A European database of resources on coastal storm impacts

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Abstract. Detailed information on coastal storm impacts is crucial to evaluate the degree of damages caused by floods, implementing effective recovery actions for risk prevention and preparedness, and to design appropriate coastal zone management plans. This article presents a new database containing information on extreme storm events that generated damage and flooding along European coastlines between 2010 and 2020. The storm events, associated with specific locations, define the test cases which are then used to retrieve information from different extreme coastal storms that hit the same area. The database ~~is a workbook that~~ collects items organised in worksheets and constitutes an inventory of resources ~~defined as a collection of~~with different types of information used to characterize ~~the~~ a storm event (i.e., hydrodynamics, weather information) and its consequences (impacts, flood extent, etc.). The guidelines and polygons in GeoJSON format that define the domain of the sites are also provided together with the ~~workbook~~database. The database contains 11 coastal storm events, 26 sites, 28 test cases, and 232 resources and is designed to allow the addition of new events and resources. Descriptive statistical analyses were performed to define the types and topics addressed by the resources and the distribution of types of resources per country. Lastly, an example of application of the database to European-scale flood modelling is provided.

1 Introduction

Coastal flood events generate every year critical damage and economic losses along European coastlines. Vousdoukas et al., 2020) estimates that coastal flooding produces losses of 1.4 billion euro and affects hundreds of thousands of people each year. The trend in economic losses due to natural hazards has been rising since the early 20th century (Svetlana et al., 2015), despite the growing cooperation between countries in managing flood risk (Hall et al., 2015), the existence of specific policies at European level (e.g., EU Floods Directive 2007/60/EC), and significant research efforts (Baldassarre et al., 2018). The extent of low-lying coastal areas subject to flood risk is expected to increase due to relative sea-level rise and the potential increase in storm frequency due to climate change (Vousdoukas et al., 2016b; Magnan et al., 2022; Le Gal et al., 2023). Additionally, the socio-economic pressure on coastal areas will intensify the exposure component of the risk (Van Dongeren et al., 2018). Therefore, the study, monitoring, and forecasting of coastal floods are crucial for risk managers to tackle current and future challenges for coastal communities.

Databases collecting qualitative and quantitative physical and socio-economic information related to storm impacts have become essential tools, providing coastal managers with access to up-to-date and accurate information. There are databases that collect events at the national level, such as, among others, the French Base des Donnèes Historiques sur les Inondations (Lang et al., 2016), the Italian Sistema Informativo sulle Catastrofi Idrogeologiche (Guzzetti and Tonelli, 2004), the Spanish Catálogo Nacional de Inundaciones Históricas (Pascual and Bustamante, 2014), the Swiss Flood and Landslide Damage Database (Hilker et al., 2009), and the Surge Watch database (https://www.surgewatch.org) of coastal flood events in the UK covering the period 1915-2016 (Haigh et al., 2017). However, due to language and cultural barriers, compiling reliable information becomes problematic when the scale of the analysis is supra-national. Additionally, the lack of a common methodological framework for structuring a database may lead to inconsistencies in terms of the "extent" and "completeness" of the datasets (Paprotny et al., 2018b).

There are also global databases that are widely used, such as the NatCatSERVICE[1] and the EM-DAT[2]. Such databases include information on different hazards and are mainly focused on collecting data on economic losses and disasters defined following specific criteria (Mazhin et al., 2021). The EM-DAT collects information on disasters derived from a wide range of hazards (earthquakes, drought, floods, storms, etc.), which are defined through specific criteria and does not consider less significant, although impacting, events, introducing a so-called threshold bias, as defined by Gall et al. (2009). It represents a global DB that contains valuable information, it is widely used, but it could be prone to missingness (Jones et al., 2022), and collects information at a large scale that cannot be exploited for local scales studies. Studies that need information at a more detailed scale should rely on databases at the national level (Mazhin et al., 2021).

Several efforts have been made to create databases that include a specific reference to coastal flood impact at the European level. The most relevant ones are the Resilience-Increasing Strategies for Coasts – toolKIT (RISC-KIT Database[3]) (Ciavola et al., 2018) and the Historical Analysis of Natural Hazards in Europe (HANZE Database) (Paprotny et al., 2018a, 2023).

