conversely, a small  
415 depression crossing at a maximum tide coefficient during high tide with light winds reported  
416 can produce washover without creating major disturbances in tree-ring patterns, and this is  
417 one of the last remaining questions for the 1972 hypothesis. The crossing of a storm  
418 producing very high winds and widespread marine flooding may be the only hypothetical  
419 correspondence between the two methods, as this study shows for the 1990 events.

420 This study shows that this precise scenario may have only appeared three times during the last  
421 61 years. The winter of 1989-90 data showed a major disturbed season from both proxies,  
422 and in meteorological archives. With more uncertainties in the sedimentological and  
423 meteorological sources, 1978 is also interpreted as a storm-year in both proxies. However, the  
424 possible confusion regarding the precise sedimentological year crossing two possible storms  
425 (December 1976 and January 1978), and the lack of wind speed details do not enable a clear  
426 interpretation. In 1972, the combination of proxies is not robust either: significant marine  
427 flooding is found in numerous cores; the dendrochronological signature is lacking as this  
428 storm caused mainly northwesterly high winds, i.e. perpendicular to the cores extracted from  
429 trees. Historical sources reveal that the 1972 event was very destructive. Data from the two  
430 methods complement one another by identifying different types of impacts from an extreme  
431 wind event.

432 The availability of valid historical data remains crucial, enabling the understanding of events  
433 extracted from tree-ring analyses. The main limit in tree-ring research is its potential  
434 destructive impact: in order to avoid felling most of the trees on the back dune, only cores are  
435 extracted from trees depending on the direction of their tilt, which reflects the most accurate  
436 impact of the winds on the trees. The observation of these cores does not reveal events  
437 originating out of the main tilting direction, which might have had a strong impact on tree-  
438 ring patterns. Although most of strongest storm winds of the study area come from the SW,  
439 some storms hit the area from another direction, as during the 1972 event. This event is  
440 invisible without a full view of the tree-ring patterns on the trunks, i.e. invisible without  
441 sawing the trees or multiplying the orientations of cores through the trunks. The dendrological  
442 process-event-response analysis associated to index values, elaborated from Shroder, 1980

443 and Shroder, 1978 is robust; however, the time lapse for recovery after a geomorphic impact  
444 (here occasional severe winds) is unknown. As for caution, we used the first year of  
445 occurrence of tree-ring disturbance, letting the following years in the shadow, unsure of the  
446 ability of the tree to reveal successive event. The more common use of dendrochronology in  
447 coastal environments to document severe winds is needed to refine the method and better  
448 understand the behavior of tree rings under such a forcing. From detailed meteorological data  
449 such as wind direction or intensity, we were able to confirm the dendrochronological findings,  
450 as tree-ring analysis is an accurate biological dating (Speer, 2012). The TRW variation is  
451 calculated with precise measurements and consequently exposes robust results. Concerning  
452 the sedimentological method, it is considered as fully reliable as the typical event layer is  
453 composed of texturally different sediments contrasting to the usual deposits of the  
454 sedimentation area (Chaumillon et al., 2017). Comparing to the TRW method,  
455 sedimentological dating is exposed to a lower accuracy (Binford, 1990). To build an accurate  
456 comparison with the tree-ring dating, only the more precise part of the core (the fifteen upper  
457 centimeters in this study corresponding to the stand lifespan) is analyzed. Dates found in this  
458 section reached a maximum uncertainty of four year, the crossing of washovers observed with  
459 historical data is precise enough to set solid storm hypotheses. We nowadays need other  
460 recent back barrier stratigraphical studies to compare washovers found in the Traicts du  
461 Croisic with other western France lagoonal sequences. Recent study cases of storm deposits  
462 are missing in the area; we can't compare today these sedimentological analyses with other  
463 identical setting areas nearby. However, historical data are also used here to confirm if coarse  
464 sand layers observed within the sedimentological cores were linked to the crossing of high  
465 tide coefficients and strong winds. Throughout their storm damage details, they documented  
466 breaches and marine flooding reported elsewhere in and around the vicinity of the study area.  
467 They can assure that dendrochronological and sedimentological hypotheses are reliable in  
468 spite of disadvantages described in this section.

469 Despite these slight limitations, both methods are efficient in their own way, and their  
470 combination helps the understanding of storm impact distribution in a specific area. The  
471 results emphasize that tree-rings can be used as a proxy to reveal severe wind conditions due  
472 to storms; however, the temporal and spatial resolution of the results is limited to the spatial  
473 distribution of trees and to their lifespan. The crossing of ancient geographical documents  
474 such as old map and aerial photography is needed to sample a relevant stand.  
475 Sedimentological archives extracted from stratigraphic cores are also relevant, showing a

476 good correlation with historical written sources where well-known marine flooding events are  
477 recorded. As a perspective, tree rings and sediment archives can be used as indicators  
478 regarding the environmental vulnerability to storm hazard, depending on the dimensions of  
479 the protecting dune, the presence and type of vegetation on the dune, the orientation of the  
480 coastline and more generally on the sedimentary dynamics of each area.

481

## 482 **6. Conclusion**

483 This paper shows that multi-proxies analyses are necessary to collect sufficient information to  
484 characterize coastal storms and their potential impacts. The methods, sedimentology and  
485 dendrochronology, complement the historical archives by attesting their reliability at a  
486 specific location. Sedimentology and dendrochronology have respective methodological and  
487 analytical limitations, (restraining a rigorous crossing for the construction of a coupled and  
488 unique storm chronology). The dendrochronological approach can be improved by  
489 multiplying the orientation of cores (or analyzing discs, supposing that several trees are  
490 felled). However, both are effective in detecting major recent storms in the study area using  
491 distinct environmental parameters. Sedimentology applied at a distance from the sea detects  
492 extreme wind events causing inland marine flooding, while dendrochronology detects major  
493 storms if they do not occur in successive years, due to the disturbance of tree-ring patterns  
494 that can last for several years. Both methods are thus effective in recording storm events.

495 The combination of the two methods clearly highlights three years, i.e. severe storms in 1990,  
496 1978 and 1972. The results clearly show that or most known storm events recorded are  
497 recognized from the natural proxies investigated. Dendrochronology and sedimentology can  
498 thus be used together, or separately, as reliable approaches to understand the main  
499 meteorological parameters of past storms in the absence of written sources.

