https://doi.org/10.5194/egusphere-2026-3658
Preprint. Discussion started: 15 July 2026

Chasing a millennium of European storms: a synthesis of three decades of multidisciplinary research

Pierre Pouzet[1]

[1]**Univ Angers**, Nantes Université, Le Mans Université, CNRS, Laboratoire de Planétologie et Géosciences, **LPG** UMR 6112, 49000 Angers, France

Correspondence to: Pierre Pouzet (pierre.pouzet@univ-angers.fr)

Abstract

Understanding the long-term variability of coastal storms is essential for assessing future coastal risks in a context of accelerating climate change and sea-level rise. This study synthesizes eighty-one historical and geophysical storm chronologies from western Europe to investigate storm activity over the last millennium. To compare heterogeneous records, a decadal *Storm Index (SI)* was developed to quantify the relative occurrence of storm impacts within eight geographical regions and was visualized using a novel *"storm stripes"* approach designed to highlight both temporal and spatial variations in storm activity.

The synthesis reveals substantial regional differences in storm occurrence through time. The decrease in air and Sea Surface Temperatures (SST) since 1300 during the early LIA may have favoured higher storm activity in northern Europe, peaking around 1450-1470 during one of its coolest phases, characterized by weak northern European SST and a significant AMO trough. While the early LIA was mainly driven by NAO+ patterns, transitional NAO+ to NAO- phases may have led to the stormiest periods in the north. Conversely, the increase in air temperature and Mediterranean SST during the late LIA may explain the significant later stormy phase in the western Mediterranean, consistent with a large-scale NAO- phase but with its stormiest peak (1760–1850 AD) linked to a NAO- to NAO+ transitional period at a finer temporal scale. These contrasting patterns appear broadly consistent with variations in the North Atlantic Oscillation, although the influence of other modes of climate variability remains uncertain. By combining historical and geophysical evidence at a continental scale, this study provides a new perspective on the long-term evolution of European coastal storm activity. The results highlight the complexity of storm–climate interactions and demonstrate the value of multidisciplinary paleostorm reconstructions for improving our understanding of future climate adaptation and coastal mitigation strategies.

https://doi.org/10.5194/egusphere-2026-3658
Preprint. Discussion started: 15 July 2026

1 Introduction

1.1 Paleostorm research applied to coastal societal concerns

In the current context of climate change, the study of extreme coastal events has become a major environmental challenge. According to recent findings from the Intergovernmental Panel on Climate Change (IPCC), the rising sea levels could ultimately displace 280 million people worldwide (IPCC, 2019). With nearly half of the global population living within 150 km off the coast (Cosby et al., 2024), coastal storms and marine flooding of low-lying areas poses a significant and ongoing threat to nearshore societies. As coastal environments are among the most vulnerable regions to the increasing impacts of climate change and sea-level rise (Masson-Delmotte et al., 2021), particularly in densely populated low-lying areas exposed to marine flooding or shoreline erosion. By reconstructing past storm activity over centennial to millennial timescales, paleostorm archives improve the understanding of the natural variability of extreme coastal events. These reconstructions help identify periods of enhanced storminess and links between atmospheric-oceanic forcing mechanisms and coastal impacts (Lamb and Frydendahl, 1991; Sorrel et al., 2012). Such information is particularly valuable for refining predictive models of future coastal risks under ongoing climate change, as modern observations alone may underestimate the full range of natural storm variability.

Beyond climatological reconstruction, paleostorm studies also provide essential insights into the long-term resilience and vulnerability of coastal socio-ecosystems. Sedimentary and geomorphological archives document the cumulative impacts of repeated extreme events on coastal sensible systems such as barrier, dunes, marshes, lagoons, estuaries, and cliffs, allowing the identification of thresholds of coastal destabilization and recovery capacities following major disturbances (LeBlanc et al., 2017). These archives reveal how coastal landscapes have responded to past phases of increased storminess and sea-level fluctuations, giving interesting analogues for present-day environmental changes. In Europe, where many ancient cultural heritage sites and present urbanized areas are concentrated along the coastline, understanding the historical frequency and intensity of extreme marine events has become a major societal challenge (Gerrard and Petley, 2013). Paleotempestology thus increasingly supports coastal risk management policies by informing shoreline planning and flood prevention strategies. The multidisciplinary nature of the field, combining earth science approaches (*e.g.* sedimentology, geomorphology and climatology) and humanities (with particularly the use historical written archives), further strengthens its capacity to address the complex interactions between coastal dynamics under climate variability, with the consideration of the evolution of human societies over long timescales (Ding et al., 2026; Kaniewski et al., 2016).

1.2 Tree decades of European paleostorm research

Paleotempestology emerged during the early 1990s through pioneering sedimentological studies imported from the American Atlantic basin by Liu and Fearn (Liu and Fearn, 1993, 2000) along the Gulf of Mexico coast. These studies introduced the concept of marine *“washover”* deposits preserved in coastal lagoons, marshes, and lakes as sedimentary

https://doi.org/10.5194/egusphere-2026-3658
Preprint. Discussion started: 15 July 2026

archives of past tropical cyclones. Their methodological framework, based on the identification of coarse marine layers transported inland during extreme events, rapidly became a cornerstone of paleostorm reconstruction worldwide. Although initially developed in microtidal tropical environments, these approaches progressively expanded to a wide range of coastal settings and climatic regions, including Europe.

After a rich historical work analyzing a millenary of past event (Lamb and Frydendahl, 1991), the development of European paleostorm research initially followed distinct regional trajectories controlled by coastal geomorphology and hydrodynamic conditions. Along the macrotidal coasts of the North Atlantic, the English Channel and the British Isles presented early studies mainly focusing on geomorphological evidence such as *cliff-top storm deposits* (CTSD), which are less affected by tidal variability and preserve signatures of extreme wave impacts (*e.g.* Fichaut and Suanez, 2011; Hall et al., 2006; Hansom et al., 2008). In contrast, sedimentological reconstructions based on lagoonal and back-barrier deposits were first extensively developed along the microtidal Mediterranean coasts of southern France during the 2000s (*e.g.* Dezileau et al., 2011; Kaniewski et al., 2016; Sabatier et al., 2008). From the beginning of the 2010s onward, these approaches progressively expanded toward the macrotidal environments of western Europe, including the Atlantic French coast and several English Channel or British low-lying coastal systems (*e.g.* Baltzer et al., 2014; Orme et al., 2015; Sorrel et al., 2012).

Over the last three decades, European paleostorm studies have also benefited from major methodological diversification. While early reconstructions mainly relied on grain-size analyses to identify marine incursions within coastal sedimentary sequences, a wide range of complementary proxies are now commonly employed. Organic matter, geochemistry, magnetic susceptibility, colorimetry, clay minerals, pollen assemblages, foraminifera, radiography, and faunal indicators are now combined to improve the detection and interpretation of past extreme events (Goslin et al., 2018). The development of tsunami research, particularly along the Portuguese coast following investigations of the 1755 Lisbon event, also contributed to the refinement and diffusion of sedimentological and geochemical approaches later applied to storm reconstructions. (Abrantes et al., 2008). More recently, European paleotempest research has progressively integrated additional indicators beyond classical washover deposits. Studies based on beach ridges, coastal dune erosion, lacustrine sediments, estuarine and deltaic archives, or terrasse sedimentation have improved the understanding of long-term storm impacts on coastal systems (Adolph et al., 2024; Hess et al., 2024; Kerverdo et al., 2026; Van Vliet Lanoe et al., 2017). Other emerging approaches, including biological indicators such as tree-ring (Pouzet et al., 2025), have further expanded the range of available archives for reconstructing past storm variability. Together, these developments illustrate the rapid expansion of European paleostorm research over the last three decades and highlight the increasingly multidisciplinary nature of the field. And concurrently, the 2000 and 2010 decade are also periods of great new discoveries for European storm written archives methodologies (Athimon, 2019; Blanchemanche, 2009; Brázdil et al., 2005; Camuffo et al., 2000; Sarrazin, 2012).

1.3 The challenge of understanding extratropical storm climatology

However, even if three decades of European paleotempest research have considerably advanced our understanding of the environmental and societal impacts of these events, their climatological implications remain only partially understood. While the influence of climate change on tropical cyclones is well documented, with an increase of Sea Surface Temperature (SST) that directly influence the increasing intensity observed on the most intense events ; its impact on extratropical storms remains uncertain (Masson-Delmotte et al., 2021). During the last decades, the IPCC has observed a poleward drift in extratropical storm trajectories over recent decades in both hemispheres but highlights the difficulty of assessing the future effects of rising greenhouse gas emissions on these storms (Wang et al., 2006). Currently, the increase in associated precipitation is also widely accepted by the scientific community (Semmler and Jacob, 2004). Although European coastal extreme events are becoming more frequent due to global mean sea-level rise (Vousdoukas et al., 2017), the long-term climatological dynamics of storms affecting Europe remain poorly understood. While most reconstructions of stormy dynamics at a wide scale focus on the recent past, *i.e.*, since the use of meteorological data and reanalysis (Matulla et al., 2008; Morim et al., 2025; Ulbrich and Christoph, 1999), it remains a true challenge today to evaluate the evolution of these physical processes over long timescales.

If European intense storms have always occurred throughout history, the variation of its activity mostly depends on climatological and oceanological factor, such as the North Atlantic Oscillation (NAO), the Atlantic Meridional Overturning Circulation (AMOC), or the temperature variation patterns (Mann et al., 2009; Pinto and Raible, 2012; Trouet et al., 2012). Regional, historical works already proved the occurrence of several very intense events dated to 1351, 1469 or 1645 (Pouzet and Maanan, 2020) ; however, numerous more events that are not known at the present day may have also deeply impacted coastal communities. Following first assessments made by H.H. Lamb (Lamb, 1980), as the Jet Stream shows significant latitudinal variations during recent decades and as it deeply influences the storm occurrence over Europe, storm dynamics may have latitudinally varied throughout history, possibly following the Jet Stream path depending on NAO records. However, further work must be done to complete these first assumptions, and to understand if other patterns such as the El Niño Southern Oscillation (ENSO) or the Atlantic Ocean warming (Atlantic Multi-decadal Oscillation, AMO index) may also be important in storm development (Hess et al., 2024; Luterbacher et al., 2002). Despite the absence of a clear scientific consensus regarding the mechanisms controlling Europeaner extratropical storm activity (Masson-Delmotte et al., 2021), this review seeks to refine our understanding of storm variability over the last millennium through the synthesis of eighty-one major European storm chronologies based on both historical and geophysical evidence.

https://doi.org/10.5194/egusphere-2026-3658
Preprint. Discussion started: 15 July 2026

2. Materials and Methods

2.1 Multidisciplinary storm archives and datasets

To unlock these scientific barriers, this paper aims to take a temporal depth to apprehend the long-term evolution of coastal storm impacts recorded in both geophysical and historical archives. A substantial time depth in the understanding of long-term storm dynamics is obtained with historical written archives that provide valuable qualitative insights for historical events. By examining old manuscripts, ship logs, newspapers, chronicles, and administrative records, the overall impact and activity fluctuation of storms over centuries can be retraced (*e.g.* Athimon, 2021; Camuffo et al., 2000; Sarrazin, 2012). These sources can reveal how communities perceived and responded to extreme weather, offering cultural and societal context that modern data cannot provide (Soens, 2018). However, historical records are often fragmentary, subjective, and may be geographically biased as they may favour populated regions. Their interpretation requires careful cross-referencing and contextualization, and many events may be underreported or exaggerated due to the narrative nature of the sources (Athimon, 2021). In opposition, geophysical archives, such as sediment cores, beach ridges, coral records, tree rings, cliff-top storm deposits (CTSD), and speleothems, offer physical evidence of past storm activity. For instance, washover deposits in coastal sediments can indicate the occurrence of an historical severe storm, sometimes over millennia (Dezileau et al., 2016; Orme et al., 2016). These archives provide objective, long-term data that can complement or extend beyond written history (Pouzet and Maanan, 2020). However, they often lack precise dating or direct linkage to specific events, and interpreting storm signals require distinguishing them from other geological processes such as tsunami (Williams and Hall, 2004). Additionally, their resolution may vary depending on the archive type and environmental conditions.

The crossing of both geophysical and historical approaches allows us to better consider each possibility and to not avoid a significant storm record that can be missed by one of the two approaches and allows for a more comprehensive understanding of past storm events. Historical records provide detailed narratives and social context, while geophysical data offer objective, long-term evidence. Cross-referencing both strengthen the reliability of interpretations and help bridge gaps in time, geography, or data precision. To understand precisely how storm activity has evolved over the past centuries in western Europe, eighty-one storm chronologies, coming from geophysical or historical studies, have been scrutinized at a decadal scale (Fig. 1). For each reference, a decade has been considered as *"stormy"* if at least one significant storm (*i.e.*, storm recorded by geophysical methods or storm characterised as impacting by historical studies) occurred during its timelapse. The trends observed over the past centuries could help understand how winter storms affecting Europe develop, and what oceanological and climatological mechanisms may influence them, thereby allowing future societies to better prepare and protect themselves against these hazards in the current context of climate change.

https://doi.org/10.5194/egusphere-2026-3658
Preprint. Discussion started: 15 July 2026

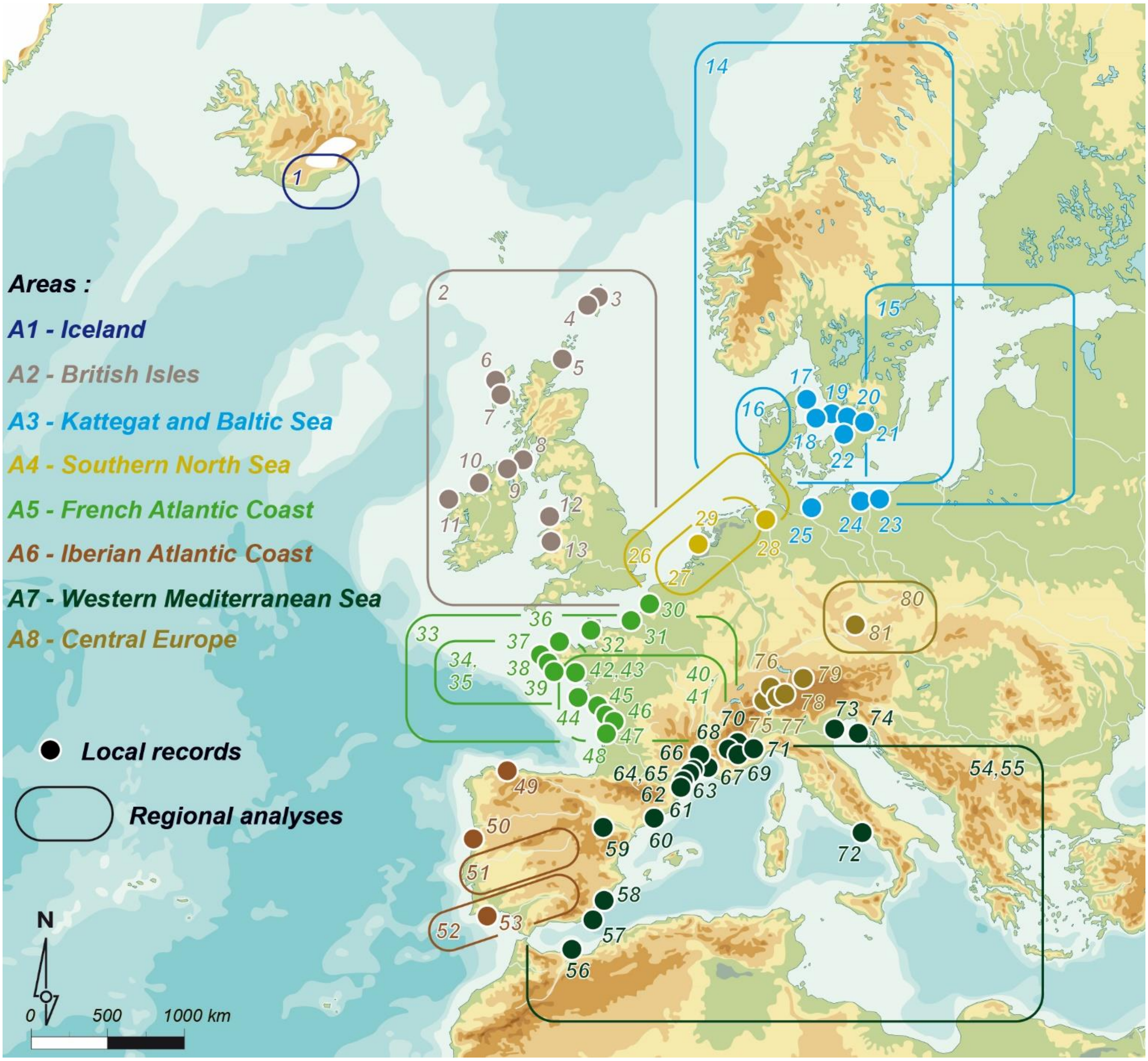


Figure 1: Localisation of the sites studied in each scientific reference and presentation of the eight geographical areas. Local records correspond to precise geophysical archives and regional analyses refer to larger scale historical references with written documents. The topographic and bathymetric base map is derived from the GEBCO global dataset (GEBCO Compilation Group).

