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

3

4 Pouzet Pierre^{1*}, Robin Marc¹, Decaulne Armelle², Gruchet Bastien³, Maanan Mohamed¹

5

6 ¹ Université de Nantes, LETG CNRS, Nantes, France.

7 ² CNRS LETG, Nantes, France.

8 ³ IGARUN, Université de Nantes, France.

9 * Corresponding author. E-mail: pierre.pouzet@univ-nantes.fr

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}Pb) and cesium (^{137}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}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}Pb and ^{137}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 γ 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_n is the tree-ring width at year n and TRW_{n-1} 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_n (as a percentage) is the Index of Storm Disturbance of the year n, DT_n is the*
225 *number of disturbed trees during the year n and LT_n 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 ²¹⁰Pb 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⁻¹
233 was estimated, used to extrapolate ages by assuming that the mean sedimentation rate was
234 constant for horizons beyond the timescale covered by ²¹⁰Pb. The sedimentary ¹³⁷Cs profile
235 helped to estimate that the ²¹⁰Pb chronology ranges from 1916 AD (Anno Domini) ± 13 years
236 to 2016 AD: ¹³⁷Cs activities disappear below the deep “nuclear weapons tests” peak at about
237 12-13 cm, in 1963 according to ²¹⁰Pb dating. The 1986 Chernobyl accident can also be
238 estimated with a small rebound of the ¹³⁷Cs curve at 7 cm depth from ²¹⁰Pb 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 μ m to 180 μ 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 μ 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 μ 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

507 **8. References**

- 508 Athimon, E., Maanan, M., 2018. Severe storm, coastal flood damage, adaptation and resilience of
509 societies during the Little Ice Age (West of France). *Prog. Hum. Geogr.* Submitted.
- 510 Athimon, E., Maanan, M., Sauzeau, T., Sarrazin, J.-L., 2016. Vulnérabilité et adaptation des sociétés
511 littorales aux aléas météo-marins entre Guérande et l'île de Ré, France (XIVe - XVIIIe siècle).
512 *VertigO - Rev. Électronique En Sci. Environ.* <https://doi.org/10.4000/vertigo.17927>
- 513 Baldock, T.E., Weir, F., Hughes, M.G., 2008. Morphodynamic evolution of a coastal lagoon entrance
514 during swash overwash. *Geomorphology* 95, 398–411.
515 <https://doi.org/10.1016/j.geomorph.2007.07.001>
- 516 Baumann, J., Chaumillon, E., Schneider, J.-L., Jorissen, F., Sauriau, P.-G., Richard, P., Bonnin, J.,
517 Schmidt, S., 2017. Contrasting sediment records of marine submersion events related to
518 wave exposure, Southwest France. *Sediment. Geol.* 353, 158–170.
519 <https://doi.org/10.1016/j.sedgeo.2017.03.009>
- 520 Begét, J.E., Stone, D.B., Hawkins, D.B., 1990. Paleoclimatic forcing of magnetic susceptibility
521 variations in Alaskan loess during the late Quaternary. *Geology* 18, 40–43.
522 [https://doi.org/10.1130/0091-7613\(1990\)018<0040:PFOMSV>2.3.CO;2](https://doi.org/10.1130/0091-7613(1990)018<0040:PFOMSV>2.3.CO;2)
- 523 Begin, Y., 1990. The Effects of Shoreline Transgression on Woody Plants, Upper St. Lawrence Estuary,
524 Quebec. *J. Coast. Res.* 6.
- 525 Begin, Y., Langlais, D., Cournoyer, L., 1991. A Dendrogeomorphic Estimate of Shore Erosion, Upper St.
526 Lawrence Estuary, Quebec. *J. Coast. Res.* 7.
- 527 Berkelhammer, M., Stott, L., 2011. Correction to “Recent and dramatic changes in Pacific storm
528 trajectories as recorded in the $\delta^{18}O$ of Bristlecone Pine tree ring cellulose.” *Geochem.*
529 *Geophys. Geosystems* 12, Q09002. <https://doi.org/10.1029/2011GC003765>
- 530 Berkelhammer, M.B., Stott, L.D., 2008. Recent and dramatic changes in Pacific storm trajectories
531 recorded in $\delta^{18}O$ from Bristlecone Pine tree ring cellulose. *Geochem. Geophys. Geosystems*
532 9, Q04008. <https://doi.org/10.1029/2007GC001803>
- 533 Binford, M.W., 1990. Calculation and uncertainty analysis of ^{210}Pb dates for PIRLA project lake
534 sediment cores. *J. Paleolimnol.* 3, 253–267. <https://doi.org/10.1007/BF00219461>
- 535 Bloemendal, J., deMenocal, P., 1989. Evidence for a change in the periodicity of tropical climate
536 cycles at 2.4 Myr from whole-core magnetic susceptibility measurements. *Nature* 342, 897–
537 900. <https://doi.org/10.1038/342897a0>
- 538 Bouchard, F., Francus, P., Pienitz, R., Laurion, I., 2011. Sedimentology and geochemistry of
539 thermokarst ponds in discontinuous permafrost, subarctic Quebec, Canada. *J. Geophys. Res.*
540 *Biogeosciences* 116, G00M04. <https://doi.org/10.1029/2011JG001675>
- 541 Boudiere, E., Maisondieu, C., Arduin, F., Accensi, M., Pineau-Guillou, L., Lepasqueur, J., 2013. A
542 suitable metocean hindcast database for the design of Marine energy converters. *Int. J. Mar.*
543 *Energy* 3–4. <https://doi.org/10.1016/j.ijome.2013.11.010>
- 544 Bregy, J.C., Wallace, D.J., Minzoni, R.T., Cruz, V.J., 2018. 2500-year paleotempestological record of
545 intense storms for the northern Gulf of Mexico, United States. *Mar. Geol., Geological*
546 *Records of Extreme Wave Events* 396, 26–42. <https://doi.org/10.1016/j.margeo.2017.09.009>
- 547 Brienen, R.J.W., Helle, G., Pons, T.L., Guyot, J.-L., Gloor, M., 2012. Oxygen isotopes in tree rings are a
548 good proxy for Amazon precipitation and El Niño-Southern Oscillation variability. *Proc. Natl.*
549 *Acad. Sci.* 109, 16957–16962. <https://doi.org/10.1073/pnas.1205977109>
- 550 Buynevich, I., Klein, A., FitzGerald, D., Cleary, W., Hein, C., Veiga, F., Angulo, R., Asp, N., Petermann,
551 R., 2011. Geological legacy of storm erosion along a high-energy indented coastline: northern
552 Santa Catarina, Brazil. *J. Coast. Res.* 1840–1844.
- 553 Chagué-Goff, C., 2010. Chemical signatures of palaeotsunamis: A forgotten proxy? *Mar. Geol.* 271,
554 67–71. <https://doi.org/10.1016/j.margeo.2010.01.010>
- 555 Chagué-Goff, C., Szczuciński, W., Shinozaki, T., 2017. Applications of geochemistry in tsunami
556 research: A review. *Earth-Sci. Rev.* 165, 203–244.
557 <https://doi.org/10.1016/j.earscirev.2016.12.003>

558 Chaumillon, E., Bertin, X., Fortunato, A.B., Bajo, M., Schneider, J.-L., Dezileau, L., Walsh, J.P.,
559 Michelot, A., Chauveau, E., Créach, A., Hénaff, A., Sauzeau, T., Waeles, B., Gervais, B., Jan, G.,
560 Baumann, J., Breilh, J.-F., Pedreros, R., 2017. Storm-induced marine flooding: Lessons from a
561 multidisciplinary approach. *Earth-Sci. Rev.* 165, 151–184.
562 <https://doi.org/10.1016/j.earscirev.2016.12.005>

563 Chauveau, E., Chadenas, C., Comentale, B., Pottier, P., Blanlœuil, A., Feuillet, T., Mercier, D., Pourinet,
564 L., Rollo, N., Tillier, I., Trouillet, B., 2011. Xynthia : leçons d’une catastrophe. *Cybergeo Eur. J.*
565 *Geogr.* <https://doi.org/10.4000/cybergeo.23763>

566 Coor, J.L., Donoghue, J., Wang, Y., Das, O., Kish, S., Elsner, J., Hu, X.B., Niedoroda, A.W., Ye, M., 2009.
567 Development of a Long-Term Storm History for the Northwest Florida Coast Using Multiple
568 Proxies. *AGU Fall Meet. Abstr.* 11.