500

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506

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801 <http://tempetes.meteofrance.fr/Tempete-du-13-fevrier-1972.html>

802 <http://tempetes.meteo.fr/Tempete-du-15-decembre-1979.html>

803 <http://tempetes.meteofrance.fr/Daria-le-25-janvier-1990.html>

- 804 <http://tempetes.meteofrance.fr/Herta-le-03-fevrier-1990.html>
- 805 <http://tempetes.meteofrance.fr/Viviane-du-26-au-28-fevrier-1990.html>
- 806 - Nantes Municipal Archives Nantes :
- 807 1038 W 327
- 808 23 Z 355
- 809 24 PRES 152, 05/02/1990, Presse Océan
- 810 24 PRES 152, 27-28/02/1990, Presse Océan
- 811 - Departmental archives of Vendée :
- 812 1856 W 38
- 813 78/31 1953-1975 – tempête du 13 février 1972
- 814 - Other :
- 815 Le Marin 20 Janvier 1978 N°1595
- 816 MetMar 1978 N°101

PRE-PRINT

817 Fig. 1. Study area. A. General overview; B. Forested area on Pen Bron dune; C. Traict du  
818 Croizic back barrier

819 Fig. 2. Wind activity at the study site from reanalysis data

820 Fig. 3. Tree-ring patterns in A. Trees not affected by strong episodic winds; B. Trees affected  
821 by strong winds during episodic storms; C. Schematic representation of growth rings of the C  
822 and D axes of one tree over time and their signals due to strong winds during storms

823 Fig. 4. Sedimentological results

824 Fig. 5. Temporal distribution of tree-ring disturbances (reaction wood occurrence and storm  
825 signals) and calculation details of the Index of Storm Disturbance

826 Fig. 6. Index of Storm Disturbance over time

827 Fig. 7. The ten highest wind speed records from November 1993 to October 2012, calculated  
828 from reanalysis data

829 Fig. 8. Characterization of annual winds from November 1993 to October 2012, calculated  
830 from reanalysis data, and percentage of SW winds

831 Fig. 9. Intense (A) and extreme (B) wind records per tree years from November 1993 to  
832 October 2012, calculated from reanalysis data

833 Fig. 10. Winds recorded during the storms of March 13, 1967 (A), February 13, 1972 (B) and  
834 December 15, 1979 (C), from Meteo France