Firstly, to highlight the scientific context of the studies retained in our analysis, a qualitative characterization of the eighty-one storm chronologies was conducted through a systematic classification of each record according to archive type, geographic area and specific environmental setting. Metadata extracted from the database were processed using *pandas, matplotlib, numpy, plotly* and *networkx* libraries of *python 3.13* language with *PyCharm 2025.1.3* software. These graphical

https://doi.org/10.5194/egusphere-2026-3658
Preprint. Discussion started: 15 July 2026

approaches enabled the identification of dominant archive–environment associations, regional specificities, and methodological trends in European paleostorm research.

2.2 Storm impact extraction from eighty-one chronologies

Storm studies conducted by historians offer crucial insights into the frequency and intensity of past storm events, particularly for periods predating instrumental records. For this study, we compiled a dataset from peer-reviewed publications and regional monographs that document storm impacts based on documentary evidence from written archives. Studies were selected based on their resolution (spatial and temporal) and the transparency and robustness of their methodology. Particular attention was given to the quality and reliability of the primary sources used, notably when studies were grounded in diverse archival materials such as (i) ancient maps, (ii) narrative sources (chronicles, diaries, memoirs, registers), and (iii) administrative or observational documents (account books, post-disaster surveys, repair records, barometric observations, newspaper articles). These materials provide valuable descriptive data on the storms themselves, with additional information related to the damage they caused, and societal responses and adaptations. To be considered reliable, historical data had to be critically assessed regarding authorship (*e.g.*, whether the author was a direct witness or not), the institutional context of the document's production, and the possibility of corroboration with independent sources; and only sources demonstrating rigorous methodological handling of these aspects were retained. Furthermore, studies were favored when the storm chronologies avoided conflating storms with other similar hazards (*e.g.*, tsunamis) and when clear efforts were made to avoid cross-referencing within the same archival base or from overlapping historical studies. For each reference, stormy decades were identified when the original publication either explicitly highlighted a significant storm with major impacts or provided sufficiently detailed annual or decadal event listings. Consequently, a decade was considered as *"stormy"* if at least one storm was classified as significant by the historical study. No distinction was made based on the number or intensity of storms within a given decade, to be consistent with the geophysical chronologies.

In parallel, we collected geophysical data indicative of past storm activity from renowned geophysical studies that presented long-term reconstructions based on high-resolution proxies such as washover layers, dune mobility, cliff-top storm deposits or beach ridge evolution. These datasets were selected based on the quality of their chronological control (e.g., radiocarbon, ^{210}Pb/^{137}Cs or optically stimulated luminescence dating) and the continuity and resolution of their sedimentary or geophysical records. Their interpretation in terms of storm frequency or magnitude has also been taken into account. Decadal storminess was inferred when proxies exhibited clear signals of increased storm deposition in each decade. To avoid overlaps between other regional geophysical and historical studies, only the geophysical data provided by each individual study were considered. Cross-validation using multiple proxies or comparisons with known historical events (and particularly those already included as historical references in this review) were deliberately excluded. Furthermore, only chronologies that clearly identified storm-related impacts were retained in the dataset. Studies with ambiguous signals, where the recorded events could plausibly be attributed to other natural hazards such as tsunamis, were systematically

https://doi.org/10.5194/egusphere-2026-3658
Preprint. Discussion started: 15 July 2026

excluded. This selection aimed to ensure the specificity of the storm signal, relying on sources that provided explicit interpretation, consistent criteria for storm attribution. Where possible, supporting contextual or proxy evidence confirming the storm-related origin of the events has been considered. If a specific storm event was precisely dated, the corresponding decade was directly attributed. When dating allowed for a margin of uncertainty, all decades falling within that range were considered. Finally, for studies conducted at broader temporal scales that identified phases of increased storm activity (such as *"storminess"* periods) rather than discrete events, the entire duration of those periods was integrated into the storm chronologies. Information regarding the type of interpretation used in each study is detailed in Table 1.

ID	Source	DOI / ISBN / URL	Area	Site	Type	Name *(so called)*	Timescale
1	(Jackson et al., 2005)	https://doi.org/10.1130/G21489.1	Iceland	Holmsa, Iceland	River sediment	Wind episodes	10 kBP
2	(Lamb and Frydendahl, 1991)	ISBN-13 978-0521619318	British Isles	Wales, England, Ireland and Scotland	Historical sources	Historic storms	1500-2000 AD
3	(Hess et al., 2024)	https://doi.org/10.1002/jqs.3568	British Isles	Sheltand Isles, Scotland	Lake / Loch sedimentology	More frequent storm flooding	1,5 kBP
4	(Hansom and Hall, 2009)	https://doi.org/10.1016/j.quaint.2007.11.010	British Isles	Sheltand Isles, Scotland	Cliff-top storm deposits	Exceptional storm activity	1,5 kBP
5	(McIlvenny et al., 2013)	http://dx.doi.org/10.1016/j.margeo.2012.10.014	British Isles	Dunnet Bay, Scotland	Bay sedimentation	Climatic instability	8 kBP
6	(Orme et al., 2016)	10.1016/j.quascirev.2015.10.045	British Isles	Outer Hebrides, Scotland	Lake / Loch sedimentology	Higher storminess	3 kBP
7	(Gilbertson	https://doi.org/10.1006/jasc.1998.0	British	Outer	Dune	Notable	14 kBP

https://doi.org/10.5194/egusphere-2026-3658
Preprint. Discussion started: 15 July 2026

	et al., 1999)	360	Isles	Hebrides, Scotland	sedimentology	sand drift	
8	(Kylander et al., 2019)	https://doi.org/10.1111/bor.12409	British Isles	Laphroaig bog, Scotland	Peat bog	Periods of greater storminess	6.5 kBP
9	(Wilson et al., 2004)	https://doi.org/10.1191/0959683604hl716rp	British Isles	Northern coast of Northern Irland	Dune sedimentology	Climatic deterioration episodes	7 kBP
10	(Sjöström et al., 2026)	https://doi.org/10.1016/j.quascirev.2026.109901	British Isles	Glenties Bog, Ireland	Peat bog	Storminess	4 kBP
11	(Sjöström et al., 2024)	https://doi.org/10.1016/j.quascirev.2024.108803	British Isles	Roycarter Bog, Ireland	Peat bog	Storm periods	8 kBP
12	(Bailey et al., 2001)	https://doi.org/10.1016/S0277-3791(00)00053-6	British Isles	Aberffraw dunes, Wales	Dune sedimentology	Sand movement evidences	1000 – 2000 AD
13	(Orme et al., 2015)	https://doi.org/10.1002/jqs.2792	British Isles	Cors Fochno, Wales	Peat bog	Peaks in storminess	4,5 kBP
14	(Lamb and Frydendahl, 1991)	ISBN-13 978-0521619318	Kattegat and Baltic Sea	Western North Sea : Norway, Sweden, Denmark	Historical sources	Historic storms	1500-2000 AD
15	(Leszczyńska et al., 2025)	https://doi.org/10.1016/j.earscirev.2025.105137	Kattegat and Baltic Sea	Entiere Baltic Sea	Historical sources	Storms	1300-1800 AD
16	(Clemmensen et al.,	https://doi.org/10.1016/j.geomorph.2008.10.003	Kattegat and Baltic	Jutland, Danemark	Dune sedimentol	Major aeolian	6,5 kBP

https://doi.org/10.5194/egusphere-2026-3658
Preprint. Discussion started: 15 July 2026

	2009)		Sea		ogy	activity events	
17	(Hansen, 2017)	https://www.geocenter.dk/wp-content/uploads/2018/07/geoviden-2-2017.pdf	Kattegat and Baltic Sea	Laeso, Danemark	Beach ridge	Beach ridge pulse	5 kBP
18	(Clemmensen et al., 2007)	https://doi.org/10.1016/j.sedgeo.2007.01.025	Kattegat and Baltic Sea	Anholt island, Denmark	Dune sedimentology	Period of storminess increase	7 kBP
19	(Jong et al., 2006)	https://doi.org/10.1002/jqs.1011	Kattegat and Baltic Sea	Halland, Sweden	Peat bog	Strongly increased storminess	6,5 kBP
20	(Sjöström et al., 2022)	https://doi.org/10.1016/j.chemgeo.2022.120881	Kattegat and Baltic Sea	South-western Sweden	Peat bog	Paleodust from storm condition	4,5 kBP
21	(Kylander et al., 2023)	https://doi.org/10.1016/j.quascirev.2022.107854	Kattegat and Baltic Sea	Store Moss, Sweden	Peat bog	Stormier periods	5 kBP
22	(Björckl and Clemmensen, 2004)	https://doi.org/10.1191/0959683604hl746rp	Kattegat and Baltic Sea	South-western Sweden	Peat bog	Storminess	6 kBP
23	(Reimann et al., 2011)	https://doi.org/10.1016/j.geomorph.2011.04.017	Kattegat and Baltic Sea	Swina barrier, Poland	Dune sedimentology	Stormier periods	5 kBP
24	(Lampe and Lampe, 2021)	https://doi.org/10.1177/0959683620981703	Kattegat and Baltic Sea	Usedom island, Germany / Poland fronter	Dune sedimentology	Cold and windy climate phases	5 kBP
25	(Adolph et al., 2024)	https://doi.org/10.5194/cp-20-2143-2024	Kattegat and Baltic Sea	Schweriner See, Germany	Lake / Loch sedimentol	Storminess	3 kBP

					ogy		
26	(Soens, 2018)	https://doi.org/10.1093/pastj/gty018	Southern North Sea	Southern North Sea	Historical sources	Significant floods	1250-2000 AD
27	(Lamb and Frydendahl, 1991)	ISBN-13 978-0521619318	Southern North Sea	Southern North Sea : Netherland, Belgium, Germany	Historical sources	Historic storms	1500-2000 AD
28	(Peng et al., 2019)	https://doi.org/10.1016/j.gloplacha.2019.04.006	Southern North Sea	Meuse River, Netherlands	River sediment	Paleoflood	10kBP
29	(Jelgersma et al., 1995)	https://doi.org/10.1016/0025-3227(95)00061-3	Southern North Sea	North-Holland, Netherlands	Dune sedimentology	Storm surge levels	5 kBP
30	(Van Vliet Lanoe et al., 2017)	10.1127/zdgg/2016/0043	French Atlantic Coast	Picardy, France	Dune sedimentology	Storm	1,5 kBP
31	(Sorrel et al., 2009)	https://doi.org/10.1016/j.quascirev.2008.11.009	French Atlantic Coast	Seine estuary, France	Bay sedimentation	High storminess	5 kBP
32	(Van Vliet Lanoe et al., 2017)	10.1127/zdgg/2016/0043	French Atlantic Coast	West Cotentin, France	Dune sedimentology	Storm	1,5 kBP
33	(Lamb and Frydendahl, 1991)	ISBN-13 978-0521619318	French Atlantic Coast	North Western France	Historical sources	Historic storms	1500-2000 AD
34	(Gorczyńska et al., 2023)	https://doi.org/10.1016/j.aeolia.2022.100851	French Atlantic	Brittany, France	Dune sedimentol	Main periods of	6 kBP

			Coast		ogy	aeolian activity	
35	(Regnauld, 1999)	https://www.persee.fr/doc/quate_1142-2904_1999_num_10_2_1641	French Atlantic Coast	Brittany, France	Multiple types	Storm deposits	10 kBP
36	(Van Vliet Lanoe et al., 2017)	10.1127/zdgg/2016/0043	French Atlantic Coast	Northern Brittany, France	Dune sedimentology	Storm	1,5 kBP
37	(Stéphan et al., 2026)	https://doi.org/10.1016/j.aeolia.2026.101048	French Atlantic Coast	Beniguet Island, France	Dune sedimentology	Coastal sand-drift events	4 kBP
38	(Ehrhold et al., 2021)	https://doi.org/10.1016/j.palaeo.2021.110525	French Atlantic Coast	Bay of Brest, France	Bay sedimentation	Increased paleo-storm activity	5 kBP
39	(Van Vliet Lanoe et al., 2014)	10.1177/0959683613519687	French Atlantic Coast	Audierne Bay, France	Bay sedimentation	Stormines s	8 kBP
40	(Athimon, 2021)	978-2846545433	French Atlantic Coast	Central Western France	Historical sources	Storm	1300 - 1800 AD
41	(Sarrazin, 2012)	https://doi.org/10.4000/norois.4034	French Atlantic Coast	Central Western France	Historical sources	Vimers	1300 - 1600 AD
42	(Pouzet and Maanan, 2020)	https://doi.org/10.1038/s41598-020-69069-w	French Atlantic Coast	Southern Brittany	Back barrier lagoon	Historical storm	4,5 kBP
43	(Pouzet et al., 2019)	https://doi.org/10.1016/j.margeo.2018.10.014	French Atlantic Coast	Southern Brittany	Back barrier lagoon	Historical storm	1700 - 2000 AD
44	(Pouzet et al., 2018)	https://doi.org/10.1177/0309133318776500	French Atlantic Coast	Yeu island, France	Coastal marshes	Yeu stormy periods	8 kBP

https://doi.org/10.5194/egusphere-2026-3658
Preprint. Discussion started: 15 July 2026