569 Das, O., Wang, Y., Donoghue, J., Xu, X., Coor, J., Elsner, J., Xu, Y., 2013. Reconstruction of paleostorms
570 and paleoenvironment using geochemical proxies archived in the sediments of two coastal
571 lakes in northwest Florida. *Quat. Sci. Rev.* 68, 142–153.
572 <https://doi.org/10.1016/j.quascirev.2013.02.014>

573 Debret, M., Sebag, D., Desmet, M., Balsam, W., Copard, Y., Mourier, B., Susperrigui, A.-S., Arnaud, F.,
574 Bentaleb, I., Chapron, E., Lallier-Vergès, E., Winiarski, T., 2011. Spectrocolorimetric
575 interpretation of sedimentary dynamics: The new “Q7/4 diagram.” *Earth-Sci. Rev.* 109, 1–19.
576 <https://doi.org/10.1016/j.earscirev.2011.07.002>

577 Decaulne, A., Eggertsson, Ó., Laute, K., Beylich, A.A., 2014. A 100-year extreme snow-avalanche
578 record based on tree-ring research in upper Bødalen, inner Nordfjord, western Norway.
579 *Geomorphology, SEDIMENT FLUX AND SEDIMENT BUDGET STUDIES IN COLD*
580 *ENVIRONMENTS: NEW APPROACHES AND TECHNIQUES* 218, 3–15.
581 <https://doi.org/10.1016/j.geomorph.2013.12.036>

582 Decaulne, A., Eggertsson, Ó., Sæmundsson, Þ., 2012. A first dendrogeomorphologic approach of
583 snow avalanche magnitude–frequency in Northern Iceland. *Geomorphology, Sedimentary*
584 *fluxes and budgets in natural and anthropogenically modified landscapes – Effects of climate*
585 *change and land-use change on geomorphic processes* 167–168, 35–44.
586 <https://doi.org/10.1016/j.geomorph.2011.11.017>

587 Dewey, J.F., Ryan, P.D., 2017. Storm, rogue wave, or tsunami origin for megaclast deposits in western
588 Ireland and North Island, New Zealand? *Proc. Natl. Acad. Sci.* 114, E10639–E10647.
589 <https://doi.org/10.1073/pnas.1713233114>

590 Donnelly, J.P., Butler, J., Roll, S., Wengren, M., Webb, T., 2004. A backbarrier overwash record of
591 intense storms from Brigantine, New Jersey. *Mar. Geol., Storms and their significance in*
592 *coastal morpho-sedimentary dynamics* 210, 107–121.
593 <https://doi.org/10.1016/j.margeo.2004.05.005>

594 Eden, D.N., Page, M.J., 1998. Palaeoclimatic implications of a storm erosion record from late
595 Holocene lake sediments, North Island, New Zealand. *Palaeogeogr. Palaeoclimatol.*
596 *Palaeoecol.* 139, 37–58. [https://doi.org/10.1016/S0031-0182\(97\)00136-3](https://doi.org/10.1016/S0031-0182(97)00136-3)

597 Everham, E.M., Brokaw, N.V.L., 1996. Forest damage and recovery from catastrophic wind. *Bot. Rev.*
598 62, 113–185. <https://doi.org/10.1007/BF02857920>

599 Feal-Pérez, A., Blanco-Chao, R., Ferro-Vázquez, C., Martínez-Cortizas, A., Costa-Casais, M., 2014. Late-
600 Holocene storm imprint in a coastal sedimentary sequence (Northwest Iberian coast). *The*
601 *Holocene* 24, 477–488. <https://doi.org/10.1177/0959683613520257>

602 Feuillet, T., Chauveau, É., Pourinet, L., 2012. Xynthia est-elle exceptionnelle ? Réflexions sur
603 l’évolution et les temps de retour des tempêtes, des marées de tempête, et des risques de
604 surcotes associés sur la façade atlantique française. *Noréis* n° 222, 27–44.

605 Frappier, A.B., Sahagian, D., Carpenter, S.J., González, L.A., Frappier, B.R., 2007. Stalagmite stable
606 isotope record of recent tropical cyclone events. *Geology* 35, 111–114.
607 <https://doi.org/10.1130/G23145A.1>

608 Gardner, T.A., Côté, I.M., Gill, J.A., Grant, A., Watkinson, A.R., 2005. Hurricanes and Caribbean Coral
609 Reefs: Impacts, Recovery Patterns, and Role in Long-Term Decline. *Ecology* 86, 174–184.
610 <https://doi.org/10.1890/04-0141>

611 Garnier, E., Ciavola, P., Spencer, T., Ferreira, O., Armaroli, C., Mclvor, A., 2017. Historical analysis of
612 storm events: Case studies in France, England, Portugal and Italy. *Coast. Eng.*
613 <https://doi.org/10.1016/j.coastaleng.2017.06.014>

614 Gärtner, H., 2007. Tree roots — Methodological review and new development in dating and
615 quantifying erosive processes. *Geomorphology* 86, 243–251.
616 <https://doi.org/10.1016/j.geomorph.2006.09.001>

617 Gärtner, H., Schweingruber, F.H., Dikau, R., 2001. Determination of erosion rates by analyzing
618 structural changes in the growth pattern of exposed roots. *Dendrochronologia* 19, 81–91.

619 Goslin, J., Clemmensen, L.B., 2017. Proxy records of Holocene storm events in coastal barrier
620 systems: Storm-wave induced markers. *Quat. Sci. Rev.* 174, 80–119.
621 <https://doi.org/10.1016/j.quascirev.2017.08.026>

622 Gottschalk, M.K.E., 1977. Stormvloed en rivieroverstromingen in Nederland, vol.3. Van Gorcum &
623 Comp, Assen/Amsterdam.

624 Grissino-Mayer, H.D., 2003. A Manual and Tutorial for the Proper Use of an Increment Borer. *Tree-*
625 *Ring Res.*

626 Hall, A.M., Hansom, J.D., Williams, D.M., Jarvis, J., 2006. Distribution, geomorphology and lithofacies
627 of cliff-top storm deposits: Examples from the high-energy coasts of Scotland and Ireland.
628 *Mar. Geol.* 232, 131–155. <https://doi.org/10.1016/j.margeo.2006.06.008>

629 Hansom, J.D., Hall, A.M., 2009. Magnitude and frequency of extra-tropical North Atlantic cyclones: A
630 chronology from cliff-top storm deposits. *Quat. Int., Hurricanes and Typhoons: From the*
631 *Field Records to the Forecast* 195, 42–52. <https://doi.org/10.1016/j.quaint.2007.11.010>

632 Hickey, K.R., 1997. Documentary records of coastal storms in Scotland, 1500- 1991 A.D. PhD Thesis
633 602.

634 Hippensteel, S.P., Martin, R.E., 1999. Foraminifera as an indicator of overwash deposits, Barrier
635 Island sediment supply, and Barrier Island evolution: Folly Island, South Carolina.
636 *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 149, 115–125. [https://doi.org/10.1016/S0031-](https://doi.org/10.1016/S0031-0182(98)00196-5)
637 [0182\(98\)00196-5](https://doi.org/10.1016/S0031-0182(98)00196-5)

638 Hitz, O.M., Gärtner, H., Heinrich, I., Monbaron, M., 2008. Application of ash (*Fraxinus excelsior* L.)
639 roots to determine erosion rates in mountain torrents. *CATENA* 72, 248–258.
640 <https://doi.org/10.1016/j.catena.2007.05.008>

641 Hohl, R., Schweingruber, F.H., Schiesser, H.-H., 2002. Reconstruction of Severe Hailstorm Occurrence
642 with Tree Rings: A Case Study in Central Switzerland. *Tree-Ring Res.*

643 Hongo, C., 2018. The Hydrodynamic Impacts of Tropical Cyclones on Coral Reefs of Japan: Key Points
644 and Future Perspectives, in: *Coral Reef Studies of Japan, Coral Reefs of the World*. Springer,
645 Singapore, pp. 163–173.

646 Kenney, W.F., Brenner, M., Arnold, T.E., Curtis, J.H., Schelske, C.L., 2016. Sediment cores from
647 shallow lakes preserve reliable, informative paleoenvironmental archives despite hurricane-
648 force winds. *Ecol. Indic.* 60, 963–969. <https://doi.org/10.1016/j.ecolind.2015.08.046>

649 Lafon, C.W., Speer, J.H., 2002. Using dendrochronology to identify major ice storm events in oak
650 forests of southwestern Virginia. *Clim. Res.* 20, 41–54.

651 Lamb, H., Frydendahl, K., 1991. *Historic Storms of the North Sea, British Isles and Northwest Europe*.
652 Cambridge University Press.

653 Lamb, H.H., 1995. *Climate, History and the Modern World*, 2 edition. ed. Routledge, London.

654 Le Roy, S., Pedreros, R., André, C., Paris, F., Lecacheux, S., Marche, F., Vinchon, C., 2015. Coastal
655 flooding of urban areas by overtopping: dynamic modelling application to the Johanna storm
656 (2008) in Gâvres (France). *Nat Hazards Earth Syst Sci* 15, 2497–2510.
657 <https://doi.org/10.5194/nhess-15-2497-2015>

658 Lima, A.L., Hubeny, J.B., Reddy, C.M., King, J.W., Hughen, K.A., Eglinton, T.I., 2005. High-resolution
659 historical records from Pettaquamscutt River basin sediments: 1. 210Pb and varve

660 chronologies validate record of ¹³⁷Cs released by the Chernobyl accident. *Geochim.*
661 *Cosmochim. Acta* 69, 1803–1812. <https://doi.org/10.1016/j.gca.2004.10.009>

662 Liu, K., 2004. Paleotempestology: Geographic Solutions to Hurricane Hazard Assessment and Risk
663 Prediction, in: Janelle, D.G., Warf, B., Hansen, K. (Eds.), *WorldMinds: Geographical*
664 *Perspectives on 100 Problems*. Springer, Dordrecht, pp. 443–448.