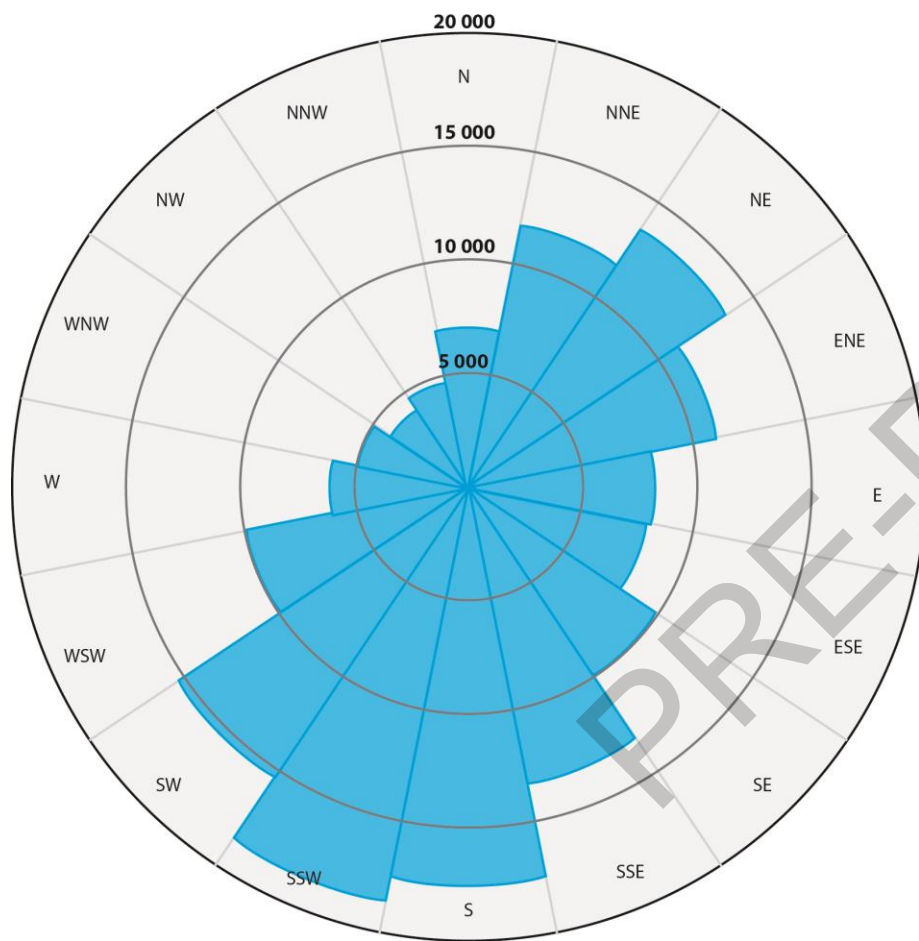
835

836

Fig. 1



A. Number of prevailing winds



B. Average speeds of prevailing winds

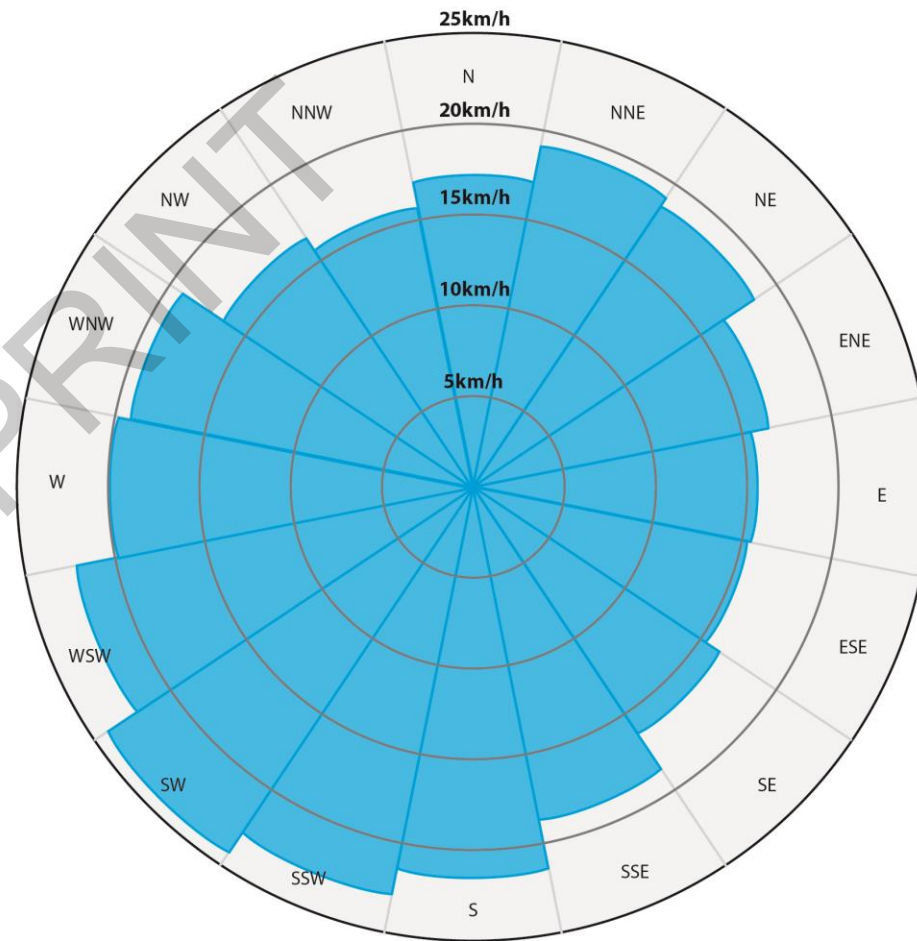


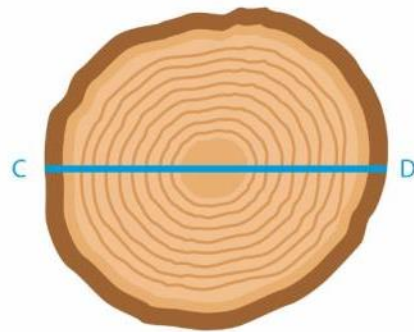
Fig. 2

Fig. 3

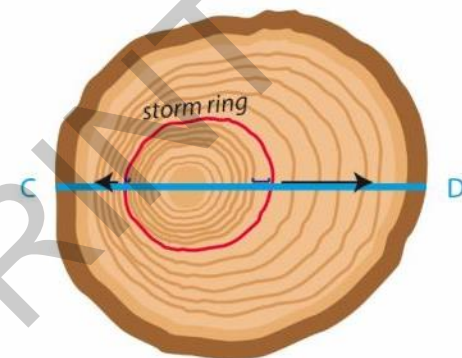
### Tree evolution

### Tree-ring patterns

#### A. Stand undisturbed by winds



#### B. Stand disturbed by strong winds



— Observable disproportions for the same tree year      → Eccentricity growth      — Sample axes

(Created with Freepik © templates)

#### C. Example of storm-type signal identified in tree-ring widths

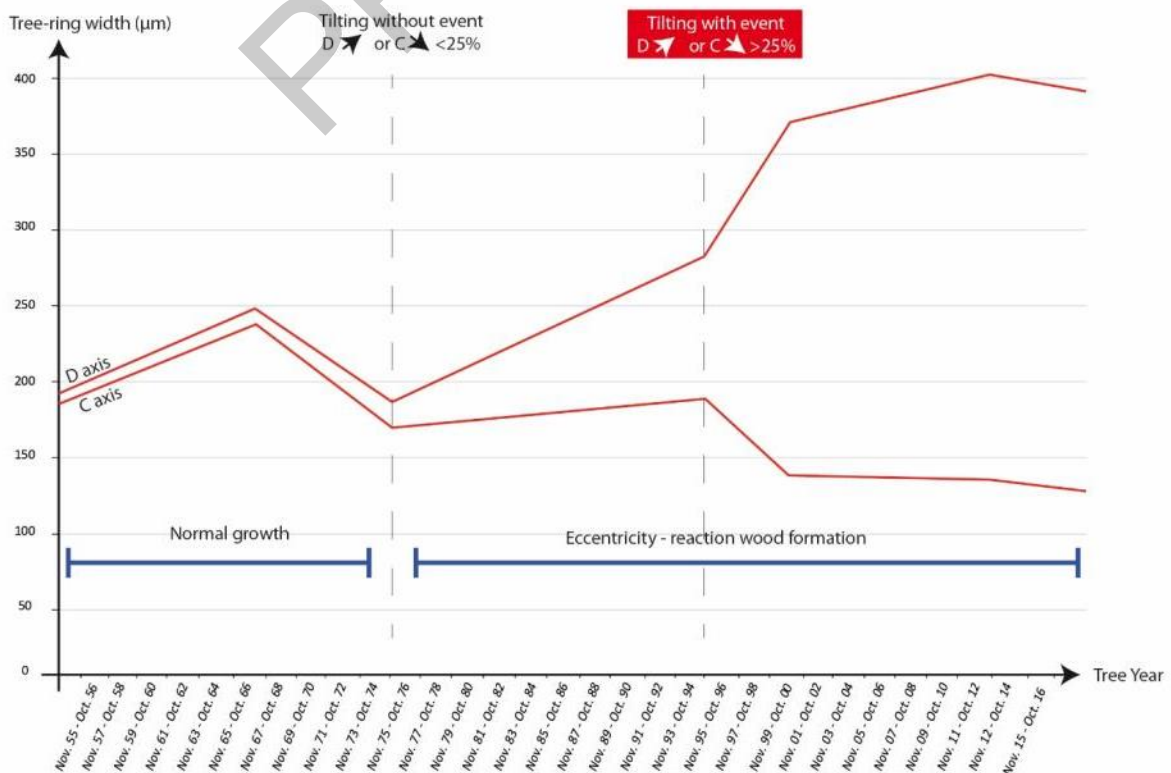
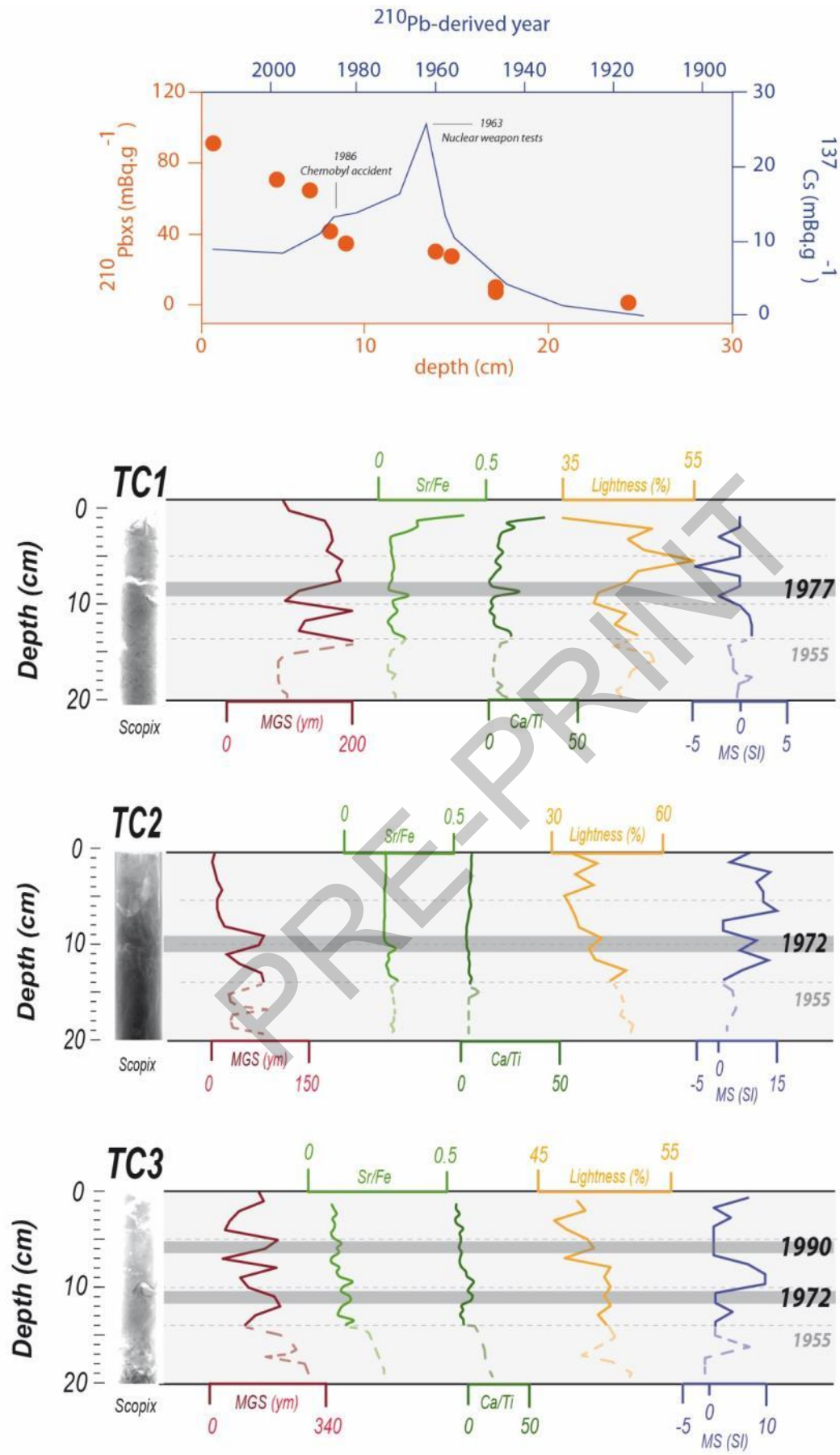