45	(Maanan et al., 2022)	https://doi.org/10.3390/atmos13020151	French Atlantic Coast	Belle Henriette lagoon, France	Back barrier lagoon	Storms with marine flooding	1,5 kBP
46	(Poirier et al., 2017)	http://dx.doi.org/10.1016/j.palaeo.2017.07.037	French Atlantic Coast	Pertuis Charentais, France	Bay sedimentation	Coarse-grained sedimentation pulses	3 kBP
47	(Breilh et al., 2014)	https://doi.org/10.1016/j.gloplacha.2014.08.013	French Atlantic Coast	Charente-Maritime, France	Historical sources	Storm	1500-2000 AD
48	(Clarke et al., 2002)	https://doi.org/10.1191/0959683602hl539rr	French Atlantic Coast	Aquitaine, France	Dune sedimentology	Sand invasion	4 kBP
49	(Feal-Pérez et al., 2014)	https://doi.org/10.1177/0959683613520257	Iberian Atlantic Coast	Eo Estuary, Spain	Estuary sedimentation	Climatic periods	2 kBP
50	(Clarke and Rendell, 2006)	https://doi.org/10.1191/0959683606hl932rp	Iberian Atlantic Coast	Western Portugal	Dune sedimentology	Dune transgression due to storminess	10 kBP
51	(Benito et al., 2003)	https://doi.org/10.1023/A:1023417102053	Iberian Atlantic Coast	Tagus basin, Spain	Multiple types	High flood frequencies	1 kBP
52	(Ortega and Garzón, 2009)	https://doi.org/10.5194/nhess-9-229-2009	Iberian Atlantic Coast	Guadiana River, Spain	River sediment	Palaeofloods	3,5 kBP
53	(Feist et al., 2019)	https://doi.org/10.1016/j.sedgeo.2019.06.004	Iberian Atlantic Coast	Boca do Rio, Portugal	Back barrier lagoon	Extreme events	4 kBP

https://doi.org/10.5194/egusphere-2026-3658
Preprint. Discussion started: 15 July 2026

54	(Doensen et al., 2025)	https://doi.org/10.5194/cp-21-1305-2025	Western Mediterranean Sea	Mediterranean Sea	Climatological simulation	Mensual cyclone frequency	1500 BC – 1850 AD
55	(Benito et al., 2015)	https://doi.org/10.1016/j.catena.2014.11.014	Western Mediterranean Sea	Mediterranean sea	Multiple types	Flooding episodes	10 kBP
56	(Raji et al., 2015)	https://doi.org/10.5194/nhess-15-203-2015	Western Mediterranean Sea	Marchica Lagoon, Morocco	Back barrier lagoon	Storm	1 kBP
57	(Dezileau et al., 2016)	https://doi.org/10.5194/cp-12-1389-2016	Western Mediterranean Sea	Mar Menor, Spain	Back barrier lagoon	High storm activity periods	6,5 kBP
58	(Benito et al., 2010)	https://doi.org/10.1016/j.gloplacha.2009.11.007	Western Mediterranean Sea	Guadalentin river, Spain	Multiple types	Palaeo and historical floods	1 kBP
59	(Moreno et al., 2008)	10.1007/s10933-008-9209-3	Western Mediterranean Sea	Taravilla Lake, Spain	Lake / Loch sedimentology	Floods	2 kBP
60	(Camuffo et al., 2000)	https://doi.org/10.1023/A:1005607103766	Western Mediterranean Sea	Barcelona, Spain	Historical sources	Sea storms	1300-1850 AD
61	(Degeai et al., 2015)	https://doi.org/10.1016/j.quascirev.2015.10.009	Western Mediterranean Sea	Bagnas Pond, France	Back barrier lagoon	Storm periods	3 kBP
62	(Blanchemanche, 2009)	https://www.persee.fr/doc/amime_0758-7708_2009_num_27_1_1900	Western Mediterranean Sea	Lez river, France	Historical sources	Floods	1300 - 2000 AD
63	(Sabatier et al., 2008)	https://doi.org/10.1016/j.margeo.2008.03.001	Western Mediterra	Pierre Blanche	Back barrier	Storm events	1700 - 2000

https://doi.org/10.5194/egusphere-2026-3658
Preprint. Discussion started: 15 July 2026

			nean Sea	lagoon, France	lagoon		AD
64	(Sabatier et al., 2012)	https://doi.org/10.1016/j.yqres.2011.09.002	Western Mediterranean Sea	Pierre Blanche lagoon, France	Back barrier lagoon	Paleostorm events	7 kBP
65	(Dezileau et al., 2011)	https://doi.org/10.1016/j.palaeo.2010.11.009	Western Mediterranean Sea	Aigues Mortes Gulf	Back barrier lagoon	Periods of most frequent superstorms strikes	1,5 kBP
66	(Sheffer et al., 2003)	https://doi.org/10.1029/2003WR002468	Western Mediterranean Sea	Ardèche river, France	Palaeo and historical sources	Paleoflood	5,5 kBP
67	(Sheffer et al., 2008)	https://doi.org/10.1016/j.geomorph.2007.02.034	Western Mediterranean Sea	Gardon river, France	Palaeo and historical sources	Catastrophic floods	1200 - 2000 AD
68	(Sabatier et al., 2017)	https://doi.org/10.1016/j.quascirev.2017.06.019	Western Mediterranean Sea	Savines Lake, France	Lake / Loch sedimentology	High flood frequency and intensity periods	6 kBP
69	(Prosper-Laget et al., 2009)	https://www.persee.fr/doc/amime_0758-7708_2009_num_27_1_1894	Western Mediterranean Sea	Ubaye, France	Flood chronicles	Floods	1600 - 2000 AD
70	(Wilhelm et al., 2012)	http://dx.doi.org/10.1016/j.yqres.2012.03.003	Western Mediterranean Sea	Lake Allos, Mediterranean French Alps	Lake / Loch sedimentology	Floood events resulting of intense meso-scale precipitati	1,5 kBP

https://doi.org/10.5194/egusphere-2026-3658
Preprint. Discussion started: 15 July 2026

						on events.	
71	(Kerverdo et al., 2026)	https://doi.org/10.1016/j.quascirev.2025.109749	Western Mediterranean Sea	Roya Valley, France	Fluvial terraces sedimentology	Enhanced deposit preservation	12 kBP
72	(Budillon et al., 2005)	https://doi.org/10.5194/adgeo-2-123-2005	Western Mediterranean Sea	Salerno Bay, Italia	Bay sedimentation	Storm events	1 kBP
73	(Camuffo et al., 2000)	https://doi.org/10.1023/A:1005607103766	Western Mediterranean Sea	Venice, Italia	Historical sources	Sea storms	780-1820 AD
74	(Kaniewski et al., 2016)	https://doi.org/10.1038/srep25197	Western Mediterranean Sea	Central Mediterranean	Palaeo and historical sources	Enhanced storminess and coastal flooding periods	4,5 kBP
75	(Schulte et al., 2019)	https://doi.org/10.1016/j.gloplacha.2019.05.011	Central Europe	Bernese Alps, Switzerland	Floodplains and Lake sediments	Flood pulses	1400 - 2000 AD
76	(Schulte et al., 2015)	https://doi.org/10.5194/hess-19-3047-2015	Central Europe	Hasli Valley, Switzerland	River sediment	Palaeofloods	2,5 kBP
77	(Wirth et al., 2013)	https://doi.org/10.1016/j.quascirev.2013.09.002	Central Europe	Central Alps	Lake / Loch sedimentology	Flood frequency phases	10 kBP
78	(Amann et al., 2015)	https://doi.org/10.1016/j.quascirev.2015.03.002	Central Europe	Lake Oeschinen, Switzerlan	Lake / Loch sedimentology	Flood frequency phases	1 kBP

https://doi.org/10.5194/egusphere-2026-3658
Preprint. Discussion started: 15 July 2026

				d			
79	(Glur et al., 2013)	https://doi.org/10.1038/srep02770	Central Europe	Central Switzerland	Lake / Loch sedimentology	High flood frequency	2,5 kBP
80	(Brázdil et al., 2005)	https://doi.org/10.1007/s10584-005-5924-1	Central Europe	Czech Republic	Historical sources	Strong winds "Gale" with damages	1500-2000 AD
81	(Brázdil et al., 2006)	https://doi.org/10.1623/hysj.51.5.739	Central Europe	Vlata, Pragues, Czech Republic	Documentary and instrumental data	Floods	1500-2000 AD

Table 1. Chronologies used to review historical storm impacts along European coastlines during the last millenary

To reconstruct each storm chronology from bibliographic datasets, we then designed a visualization framework that translates manually coded storm occurrences into detailed decadal timelines. Source data were extracted from an Excel file, where each row represents a distinct bibliographic reference and each column corresponds to a decade from AD 1000 to 2000. As storm events were coded as binary values (0 for a *"non-stormy"* decade or 1 for a *"stormy"* decade), framed by markers ('S' and 'E') indicating the temporal scope of each study (*"Start"* for the decade+1 and *"End"* for the ongoing decade) displayed as a grey background. These data were parsed and plotted using *Python's Matplotlib* library, with color-coded horizontal lines representing the presence and continuity of storm evidence per source. Geographic areas were distinguished by a unique color scheme, and both global and area-specific figures were produced to facilitate comparative analysis of temporal storm clustering across regions. The storm chronology definition is made with the *pandas, matplotlib* and *os* libraries of *python 3.13 language* with *PyCharm 2025.1.3* software.

2.3 Chronologies regionalization and storm strips definition

The differentiation into eight geographic areas—namely *A1 Iceland, A2 British Isles, A3 Kattegat and Baltic Sea, A4 Southern North Sea, A5 French Atlantic Coast, A6 Iberian Atlantic Coast, A7 Western Mediterranean Sea*, and *A8 Central Europe*—follows primarily a meso-scale segmentation commonly adopted in historical storm analysis. This classification aims to reflect coherent climatic and documentary patterns across space. An exception was made for the highly renowned

https://doi.org/10.5194/egusphere-2026-3658
Preprint. Discussion started: 15 July 2026

broad dataset from (Lamb and Frydendahl, 1991), which originally encompassed a large part of Northern Europe; this source was subdivided into the four distinct regional chronologies (A2 to A5 areas) to allow for more precise spatial resolution in the reconstruction of storm activity across northern Europe.

According to the scale of each geographical area, the *Storm Index (SI)* represents the proportion of sites (*i.e.* scientific references) affected by a storm within a given decade. It is calculated using the formula:

$$SI = \frac{IC}{TC}$$

where *IC* is the number of sites impacted by a storm during the decade, and *TC* is the total number of sites retained in this review for that same period.

To visualize the temporal distribution of storm-related impacts extracted from bibliographic references, we developed a Python-based approach that converts tabulated regional data into *"storm stripes"*. Each row of an Excel spreadsheet corresponds to a geographic region, with columns representing standardized decadal frequencies normalized between 0 and 1. Using *Matplotlib*, we generated individual stripe plots for each region, where color intensity (from white to red) reflects the relative frequency of storm impacts per decade. A global figure combining all regions was also produced, preserving a uniform scale and integrating a shared color bar. This method allows a temporal trends comparison in storm-related activity across different areas. This methodology explains how the SI index is then visualized as *"storm stripes",* with color intensity reflecting the SI value — from 0 (white, no region affected) to 1 (red, all regions affected). The storm stripes definition is made with the *pandas, matplotlib* and *os* libraries of *python 3.13* language with *PyCharm 2025.1.3* software.

3. Results

3.1 Spatial and typological distribution of the eighty-one storm chronologies studied

The eighty-one chronologies studied are presented in Table 1. Among them, fifteen are historical chronologies built from written archives, fifty-eight comes from geophysical records, one has been made from models, and the seven others crosses multidisciplinary approaches (including combined approaches paleo and historical methodologies; and other statistical developments). These records come from a diversity of environments such as erosional coasts (cliffs (Hansom and Hall, 2009)), depositional environments (bays, dunes, lakes, rivers or floodplains (Adolph et al., 2024; McIlvenny et al., 2013; Peng et al., 2019)) or coastal lowland areas (peat bogs, estuaries, back-barrier lagoons, coastal marshes (Jong et al., 2006; Pouzet and Maanan, 2020; Sorrel et al., 2009)) with multiple storm detection methods such as sediment coring and analyses, isotopic dating, boulder identification or numerical approaches. The distribution of archive types across the eight European

https://doi.org/10.5194/egusphere-2026-3658
Preprint. Discussion started: 15 July 2026

geographic areas reveals a marked regional specialization in paleostorm reconstruction approaches (Fig. 2). The British Isles also present a particularly wide range of archive types, including peat bogs, loch sediments, cliff-top storm deposits, and documentary evidence, reflecting both the environmental diversity of the region and a particular long-standing interdisciplinary research tradition (Sjöström et al., 2026). These environments are highly sensitive to storm processes, which explains their recurrent use for reconstructing past extreme storm activity. The French Atlantic coast appears as one of the most methodologically diverse regions, combining coastal sedimentary records with a rich amount of historical sources and wetland archives (Pouzet and Maanan, 2020). In contrast, the Kattegat and Baltic Sea area is characterized by a stronger reliance on continental humid archives such as peat bogs and lake sediments, linked to the abundance of postglacial wetland systems and favorable preservation conditions (Kylander et al., 2023). Clear contrasts also emerge between northern Europe and the Mediterranean region. The Western Mediterranean Sea exhibits the highest methodological heterogeneity, with numerous archive categories represented but generally with fewer repetitions for each type. This region combines mainly lagoonal and lacustrine sedimentary records crossed with historical archives, suggesting a more integrative reconstruction strategy adapted to the strong environmental variability of the Mediterranean basin (Kaniewski et al., 2016).

https://doi.org/10.5194/egusphere-2026-3658
Preprint. Discussion started: 15 July 2026