665 Liu, K., Fearn, M.L., 2000. Reconstruction of Prehistoric Landfall Frequencies of Catastrophic
666 Hurricanes in Northwestern Florida from Lake Sediment Records. *Quat. Res.* 54, 238–245.
667 <https://doi.org/10.1006/qres.2000.2166>

668 Liu, K., Fearn, M.L., 1993. Lake-sediment record of late Holocene hurricane activities from coastal
669 Alabama. *Geology* 21, 793–796. [https://doi.org/10.1130/0091-](https://doi.org/10.1130/0091-7613(1993)021<0793:LSROLH>2.3.CO;2)
670 [7613\(1993\)021<0793:LSROLH>2.3.CO;2](https://doi.org/10.1130/0091-7613(1993)021<0793:LSROLH>2.3.CO;2)

671 Lomenick, T.F., Tamura, T., 1965. Naturally Occurring Fixation of Cesium-137 on Sediments of
672 Lacustrine Origin. *Soil Sci. Soc. Am. J.* 29, 383–387.
673 <https://doi.org/10.2136/sssaj1965.03615995002900040012x>

674 Lozano, I., Devoy, R.J.N., May, W., Andersen, U., 2004. Storminess and vulnerability along the Atlantic
675 coastlines of Europe: analysis of storm records and of a greenhouse gases induced climate
676 scenario. *Mar. Geol., Storms and their significance in coastal morpho-sedimentary dynamics*
677 210, 205–225. <https://doi.org/10.1016/j.margeo.2004.05.026>

678 Lu, H., An, Z., 1998. Paleoclimatic significance of grain size of loess-palaeosol deposit in Chinese Loess
679 Plateau. *Sci. China Ser. Earth Sci.* 41, 626–631. <https://doi.org/10.1007/BF02878745>

680 Malik, I., 2008. Dating of small gully formation and establishing erosion rates in old gullies under
681 forest by means of anatomical changes in exposed tree roots (Southern Poland).
682 *Geomorphology* 93, 421–436. <https://doi.org/10.1016/j.geomorph.2007.03.007>

683 Martin, J.-P., Germain, D., 2016. Can we discriminate snow avalanches from other disturbances using
684 the spatial patterns of tree-ring response? Case studies from the Presidential Range, White
685 Mountains, New Hampshire, United States. *Dendrochronologia* 37, 17–32.
686 <https://doi.org/10.1016/j.dendro.2015.12.004>

687 Martin, L., Mooney, S., Goff, J., 2014. Coastal wetlands reveal a non-synchronous island response to
688 sea-level change and a palaeostorm record from 5.5 kyr to present. *The Holocene* 24, 569–
689 580. <https://doi.org/10.1177/0959683614522306>

690 May, S.M., Brill, D., Leopold, M., Callow, J.N., Engel, M., Scheffers, A., Opitz, S., Norpoth, M.,
691 Brückner, H., 2017. Chronostratigraphy and geomorphology of washover fans in the Exmouth
692 Gulf (NW Australia) – A record of tropical cyclone activity during the late Holocene. *Quat. Sci.*
693 *Rev.* 169, 65–84. <https://doi.org/10.1016/j.quascirev.2017.05.023>

694 Migeon, S., Weber, O., Faugeres, J.-C., Saint-Paul, J., 1998. SCOPIX: A new X-ray imaging system for
695 core analysis. *Geo-Mar. Lett.* 18, 251–255. <https://doi.org/10.1007/s003670050076>

696 Mix, A.C., Harris, S.E., Janecek, T.R., 1995. Estimating lithology from nonintrusive reflectance spectra :
697 *Leg* 138.

698 Naquin, J.D., Liu, K., McCloskey, T.A., Bianchette, T.A., 2014. Storm deposition induced by hurricanes
699 in a rapidly subsiding coastal zone. *J. Coast. Res.* 308–313. [https://doi.org/10.2112/SI70-](https://doi.org/10.2112/SI70-052.1)
700 [052.1](https://doi.org/10.2112/SI70-052.1)

701 Nodine, E.R., Gaiser, E.E., 2015. Seasonal differences and response to a tropical storm reflected in
702 diatom assemblage changes in a southwest Florida watershed. *Ecol. Indic.* 57, 139–148.
703 <https://doi.org/10.1016/j.ecolind.2015.04.035>

704 Noren, A.J., Bierman, P.R., Steig, E.J., Lini, A., Southon, J., 2002. Millennial-scale storminess variability
705 in the northeastern United States during the Holocene epoch. *Nature* 419, 821–824.
706 <https://doi.org/10.1038/nature01132>

707 Olthof, I., King, D.J., Lautenschlager, R.A., 2003. Overstory and understory leaf area index as
708 indicators of forest response to ice storm damage. *Ecol. Indic.* 3, 49–64.
709 [https://doi.org/10.1016/S1470-160X\(03\)00010-4](https://doi.org/10.1016/S1470-160X(03)00010-4)

- 710 Orme, L.C., Davies, S.J., Duller, G. a. T., 2015. Reconstructed centennial variability of Late Holocene
711 storminess from Cors Fochno, Wales, UK. *J. Quat. Sci.* 30, 478–488.
712 <https://doi.org/10.1002/jqs.2792>
- 713 Parsons, M.L., 1998. Salt Marsh Sedimentary Record of the Landfall of Hurricane Andrew on the
714 Louisiana Coast: Diatoms and Other Paleoindicators. *J. Coast. Res.* 14, 939–950.
715 <https://doi.org/10.2307/4298846>
- 716 Peng, Y., Xiao, J., Nakamura, T., Liu, B., Inouchi, Y., 2005. Holocene East Asian monsoonal
717 precipitation pattern revealed by grain-size distribution of core sediments of Daihai Lake in
718 Inner Mongolia of north-central China. *Earth Planet. Sci. Lett.* 233, 467–479.
719 <https://doi.org/10.1016/j.epsl.2005.02.022>
- 720 Pierce, J.W., 1970. Tidal Inlets and Washover Fans. *J. Geol.* 78, 230–234.
721 <https://doi.org/10.1086/627504>
- 722 Polonia, A., Bonatti, E., Camerlenghi, A., Lucchi, R.G., Panieri, G., Gasperini, L., 2013. Mediterranean
723 megaturbidite triggered by the AD 365 Crete earthquake and tsunami. *Sci. Rep.* 3, 1285.
724 <https://doi.org/10.1038/srep01285>
- 725 Pouzet, P., Creach, A., Godet, L., 2015. Dynamique de la démographie et du bâti dans l'ouest du
726 Marais poitevin depuis 1705. *Norois Environ. Aménagement. Société* 83–96.
727 <https://doi.org/10.4000/norois.5589>
- 728 Pouzet, P., Maanan, M., Schmidt, S., Athimon, E., Robin, M., 2018. Three centuries of historical and
729 geological data for the marine deposit reconstruction: examples from French Atlantic coast.
730 *Mar. Geol.* Submitted.
- 731 Ritchie, J.C., McHenry, J.R., 1990. Application of Radioactive Fallout Cesium-137 for Measuring Soil
732 Erosion and Sediment Accumulation Rates and Patterns: A Review. *J. Environ. Qual.* 19, 215–
733 233. <https://doi.org/10.2134/jeq1990.00472425001900020006x>
- 734 Rovera, G., Lopez Saez, J., Corona, C., Stoffel, M., Berger, F., 2013. Preliminary quantification of the
735 erosion of sandy-gravelly cliffs on the island of Porquerolles (Provence, France) through
736 dendrogeomorphology, using exposed roots of Aleppo pine (*Pinus halepensis* Mill.). *Geogr.*
737 *Fis. E Din. Quat.* 36, 181–187.
- 738 Roy, P.D., Caballero, M., Lozano, R., Ortega, B., Lozano, S., Pi, T., Israde, I., Morton, O., 2010.
739 Geochemical record of Late Quaternary paleoclimate from lacustrine sediments of paleo-lake
740 San Felipe, western Sonora Desert, Mexico. *J. South Am. Earth Sci.* 29, 586–596.
741 <https://doi.org/10.1016/j.jsames.2009.11.009>
- 742 Sabatier, P., Dezileau, L., Briquet, L., Colin, C., Siani, G., 2010. Paleostorm events revealed by clay
743 minerals and geochemistry in coastal lagoon: a study case of Pierre Blanche (NW
744 Mediterranean Sea). *Sediment. Geol.* 228, 205–217.
- 745 Sabatier, P., Dezileau, L., Colin, C., Briquet, L., Bouchette, F., Martinez, P., Siani, G., Raynal, O., Von
746 Grafenstein, U., 2012. 7000 years of paleostorm activity in the NW Mediterranean Sea in
747 response to Holocene climate events. *Quat. Res.* 77, 1–11.
748 <https://doi.org/10.1016/j.yqres.2011.09.002>
- 749 Sabatier, P., Dezileau, L., Condomines, M., Briquet, L., Colin, C., Bouchette, F., Le Duff, M.,
750 Blanchemanche, P., 2008. Reconstruction of paleostorm events in a coastal lagoon (Hérault,
751 South of France). *Mar. Geol.* 251, 224–232. <https://doi.org/10.1016/j.margeo.2008.03.001>
- 752 Schweingruber, F.H., 1996. Tree rings and environment dendroecology. Haupt,
753 Berne ;Stuttgart ;Vienna.
- 754 Scoffin, T.P., 1993. The geological effects of hurricanes on coral reefs and the interpretation of storm
755 deposits. *Coral Reefs* 12, 203–221. <https://doi.org/10.1007/BF00334480>
- 756 Scott, D.B., Collins, E.S., Gayes, P.T., Wright, E., 2003. Records of prehistoric hurricanes on the South
757 Carolina coast based on micropaleontological and sedimentological evidence, with
758 comparison to other Atlantic Coast records. *GSA Bull.* 115, 1027–1039.
759 <https://doi.org/10.1130/B25011.1>
- 760 Shroder, J., 1980. Dendrogeomorphology: review and new techniques of tree-ring dating. *Prog. Phys.*
761 *Geogr. Earth Environ.* 4, 161–188. <https://doi.org/10.1177/030913338000400202>