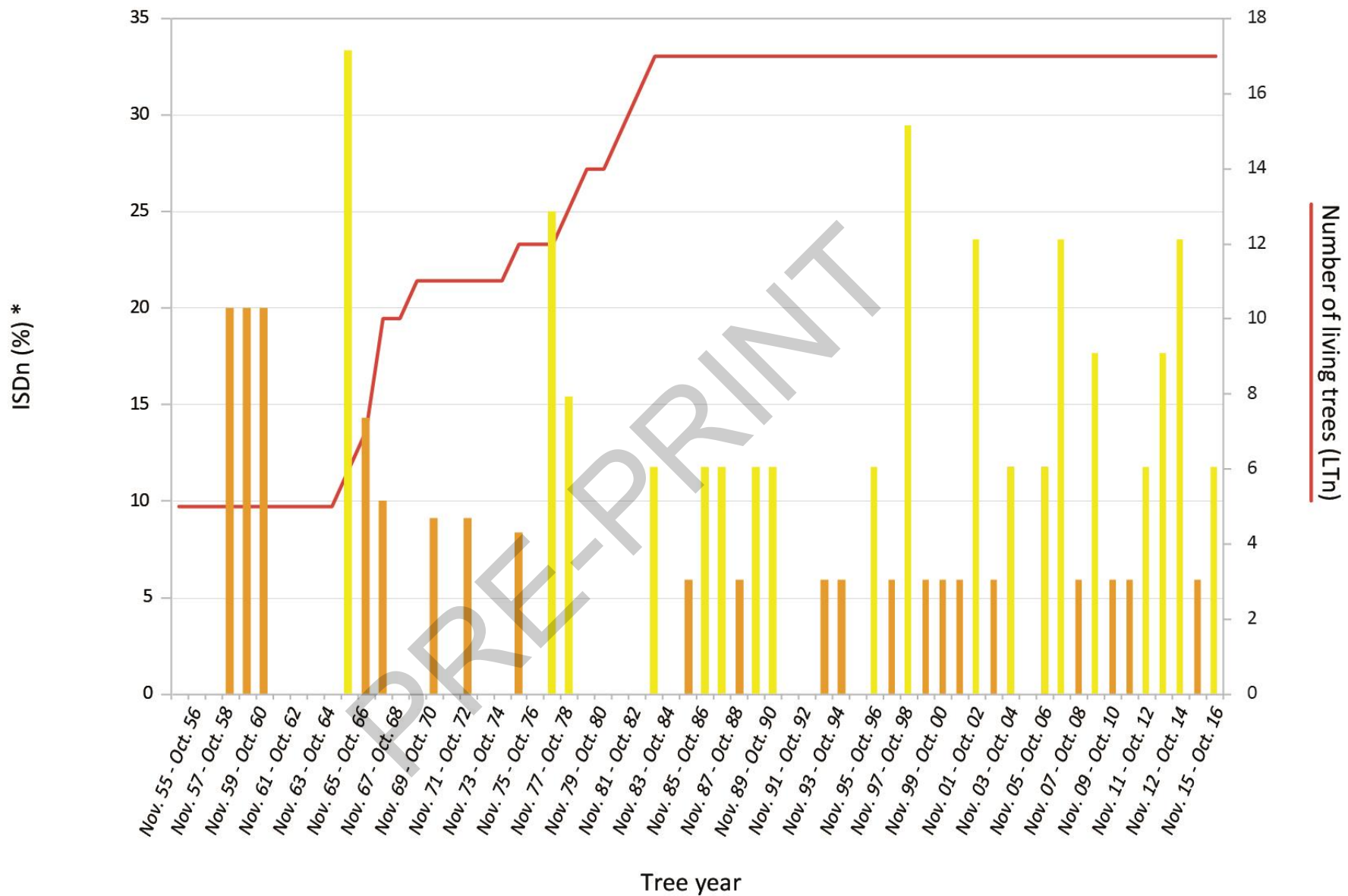
Fig. 4



1940 : Dates AD found with dating in sedimentological and historical archives for probable extreme wave event



Fig. 6



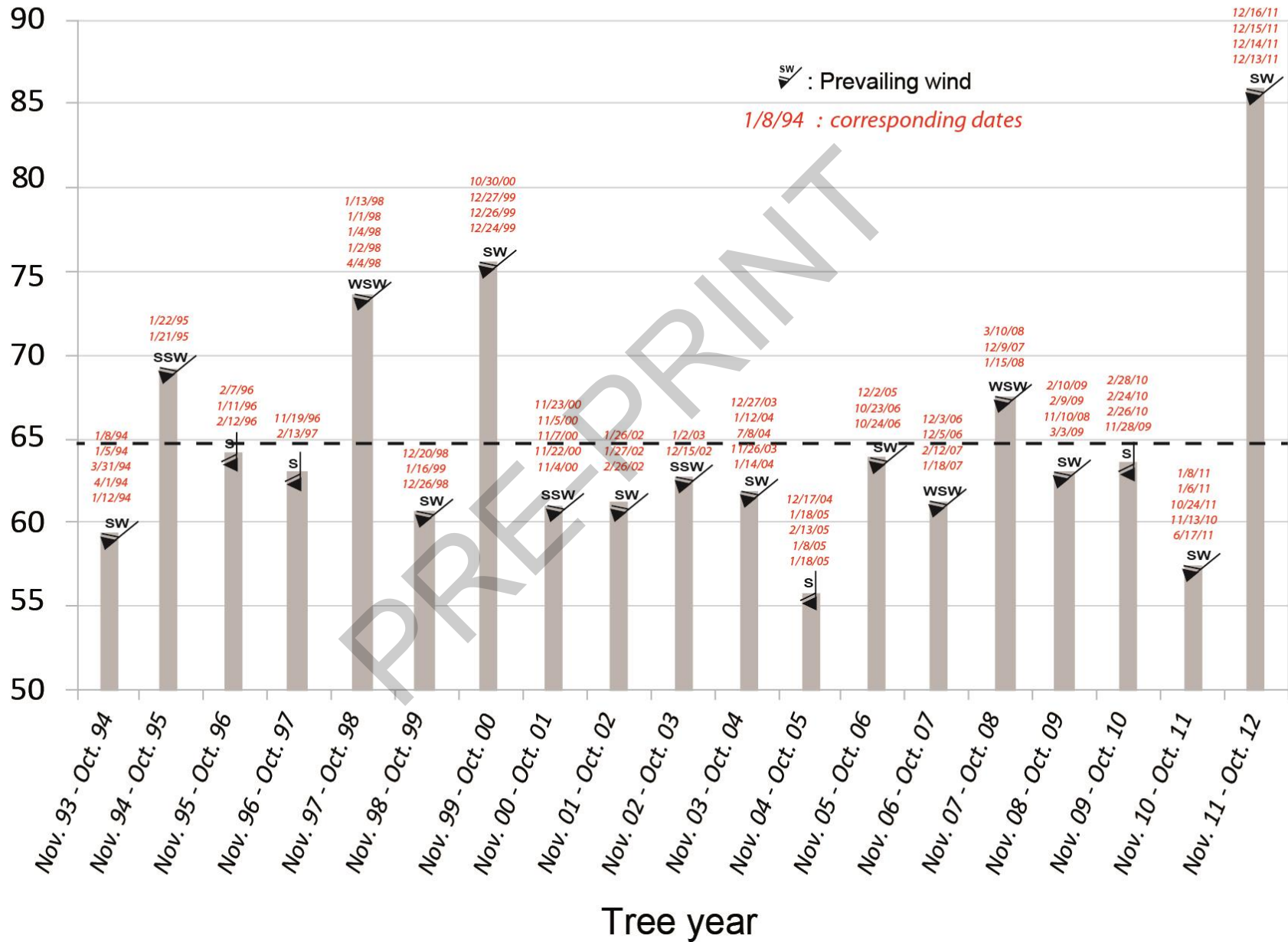
\*Disturbed year arrested because of more than one sample is affected