During the EU Seventh Framework Program (FP7), the RISC-KIT EU FP7 project created a WEB-GIS storm impact repository (Ciavola et al., 2018). This database contains data related to 318 storm-generated impacts along the coasts of Europe including hydrodynamic and wind conditions registered during storm events (updated up to 2017). The RISC-KIT database includes the compilation of the information on online forms to avoid losing the information in case that a hyperlink or a resource is removed from the internet. However, the compilation, amendment/update of the information contained therein can only be done by an authorized operator. The data was freely available for consultation and download for the

[1] https://www.munichre.com/en/solutions/for-industry-clients/natcatservice.html
[2] https://www.emdat.be/
[3] http://risckit.cloudapp.net/risckit

duration of the project. However, it did not allow new entries nor changes to the existing ones without a previous request for registration. Furthermore, as the database was financed by specific project funds, public access to the database is no longer available. Also, the French Base des Données Historiques sur les Inondations is no longer accessible because it has been closed for security reasons.

The HANZE database was developed under the umbrella of the EU FP7 RAIN project (Risk Analysis of Infrastructure Networks in Response to Extreme Weather) and the EU Horizon 2020 Programme project BRIGAID (Bridging the Gap for Innovations in Disaster Resilience). Originally, the database was a collection of fluvial, coastal, and compound events that affected European coastlines between 1870 and 2016. The HANZE database has been recently updated to include new events up to 2020 and to update the previous version (Paprotny et al., 2023). Information regarding the duration of the events, affected locations, and losses and damages is provided, when available, for each entry. The database is open-access and can be downloaded from Zenodo[4]. The methods and criteria used to build the database are presented in Paprotny et al. (2023). The HANZE database is provided in several .csv files and georeferenced information. Sources are listed together with the hyperlinks. It includes different types of events (coastal, flash floods, river, river-coastal). For the present work, the information included in the original database was used.

Despite the great effort in creating different databases, for most of them the content has not been regularly updated and some of them have been disabled or are not open access. In addition, some of the existing databases report pre-elaborated information that might generate bias for the user in the absence of guidelines for data interpretation. The database presented here focuses on resources defined as a collection of different types of information that can be used to characterize the event (i.e., hydrodynamics and weather information) and its consequences (impacts, including beach erosion, flood extent, etc.). The only data actively handled by the operator ~~The only data manipulated~~ is the association of the storm to one site and the selection of the reference date. This choice was made to avoid data manipulation and possible misinterpretations of the authors of the database, giving the user the freedom to choose and analyse the resources and the collected information according to specific needs.

Users are allowed to use and edit the database for different purposes (e.g., flood model validation, shoreline displacement studies, storm impact assessment, etc.). ~~In the framework of this work, a “resource” is any digital or paper-based source of information that provides details, descriptions, images, or any material related to extreme coastal storms. The database benefits from the information included in the existing ones, providing all the available sources, categorised according to the type of resource (e.g. scientific reports, media) and topic (e.g. weather, hydrodynamics, impacts).~~

The database presented in this paper ~~has been~~was developed in the framework of the H2020 European project ECFAS (A proof-of-concept for the implementation of a European Copernicus Coastal Flood Awareness System, GA n° 101004211). The project aimed to implement a Proof-of-Concept that can contribute to the evolution of the Copernicus Emergency

[4] https://zenodo.org/records/11259233~~https://zenodo.org/records/8410025~~

Management System (CEMS) by building a European Coastal Flood Awareness System, also generating coastal products to be added to the CEMS Risk and Recovery products portfolio. The objectives and capabilities of the ECFAS Database are:

- To provide a list of resources specifically related to coastal storms.
- To provide an intuitive searchable tool where synoptic, meteorological, and hydrodynamic data of coastal storms, together with related coastal flood and impacts information, are organised as a collection of records that can be queried or retrieved based on users' needs and purposes.

This paper aims to present the ECFAS Database of resources (ECFAS DB) and its structure. Section 2 presents the database components and the information provided by each component. Section 3 presents the main statistics derived from the database contents. In Section 4, an example of the application of the database within the ECFAS project is given, and Section 5 includes a brief discussion and some conclusive remarks.

2 The ECFAS Database of resources

The ECFAS Database of resources collects information on coastal events affecting locations along European coasts from 2010-2020.

An event is defined as a (marine) storm that was able to cause considerable flooding and impacts along European coastal areas. Three inclusion criteria were defined to identify and select an event to be added in the DB, specifically:

1. if it is included in CEMS activations and/or
2. in relevant and already available databases;
3. it has to be reported in at least one official/reliable source of information (institutional websites, scientific articles, technical reports, etc.) and in other different types of resources.