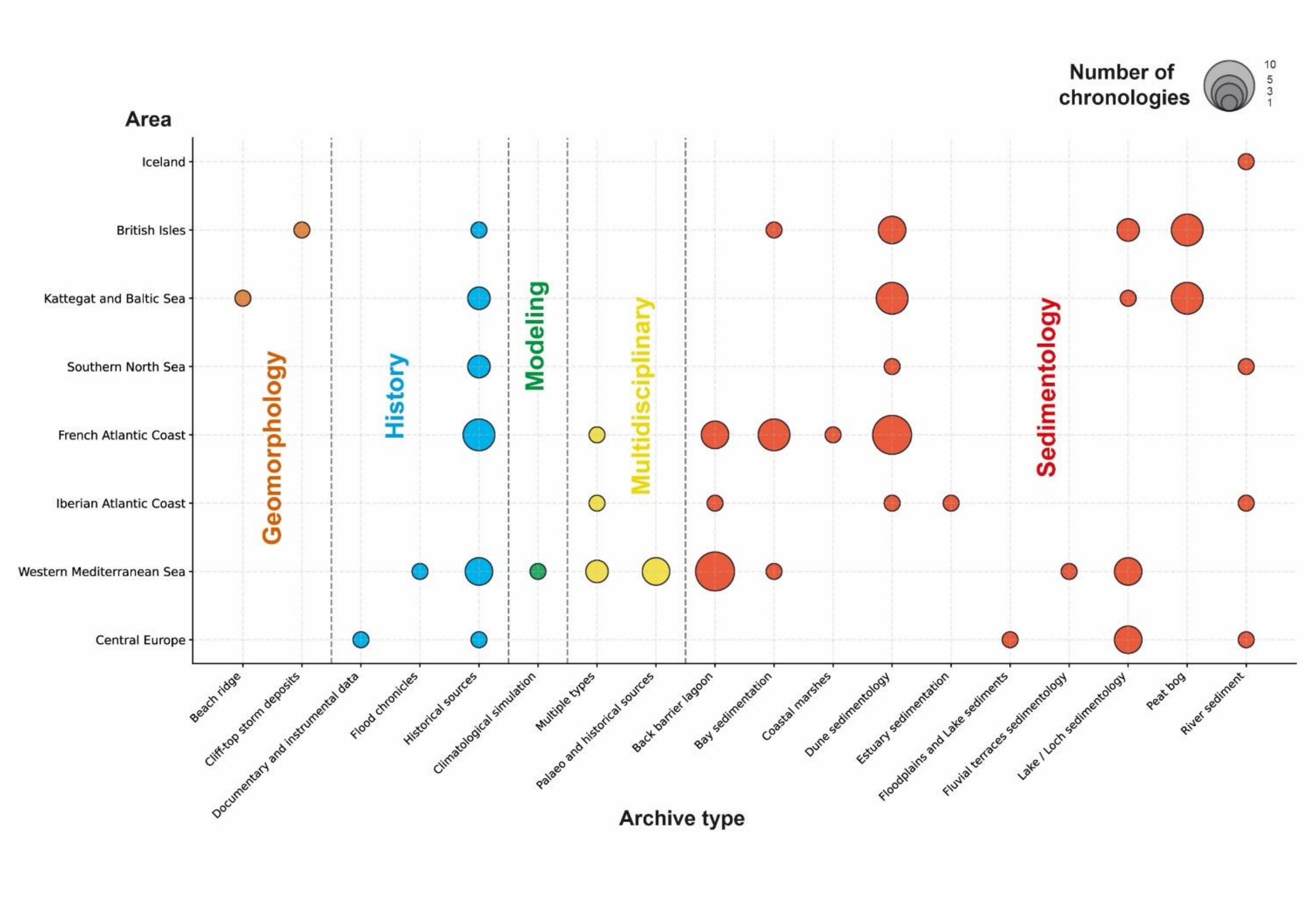


Figure 2. Archive type distribution per geographical areas for the eighty-ones storm chronologies studied

Table 1 also presents the terminology used by the different scientific teams to describe the historical coastal extreme events documented in their chronologies. Figure 3 synthesizes these archive and reconstruction categories and groups them into five major classes: *climate-*, *flood-*, *morphology-*, *storm-*, and *wind*-related categories. Storm-related terms (*e.g.* "*Storminess", "Storm deposits", "Storm periods"*) are directly derived from the etymology of the word *"storm"* and explicitly refer to storm impacts. Flood-related terminology (*e.g. "Storm surge levels", "Palaeofloods", "Flood pulses"*) and wind-related terminology (*e.g. "Wind episodes", "Major aeolian activity events"*) refer respectively to hydrodynamic and aeolian processes induced by storm activity. In contrast, climate-related terms (*e.g. "Climatic instability", "Climatic deterioration episodes", "Cold and windy climate phases"*) describe broader climatic conditions operating over longer temporal scales, which may favour increased storm activity without directly referring to specific storm, wind, or flood parameters. Finally, morphology-related terminology, such as *"Sand movement evidences"* or *"Coastal sand-drift events"*, refers to significant coastal sediment displacement associated with storm conditions or periods of enhanced storm activity. While dune

https://doi.org/10.5194/egusphere-2026-3658
Preprint. Discussion started: 15 July 2026

environments encompass nearly all terminology categories and logically concentrate most wind-related terms, back-barrier lagoons and peat bog archives are predominantly used to characterize individual storm events and periods of enhanced storm activity. In contrast, river and lake/loch archives mainly document flood-related storm impacts, as hydrological and lacustrine water-level fluctuations are the major controlling parameters within these depositional environments. Historical sources are strongly hazard-oriented and almost exclusively employ storm- and flood-related terminology. The figure also highlights the strong specialization of several archive types. Morphology-related terminology is largely associated with dune sedimentology, reflecting the importance of the aeolian transport and of important coastal sediment remobilization processes in these environments. Conversely, climate-related terminology remains comparatively rare and is preferentially linked to estuarine, bay or dune archives, where broader climatic variability is often investigated over longer temporal scales rather than individual storm events.

https://doi.org/10.5194/egusphere-2026-3658
Preprint. Discussion started: 15 July 2026

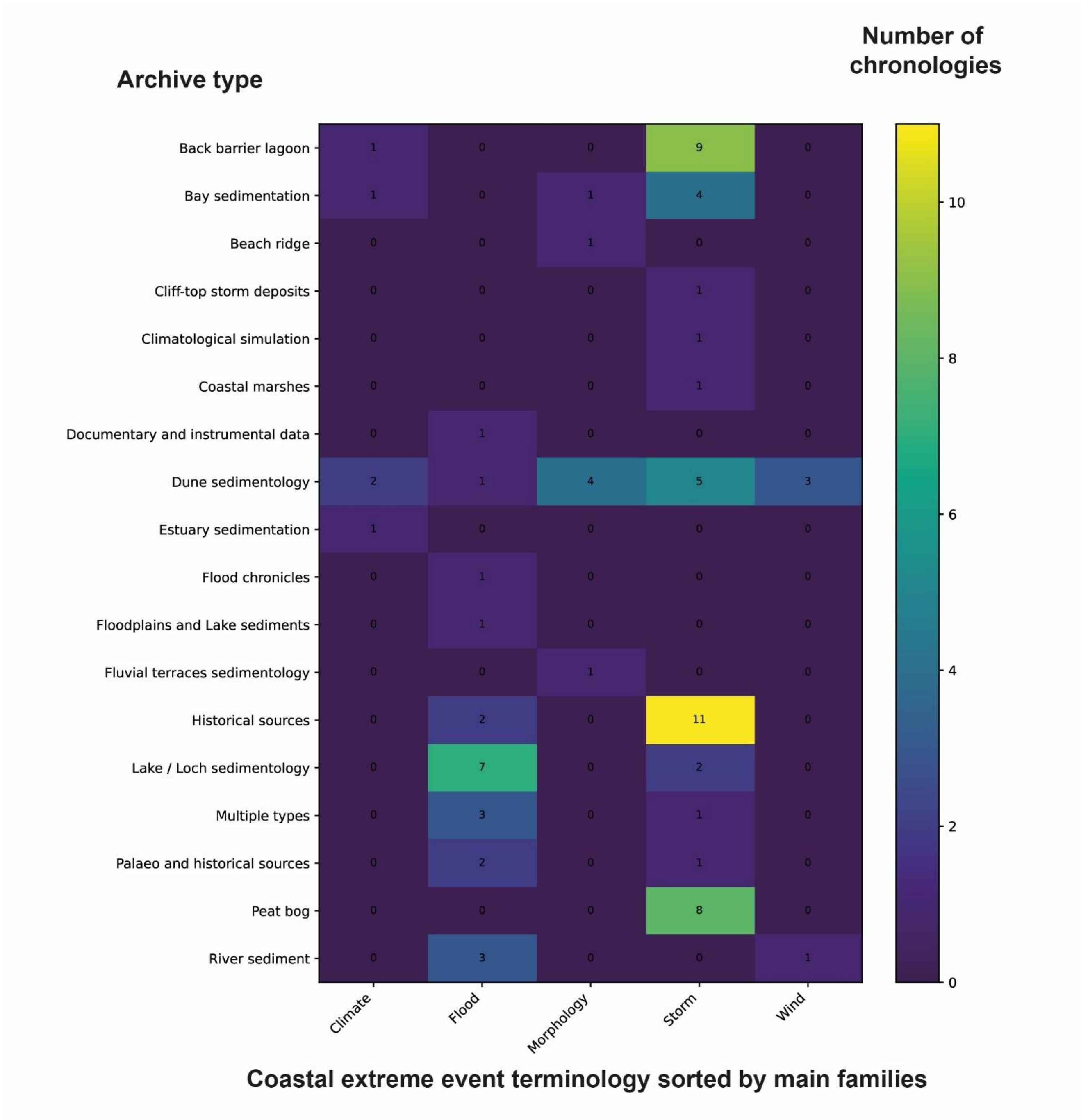


Figure 3. Heatmap of storm-reconstruction categories by archive type

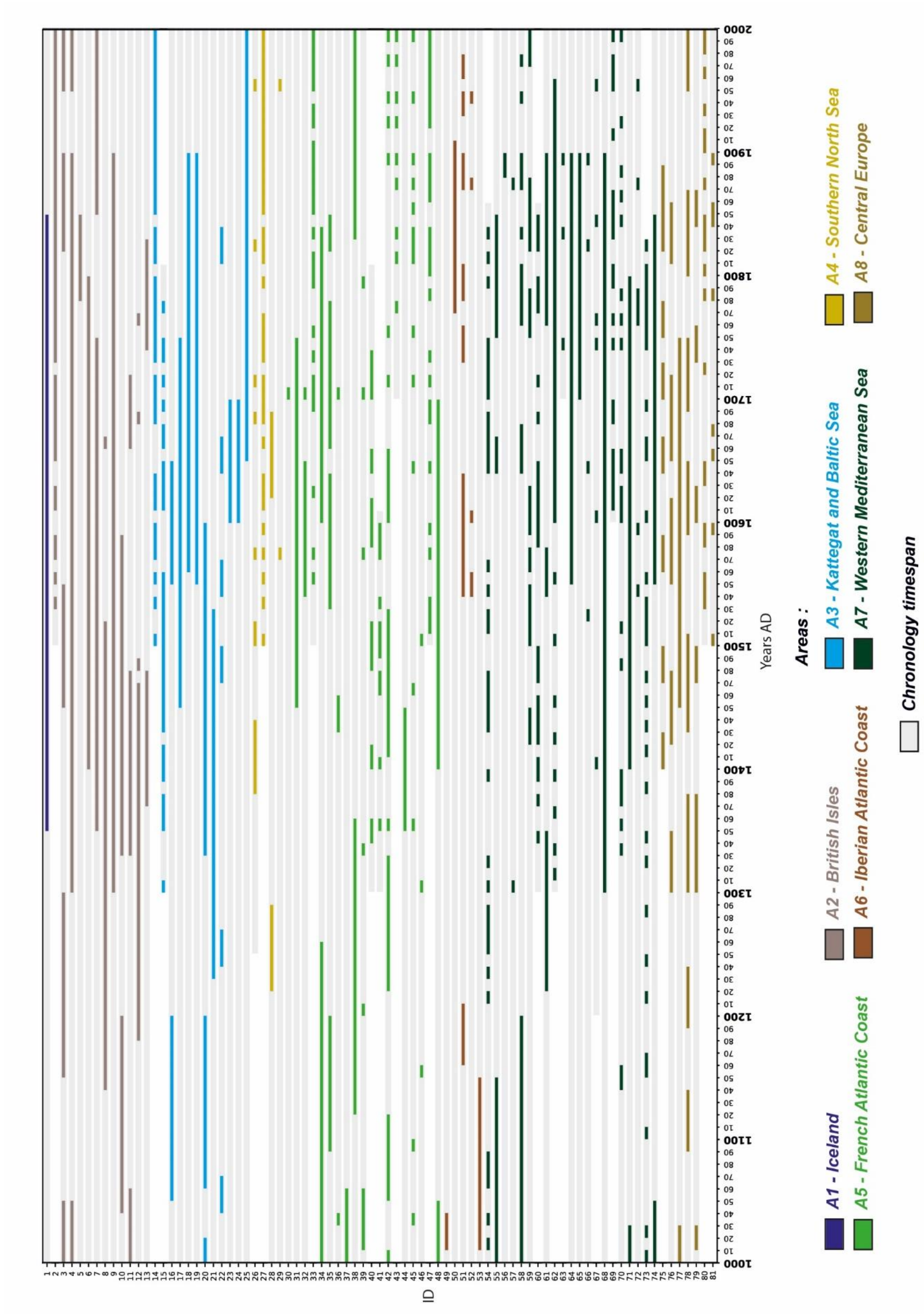
https://doi.org/10.5194/egusphere-2026-3658
Preprint. Discussion started: 15 July 2026

3.2 Offering a decadal resolution for the last millenary coastal storm European chronologies

The identification of a storm period may be distinct depending on each discipline. The *"storminess"* notion is widely used in sedimentological studies for larger phases of increased storm activity, particularly in northern Europe (*e.g.* Björckl and Clemmensen, 2004; Orme et al., 2016). On the opposite, several local historical storm terms such as *"vimers"* may also be introduced by historians for precise impacts related to a single storm (Sarrazin, 2012). Consequently, geophysical approaches encompass broader temporal scales, enabling researchers to take a long-term perspective over the past millennia albeit with lower chronological resolution. In contrast, historical studies often concentrate on the last few centuries, providing a more detailed and context-rich understanding of how storms have affected coastal communities. The integration of these complementary approaches therefore constitutes the main strength of this analysis, as it enables the reconstruction of storm variability across multiple temporal scales while simultaneously combining (i) the long-term continuity provided by geophysical archives with (ii) the high-resolution societal and environmental information derived from historical sources.

These eighty-one chronologies have been grouped in geographical areas (Fig. 1) to underline regional storm trends and understand possible latitudinal distinctions inside the western European coasts. Excepted for the Iceland where the information is sparse, each geographical area is today densely studied. Figure 4 presents each storm chronology studied at a decadal scale, with the grey shade indicating their own timespans. The colored bars indicate if at least one impacting storm was mentioned during a decade of each chronology. At the pan-Western European scale, despite marked heterogeneity in storm impact records, storm chronologies provide relatively continuous temporal coverage across large sectors of the European coastline throughout the last millennium. More precisely, the post-1300 AD period represents the best-covered interval of the database, with more than 85% of the studied chronologies remaining continuously active (*i.e.,* at least 70 out of 81 records providing data). Coverage reaches its maximum between 1500 and 1800 AD, when more than 95% of the chronologies are simultaneously represented. A slight decline is observed after 1800 AD, as the proportion of active chronologies decreases to approximately 90–95%. These patterns are primarily explained by the temporal distribution of historical documentary sources, many of which are restricted to the Little Ice Age (LIA) and do not extend into either the Medieval Warm Period (MWP) or the Industrial Era Warming (IEW). Consequently, the LIA emerges as the interval with the highest concentration of available storm records, providing an exceptionally robust temporal framework for investigating decadal-scale variations in storm activity within this climatically significant period.

https://doi.org/10.5194/egusphere-2026-3658
Preprint. Discussion started: 15 July 2026



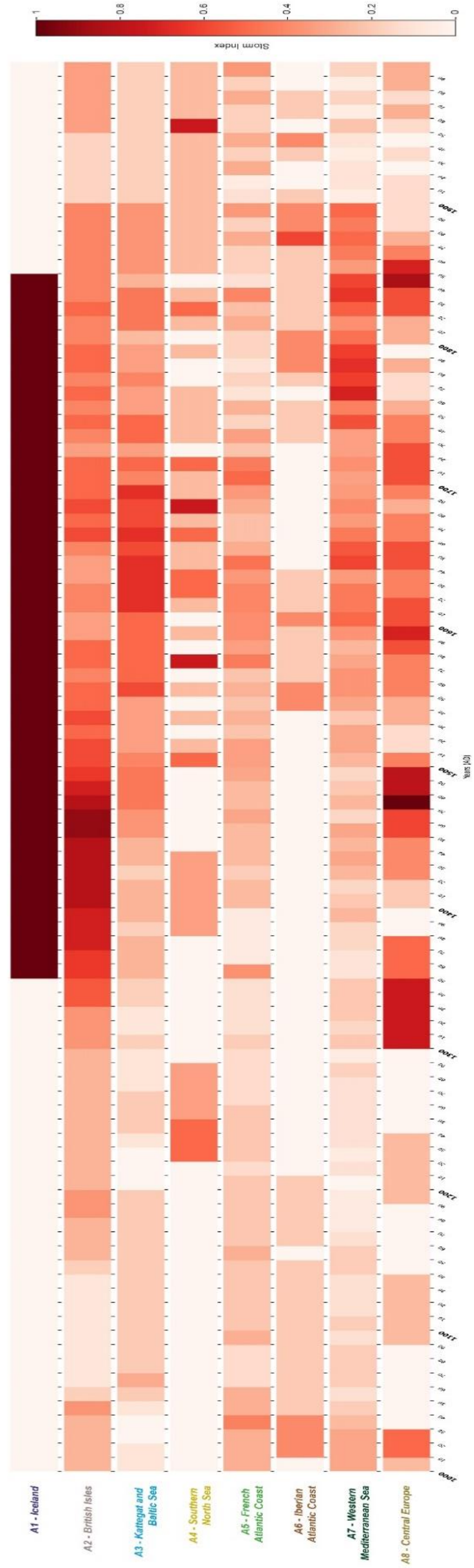
https://doi.org/10.5194/egusphere-2026-3658
Preprint. Discussion started: 15 July 2026

Figure 4. Detailed storm impact chronologies recorded for each scientific references per decades.