\*Disturbed year disregarded because only one sample is affected

# Average for the ten highest winds of each tree year (km/h)

(mean = 64.9 km/h)

Fig. 7



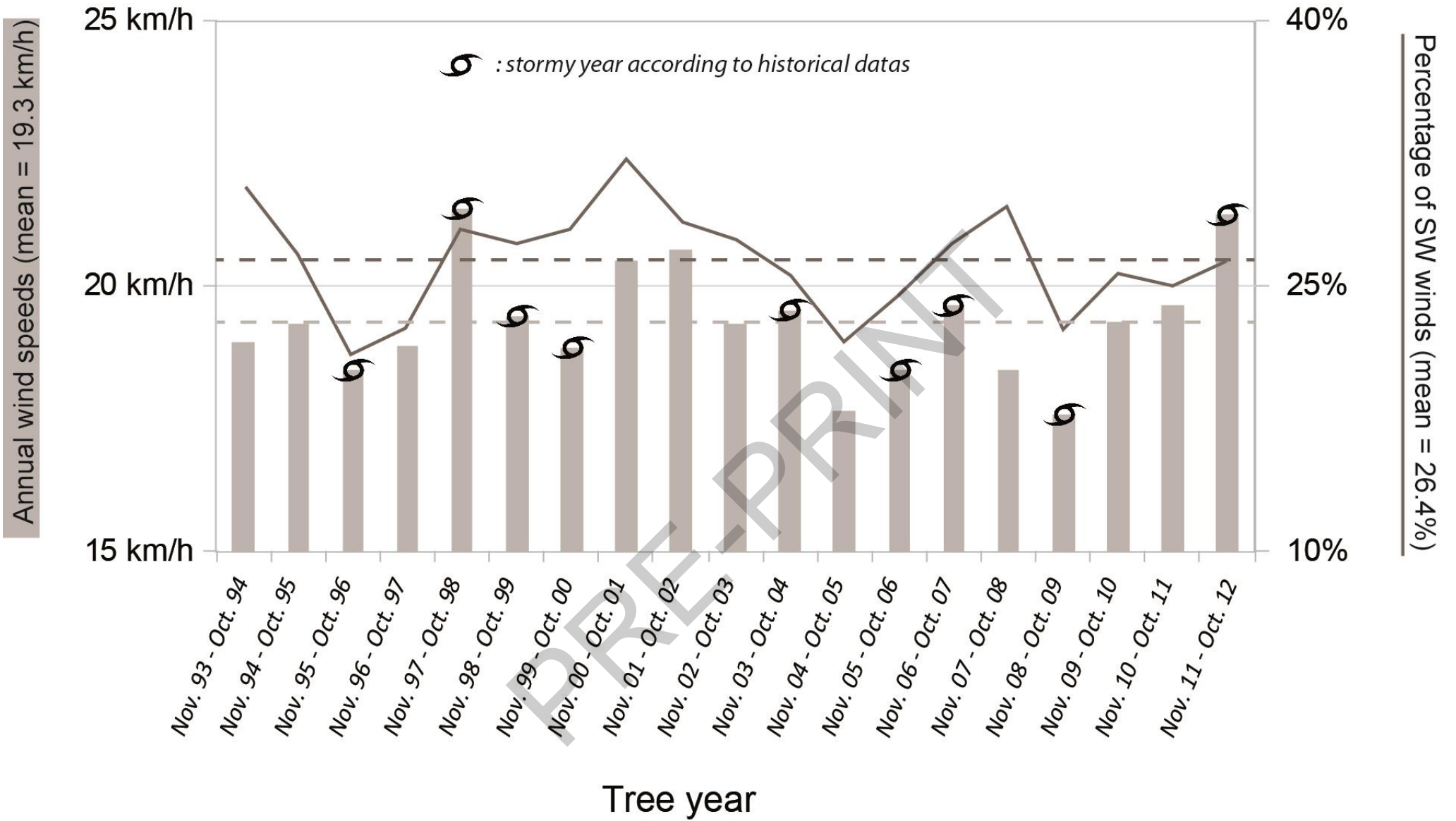
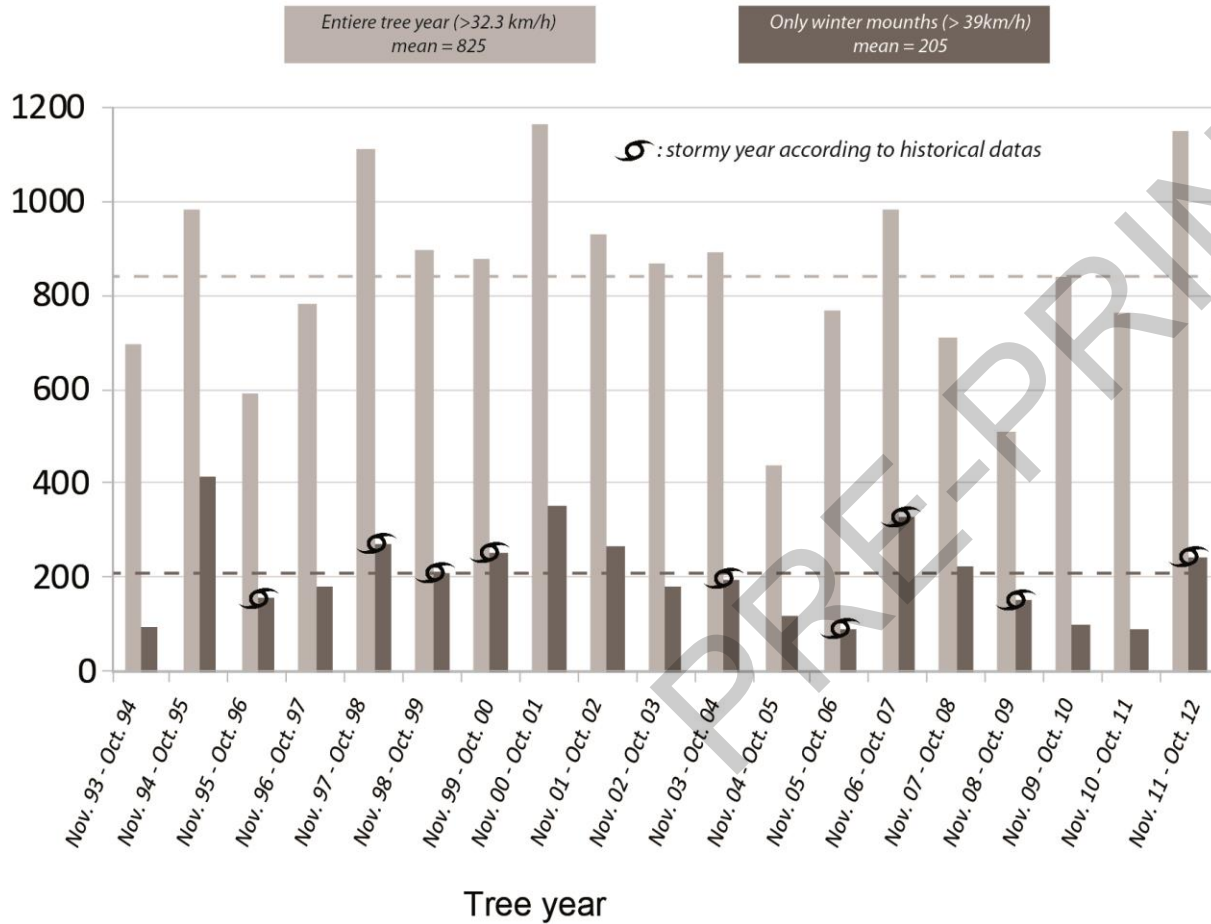