The project's partners provided information on storms that generated floods and impacts in their countries. In some cases, the identified events were found to be part of a cluster of storms. In those cases, they were included as a single entry in the database, but a flag was added to take into account the nature of the storm. If necessary, any user can manually update the DB based on specific needs, following the standardised criteria described above, ensuring that the data is consistent and comparable. The final product ~~It~~ is structured around three components, the Guidelines, the Polygons, and the resources, each containing information and/or data (Figure 1). The guidelines were implemented to provide potential, even non-expert, users with clear information on key aspects of the database such as the rationale behind the product, the definitions of the different components and items (e.g., how a "storm" is defined as well as a "test case"), the sources of information and their characteristics, etc. This can support the proper and coherent use of the dataset. A future development could be the construction of a GUI to allow direct on-screen data addition through georeferencing and databasing online tools. Therefore, ~~The~~the Guidelines is a ~~PDF~~ document providing the content and structure of the organised collection of spreadsheets.

Besides, the Guidelines document includes instructions on how to query and retrieve the necessary information from the spreadsheets for the users’ purposes. The polygons and resources are described in the next paragraphs.

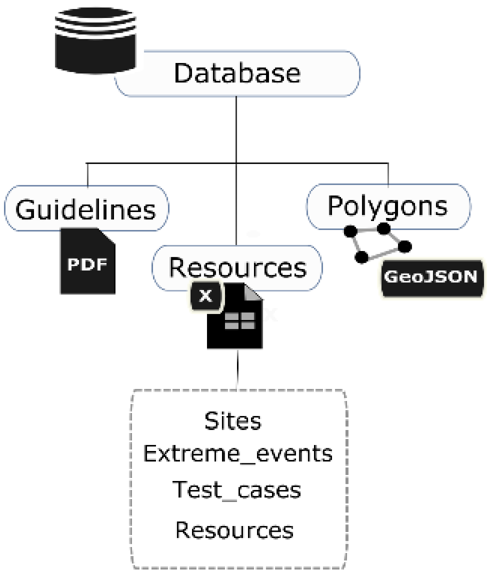

Figure 1: Structure of the ECFAS Database of Resources.

In the framework of this work, a “resource” is any digital or paper-based source of information that provides details, descriptions, images, or any material related to extreme coastal storms. The database benefits from the information included in the existing ones, providing all the available sources, categorised according to the type of resource (e.g. scientific reports, media) and topic (e.g. weather, hydrodynamics, impacts).

2.1 Polygons

The polygons, provided in GeoJSON format, define the Area of Interest (AoI) for each site (26 sites, Figure 2). The selection and definition of the sites are intended to represent as much as possible different coastal regions (Vousdoukas et al., 2016a; Fernández-Montblanc et al., 2019) and, thus, the heterogeneity of the European coastlines. Furthermore, the selection of the sites was carried out considering events that were able to generate considerable coastal floods and impacts.