3.3 Introducing the storm stripes to understand historical storm activity

To offer a better view of the last millenary evolution of European storm activity, a *Storm Index* (SI) is measured at a decadal resolution for the eight geographical areas defined in Fig. 1. For each geographical areas, the SI corresponds to the rate of the storm impacted chronologies sum over the number of chronologies available (or active) for each decade. The storm stripes presented in Fig. 5 then sum up the detailed storm impact data of Fig. 4 and help to highlight the evolution of the SI index decade by decade for each area, offering storm activity regional tendencies. If the results of this index must be taken with a precaution for the A1 Iceland area as only one geophysical chronology is available in literature, several significant temporal tendencies may be estimated for the other areas. The A2 British Isles chronology, based on 12 chronologies (including eleven from geophysical sources and one historical review) the storm activity is consistent since AD 1200 and a clear peak is noticeable during the 15th century. The twelve chronologies (with ten geophysical and two historical studies) recorded at the A3 Kattegat and Baltic Sea present a later high SI period during the 17th century. In the A4 Southern North Sea zone, sparser impact may be detected because only four storm chronologies are available with two historical reviews starting later than the geophysical reviews. No robust trends can be estimated for this area. Along the French Atlantic Coast, a dense documentation is available in scientific literature with 19 studies including 4 historical and 15 geophysical records. Even if the storm activity seems consistent over the last millenary, an increase in storm impacts is highlighted between the end of the 16th century and the beginning of the early-18th century. The A6 Iberian Atlantic Coast storm activity (five geophysical chronologies) seems to follow the trends of the A7 Western Mediterranean Sea storm activity (17 geophysical and four historical sources) with particularly intense storm activity from the late-18th century to nearly AD 1900. Finally, from the seven chronologies studied in central Europe (including two historical study and five geophysical archives), a significant variation of storm activity is presented during the entire chronology with peaks in the early 14th, late 15th and mid-19th centuries.

https://doi.org/10.5194/egusphere-2026-3658
Preprint. Discussion started: 15 July 2026



https://doi.org/10.5194/egusphere-2026-3658
Preprint. Discussion started: 15 July 2026

Figure 5. Storm stripes synthesis for each European geographical area.

Overall, at the entire western European Atlantic coast scale, a southward shift of SI may be discussed starting for the British Isles area which underwent a deeper storm activity earlier (1350-1500 AD) than the French Atlantic Coast zone (1550-1750 AD) and ending with the Mediterranean basin that has mostly been struck later in the last centuries (1750-1900 AD). As the finding of precise storm impacts during the last decades in geophysical archives still remains today an important challenge in sedimentology with the crossing of multiple dating techniques and recent sediment uncertainties (*i.e.* Andersen, 2017; Dietz et al., 2021; Purkis et al., 2025) ; and as most historical works aims to understand ancient storm activity (*e.g.* Camuffo et al., 2000; Leszczyńska et al., 2025; Sarrazin, 2012); it remains not possible to discuss any viable tendencies for the 20th century from this work.

4. Discussion

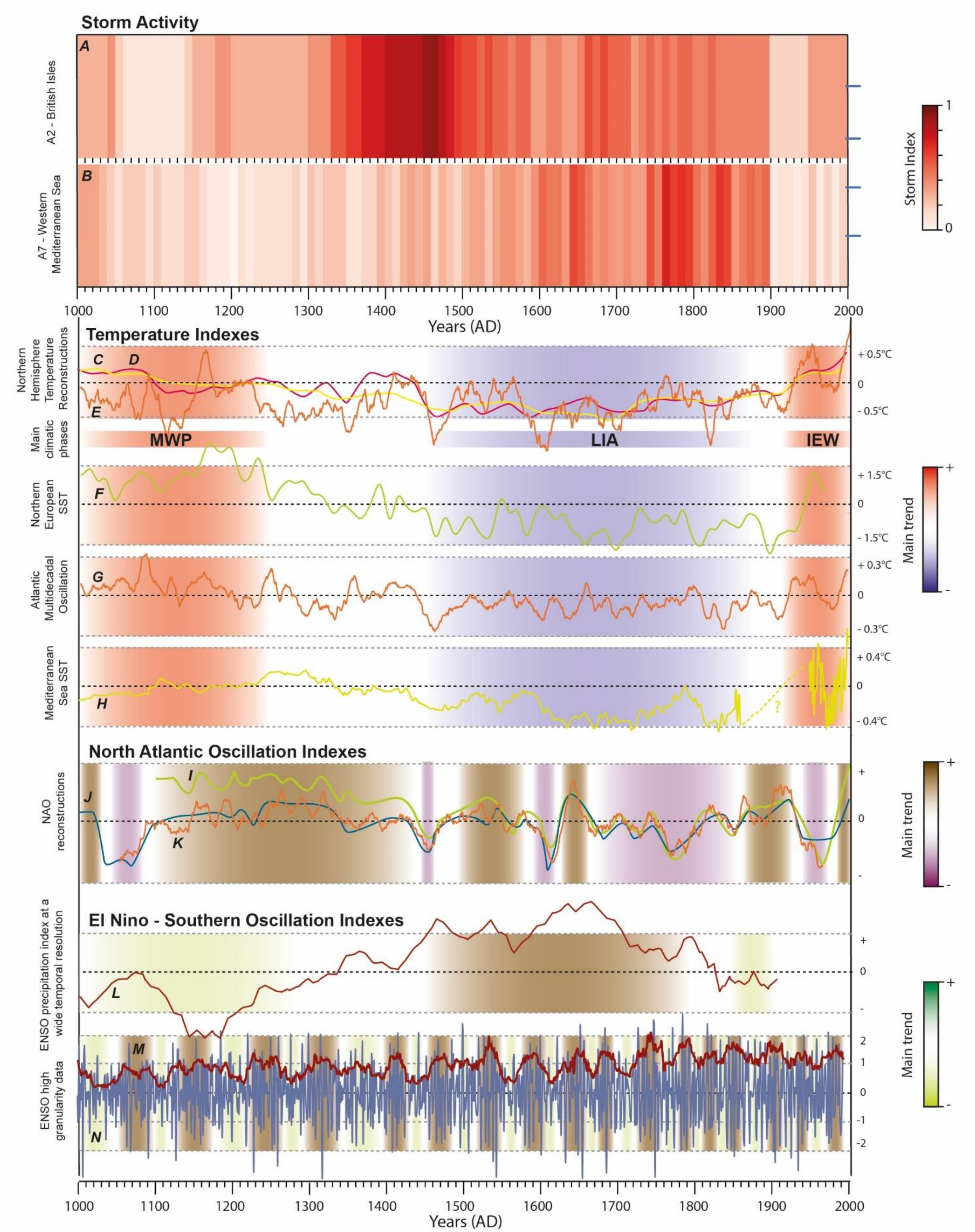
The most significant observation obtained from the Storm Stripes is the possible shift of coastal storm activity observed during the last millenary along the European Atlantic coast, and more particularly in the timespan of the Little Ice Age (LIA). Figure 5 shows that even if the storm activity recorded in the A2 British Isles is consistent during the entire chronology, a clear increase of the frequency of intense storm is observed in the early LIA between 1300 and 1500. Still on western Europe but at lower latitudes, A3 Kattegat and Baltic Sea, A4 Southern North Sea and A5 French Atlantic Coast areas present later high SI during the mid-LIA. At the southern part of the European Atlantic coast, the A6 Iberian Atlantic Coast and mainly the A7 Western Mediterranean Sea areas show clear responses to storm activity in the late-LIA and during the beginning of the Industrial Era Warming (IEW) between 1750 and 1900.

For two widely studied areas with respectively 12 and 21 chronologies reviewed, the significant storm activity duality between the northern A2 British Isles and the southern A7 Western Mediterranean Sea areas are presented in the upper part of the Fig. 6 (A & B). These two most significant and clear chronologies are compared to the evolution of air and sea surface temperatures. Northern hemisphere temperature anomalies are presented in Fig. 6 C to E (Ljungqvist, 2010; Luterbacher et al., 2016; Mann et al., 2008) and summarized as the three main last millenary climatological phases : the Medieval Warm Period (MWP), the Little Ice Age (LIA) and the Industrial Era Warming (IEW). As the main A2 British Isles high SI phase is observed during the early LIA since 1300, the general trend linked to this phase is logically a general decease of temperature. More precisely, the peak of storm activity recorded between 1450 and 1470 AD is consistent with a significant temperature decrease that leads to one of the coldest LIA phases. On the other hand, the A7 Western Mediterranean Sea storm activity may be consistent with the long-term general temperature increase observed during the LIA-IEW transition. Comparisons of the A2-A7 SI observations with the Northern European Sea Surface Temperature (SST) (Cunningham et al.,

https://doi.org/10.5194/egusphere-2026-3658
Preprint. Discussion started: 15 July 2026

2013), the Atlantic Multidecadal Oscillation (AMO) (Wang et al., 2017) and the Mediterranean SST (Marriner et al., 2022) may also explain this latitudinal duality. The A2 British Isles early LIA storm activity is concomitant with a long-term decrease of Northern European SST and its most significant storm activity peak is related to a significant AMO trough. On the other hand, the S7 Western Mediterranean Sea storm increase period is also related to long-term increase of the Mediterranean SST, even if tendencies may be less speaking for the more stable AMO index.

https://doi.org/10.5194/egusphere-2026-3658
Preprint. Discussion started: 15 July 2026



https://doi.org/10.5194/egusphere-2026-3658
Preprint. Discussion started: 15 July 2026

Figure 6. Climatological implications over the last millenary and comparison of the (A) A2-British Isles and (B) A7- Western Mediterranean Storm Indexes with: Temperature Anomalies (compared to 1881-1980 for references C: Mann et al. (2008) (Mann et al., 2008) and D: Ljungqvist (2010) (Ljungqvist, 2010) ; and compared to 1961-1990 with 21-yr normalised raw data for reference E : Luterbacher et al. (2016) (Luterbacher et al., 2016), data available at https://www.ncei.noaa.gov/access/paleo-search/study/19600 ; main climatic phases are the Medieval Warm Period as MWP, the Little Ice Age as LIA and the Industrial Era Warming as IEW) ; with Northern European Sea Surface Temperature Anomaly (compared to the 1956-1973, reference F: Cunningham et al. (2013) (Cunningham et al., 2013), data available at https://www.ncei.noaa.gov/access/paleo-search/study/14193) ; with the Atlantic Multidecadal Oscillation (compared to the 21yr-normalized 1985-2015 Temperature Anomaly, reference G: Wang et al. (2017) (Wang et al., 2017), data available at https://www.ncei.noaa.gov/access/paleo-search/study/22031); with Mediterranean Sea Surface Temperature sequences anomalies, reference H: Marriner et al. (2022)(Marriner et al., 2022)) ; with North Atlantic Oscillation Indexes (normalized indexes for references I: Trouet et al. (2009) (Trouet et al., 2009) and J: Proctor et al. (2000) (Proctor et al., 2000); and yearly data analyse for reference K: Ortega et al. (2015) (Ortega et al., 2015) with raw data available at https://catalog.data.gov/dataset/noaa-wds-paleoclimatology-north-atlantic-oscillation-1000-year-model-tested-reconstruction) ; and with El Nino - Southern Oscillation Indexes (with a precipitation index at a wide temporal resolution for reference L: Yan et al. (2011) (Yan et al., 2011), data available at https://www.ncei.noaa.gov/access/paleo-search/study/12203; and with high granularity resolution for M: 21-yr running ENSO variance of the N: interannual ENSO variability extracted of the Li et al. (2011) study (Li et al., 2011), data available at https://www.ncei.noaa.gov/access/paleo-search/study/11194).

The influence of the North Atlantic Oscillation (NAO, Fig. 6 I to K (Ortega et al., 2015; Proctor et al., 2000; Trouet et al., 2009)) and of El Niño Southern Oscillation (ENSO, Fig. 6 L to N (Li et al., 2011; Yan et al., 2011)), two of the most documented climatological indices during the last millenary, on European storm activity are also discussed. The NAO evolution has been proven to have a deep influence on winter European climatology during which most of the extratropical storms occur (Rogers, 1997; Scaife et al., 2008). During the last decades, NAO+ phases are generally linked to higher storm activity other northern Europe, whereas negative phases underwent significant storm activity along the Mediterranean basin (Cassou et al., 2004; López-Moreno et al., 2011; Priestley et al., 2023). This works follows that observations made in recent decades may be extended to the last millenary, however, with a nuance in this observation. If the A2 British Isles high storm activity phase during the late LIA is mostly linked to NAO+ observations, its most intense storm period is mainly linked to a NAO+ to NAO- transitional phase. This observation may be consistent with the work made by Trouet et al. (2012) (Trouet et al., 2012) which explained that NAO+ implicates increase in storm frequency in the North Atlantic region, and increased intensity would be consistent with NAO- during the LIA also induced by a steepening of the meridional temperature gradient as the poles cooled more strongly than the tropics from the MCA into the LIA. In the same way, the A7 Western Mediterranean Basin high stormy period at the LIA-IEW transition is globally consistent with a long-term NAO- period. However, its most intense stormy timespan between 1760 and 1850 is also linked to a NAO- to NAO+ transitional phase at a more precise resolution.