Fig. 8

### A. Intense wind speeds :

Number superiors to the 9<sup>th</sup> decile



### B. Extreme wind speeds :

Number superior to the Beaufort 9 rank (75 km/h)

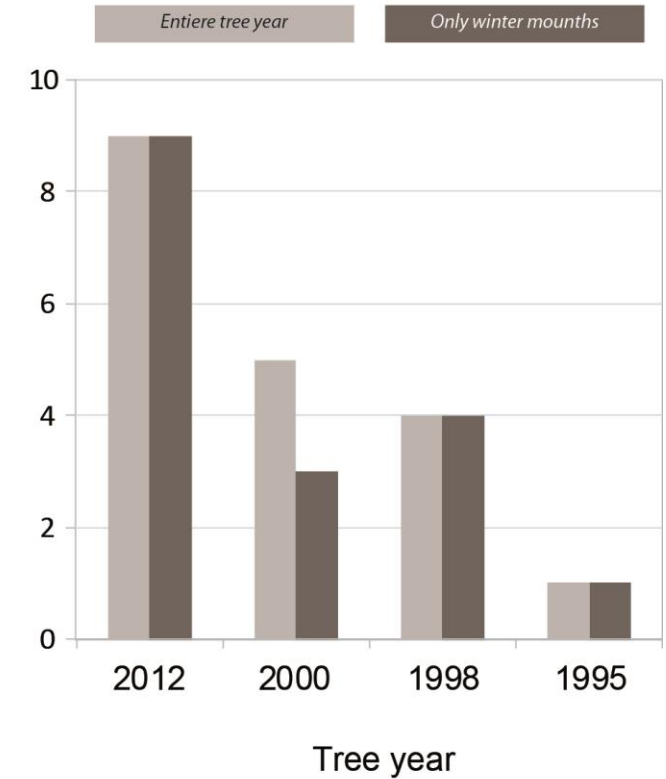
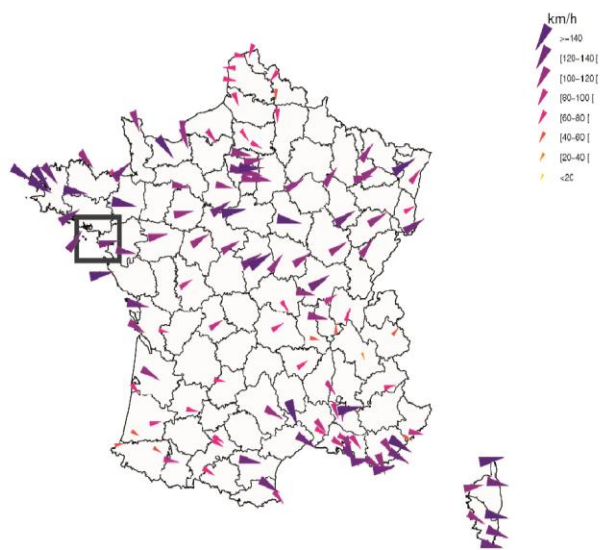


Fig. 9

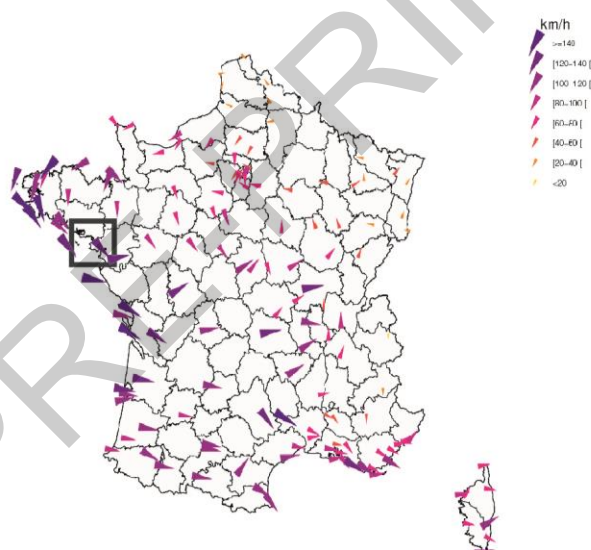
Fig. 10

A. Two-day maximum instant wind speeds  
3/13/67



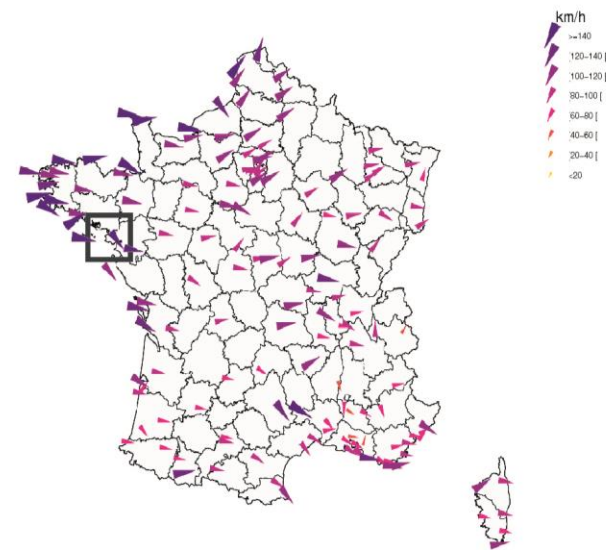
Edité le : 06/12/2016 - Données du : 23/07/2014 à 15:55 UTC