- 762 Shroder, J.F., 1978. Dendrogeomorphological Analysis of Mass Movement on Table Cliffs Plateau,
763 Utah. *Quat. Res.* 9, 168–185. [https://doi.org/10.1016/0033-5894\(78\)90065-0](https://doi.org/10.1016/0033-5894(78)90065-0)
- 764 Speer, J.H., 2012. *Fundamentals of Tree Ring Research*, 2 edition. ed. University of Arizona Press,
765 Tucson, Ariz.
- 766 Stager, J.C., Cumming, B.F., Laird, K.R., Garrigan-Piela, A., Pederson, N., Wiltse, B., Lane, C.S., Nester,
767 J., Ruzmaikin, A., 2017. A 1600-year diatom record of hydroclimate variability from Wolf
768 Lake, New York. *The Holocene* 27, 246–257. <https://doi.org/10.1177/0959683616658527>
- 769 Steers, J.A., Stoddart, D.R., Bayliss-Smith, T.P., Spencer, T., Durbidge, P.M., 1979. The Storm Surge of
770 11 January 1978 on the East Coast of England. *Geogr. J.* 145, 192–205.
771 <https://doi.org/10.2307/634386>
- 772 Switzer, A.D., Jones, B.G., 2008. Large-scale washover sedimentation in a freshwater lagoon from the
773 southeast Australian coast: sea-level change, tsunami or exceptionally large storm? *The*
774 *Holocene* 18, 787–803. <https://doi.org/10.1177/0959683608089214>
- 775 Travis, D., Meentemeyer, V., 1991. Influence of glaze ice storms on growth rates of loblolly pine *Pinus*
776 *taeda* and shortleaf pine *Pinus echinata* in the Southern Appalachian Piedmont. *Clim. Res. -*
777 *Clim. RES* 1, 199–205. <https://doi.org/10.3354/cr001199>
- 778 Walling, D.E., He, Q., 1999. Improved Models for Estimating Soil Erosion Rates from Cesium-137
779 Measurements. *J. Environ. Qual.* 28, 611–622.
780 <https://doi.org/10.2134/jeq1999.00472425002800020027x>
- 781 Wang, P., Horwitz, M.H., 2007. Erosional and depositional characteristics of regional overwash
782 deposits caused by multiple hurricanes. *Sedimentology* 54, 545–564.
783 <https://doi.org/10.1111/j.1365-3091.2006.00848.x>
- 784 Wassmer, P., Schneider, J.-L., Fonfrège, A.-V., Lavigne, F., Paris, R., Gomez, C., 2010. Use of
785 anisotropy of magnetic susceptibility (AMS) in the study of tsunami deposits: Application to
786 the 2004 deposits on the eastern coast of Banda Aceh, North Sumatra, Indonesia. *Mar. Geol.*
787 275, 255–272. <https://doi.org/10.1016/j.margeo.2010.06.007>
- 788 Yu, K.-F., Zhao, J.-X., Shi, Q., Meng, Q.-S., 2009. Reconstruction of storm/tsunami records over the
789 last 4000 years using transported coral blocks and lagoon sediments in the southern South
790 China Sea. *Quat. Int.* 195, 128–137. <https://doi.org/10.1016/j.quaint.2008.05.004>
- 791 Zecchetto, S., Umgiesser, G., Brocchini, M., 1997. Hindcast of a storm surge induced by local real
792 wind fields in the Venice Lagoon. *Cont. Shelf Res.* 17, 1513–1538.
793 [https://doi.org/10.1016/S0278-4343\(97\)00023-X](https://doi.org/10.1016/S0278-4343(97)00023-X)
- 794 Zhu, Z., Feinberg, J.M., Xie, S., Bourne, M.D., Huang, C., Hu, C., Cheng, H., 2017. Holocene ENSO-
795 related cyclic storms recorded by magnetic minerals in speleothems of central China. *Proc.*
796 *Natl. Acad. Sci.* 114, 852–857. <https://doi.org/10.1073/pnas.1610930114>
797

798 Primary Sources of historical archives:

799 - Meteo France :