Although ENSO primarily influences the climate of the Pacific Basin (Yeh et al., 2009), it has also been linked to the NAO in recent decades. Several studies suggest that positive ENSO phases (*i.e. "El Niño"*) may be associated with negative NAO situation (King et al., 2023, however this observation is no fully direct and symmetric), and conversely, indirectly influencing European winter climatology. El Niño events can increase the frequency of negative NAO phases during boreal winter, particularly in late winter (January-March and especially in February), by altering large-scale weather regimes over the North Atlantic and Europe (Moron and Plaut, 2003). According to the work of Cassou et al. (2004) (Cassou et al., 2004),

https://doi.org/10.5194/egusphere-2026-3658
Preprint. Discussion started: 15 July 2026

the response of North Atlantic–European winter circulation regimes to ENSO is asymmetric, with La Niña events exhibiting a clearer and more robust influence on ridge/blocking-like regimes than El Niño events. Furthermore, the Madden-Julian Oscillation (MJO) plays a key role in this relationship, as ENSO modulates the strength of MJO-to-NAO teleconnections, with El Niño enhancing MJO-related positive NAO responses through a tropospheric pathway, whereas La Niña favours negative NAO responses through a stratospheric pathway (Lee et al., 2019). Jiménez-Esteve and Domeisen (2020) (Jiménez-Esteve and Domeisen, 2020) also demonstrated that the ENSO–NAO teleconnections are nonlinear, with strong El Niño events producing a substantially larger North Atlantic response than La Niña events of comparable magnitude ; they also highlight the importance of tropical Pacific SST anomalies in shaping the magnitude and asymmetry of the North Atlantic response. These findings highlight the intricate interplay between tropical Pacific variability and North Atlantic atmospheric dynamics, underlining the importance of considering both ENSO and MJO phases when assessing European winter climate variability. Extended to the last millenary and both at a wide temporal resolution (Fig. 6 L) and with high granularity (Fig. 6 M & N), this work cannot confirm or infirm these assumptions. Whether these relationships remain detectable over centennial timescales and are reflected in reconstructed storm variability remains, however, largely unexplored. Figure 6 shows that the A2 British Isles storm activity may eventually be consistent with an ENSO negative to positive long-term transition and the A7 Western Mediterranean Basin high SI phase coincide with a long-term positive to negative ENSO variation. However, the long-term ENSO+ situation may be consistent with the LIA climatological phase and possibly linked to weaker air and sea surface temperatures over western Europe. Future studies combining paleoclimatic reconstructions and climate-model simulations could help clarify the extent to which ENSO-related variability contributes to long-term changes in European storminess and hydroclimatic extremes.

5. Conclusion

This review synthesizes eighty-one historical and geophysical storm chronologies to provide a new perspective on the long-term evolution of coastal storm activity across western Europe during the last millennium. By combining multidisciplinary archives within a common decadal framework and through the development of the Storm Index and storm stripes visualization, the study highlights significant regional differences in storm occurrence through time. The results notably suggest a possible latitudinal shift in storm activity during the Little Ice Age, with enhanced storminess occurring earlier in northern Europe and later along the Iberian and western Mediterranean coasts. These patterns appear broadly consistent with reconstructed changes in climate and oceanic conditions over the last millennium. Enhanced storm activity in northern Europe during the early Little Ice Age coincides with a period of a decrease of temperatures, declining North Atlantic sea-surface temperatures, and a marked negative phase of the AMO, whereas the later increase in storm activity observed in the western Mediterranean occurred during a phase of regional warming and increasing Mediterranean sea-surface temperatures. In addition, the spatial distribution of storm activity shows a broad correspondence with long-term variations in the North

https://doi.org/10.5194/egusphere-2026-3658
Preprint. Discussion started: 15 July 2026

Atlantic Oscillation, highlighting the potential role of large-scale atmospheric circulation in controlling centennial-scale storm patterns across western Europe.

Beyond documenting temporal fluctuations in storm activity, these findings emphasize the need to better understand the spatial organization of past extreme events across Europe. Future research should therefore focus not only on the frequency and intensity of historical storms, but also on their trajectories, including propagation patterns of regional impacts through time that may help to precise the present hypotheses developed in this paper. Integrating historical archives, geophysical records, and climatic reconstructions within spatially explicit approaches may provide new insights into the mechanisms controlling the long-term storm variability and improve assessments of future coastal risks under ongoing climate change.

6. Data availability statement

The datasets generated during and/or analysed during the current study will be published as a supplementary material should the paper be accepted.

7. Competing interests

The author(s) declare no competing financial and non-financial interests.

8. Financial support

This works has been funded by the Agence Nationale de la Recherche (ANR) through the HiStoTracks project (Historical Storm Tracks Facing Climate Change in coastal socio-ecological systems: ANR-25-CE55-2750); with the support of the Pays de la Loire region through the GEOCLIM Pulsar program.

9. References

Abrantes, F., Alt-Epping, U., Lebreiro, S., Voelker, A., and Schneider, R.: Sedimentological record of tsunamis on shallow-shelf areas: The case of the 1969 AD and 1755 AD tsunamis on the Portuguese Shelf off Lisbon, Marine Geology, 249, 283–293, https://doi.org/10.1016/j.margeo.2007.12.004, 2008.

Adolph, M.-L., Czerwiński, S., Dreßler, M., Strobel, P., Bliedtner, M., Lorenz, S., Debret, M., and Haberzettl, T.: North Atlantic Oscillation polarity during the past 3000 years derived from sediments of a large lowland lake, Schweriner See, in NE Germany, Climate of the Past, 20, 2143–2165, https://doi.org/10.5194/cp-20-2143-2024, 2024.

Amann, B., Szidat, S., and Grosjean, M.: A millennial-long record of warm season precipitation and flood frequency for the North-western Alps inferred from varved lake sediments: implications for the future, Quaternary Science Reviews, 115, 89–100, https://doi.org/10.1016/j.quascirev.2015.03.002, 2015.

Andersen, T. J.: Some Practical Considerations Regarding the Application of 210Pb and 137Cs Dating to Estuarine Sediments, in: Applications of Paleoenvironmental Techniques in Estuarine Studies, edited by: Weckström, K., Saunders, K. M., Gell, P. A., and Skilbeck, C. G., Springer Netherlands, Dordrecht, 121–140, https://doi.org/10.1007/978-94-024-0990-1_6, 2017.

Athimon, E.: “Vimers de mer” et sociétés dans les provinces de la facade atlantique du royaume de France (XIVe-XVIIIe siècle), phdthesis, Université de Nantes, 2019.

Athimon, E.: Tempêtes et submersions marines dans les territoires de la côte atlantique (XIVe-XVIIIe siècle), Les Indes Savantes., 397 pp., 2021.

Bailey, S. D., Wintle, A. G., Duller, G. A. T., and Bristow, C. S.: Sand deposition during the last millennium at Aberffraw, Anglesey, North Wales as determined by OSL dating of quartz, Quaternary Science Reviews, 20, 701–704, https://doi.org/10.1016/S0277-3791(00)00053-6, 2001.

Baltzer, A., Walter-Simonnet, A.-V., Mokeddem, Z., Tessier, B., Goubert, E., Cassen, S., and Diffo, A.: Climatically-driven impacts on sedimentation processes in the Bay of Quiberon (south Brittany, France) over the last 10,000 years, The Holocene, 24, 679–688, https://doi.org/10.1177/0959683614526933, 2014.

Benito, G., Díez-Herrero, A., and Fernández de Villalta, M.: Magnitude and Frequency of Flooding in the Tagus Basin (Central Spain) over the Last Millennium, Climatic Change, 58, 171–192, https://doi.org/10.1023/A:1023417102053, 2003.

Benito, G., Rico, M., Sánchez-Moya, Y., Sopeña, A., Thorndycraft, V. R., and Barriendos, M.: The impact of late Holocene climatic variability and land use change on the flood hydrology of the Guadalentín River, southeast Spain, Global and Planetary Change, 70, 53–63, https://doi.org/10.1016/j.gloplacha.2009.11.007, 2010.

Benito, G., Macklin, M. G., Zielhofer, C., Jones, A. F., and Machado, M. J.: Holocene flooding and climate change in the Mediterranean, CATENA, 130, 13–33, https://doi.org/10.1016/j.catena.2014.11.014, 2015.

Björckl, S. and Clemmensen, L. B.: Aeolian sediment in raised bog deposits, Halland, SW Sweden: a new proxy record of Holocene winter storminess variation in southern Scandinavia?, The Holocene, 14, 677–688, https://doi.org/10.1191/0959683604hl746rp, 2004.

Blanchemanche, P.: Crues historiques et vendanges en Languedoc méditerranéen oriental : la source, le signal et l’interprétation, Archéologie du Midi Médiéval, 27, 225–235, https://doi.org/10.3406/amime.2009.1900, 2009.

Brázdil, R., Pfister, C., Wanner, H., Storch, H. V., and Luterbacher, J.: Historical Climatology In Europe – The State Of The Art, Climatic Change, 70, 363–430, https://doi.org/10.1007/s10584-005-5924-1, 2005.

Brázdil, R., Kundzewicz, Z. W., and Benito, G.: Historical hydrology for studying flood risk in Europe, Hydrological Sciences Journal, 51, 739–764, https://doi.org/10.1623/hysj.51.5.739, 2006.

https://doi.org/10.5194/egusphere-2026-3658
Preprint. Discussion started: 15 July 2026

Breilh, J.-F., Bertin, X., Chaumillon, É., Giloy, N., and Sauzeau, T.: How frequent is storm-induced flooding in the central part of the Bay of Biscay?, Global and Planetary Change, 122, 161–175, https://doi.org/10.1016/j.gloplacha.2014.08.013, 2014.

Budillon, F., Esposito, E., Iorio, M., Pelosi, N., Porfido, S., and Violante, C.: The geological record of storm events over the last 1000 years in the Salerno Bay (Southern Tyrrhenian Sea): new proxy evidences, in: Advances in Geosciences, 6th Plinius Conference on Mediterranean Storms (2004) - 6th Plinius Conference on Mediterranean Storms, Mediterranean Sea (on board), 17–24 October 2004, 123–130, https://doi.org/10.5194/adgeo-2-123-2005, 2005.

Camuffo, D., Secco, C., Brimblecombe, P., and Martin-Vide, J.: Sea Storms in the Adriatic Sea and the Western Mediterranean during the Last Millennium, Climatic Change, 46, 209–223, https://doi.org/10.1023/A:1005607103766, 2000.

Cassou, C., Terray, L., Hurrell, J. W., and Deser, C.: North Atlantic Winter Climate Regimes: Spatial Asymmetry, Stationarity with Time, and Oceanic Forcing, Journal of Climate, 17, 1055–1068, https://doi.org/10.1175/1520-0442(2004)017<1055:NAWCRS>2.0.CO;2, 2004.

Clarke, M., Rendell, H., Tastet, J.-P., Clave, B., and Masse, L.: Late-Holocene sand invasion and North Atlantic storminess along the Aquitaine Coast, southwest France, The Holocene, 12, 231–238, https://doi.org/10.1191/0959683602hl539rr, 2002.

Clarke, M. L. and Rendell, H. M.: Effects of storminess, sand supply and the North Atlantic Oscillation on sand invasion and coastal dune accretion in western Portugal, The Holocene, 16, 341–355, https://doi.org/10.1191/0959683606hl932rp, 2006.

Clemmensen, L. B., Bjørnsen, M., Murray, A., and Pedersen, K.: Formation of aeolian dunes on Anholt, Denmark since AD 1560: A record of deforestation and increased storminess, Sedimentary Geology, 199, 171–187, https://doi.org/10.1016/j.sedgeo.2007.01.025, 2007.

Clemmensen, L. B., Murray, A., Heinemeier, J., and de Jong, R.: The evolution of Holocene coastal dunefields, Jutland, Denmark: A record of climate change over the past 5000 years, Geomorphology, 105, 303–313, https://doi.org/10.1016/j.geomorph.2008.10.003, 2009.

Cosby, A. G., Lebakula, V., Smith, C. N., Wanik, D. W., Bergene, K., Rose, A. N., Swanson, D., and Bloom, D. E.: Accelerating growth of human coastal populations at the global and continent levels: 2000–2018, Sci Rep, 14, 22489, https://doi.org/10.1038/s41598-024-73287-x, 2024.

Cunningham, L. K., Austin, W. E., Knudsen, K. L., Eiríksson, J., Scourse, J. D., WanamakerJr, A. D., Butler, P. G., Cage, A. G., Richter, T., Husum, K., Hald, M., Andersson, C., Zorita, E., Linderholm, H. W., Gunnarson, B. E., Sicre, M.-A., Sejrup, H. P., Jiang, H., and Wilson, R. J.: Reconstructions of surface ocean conditions from the northeast Atlantic and Nordic seas during the last millennium, The Holocene, 23, 921–935, https://doi.org/10.1177/0959683613479677, 2013.

Degeai, J.-P., Devillers, B., Dezileau, L., Oueslati, H., and Bony, G.: Major storm periods and climate forcing in the Western Mediterranean during the Late Holocene, Quaternary Science Reviews, 129, 37–56, https://doi.org/10.1016/j.quascirev.2015.10.009, 2015.

Dezileau, L., Sabatier, P., Blanchemanche, P., Joly, B., Swingedouw, D., Cassou, C., Castaings, J., Martinez, P., and Von Grafenstein, U.: Intense storm activity during the Little Ice Age on the French Mediterranean coast, Palaeogeography Palaeoclimatology Palaeoecology / Palaeogeography Palaeoclimatology and Palaeoecology, 299, 289–297, https://doi.org/10.1016/j.palaeo.2010.11.009, 2011.

Dezileau, L., Pérez-Ruzafa, A., Blanchemanche, P., Degeai, J. P., Raji, O., Martinez, P., Marcos, C., and Von Grafenstein, U.: Extreme storms during the last 6,500 years from lagoonal sedimentary archives in Mar Menor (SE Spain), Climate of the Past Discussions, 12, 1389–1400, https://doi.org/10.5194/cp-2016-20, 2016.

Dietz, M. E., Liu, K., Bianchette, T. A., and Smith, D.: Differentiating hurricane deposits in coastal sedimentary records: two storms, one layer, but different processes, Environ. Res. Commun., 3, 101001, https://doi.org/10.1088/2515-7620/ac26dd, 2021.

Ding, K., Li, S., Ding, A., Lu, H., Zhang, J., Xi, D., Huang, X., Lou, S., Tang, X., Qiu, X., He, L., Ma, Y., Lin, H., Zhang, S., Zhou, D., Zhou, X., Tan, Z.-M., Fu, C., and Ge, Q.: Archeological data with AI- and physics-based modeling explain typhoon-induced disasters in inland China around 3000 yr B.P., Science Advances, 12, eaeb1598, https://doi.org/10.1126/sciadv.aeb1598, 2026.

Doensen, O., Messmer, M., Kim, W. M., and Raible, C. C.: Characterization of the mean and extreme Mediterranean cyclones and their variability during the period 1500 BCE to 1850 CE, Climate of the Past, 21, 1305–1322, https://doi.org/10.5194/cp-21-1305-2025, 2025.

Ehrhold, A., Jouet, G., Le Roy, P., Jorry, S. J., Grall, J., Reixach, T., Lambert, C., Gregoire, G., Goslin, J., Roubi, A., Penaud, A., Vidal, M., and Siano, R.: Fossil maerl beds as coastal indicators of late Holocene palaeo-environmental evolution in the Bay of Brest (Western France), Palaeogeography, Palaeoclimatology, Palaeoecology, 577, 110525, https://doi.org/10.1016/j.palaeo.2021.110525, 2021.