B. Daily maximum instant wind speeds  
2/13/72



Edité le : 06/12/2016 - Données du : 23/07/2014 à 16:33 UTC

C. Daily maximum instant wind speeds  
12/15/79



Edité le : 06/12/2016 - Données du : 27/06/2014 à 14:18 UTC

□ Study site

Table 1. Coordinates of each sedimentological and dendrochronological core

Table 2. Comparison of Tree Ring Width results per tree years with recent storm inventoried in historical data

PRE-PRINT

<b>Sedimentological cores</b>				
<b>Name</b>	<b>Id</b>	<b>X (RGF lambert 93)</b>	<b>Y (RGF lambert 93)</b>	<b>Maximum Depth (cm)</b>
Traict du Croisic 1	TC1	285140.145	6704373.272	84
Traict du Croisic 2	TC2	284667.764	6704419.583	71
Traict du Croisic 3	TC3	284877.807	6704445.014	85
<b>Dendrochronological cores</b>				
<b>Name</b>	<b>Id</b>	<b>X (RGF lambert 93)</b>	<b>Y (RGF lambert 93)</b>	<b>Disturbance direction</b>
Pen Bron 1	PB01	284990.395	6705920.372	SW>NE
Pen Bron 2	PB02	284915.957	6705848.237	SW>NE
Pen Bron 3	PB03	284953.042	6705867.302	N.NW>S.SE
Pen Bron 4	PB04	284977.943	6705862.471	S.SW>N.NE
Pen Bron 5	PB05	284945.743	6705883.276	S.SW>N.NE
Pen Bron 6	PB06	284867.653	6705758.813	S.SW>N.NE
Pen Bron 7	PB07	284915.957	6705822.005	SW>NE
Pen Bron 8	PB08	284945.743	6705883.276	S.SW>N.NE
Pen Bron 9	PB09	284938.66	6705902.329	W>E
Pen Bron 10	PB10	284955.673	6705935.167	S>N
Pen Bron 11	PB11	284960.503	6705944.109	S>N
Pen Bron 12	PB12	284969.626	6705893.983	S.SW>N.NE
Pen Bron 13	PB13	284985.135	6705905.273	SW>NE
Pen Bron 14	PB14	284990.395	6705893.983	SW>NE
Pen Bron 15	PB15	284983.257	6705908.498	W.NW>E.SE
Pen Bron 16	PB16	284973.382	6705887.535	SW>NE
Pen Bron 17	PB17	284973.382	6705886.513	SW>NE