800 <http://tempetes.meteo.fr/Tempete-du-12-mars-1967.html>

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

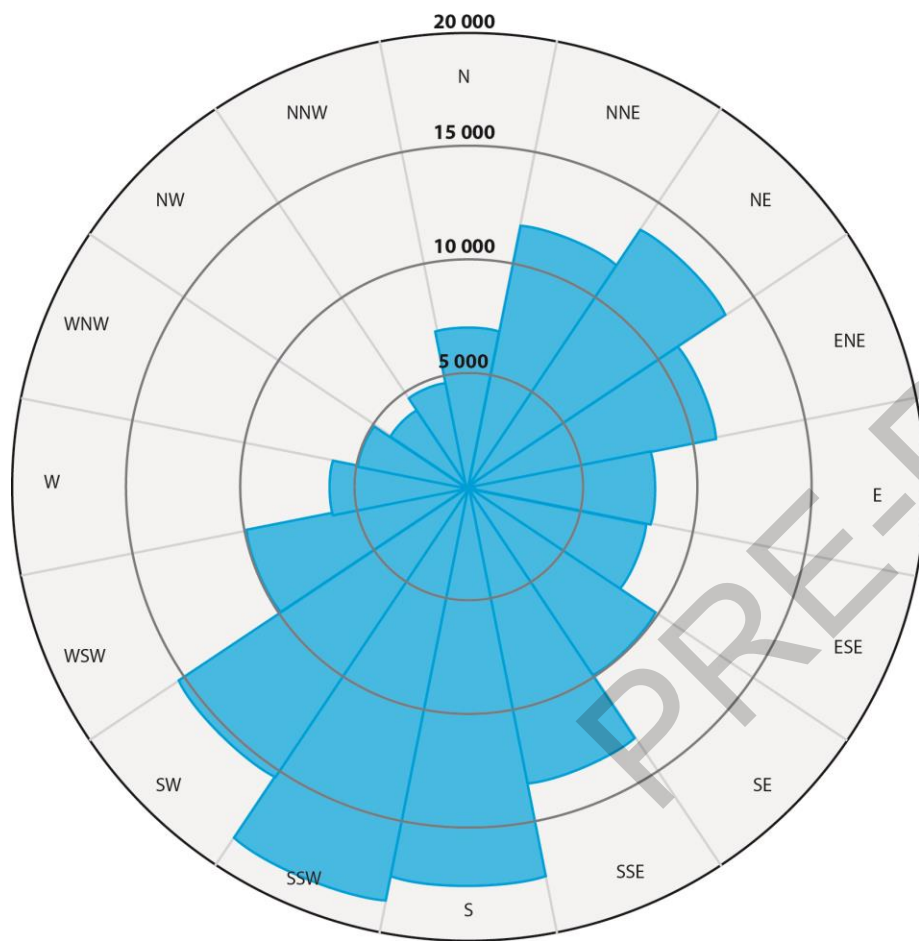
835

836

Fig. 1



A. Number of prevailing winds



B. Average speeds of prevailing winds

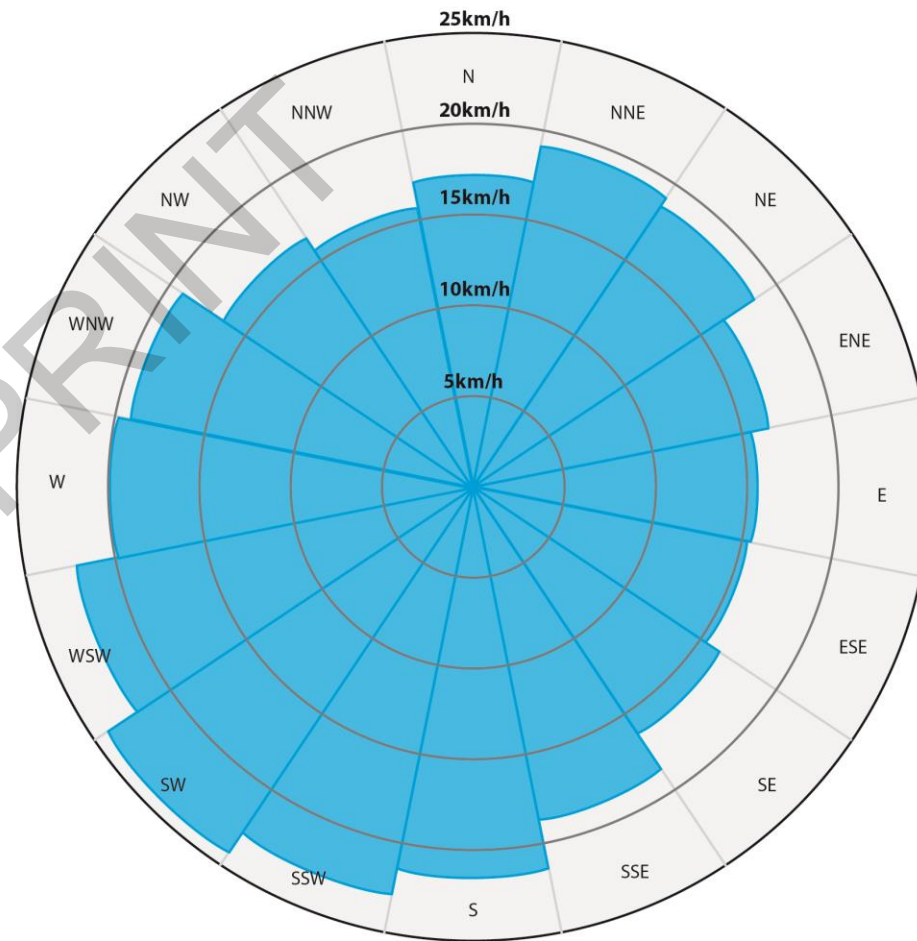


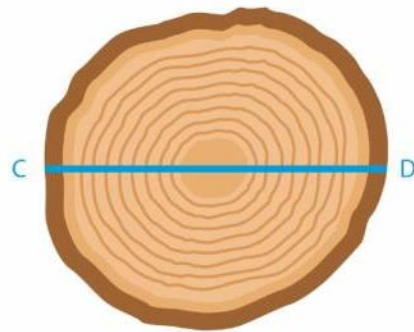
Fig. 2

Fig. 3

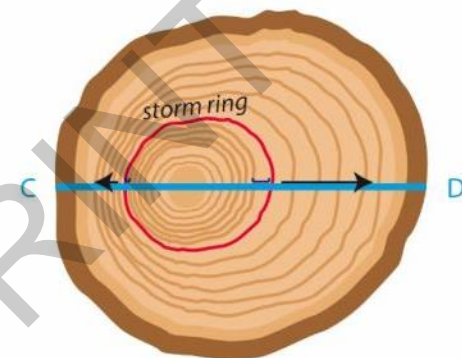
Tree evolution

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

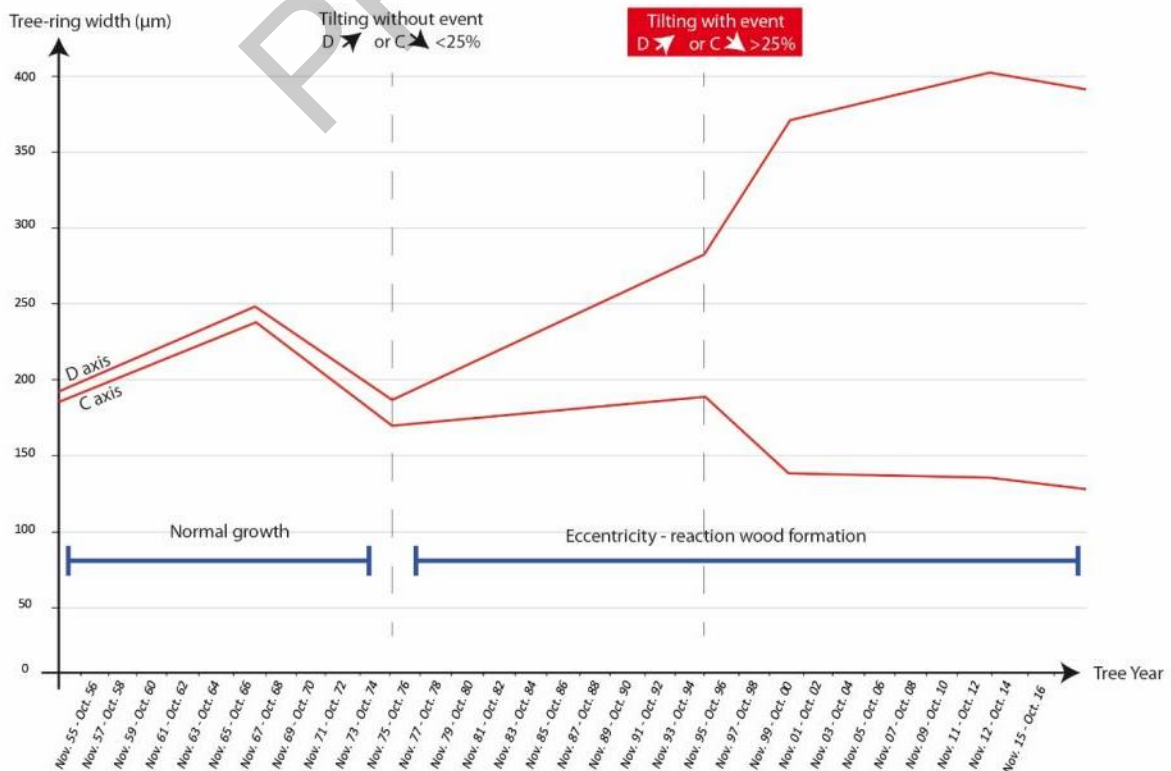
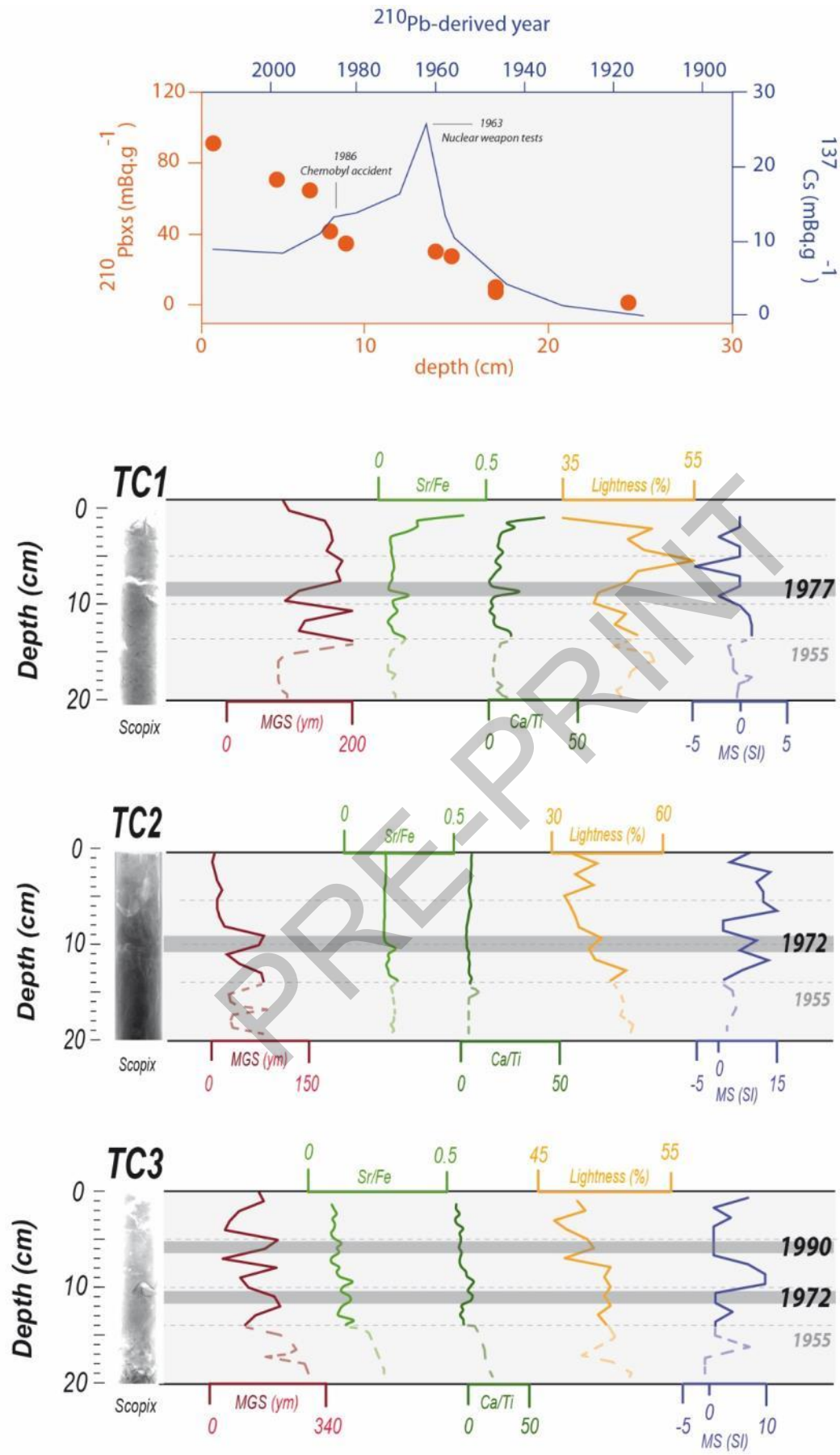