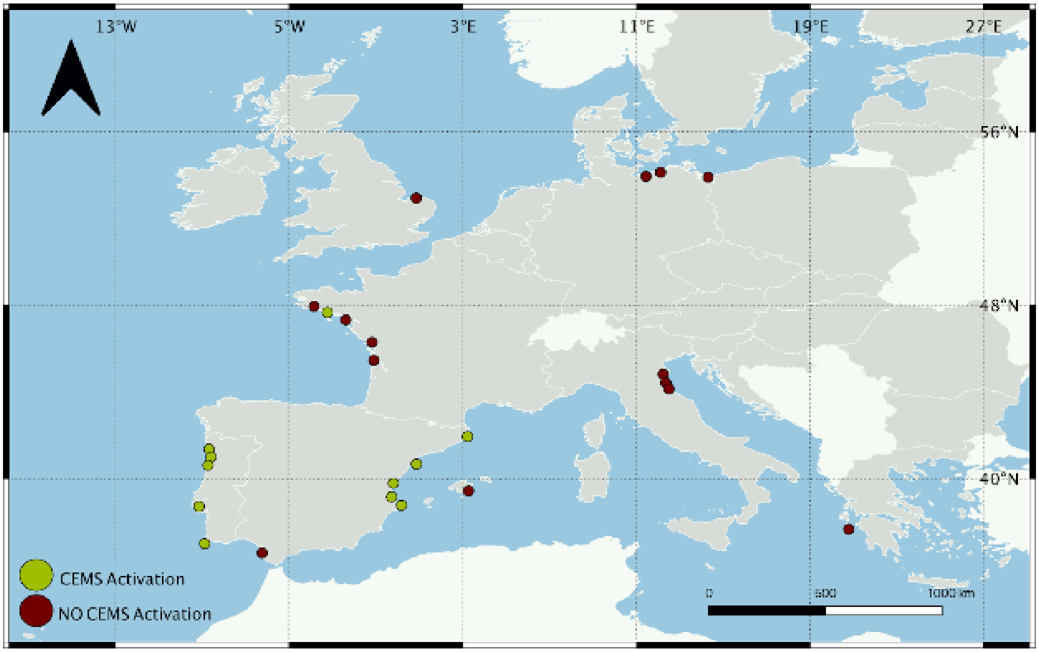

Figure 2: Distribution of the 26 sites included in the ECFAS Database of Resources. Different colours indicate the activation (green) or not (red) of CEMS in the site for the considered storms.

Entries were not pre-filtered based on a coastal flood extent threshold as done for other databases, nor on the basis of an impact threshold (economic losses, fatalities, etc.) (Paprotny et al., 2023). Some of these sites experienced flooding due to different storm events, and some storm events impacted more than one site across different countries. Therefore, a test case is defined as a site hit by an extreme meteo-marine event at a given moment. The DB contains 28 test cases. The polygons were defined based on the assessment of the areas affected by coastal flood events following the criteria below:

- If available, by considering the area of interest of the activation of the CEMS Rapid Mapping Service;
- In areas where there was no Rapid Mapping activation, the polygon extension was defined based on publicly available information related to the reported impacts and flood extent.

In both cases, if impacts were reported over a vast area, a sub-area was selected, corresponding to the portion of the territory with the ~~highest~~ larger number of reported impacts.

2.2 Resources

The resources component of the ECFAS Database contains information about sites, extreme meteo-marine events, test cases, and available resources for information retrieval (Figure 1). The spreadsheets link the “Fields” category to allow for cross-referencing, and for easy reading and possible compilation of new data. Furthermore, it guarantees that the database is a simple tool that could accommodate changes, making it a living tool. The "Sites" spreadsheet contains information indicating the country and the marine regional domain and a cross-reference to the corresponding polygon that defines each site. The

"Extreme Events" spreadsheet collects information regarding the characteristics of the coastal events, such as their official name (e.g. given by public meteo-services, and any specialised agency, or given by the press or by meteo websites), if it belongs or not to a cluster of storms (i.e., sequence of storm events occurring on successive days and affecting large portions of European coastlines), the maximum wave height (retrieved from the literature), and the total water level (i.e., considering the contribution from ocean circulation, steric sea level, tides, storm surges and waves (Irazoqui Apecechea et al., 2023)). For each extreme event, impacts are also registered following the categories defined by the nomenclature of the RISC-KIT database, such as impacts on population, environment, economy, buildings, and infrastructures (Ciavola et al., 2018). The "Resources" spreadsheet organises a collection of sources that are cross-linked to the corresponding storm event and sites. The types of resources considered to gather the information are presented in Table 1.

Table 1: Types of resources and their characteristics.

Resource	Description
News	Information published in newspapers
Scientific articles	Information derived from peer-reviewed articles
Institutional Websites	Information provided by recognised organisation
Videos	Visual information recorded by citizens or media
Technical reports	Technical documents containing quantitative analysis which are not peer-reviewed
Databases	Information is contained in both national (e.g., BDHI) and European databases (e.g., RISC-KIT)
Blog	Information gathered by people after the events (e.g., description, photos)
Others	Information from other types of resources that do not correspond with any of the above categories

Blogs and news have been included as a source of information as they have been proven effective in providing information to locate damages and consequences of coastal storms (Tschoegl et al., 2006; Santos et al., 2014). However, it is necessary to consider possible biases due to certain types of resources that could misrepresent specific impacts. For example, newspapers and media generally focus on urbanised coasts, emphasising the impacts on population and infrastructure assets (that represent accounting, threshold, and geography biases, Gall et al., (2009)), whereas impacts on natural beaches are generally overlooked (Sancho-García et al., 2021). Similar considerations can be applied to information retrieved from blogs and/or social media. However, there are several reasons why newspapers are considered a primary source of information. In fact, they cover local events and occurrences with specific and frequent information; the same event is usually reported in different newspapers, making it possible to have a variety of resources, thus allowing for comparison; newspapers archives are usually maintained through time and accessible; finally, newspaper information could be the only available source of information for historical events (La Red, 2013; Santos et al., 2014). Sancho-García et al. (2021) used news to assess extreme events damage at regional level in Spain and found that these resources, even if they could lead to some bias, offer a quick assessment of damage intensity and distribution, as well as provide essential information to identify the location of hotspots.