Table 1

Tree year (from Nov. N-1 to Oct. N)	ISD	Known storm*	Compatibility	Storm dates (month/day/year)	Main Historical Sources
2016	11,8	Yes	Yes	2/8/16	<a href="http://www.ouest-france.fr/meteo/tempete/meteo-tempete-sur-louest-139-km/h-de-vent-en-bretagne-et-normandie-4024680">http://www.ouest-france.fr/meteo/tempete/meteo-tempete-sur-louest-139-km/h-de-vent-en-bretagne-et-normandie-4024680</a>
2015	5,9	No	Yes	/	/
2014	23,5	Several	Yes	2/14/14 2/1/14 12/23/13	Archives Départementales de Loire-Atlantique, PR 967 849, du 15-16/02/2014 Archives Départementales de Loire-Atlantique, PR 967 849, du 04/02/2014 <a href="http://tempetes.meteo.fr/Tempete-Dirk-de-noel-2013.html">http://tempetes.meteo.fr/Tempete-Dirk-de-noel-2013.html</a>
2013	17,6	Yes	Yes	10/27/13	<a href="http://www.lemonde.fr/planete/article/2013/10/27/tempete-12-departements-du-nord-ouest-en-alerte-orange_3503693_3244.html">http://www.lemonde.fr/planete/article/2013/10/27/tempete-12-departements-du-nord-ouest-en-alerte-orange_3503693_3244.html</a>
2012	11,8	Yes	Yes	12/6/11	<a href="http://tempetes.meteo.fr/Tempete-Joachim-du-16-decembre-2011.html">http://tempetes.meteo.fr/Tempete-Joachim-du-16-decembre-2011.html</a>
2011	5,9	No	Yes	/	/
2010	5,9	Probably	?	2/27/10	<a href="http://tempetes.meteo.fr/Tempete-Xynthia-du-27-au-28-fevrier-2010.html">http://tempetes.meteo.fr/Tempete-Xynthia-du-27-au-28-fevrier-2010.html</a>
2009	17,6	Yes	Yes	2/9/09	<a href="http://tempetes.meteo.fr/Tempete-Quinten-du-09-au-10-fevrier-2009.html">http://tempetes.meteo.fr/Tempete-Quinten-du-09-au-10-fevrier-2009.html</a>
2008	5,9	MI	Yes	3/9/08	Archives départementales de Vendée, BIB PE 20/652, Ouest France édition Vendée Ouest, 11/03/2008 p 1,6,7,9
2007	23,5	Yes	Yes	12/8/06	<a href="http://tempetes.meteo.fr/Tempete-Vera-le-8-decembre-2006.html">http://tempetes.meteo.fr/Tempete-Vera-le-8-decembre-2006.html</a>
2006	11,8	Yes	Yes	12/1/05	Archives Départementales de Loire-Atlantique, PR 967 650, du 04/12/2005
2005	0,0	No	Yes	/	/
2004	11,8	Yes	Yes	1/12/04	<a href="http://tempetes.meteo.fr/Tempetes-successives-du-12-au-15-janvier-2004.html">http://tempetes.meteo.fr/Tempetes-successives-du-12-au-15-janvier-2004.html</a>
2003	5,9	Probably	?	1/2/03	<a href="http://tempetes.meteo.fr/Tempete-Calvann-du-02-janvier-2003.html">http://tempetes.meteo.fr/Tempete-Calvann-du-02-janvier-2003.html</a>
2002	23,5	No	No	/	/
2001	5,9	No	Yes	/	/
2000	5,9	Several	No	10/30/00 12/27/99 12/26/99	<a href="http://tempetes.meteo.fr/Tempete-Oratia-du-30-octobre-2000.html">http://tempetes.meteo.fr/Tempete-Oratia-du-30-octobre-2000.html</a> <a href="http://tempetes.meteo.fr/Martin-les-27-et-28-decembre-1999.html">http://tempetes.meteo.fr/Martin-les-27-et-28-decembre-1999.html</a> <a href="http://tempetes.meteo.fr/Lothar-le-26-decembre-1999.html">http://tempetes.meteo.fr/Lothar-le-26-decembre-1999.html</a>
1999	5,9	Yes	No	12/20/98	Archives Départementales de Loire-Atlantique PR 967 483 du 21/12/1998
1998	29,4	Several	Yes	1/13/98 1/4/98 1/2/98	Archives municipales de Nantes, 26PRESSE245, Ouest-France du 14/01/1998 <a href="http://tempetes.meteo.fr/Tempete-du-4-janvier-1998.html">http://tempetes.meteo.fr/Tempete-du-4-janvier-1998.html</a> <a href="http://tempetes.meteo.fr/Tempete-du-2-janvier-1998.html">http://tempetes.meteo.fr/Tempete-du-2-janvier-1998.html</a>
1997	5,9	No	Yes	/	/
1996	11,8	Yes	Yes	2/7/96	<a href="http://tempetes.meteo.fr/Tempete-du-7-et-8-fevrier-1996.html">http://tempetes.meteo.fr/Tempete-du-7-et-8-fevrier-1996.html</a>
1995	0,0	No	Yes	/	/
1994	5,9	MI	Yes	1/5/94	<a href="http://tempetes.meteo.fr/Tempetes-du-5-au-7-janvier-1994.html">http://tempetes.meteo.fr/Tempetes-du-5-au-7-janvier-1994.html</a>
1993	5,9	MI	Yes	9/12/93	<a href="http://tempetes.meteo.fr/Tempete-des-12-et-13-septembre-1993.html">http://tempetes.meteo.fr/Tempete-des-12-et-13-septembre-1993.html</a>
1992	0,0	Probably	?	12/18/91	<a href="http://tempetes.meteo.fr/Synthese-du-18-au-25-decembre-1991.html">http://tempetes.meteo.fr/Synthese-du-18-au-25-decembre-1991.html</a>
1991	0,0	No	Yes	/	/
1990	11,8	Several	Yes	2/26/1990 2/3/1990 1/25/1990	<a href="http://tempetes.meteo.fr/Viviane-du-26-au-28-fevrier-1990.html">http://tempetes.meteo.fr/Viviane-du-26-au-28-fevrier-1990.html</a> <a href="http://tempetes.meteo.fr/Herta-le-03-fevrier-1990.html">http://tempetes.meteo.fr/Herta-le-03-fevrier-1990.html</a> <a href="http://tempetes.meteo.fr/Daria-le-25-janvier-1990.html">http://tempetes.meteo.fr/Daria-le-25-janvier-1990.html</a>
1989	11,8	Yes	Yes	2/25/89	<a href="http://www.meteo-paris.com/chronique/annee/1989">http://www.meteo-paris.com/chronique/annee/1989</a> , with <a href="https://www.prevision-meteo.ch/almanach/1989">https://www.prevision-meteo.ch/almanach/1989</a>
1988	5,9	No	Yes	/	/
1987	11,8	Yes	Yes	10/15/87	<a href="http://tempetes.meteo.fr/L-ouragan-du-15-au-16-octobre-1987.html">http://tempetes.meteo.fr/L-ouragan-du-15-au-16-octobre-1987.html</a>
1986	11,8	Yes	Yes	12/7/86	<a href="http://www.meteo-paris.com/chronique/annee/1986">http://www.meteo-paris.com/chronique/annee/1986</a>
1985	5,9	Probably	?	11/22/84	<a href="http://tempetes.meteo.fr/Tempetes-du-22-au-24-novembre-1984.html">http://tempetes.meteo.fr/Tempetes-du-22-au-24-novembre-1984.html</a>
1984	0,0	No	Yes	/	/
1983	11,8	Yes	Yes	11/6/82	<a href="http://tempetes.meteo.fr/Tempete-du-6-au-8-novembre-1982.html">http://tempetes.meteo.fr/Tempete-du-6-au-8-novembre-1982.html</a>
1982	0,0	No	Yes	/	/
1981	0,0	No	Yes	/	/
1980	0,0	Yes	No	12/15/79	<a href="http://tempetes.meteo.fr/Tempete-du-15-decembre-1979.html">http://tempetes.meteo.fr/Tempete-du-15-decembre-1979.html</a>
1979	0,0	No	Yes	/	/
1978	15,4	Yes	Yes	1/11/78	MetMat n°101, available at <a href="http://nauticalfree.free.fr/metmar/metmar1a217.html">http://nauticalfree.free.fr/metmar/metmar1a217.html</a>
1977	25,0	Yes	Yes	12/2/76	<a href="http://tempetes.meteo.fr/Tempete-du-2-decembre-1976.html">http://tempetes.meteo.fr/Tempete-du-2-decembre-1976.html</a>
1976	0,0	No	Yes	/	/
1975	8,3	No	Yes	/	/
1974	0,0	Probably	?	2/6/74	Archives Municipales de Nantes, 24PRES 49 du 07/02/1974
1973	0,0	No	Yes	/	/
1972	9,1	Yes	No	2/13/72	<a href="http://tempetes.meteo.fr/Tempete-du-13-fevrier-1972.html">http://tempetes.meteo.fr/Tempete-du-13-fevrier-1972.html</a>
1971	0,0	No	Yes	/	/
1970	9,1	No	Yes	/	/
1969	0,0	MI	Yes	7/6/69	<a href="http://tempetes.meteo.fr/Tempete-du-06-juillet-1969.html">http://tempetes.meteo.fr/Tempete-du-06-juillet-1969.html</a>
1968	0,0	MI	Yes	1/7/68	<a href="http://tempetes.meteo.fr/Tempete-du-7-janvier-1968.html">http://tempetes.meteo.fr/Tempete-du-7-janvier-1968.html</a>
1967	10,0	Yes	No	3/12/67	<a href="http://tempetes.meteofrance.fr/Tempete-du-12-mars-1967.html">http://tempetes.meteofrance.fr/Tempete-du-12-mars-1967.html</a>
1966	14,3	No	Yes	/	/
1965	33,3	Several	Yes	1/17/65 1/16/65 1/13/65	<a href="http://www.meteo-paris.com/chronique/annee/1965">http://www.meteo-paris.com/chronique/annee/1965</a> , with <a href="https://www.infoclimat.fr/historic-details-evenement-482-archives.html">https://www.infoclimat.fr/historic-details-evenement-482-archives.html</a> for all three events
1964	0,0	Probably	?	11/1/63	Archives Départementales de Loire-Atlantique, PR 967 58 du 02-03/11/1963
1963	0,0	No	Yes	/	/
1962	0,0	No	Yes	/	/
1961	0,0	No	Yes	/	/
1960	20,0	No	Yes	/	/
1959	20,0	No	Yes	/	/
1958	20,0	No	Yes	/	/
1957	0,0	No	Yes	/	/
1956	0,0	No	Yes	/	/
1955	0,0	No	Yes	/	/

\* Known storm

Yes
Probably
No

Impacting storm(s) inventoried in the area during the studied tree year

Storm inventoried, probably impacting the area of our sampled forest

Any storm inventoried

- or MI, for Minor Impact : One or several storms inventoried with little or no impact on the studied site

Table 2