Fig. 4



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

Fig. 5

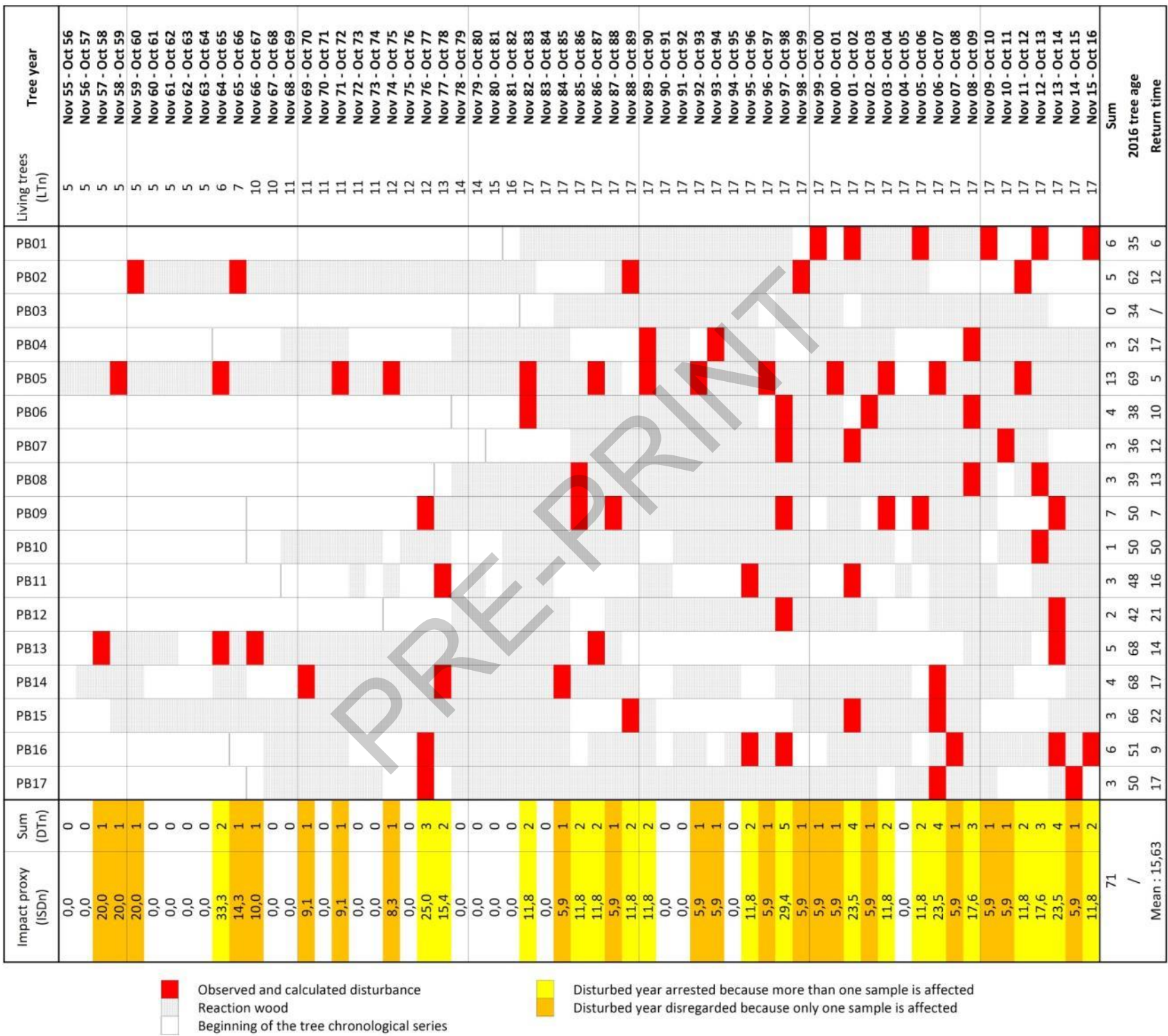
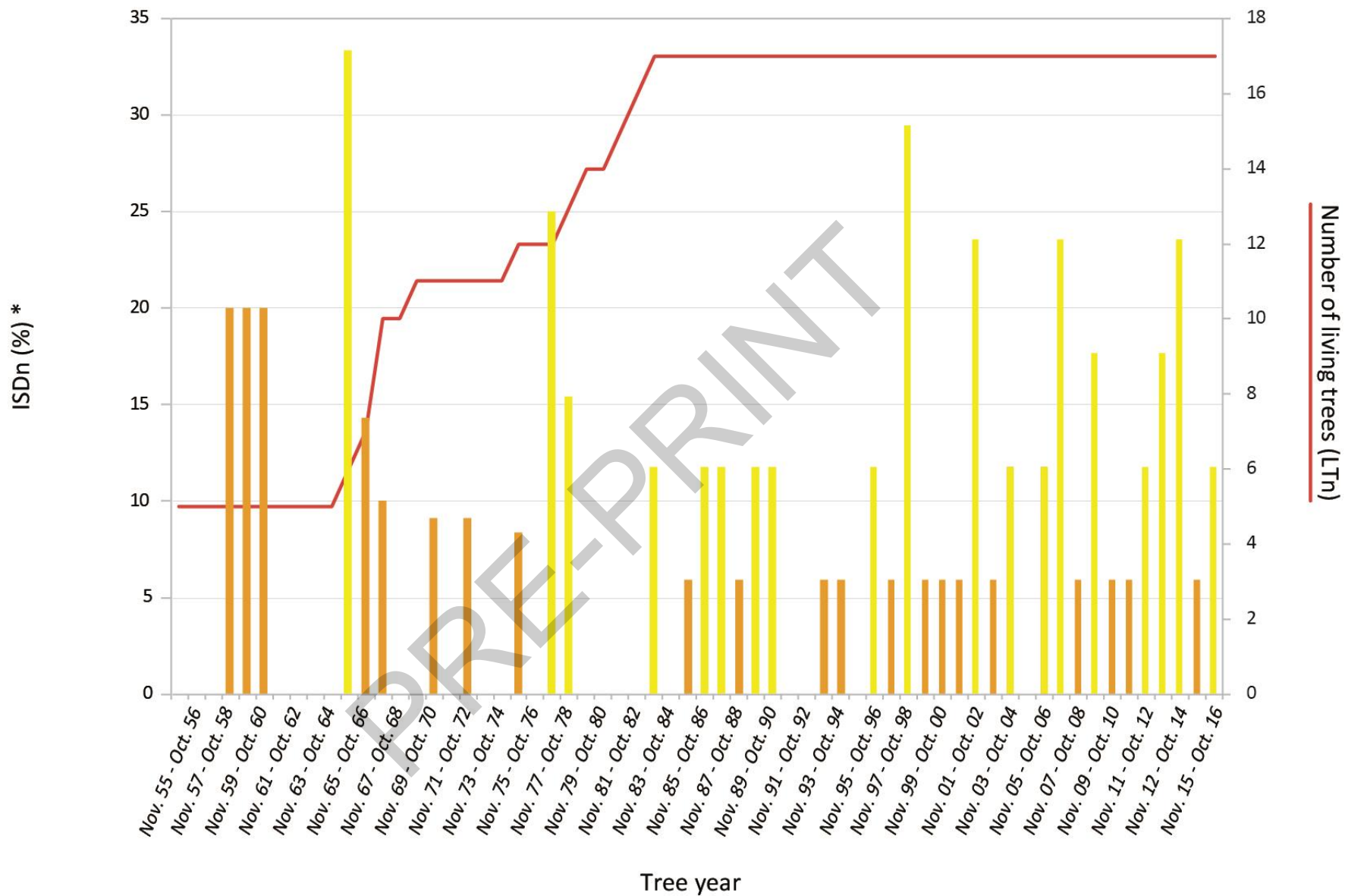


Fig. 6



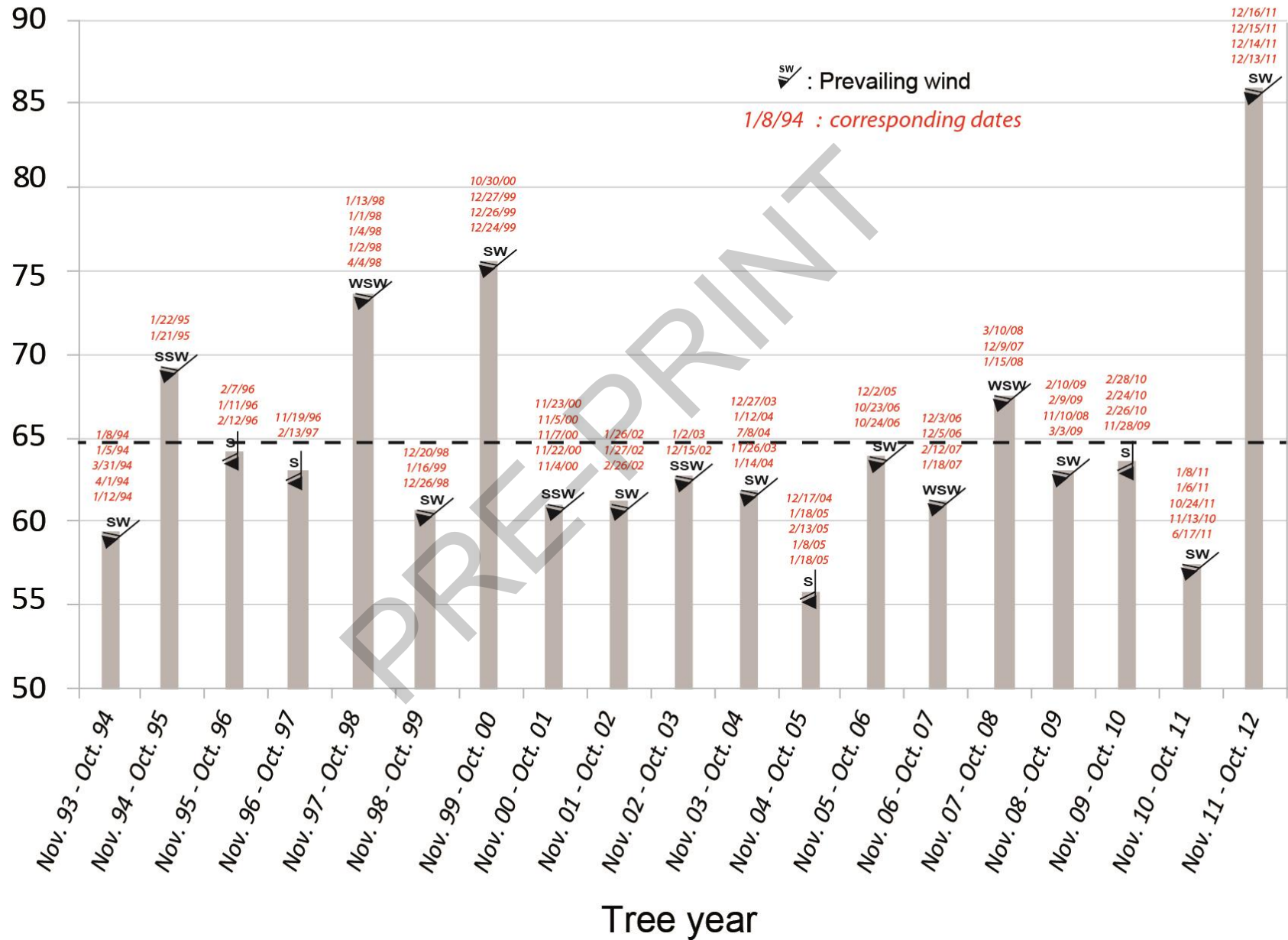
*Disturbed year arrested because of more than one sample is affected