The polygons, provided in GeoJSON format, define the Area of Interest (AoI) for each site (26 sites, Figure 2). The information retrieved from the resources covers one or several topics such as weather, synoptic situation, hydrodynamics, etc., depending on the case. The topics were categorised following Table 2.

Table 2: Topics of the resources and their characteristics.

Topic	Description
Weather	Information about precipitation, wind and temperature
Synoptic situation	Information related to storm evolution in time and space using meteo charts
Hydrodynamics	Information regarding wave parameters and~~,~~ sea level ~~and flooding information~~
Flooding	Information regarding flood characteristics
Impacts	Information regarding the impacts and consequences in the aftermath of a storm
Management/Actions	Information about the interventions carried out in the aftermath of a storm

The resources were carefully quality (cross-)checked and the hydrodynamic information of each event were retrieved only by institutional and reliable resources such as (peer-reviewed) scientific articles and/or technical reports/institutional websites of responsible entities (e.g., national or local public institutions) and/or by reliable databases (e.g., RISC-KIT Database). ~~Therefore, t~~The resources collected in the spreadsheet can be filtered by event, site, type of resource, or topic. Resource retrieval by users is facilitated by the addition of hyperlinks and complete URLs.

3 Database statistics

Table 3 shows the statistics of the DB per country in terms of the number of sites, events, test cases, and resources. France and Spain represent the majority of resources (29 and 28, respectively) due to the higher number of attributed test cases (6 and 7, respectively). On the other hand, fewer resources are relative to the test cases in Germany and Poland (5 and 0, respectively), even though both areas were hit by the same extreme storm event. In this case, such a difference in the number of resources may be a consequence of the language used in each country to release information about the event (English vs. local language).

Table 3: Statistics on spatial and temporal coverage. The Table considers only the resources that are associated with one country, excluding those giving general information about the storm or referring to more than one country.

Country	Nr. of sites	Nr. of events	Nr. of test cases	Nr. of resources
France	6	3	6	29

Spain	7	2	7	28
Italy	3	3	5	14
UK	1	1	1	13
Portugal	5	1	5	7
Germany	2	1	2	5
Greece	1	1	1	3
Poland	1	1	1	0

Another aspect to be considered is possibly associated with the storm's name, which often changes according to the affected country. A single event impacting different areas can be named differently: for instance, storm Christina in France that was named Hercules in Portugal.

The number of collected observations (occurrences) substantially differs for each type of resource (Table 4). News is the resource accounting for more than one-third of all collected observations (relative frequency = 39.3%).

Table 4: Number of resources collected per type of resource and their relative frequency.

Types of resources	Nr. of resources	%
News	83	39.3
Scientific articles	39	18.5
Institutional Websites	32	15.2
Videos	21	10.0
Technical reports	17	8.1
Databases	11	5.2
Blog	5	2.4
Others	3	1.4

The distribution of types of resources per country (Figure 3) was analysed, considering resources referring solely to the affected country. The most common resources concerning the seven storm events registered in Southern European countries (Portugal, Spain, Italy, and Greece) are "News" and "Videos". Little information was found in "Technical reports", "Scientific articles", and "Institutional websites", even though the seven events included storms of a certain magnitude such as the storm Gloria in Spain in 2020 (Amores et al., 2020; Sanuy et al., 2021) and Vaia in Italy in 2018 (Cavaleri et al., 2019; Ferrarin et al., 2020; Morucci et al., 2020). Storm events that affected France and the UK had in general a more significant impact if compared to Southern Europe.