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

Feist, L., Frank, S., Bellanova, P., Laermanns, H., Cämmerer, C., Mathes-Schmidt, M., Biermanns, P., Brill, D., Costa, P. J. M., Teichner, F., Brückner, H., Schwarzbauer, J., and Reicherter, K.: The sedimentological and environmental footprint of extreme wave events in Boca do Rio, Algarve coast, Portugal, Sedimentary Geology, 389, 147–160, https://doi.org/10.1016/j.sedgeo.2019.06.004, 2019.

Fichaut, B. and Suanez, S. S.: Quarrying, transport and deposition of cliff-top storm deposits during extreme events: Banneg Island, Brittany, Marine Geology, 283, 36–55, https://doi.org/10.1016/j.margeo.2010.11.003, 2011.

Gerrard, C. M. and Petley, D. N.: A risk society? Environmental hazards, risk and resilience in the later Middle Ages in Europe, Nat Hazards, 69, 1051–1079, https://doi.org/10.1007/s11069-013-0750-7, 2013.

https://doi.org/10.5194/egusphere-2026-3658
Preprint. Discussion started: 15 July 2026

Gilbertson, D. D., Schwenninger, J.-L., Kemp, R. A., and Rhodes, E. J.: Sand-drift and Soil Formation Along an Exposed North Atlantic Coastline: 14,000 Years of Diverse Geomorphological, Climatic and Human Impacts, Journal of Archaeological Science, 26, 439–469, https://doi.org/10.1006/jasc.1998.0360, 1999.

Glur, L., Wirth, S. B., Büntgen, U., Gilli, A., Haug, G. H., Schär, C., Beer, J., and Anselmetti, F. S.: Frequent floods in the European Alps coincide with cooler periods of the past 2500 years, Sci Rep, 3, 2770, https://doi.org/10.1038/srep02770, 2013.

Gorczyńska, A., Stéphan, P., Pailler, Y., Nicolas, C., Penaud, A., David, O., Vidal, M., and Le Gall, B.: Holocene evolution of coastal dunes in western France: Regional reconstruction from archaeological and historical data, Aeolian Research, 60, 100851, https://doi.org/10.1016/j.aeolia.2022.100851, 2023.

Goslin, J., Fruergaard, M., Sander, L., Gałka, M., Menviel, L., Monkenbusch, J., Thibault, N., and Clemmensen, L. B.: Holocene centennial to millennial shifts in North-Atlantic storminess and ocean dynamics, Scientific Reports, 8, 12778, https://doi.org/10.1038/s41598-018-29949-8, 2018.

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

Hansen, J. M.: Laeso : Opstaen, Kysttilkvaekst, kilma, vegetation, bosaettelse og saltindustri, Geocenter Danmark, 20 pp., 2017.

Hansom, J. D. and Hall, A. M.: Magnitude and frequency of extra-tropical North Atlantic cyclones: A chronology from cliff-top storm deposits, Quaternary International, 195, 42–52, https://doi.org/10.1016/j.quaint.2007.11.010, 2009.

Hansom, J. D., Barltrop, N. D. P., and Hall, A. M.: Modelling the processes of cliff-top erosion and deposition under extreme storm waves, Marine Geology, 253, 36–50, https://doi.org/10.1016/j.margeo.2008.02.015, 2008.

Hess, K., Engel, M., Patel, T., Vakhrameeva, P., Koutsodendris, A., Klemt, E., Hansteen, T. H., Kempf, P., Dawson, S., Schön, I., and Heyvaert, V. M. A.: A 1500-year record of North Atlantic storm flooding from lacustrine sediments, Shetland Islands (UK), Journal of Quaternary Science, 39, 37–53, https://doi.org/10.1002/jqs.3568, 2024.

IPCC: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate, Cambridge University Press., Cambridge, UK and New York, NY, USA, 775 pp., 2019.

Jackson, M. G., Oskarsson, N., Trønnes, R. G., McManus, J. F., Oppo, D. W., Grönvold, K., Hart, S. R., and Sachs, J. P.: Holocene loess deposition in Iceland: Evidence for millennial-scale atmosphere-ocean coupling in the North Atlantic, Geology, 33, 509–512, https://doi.org/10.1130/G21489.1, 2005.

Jelgersma, S., Stive, M. J. F., and van der Valk, L.: Holocene storm surge signatures in the coastal dunes of the western Netherlands, Marine Geology, 125, 95–110, https://doi.org/10.1016/0025-3227(95)00061-3, 1995.

Jiménez-Esteve, B. and Domeisen, D. I. V.: Nonlinearity in the tropospheric pathway of ENSO to the North Atlantic, Weather and Climate Dynamics, 1, 225–245, https://doi.org/10.5194/wcd-1-225-2020, 2020.

Jong, R. de, Björck, S., Björkman, L., and Clemmensen, L. B.: Storminess variation during the last 6500 years as reconstructed from an ombrotrophic peat bog in Halland, southwest Sweden, Journal of Quaternary Science, 21, 905–919, https://doi.org/10.1002/jqs.1011, 2006.

Kaniewski, D., Marriner, N., Morhange, C., Faivre, S., Otto, T., and Campo, E. V.: Solar pacing of storm surges, coastal flooding and agricultural losses in the Central Mediterranean, Scientific Reports, 6, https://doi.org/10.1038/srep25197, 2016.

Kerverdo, R., Lafuerza, S., Gorini, C., Fouache, E., Granjeon, D., Bianchi, N., Haghipour, N., Clementucci, R., Loget, N., Migeon, S., and Deschamps, R.: Extreme flood deposits in the Roya Valley during the Holocene: characterisation and recurrence intervals, Quaternary Science Reviews, 373, 109749, https://doi.org/10.1016/j.quascirev.2025.109749, 2026.

King, M. P., Keenlyside, N., and Li, C.: ENSO teleconnections in terms of non-NAO and NAO atmospheric variability, Clim Dyn, 61, 2717–2733, https://doi.org/10.1007/s00382-023-06697-8, 2023.

Kylander, M. E., Söderlindh, J., Schenk, F., Gyllencreutz, R., Rydberg, J., Bindler, R., Cortizas, A. M., and Skelton, A.: It's in your glass: a history of sea level and storminess from the Laphroaig bog, Islay (southwestern Scotland), Boreas, https://doi.org/10.1111/bor.12409, 2019.

Kylander, M. E., Martínez-Cortizas, A., Sjöström, J. K., Gåling, J., Gyllencreutz, R., Bindler, R., Alexanderson, H., Schenk, F., Reinardy, B. T. I., Chandler, B. M. P., and Gallagher, K.: Storm chasing: Tracking Holocene storminess in southern Sweden using mineral proxies from inland and coastal peat bogs, Quaternary Science Reviews, 299, 107854, https://doi.org/10.1016/j.quascirev.2022.107854, 2023.

Lamb, H. and Frydendahl, K.: Historic Storms of the North Sea, British Isles and Northwest Europe, Cambridge University Press, Cambridge, 232 pp., 1991.

Lamb, H. H.: Climatic fluctuations in historical times and their connexion with transgressions of the sea, storm floods and other coastal changes, in: Transgressies en occupatiegeschiedenis in de kustgebieden van Nederland en België, edited by: A Verhulst and Gottschalk, M. K. E., 251–281, 1980.

Lampe, R. and Lampe, M.: The role of sea-level changes in the evolution of coastal barriers – An example from the southwestern Baltic Sea, The Holocene, 31, 515–528, https://doi.org/10.1177/0959683620981703, 2021.

LeBlanc, A. R., Kennedy, L. M., Liu, K., and Lane, C. S.: Linking hurricane landfalls, precipitation variability, fires, and vegetation response over the past millennium from analysis of coastal lagoon sediments, southwestern Dominican Republic, J Paleolimnol, 58, 135–150, https://doi.org/10.1007/s10933-017-9965-z, 2017.

Lee, R. W., Woolnough, S. J., Charlton-Perez, A. J., and Vitart, F.: ENSO Modulation of MJO Teleconnections to the North Atlantic and Europe, Geophysical Research Letters, 46, 13535–13545, https://doi.org/10.1029/2019GL084683, 2019.

Leszczyńska, K., Alexanderson, H., Clemmensen, L. B., Giza, A., Lorenz, S., Moskalewicz, D., Oliński, P., Paprotny, D., Rosentau, A., Rutgersson, A., Stattegger, K., Szczuciński, W., Terefenko, P., Uścinowicz, G., Uścinowicz, S., and Wolski, T.: A review of storms and marine coastal flooding in the Baltic Sea – Insights from instrumental, historical and sedimentary record, Earth-Science Reviews, 266, 105137, https://doi.org/10.1016/j.earscirev.2025.105137, 2025.

https://doi.org/10.5194/egusphere-2026-3658
Preprint. Discussion started: 15 July 2026

Li, J., Xie, S.-P., Cook, E. R., Huang, G., D'Arrigo, R., Liu, F., Ma, J., and Zheng, X.-T.: Interdecadal modulation of El Niño amplitude during the past millennium, Nature Clim Change, 1, 114–118, https://doi.org/10.1038/nclimate1086, 2011.

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

Liu, K. and Fearn, M. L.: Reconstruction of Prehistoric Landfall Frequencies of Catastrophic Hurricanes in Northwestern Florida from Lake Sediment Records, Quaternary Research, 54, 238–245, https://doi.org/10.1006/qres.2000.2166, 2000.

Ljungqvist, F. C.: A new reconstruction of temperature variability in the extra-tropical northern hemisphere during the last two millennia, Geografiska Annaler: Series A, Physical Geography, 92, 339–351, https://doi.org/10.1111/j.1468-0459.2010.00399.x, 2010.

López-Moreno, J. I., Vicente-Serrano, S. M., Morán-Tejeda, E., Lorenzo-Lacruz, J., Kenawy, A., and Beniston, M.: Effects of the North Atlantic Oscillation (NAO) on combined temperature and precipitation winter modes in the Mediterranean mountains: Observed relationships and projections for the 21st century, Global and Planetary Change, 77, 62–76, https://doi.org/10.1016/j.gloplacha.2011.03.003, 2011.

Luterbacher, J., Xoplaki, E., Dietrich, D., Rickli, R., Jacobeit, J., Beck, C., Gyalistras, D., Schmutz, C., and Wanner, H.: Reconstruction of sea level pressure fields over the Eastern North Atlantic and Europe back to 1500, Climate Dynamics, 18, 545–561, https://doi.org/10.1007/s00382-001-0196-6, 2002.

Luterbacher, J., Werner, J. P., Smerdon, J. E., Fernández-Donado, L., González-Rouco, F. J., Barriopedro, D., Ljungqvist, F. C., Büntgen, U., Zorita, E., Wagner, S., Esper, J., McCarroll, D., Toreti, A., Frank, D., Jungclaus, J. H., Barriendos, M., Bertolin, C., Bothe, O., Brázdil, R., Camuffo, D., Dobrovolný, P., Gagen, M., García-Bustamante, E., Ge, Q., Gómez-Navarro, J. J., Guiot, J., Hao, Z., Hegerl, G. C., Holmgren, K., Klimenko, V. V., Martín-Chivelet, J., Pfister, C., Roberts, N., Schindler, A., Schurer, A., Solomina, O., von Gunten, L., Wahl, E., Wanner, H., Wetter, O., Xoplaki, E., Yuan, N., Zanchettin, D., Zhang, H., and Zerefos, C.: European summer temperatures since Roman times, Environ. Res. Lett., 11, 024001, https://doi.org/10.1088/1748-9326/11/2/024001, 2016.

Maanan, M., Pouzet, P., Schmidt, S., and Robin, M.: Historic Storms Detected in a Changing Environment over Recent Centuries in the Belle Henriette Lagoon, Atmosphere, 13, 151, https://doi.org/10.3390/atmos13020151, 2022.

Mann, M. E., Zhang, Z., Hughes, M. K., Bradley, R. S., Miller, S. K., Rutherford, S., and Ni, F.: Proxy-based reconstructions of hemispheric and global surface temperature variations over the past two millennia, PNAS, 105, 13252–13257, https://doi.org/10.1073/pnas.0805721105, 2008.

Mann, M. E., Zhang, Z., Rutherford, S., Bradley, R. S., Hughes, M. K., Shindell, D., Ammann, C., Faluvegi, G., and Ni, F.: Global Signatures and Dynamical Origins of the Little Ice Age and Medieval Climate Anomaly, Science, 326, 1256–1260, https://doi.org/10.1126/science.1177303, 2009.

Marriner, N., Kaniewski, D., Pourkerman, M., and Devillers, B.: Anthropocene tipping point reverses long-term Holocene cooling of the Mediterranean Sea: A meta-analysis of the basin's Sea Surface Temperature records, Earth-Science Reviews, 227, 103986, https://doi.org/10.1016/j.earscirev.2022.103986, 2022.

https://doi.org/10.5194/egusphere-2026-3658
Preprint. Discussion started: 15 July 2026

Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S. L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M. I., Huang, M., Leitzell, K., Lonnoy, E., Matthews, J. B. R., Maycock, T. K., Waterfield, T., Yelekçi, Ö., Yu, R., and Zhou, B.: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, https://doi.org/10.1017/9781009157896, 2021.

Matulla, C., Schöner, W., Alexandersson, H., von Storch, H., and Wang, X. L.: European storminess: late nineteenth century to present, Clim Dyn, 31, 125–130, https://doi.org/10.1007/s00382-007-0333-y, 2008.

McIlvenny, J. D., Muller, F. L. L., and Dawson, A.: A 7600-year sedimentary record of climatic instability in Dunnet Bay, North Scotland, Marine Geology, 335, 100–113, https://doi.org/10.1016/j.margeo.2012.10.014, 2013.

Moreno, A., Valero-Garcés, B. L., González-Sampériz, P., and Rico, M.: Flood response to rainfall variability during the last 2000 years inferred from the Taravilla Lake record (Central Iberian Range, Spain), J Paleolimnol, 40, 943–961, https://doi.org/10.1007/s10933-008-9209-3, 2008.

Morim, J., Wahl, T., Rasmussen, D. J., Calafat, F. M., Vitousek, S., Dangendorf, S., Kopp, R. E., and Oppenheimer, M.: Observations reveal changing coastal storm extremes around the United States, Nat. Clim. Chang., 15, 538–545, https://doi.org/10.1038/s41558-025-02315-z, 2025.

Moron, V. and Plaut, G.: The impact of El Niño–southern oscillation upon weather regimes over Europe and the North Atlantic during boreal winter, International Journal of Climatology, 23, 363–379, https://doi.org/10.1002/joc.890, 2003.

Orme, L. C., Davies, S. J., and Duller, G. a. T.: Reconstructed centennial variability of Late Holocene storminess from Cors Fochno, Wales, UK, Journal of Quaternary Science, 30, 478–488, https://doi.org/10.1002/jqs.2792, 2015.

Orme, L. C., Reinhardt, L., Jones, R. T., Charman, D. J., Barkwith, A., and Ellis, M. A.: Aeolian sediment reconstructions from the Scottish Outer Hebrides: Late Holocene storminess and the role of the North Atlantic Oscillation, Quaternary Science Reviews, 132, 15–25, https://doi.org/10.1016/j.quascirev.2015.10.045, 2016.

Ortega, J. A. and Garzón, G.: A contribution to improved flood magnitude estimation in base of palaeoflood record and climatic implications – Guadiana River (Iberian Peninsula), Natural Hazards and Earth System Sciences, 9, 229–239, https://doi.org/10.5194/nhess-9-229-2009, 2009.