*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



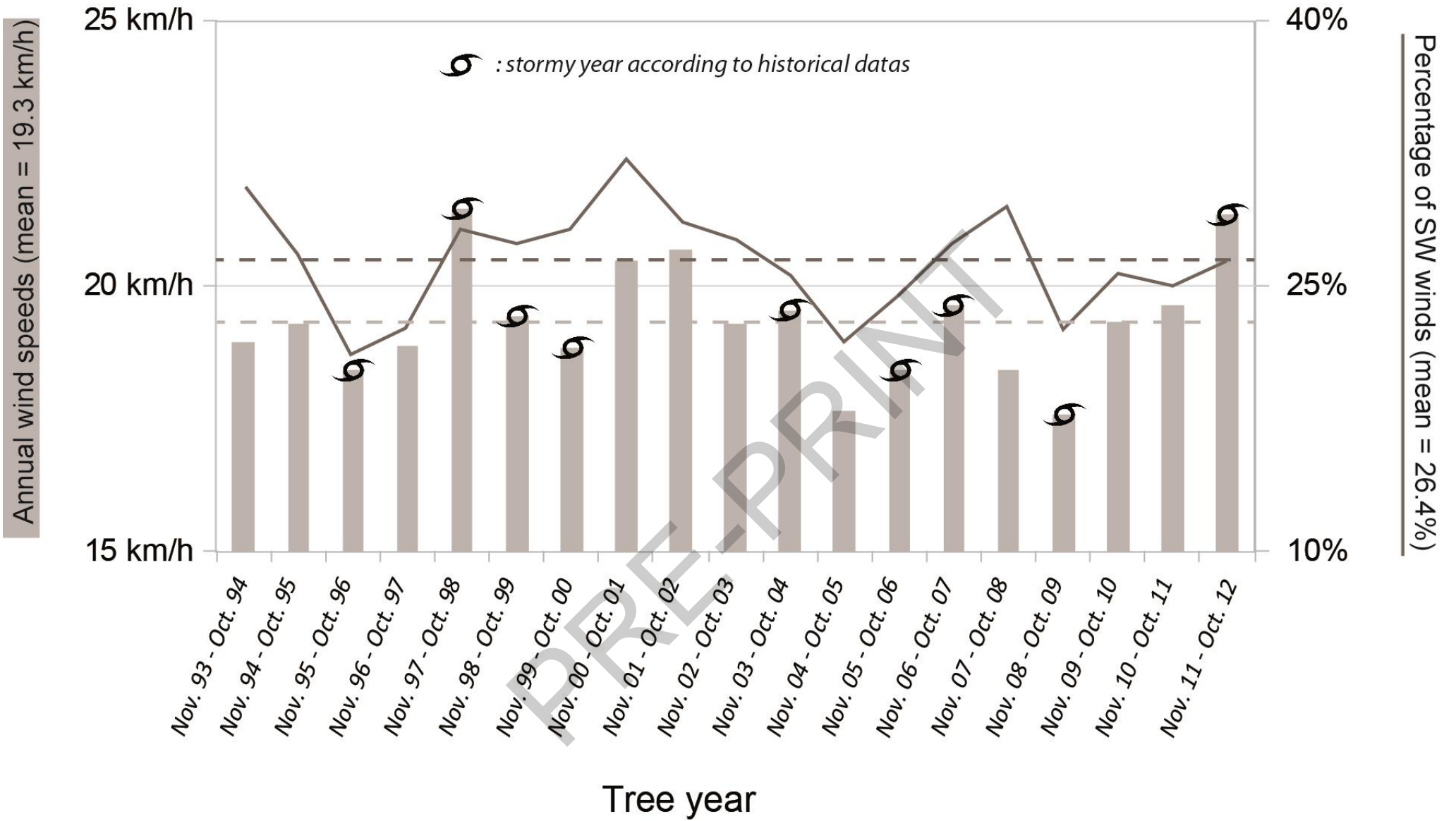
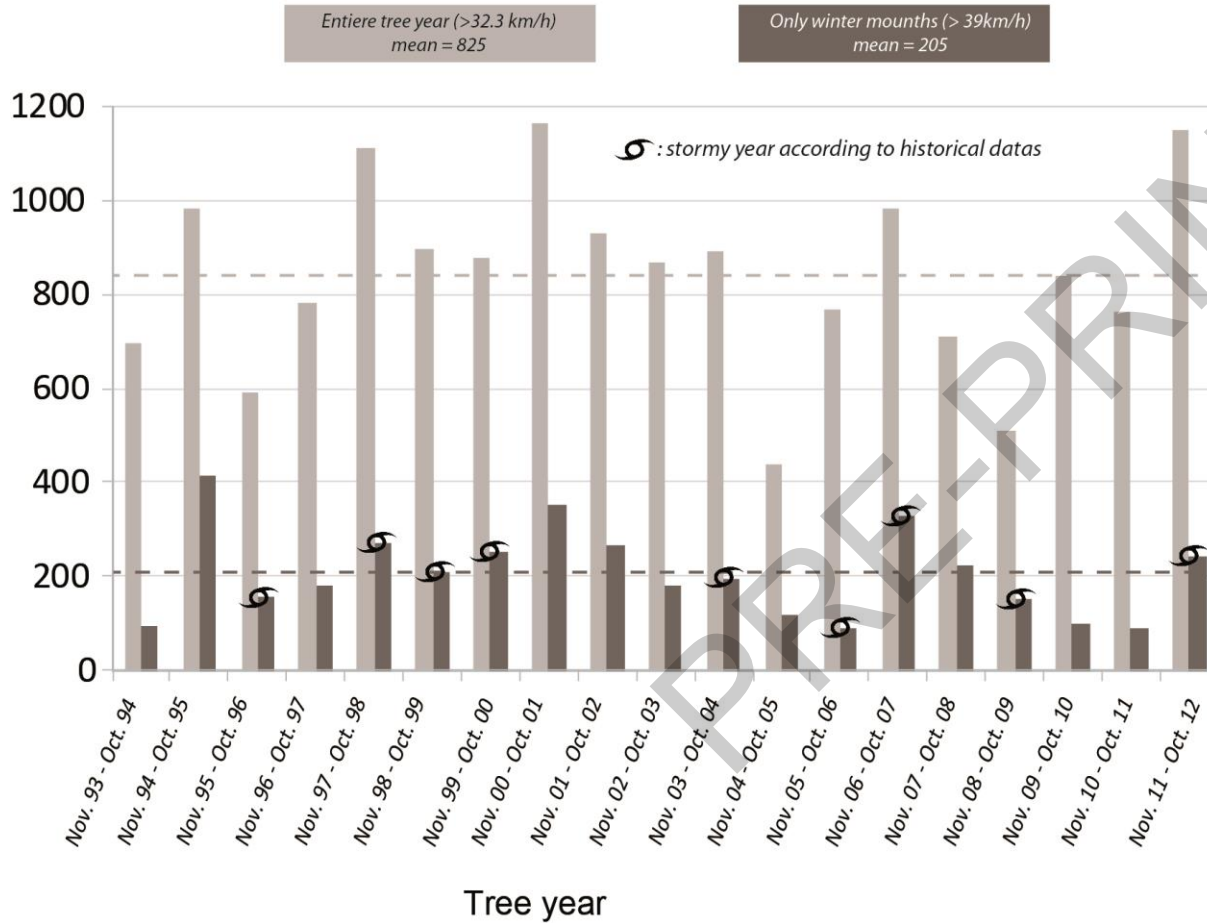