Ortega, P., Lehner, F., Swingedouw, D., Masson-Delmotte, V., Raible, C. C., Casado, M., and Yiou, P.: A model-tested North Atlantic Oscillation reconstruction for the past millennium, Nature, 523, 71–74, https://doi.org/10.1038/nature14518, 2015.

Peng, F., Prins, M. A., Kasse, C., Cohen, K. M., Van der Putten, N., van der Lubbe, J., Toonen, W. H. J., and van Balen, R. T.: An improved method for paleoflood reconstruction and flooding phase identification, applied to the Meuse River in the Netherlands, Global and Planetary Change, 177, 213–224, https://doi.org/10.1016/j.gloplacha.2019.04.006, 2019.

Pinto, J. G. and Raible, C. C.: Past and recent changes in the North Atlantic oscillation, WIREs Climate Change, 3, 79–90, https://doi.org/10.1002/wcc.150, 2012.

https://doi.org/10.5194/egusphere-2026-3658
Preprint. Discussion started: 15 July 2026

Poirier, C., Tessier, B., and Chaumillon, E.: Climate control on late Holocene high-energy sedimentation along coasts of the northeastern Atlantic Ocean, Palaeogeography, Palaeoclimatology, Palaeoecology, 485, 784–797, https://doi.org/10.1016/j.palaeo.2017.07.037, 2017.

Pouzet, P. and Maanan, M.: Climatological influences on major storm events during the last millennium along the Atlantic coast of France, Scientific Reports, 12059, 2020.

Pouzet, P., Maanan, M., Piotrowska, N., Baltzer, A., Stéphan, P., and Robin, M.: Chronology of Holocene storm events along the European Atlantic coast: New data from the Island of Yeu, France, Progress in Physical Geography: Earth and Environment, 42, 431–450, https://doi.org/10.1177/0309133318776500, 2018.

Pouzet, P., Maanan, M., Schmidt, S., Athimon, E., and Robin, M.: Correlating three centuries of historical and geological data for the marine deposit reconstruction of two depositional environments of the French Atlantic coast, Marine Geology, 407, 181–191, https://doi.org/10.1016/j.margeo.2018.10.014, 2019.

Pouzet, P., Decaulne, A., and Funatsu, B. M.: Multi-proxy documentation of past storm events in a mid-latitude coastal environment, CATENA, 257, 109118, https://doi.org/10.1016/j.catena.2025.109118, 2025.

Priestley, M. D. K., Stephenson, D. B., Scaife, A. A., Bannister, D., Allen, C. J. T., and Wilkie, D.: Return levels of extreme European windstorms, their dependency on the North Atlantic Oscillation, and potential future risks, Natural Hazards and Earth System Sciences, 23, 3845–3861, https://doi.org/10.5194/nhess-23-3845-2023, 2023.

Proctor, C. J., Baker, A., Barnes, W. L., and Gilmour, M. A.: A thousand year speleothem proxy record of North Atlantic climate from Scotland, Climate Dynamics, 16, 815–820, https://doi.org/10.1007/s003820000077, 2000.

Prosper-Laget, V., Pichard, G., Miramont, C., and Sivan, O.: Les conditions climatiques de la torrentialité au cours du Petit Age Glaciaire en Provence, Archéologie du Midi Médiéval, 27, 157–167, https://doi.org/10.3406/amime.2009.1894, 2009.

Purkis, S. J., Ward, S. N., Howes, B. J., Longenecker, J. M., Chakraborty, M. I., Kalman, A., Clement, A. C., Sharifi, A., Benzoni, F., Clarke, C., and Rodrigue, M.: A 1600-year record of extreme rainfall in northern Arabia, Science Advances, 11, eadq3173, https://doi.org/10.1126/sciadv.adq3173, 2025.

Raji, O., Dezileau, L., Von Grafenstein, U., Niazi, S., Snoussi, M., and Martinez, P.: Extreme sea events during the last millennium in the northeast of Morocco, Natural Hazards and Earth System Sciences, 15, 203–211, https://doi.org/10.5194/nhess-15-203-2015, 2015.

Regnauld, H.: L'élévation et les variations du niveau marin à l'Holocène terminal dans l'Ouest français : une approche par les dépôts de tempêtes [Sea-level elevation and variation during late holocene in western France ; storm surge relicts as indicators], Quaternaire, 10, 181–188, https://doi.org/10.3406/quate.1999.1641, 1999.

Reimann, T., Tsukamoto, S., Harff, J., Osadczuk, K., and Frechen, M.: Reconstruction of Holocene coastal foredune progradation using luminescence dating — An example from the Świna barrier (southern Baltic Sea, NW Poland), Geomorphology, 132, 1–16, https://doi.org/10.1016/j.geomorph.2011.04.017, 2011.

Rogers, J. C.: North Atlantic Storm Track Variability and Its Association to the North Atlantic Oscillation and Climate Variability of Northern Europe, Journal of Climate, 10, 1635–1647, https://doi.org/10.1175/1520-0442(1997)010<1635:NASTVA>2.0.CO;2, 1997.

Sabatier, P., Dezileau, L., Condomines, M., Briqueu, L., Colin, C., Bouchette, F., Le Duff, M., and Blanchemanche, P.: Reconstruction of paleostorm events in a coastal lagoon (Hérault, South of France), Marine Geology, 251, 224–232, https://doi.org/10.1016/j.margeo.2008.03.001, 2008.

Sabatier, P., Dezileau, L., Colin, C., Briqueu, L., Bouchette, F., Martinez, P., Siani, G., Raynal, O., and Von Grafenstein, U.: 7000 years of paleostorm activity in the NW Mediterranean Sea in response to Holocene climate events, Quaternary Research, 77, 1–11, https://doi.org/10.1016/j.yqres.2011.09.002, 2012.

Sabatier, P., Wilhelm, B., Ficetola, G. F., Moiroux, F., Poulenard, J., Develle, A.-L., Bichet, A., Chen, W., Pignol, C., Reyss, J.-L., Gielly, L., Bajard, M., Perrette, Y., Malet, E., Taberlet, P., and Arnaud, F.: 6-kyr record of flood frequency and intensity in the western Mediterranean Alps – Interplay of solar and temperature forcing, Quaternary Science Reviews, 170, 121–135, https://doi.org/10.1016/j.quascirev.2017.06.019, 2017.

Sarrazin, J.-L.: « Vimers de mer » et sociétés littorales entre Loire et Gironde (XIVe-XVIe siècle), Norois, n° 222, 91–102, 2012.

Scaife, A. A., Folland, C. K., Alexander, L. V., Moberg, A., and Knight, J. R.: European Climate Extremes and the North Atlantic Oscillation, Journal of Climate, 21, 72–83, https://doi.org/10.1175/2007JCLI1631.1, 2008.

Schulte, L., Peña, J. C., Carvalho, F., Schmidt, T., Julià, R., Llorca, J., and Veit, H.: A 2600-year history of floods in the Bernese Alps, Switzerland: frequencies, mechanisms and climate forcing, Hydrology and Earth System Sciences, 19, 3047–3072, https://doi.org/10.5194/hess-19-3047-2015, 2015.

Schulte, L., Wetter, O., Wilhelm, B., Peña, J. C., Amann, B., Wirth, S. B., Carvalho, F., and Gómez-Bolea, A.: Integration of multi-archive datasets for the development of a four-dimensional paleoflood model of alpine catchments, Global and Planetary Change, 180, 66–88, https://doi.org/10.1016/j.gloplacha.2019.05.011, 2019.

Semmler, T. and Jacob, D.: Modeling extreme precipitation events—a climate change simulation for Europe, Global and Planetary Change, 44, 119–127, https://doi.org/10.1016/j.gloplacha.2004.06.008, 2004.

Sheffer, N. A., Enzel, Y., Benito, G., Grodek, T., Poart, N., Lang, M., Naulet, R., and Cœur, D.: Paleofloods and historical floods of the Ardèche River, France, Water Resources Research, 39, https://doi.org/10.1029/2003WR002468, 2003.

Sheffer, N. A., Rico, M., Enzel, Y., Benito, G., and Grodek, T.: The Palaeoflood record of the Gardon River, France: A comparison with the extreme 2002 flood event, Geomorphology, 98, 71–83, https://doi.org/10.1016/j.geomorph.2007.02.034, 2008.

Sjöström, J. K., Bindler, R., Martínez Cortizas, A., Björck, S., Hansson, S. V., Karlsson, A., Ellerton, D. T., and Kylander, M. E.: Late Holocene peat paleodust deposition in south-western Sweden - exploring geochemical properties, local mineral sources and regional aeolian activity, Chemical Geology, 602, 120881, https://doi.org/10.1016/j.chemgeo.2022.120881, 2022.

Sjöström, J. K., Gyllencreutz, R., Martínez Cortizas, A., Nylund, A., Piilo, S. R., Schenk, F., McKeown, M., Ryberg, E. E., and Kylander, M. E.: Holocene storminess dynamics in northwestern Ireland: Shifts in storm duration and frequency between the mid- and late Holocene, Quaternary Science Reviews, 337, 108803, https://doi.org/10.1016/j.quascirev.2024.108803, 2024.

Sjöström, J. K., Martínez Cortizas, A., Nylund, A., Piilo, S. R., Orme, L. C., Gyllencreutz, R., Schenk, F., Chiverrell, R., McKeown, M., Ansberque, C., and Kylander, M. E.: A stormy past: long-term temperature evolution and volcanic activity as drivers of Holocene storminess in the eastern North Atlantic, Quaternary Science Reviews, 381, 109901, https://doi.org/10.1016/j.quascirev.2026.109901, 2026.

Soens, T.: Resilient Societies, Vulnerable People: Coping with North Sea Floods Before 1800*, Past & Present, 241, 143–177, https://doi.org/10.1093/pastj/gty018, 2018.

Sorrel, P., Tessier, B., Demory, F., Delsinne, N., and MouazÉ, D.: Evidence for millennial-scale climatic events in the sedimentary infilling of a macrotidal estuarine system, the Seine estuary (NW France), Quaternary Science Reviews, 28, 499–516, https://doi.org/10.1016/j.quascirev.2008.11.009, 2009.

Sorrel, P., Debret, M., Billeaud, I., Jaccard, S. L., McManus, J. F., and Tessier, B.: Persistent non-solar forcing of Holocene storm dynamics in coastal sedimentary archives, Nature Geoscience, 5, 892–896, https://doi.org/10.1038/ngeo1619, 2012.

Stéphan, G., Stéphan, P., Guérin, G., Suanez, S., Pailler, Y., Nicolas, C., Ribeyre, M., Onfray, M., and Malservet, H.: Late Holocene coastal sand-drift events and long-term socio-ecological resilience (Béniguet Island, Western France), Aeolian Research, 76, 101048, https://doi.org/10.1016/j.aeolia.2026.101048, 2026.

Trouet, V., Esper, J., Graham, N. E., Baker, A., Scourse, J. D., and Frank, D. C.: Persistent Positive North Atlantic Oscillation Mode Dominated the Medieval Climate Anomaly, Science, 324, 78–80, https://doi.org/10.1126/science.1166349, 2009.

Trouet, V., Scourse, J. D., and Raible, C. C.: North Atlantic storminess and Atlantic Meridional Overturning Circulation during the last Millennium: Reconciling contradictory proxy records of NAO variability, Global and Planetary Change, 84–85, 48–55, https://doi.org/10.1016/j.gloplacha.2011.10.003, 2012.

Ulbrich, U. and Christoph, M.: A shift of the NAO and increasing storm track activity over Europe due to anthropogenic greenhouse gas forcing, Climate Dynamics, 15, 551–559, https://doi.org/10.1007/s003820050299, 1999.

Van Vliet Lanoe, B., Goslin, J., Hallégouet, B., Hénaff, A., Delacourt, C., Fernane, A., Franzetti, M., Le Cornec, E., Le Roy, P., and Pénaud, A.: Middle- to late-Holocene storminess in Brittany (NW France): Part I - morphological impact and stratigraphical record, Holocene, 24, 413–433, https://doi.org/10.1177/0959683613519687, 2014.

Van Vliet Lanoe, B., Lauer, T., Meurisse-Fort, M., Gosselin, G., and Frechen, M.: Late Holocene coastal dune activity along the Dover Strait, Northern France – Insights into Middle Ages and Little Ice Age coastal dynamics constrained by optically stimulated luminescence dating, Zeitschrift der Deutschen Gesellschaft für Geowissenschaften, 168, 53–66, https://doi.org/10.1127/zdgg/2016/0043, 2017.

Vousdoukas, M. I., Mentaschi, L., Voukouvalas, E., Verlaan, M., and Feyen, L.: Extreme sea levels on the rise along Europe's coasts, Earth's Future, 5, 304–323, https://doi.org/10.1002/2016EF000505, 2017.

Wang, J., Yang, B., Ljungqvist, F. C., Luterbacher, J., Osborn, T. J., Briffa, K. R., and Zorita, E.: Internal and external forcing of multidecadal Atlantic climate variability over the past 1,200 years, Nature Geosci, 10, 512–517, https://doi.org/10.1038/ngeo2962, 2017.

Wang, X. L., Swail, V. R., and Zwiers, F. W.: Climatology and Changes of Extratropical Cyclone Activity: Comparison of ERA-40 with NCEP–NCAR Reanalysis for 1958–2001, J. Climate, 19, 3145–3166, https://doi.org/10.1175/JCLI3781.1, 2006.

Wilhelm, B., Arnaud, F., Sabatier, P., Crouzet, C., Brisset, E., Chaumillon, E., Disnar, J.-R., Guiter, F., Malet, E., Reyss, J.-L., Tachikawa, K., Bard, E., and Delannoy, J.-J.: 1400 years of extreme precipitation patterns over the Mediterranean French Alps and possible forcing mechanisms, Quaternary Research, 78, 1–12, https://doi.org/10.1016/j.yqres.2012.03.003, 2012.

Williams, D. M. and Hall, A. M.: Cliff-top megaclast deposits of Ireland, a record of extreme waves in the North Atlantic—storms or tsunamis?, Marine Geology, 206, 101–117, https://doi.org/10.1016/j.margeo.2004.02.002, 2004.

Wilson, P., McGourty, J., and Bateman, M. D.: Mid-to late-Holocene coastal dune event stratigraphy for the north coast of Northern Ireland, The Holocene, 14, 406–416, https://doi.org/10.1191/0959683604hl716rp, 2004.

Wirth, S. B., Glur, L., Gilli, A., and Anselmetti, F. S.: Holocene flood frequency across the Central Alps – solar forcing and evidence for variations in North Atlantic atmospheric circulation, Quaternary Science Reviews, 80, 112–128, https://doi.org/10.1016/j.quascirev.2013.09.002, 2013.

Yan, H., Sun, L., Wang, Y., Huang, W., Qiu, S., and Yang, C.: A record of the Southern Oscillation Index for the past 2,000 years from precipitation proxies, Nature Geosci, 4, 611–614, https://doi.org/10.1038/ngeo1231, 2011.

Yeh, S.-W., Kug, J.-S., Dewitte, B., Kwon, M.-H., Kirtman, B. P., and Jin, F.-F.: El Niño in a changing climate, Nature, 461, 511–514, https://doi.org/10.1038/nature08316, 2009.