Fig. 8

A. Intense wind speeds :
 Number superiors to the 9th decile



B. Extreme wind speeds :
 Number superior to the
 Beaufort 9 rank (75 km/h)

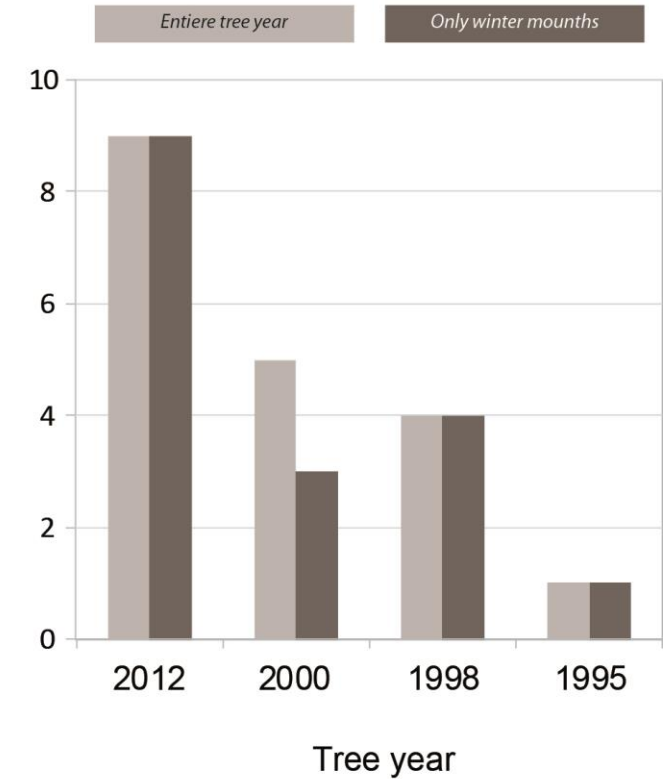
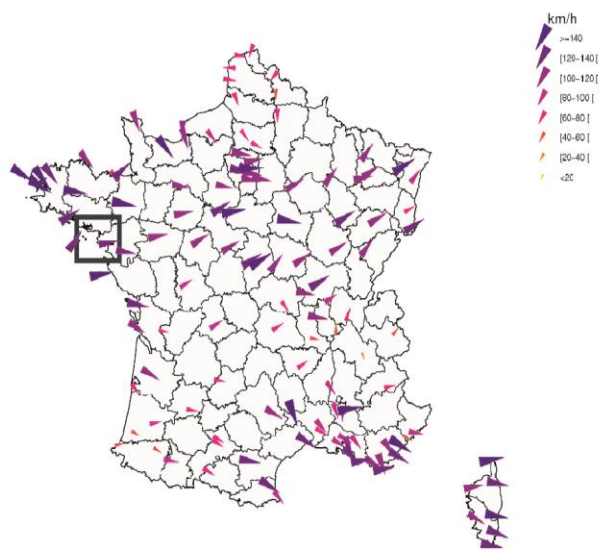


Fig. 9

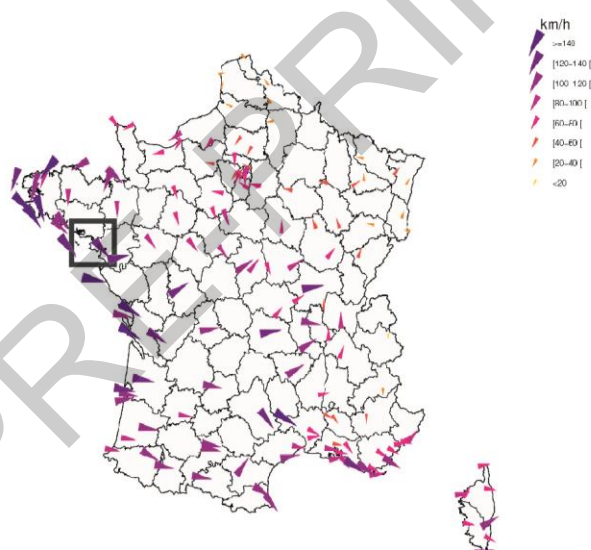
Fig. 10

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



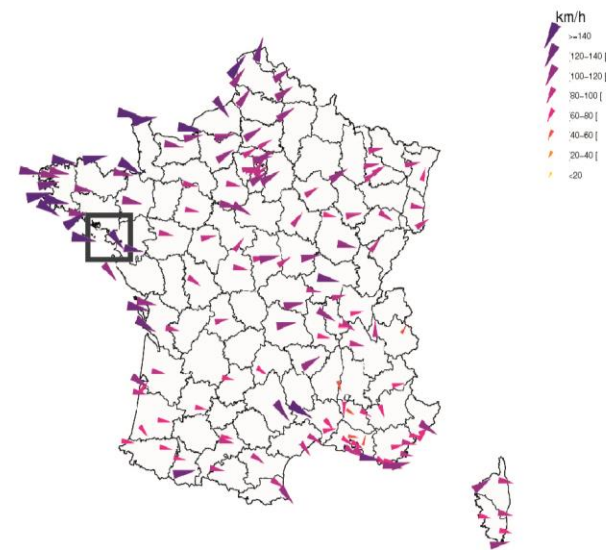
Edité le : 06/12/2016 - Données du : 23/07/2014 à 15:55 UTC

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

Sedimentological cores				
Name	Id	X (RGF lambert 93)	Y (RGF lambert 93)	Maximum Depth (cm)
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
Dendrochronological cores				
Name	Id	X (RGF lambert 93)	Y (RGF lambert 93)	Disturbance direction
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	http://www.ouest-france.fr/meteo/tempete/meteo-tempete-sur-louest-139-km/h-de-vent-en-bretagne-et-normandie-4024680
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 http://tempetes.meteo.fr/Tempete-Dirk-de-noel-2013.html
2013	17,6	Yes	Yes	10/27/13	http://www.lemonde.fr/planete/article/2013/10/27/tempete-12-departements-du-nord-ouest-en-alerte-orange_3503693_3244.html
2012	11,8	Yes	Yes	12/6/11	http://tempetes.meteo.fr/Tempete-Joachim-du-16-decembre-2011.html
2011	5,9	No	Yes	/	/
2010	5,9	Probably	?	2/27/10	http://tempetes.meteo.fr/Tempete-Xynthia-du-27-au-28-fevrier-2010.html
2009	17,6	Yes	Yes	2/9/09	http://tempetes.meteo.fr/Tempete-Quinten-du-09-au-10-fevrier-2009.html
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	http://tempetes.meteo.fr/Tempete-Vera-le-8-decembre-2006.html
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	http://tempetes.meteo.fr/Tempetes-successives-du-12-au-15-janvier-2004.html
2003	5,9	Probably	?	1/2/03	http://tempetes.meteo.fr/Tempete-Calvann-du-02-janvier-2003.html
2002	23,5	No	No	/	/
2001	5,9	No	Yes	/	/
2000	5,9	Several	No	10/30/00 12/27/99 12/26/99	http://tempetes.meteo.fr/Tempete-Oratia-du-30-octobre-2000.html http://tempetes.meteo.fr/Martin-les-27-et-28-decembre-1999.html http://tempetes.meteo.fr/Lothar-le-26-decembre-1999.html
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 http://tempetes.meteo.fr/Tempete-du-4-janvier-1998.html http://tempetes.meteo.fr/Tempete-du-2-janvier-1998.html
1997	5,9	No	Yes	/	/
1996	11,8	Yes	Yes	2/7/96	http://tempetes.meteo.fr/Tempete-du-7-et-8-fevrier-1996.html
1995	0,0	No	Yes	/	/
1994	5,9	MI	Yes	1/5/94	http://tempetes.meteo.fr/Tempetes-du-5-au-7-janvier-1994.html
1993	5,9	MI	Yes	9/12/93	http://tempetes.meteo.fr/Tempete-des-12-et-13-septembre-1993.html
1992	0,0	Probably	?	12/18/91	http://tempetes.meteo.fr/Synthese-du-18-au-25-decembre-1991.html
1991	0,0	No	Yes	/	/
1990	11,8	Several	Yes	2/26/1990 2/3/1990 1/25/1990	http://tempetes.meteo.fr/Viviane-du-26-au-28-fevrier-1990.html http://tempetes.meteo.fr/Herta-le-03-fevrier-1990.html http://tempetes.meteo.fr/Daria-le-25-janvier-1990.html
1989	11,8	Yes	Yes	2/25/89	http://www.meteo-paris.com/chronique/annee/1989 , with https://www.prevision-meteo.ch/almanach/1989
1988	5,9	No	Yes	/	/
1987	11,8	Yes	Yes	10/15/87	http://tempetes.meteo.fr/L-ouragan-du-15-au-16-octobre-1987.html
1986	11,8	Yes	Yes	12/7/86	http://www.meteo-paris.com/chronique/annee/1986
1985	5,9	Probably	?	11/22/84	http://tempetes.meteo.fr/Tempetes-du-22-au-24-novembre-1984.html
1984	0,0	No	Yes	/	/
1983	11,8	Yes	Yes	11/6/82	http://tempetes.meteo.fr/Tempete-du-6-au-8-novembre-1982.html
1982	0,0	No	Yes	/	/
1981	0,0	No	Yes	/	/
1980	0,0	Yes	No	12/15/79	http://tempetes.meteo.fr/Tempete-du-15-decembre-1979.html
1979	0,0	No	Yes	/	/
1978	15,4	Yes	Yes	1/11/78	MetMat n°101, available at http://nauticalfree.free.fr/metmar/metmar1a217.html
1977	25,0	Yes	Yes	12/2/76	http://tempetes.meteo.fr/Tempete-du-2-decembre-1976.html
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	http://tempetes.meteo.fr/Tempete-du-13-fevrier-1972.html
1971	0,0	No	Yes	/	/
1970	9,1	No	Yes	/	/
1969	0,0	MI	Yes	7/6/69	http://tempetes.meteo.fr/Tempete-du-06-juillet-1969.html
1968	0,0	MI	Yes	1/7/68	http://tempetes.meteo.fr/Tempete-du-7-janvier-1968.html
1967	10,0	Yes	No	3/12/67	http://tempetes.meteofrance.fr/Tempete-du-12-mars-1967.html
1966	14,3	No	Yes	/	/
1965	33,3	Several	Yes	1/17/65 1/16/65 1/13/65	http://www.meteo-paris.com/chronique/annee/1965 , with https://www.infoclimat.fr/historic-details-evenement-482-archives.html 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