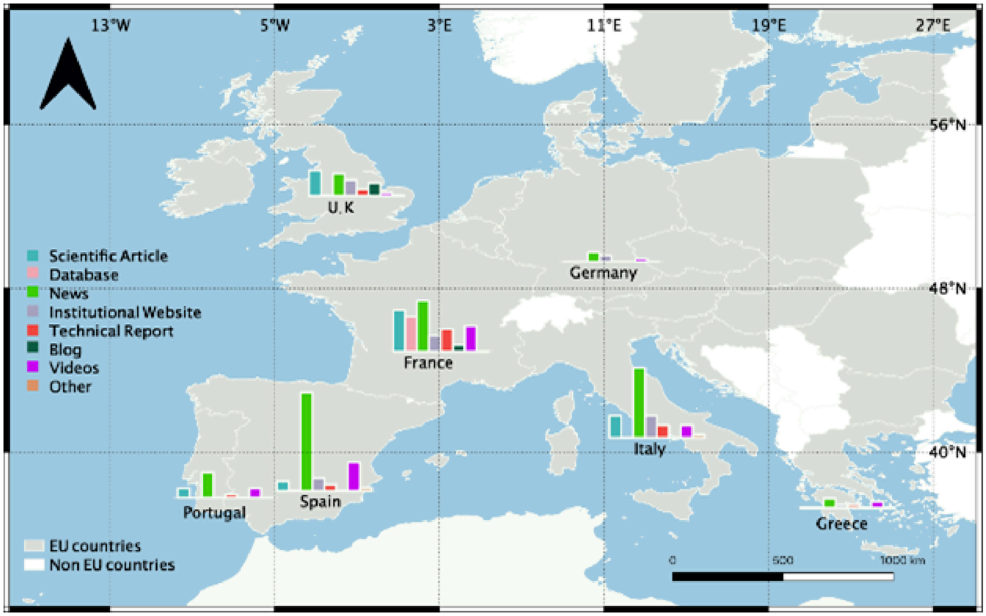

Figure 3: Distribution of the resource types per European country contained in the ECFAS Database of Resources. The histograms represent the frequencies in relation to the total number of resources. Poland was excluded because no resources were found for this country.

The number of observations (occurrences) of each topic and percentages of resources per topic are shown in Table 5. Note that each resource can refer to more than one topic. Due to the more significant presence of "News" as a resource type - responsible for 39.3% of the observations retrieved by all considered resources (Table 4) - the most covered topics are "Impacts" and "Flooding", while more technical topics, such as "Hydrodynamic", "Synoptic", and "Weather" are less frequent.

Table 5: Topics covered by the retrieved resources.

Topic	Nr. of resources	%
Impacts	161	76.3
Flooding	114	54.0
Hydrodynamic	56	26.5
Synoptic	37	17.5
Management/Actions	35	16.6
Weather	18	8.5

Resources information "Management/Actions" that refers to response actions taken after events are not quite frequent considering the number of events accounted for in the database (13), which may indicate little disclosure of information about costs and measures taken after the events. Moreover, the news tends to report the impacts during or in the immediate aftermath of the event because this strikes the most the listeners' interest. The recovery phase could be slow and take time, and it is therefore less interesting/catchy. This is one of the main reasons why the news does not always report on the precise quantification of the damages (direct and indirect) carried out after the occurrence of an impacting event and on recovery actions unless the event is of such a magnitude that it remains in the political and cultural "agenda" for a longer period.

3.1 The example of storm Christina: different countries on the path of one single event

Storm Christina affected several areas across Europe from 5 to 7 January 2014. The event is present in other databases (RISC- KIT, SurgeWatch, and Base des Donnèes Historiques sur les Inondations) due to the severe consequences recorded following the storm's passage. The extensive attention given to the storm in Portugal and France enabled to collect a significant number of resources into the DB. A total of 8 test cases were defined: 3 test cases in France and 5 in Portugal. The event was called differently in the two countries: Hercules in Portugal and Christina in France. The latter name was given by the University of Berlin, the institution that started to establish names for low- and high-pressure systems back in 1954 (Kotroni et al., 2021). On the other hand, Hercules was the name given by The Weather Channel, a North American private TV Channel (Santos et al., 2014). The information related to the storm Christina in France and Portugal is shown in Figure 4. According to the types of resources (Figure 4 (a)), neither "Blogs" nor "Others" are present in the database for this storm. Resources collected from the category "Database" and "Institutional websites" were related to the passage of Christina in France only. The type "Scientific article" was found for Portugal only. Furthermore, the percentage of "Technical reports" is higher in France (7.7%) than in Portugal (2.6%), possibly because in the former country there are institutional responsibilities that request report provision.

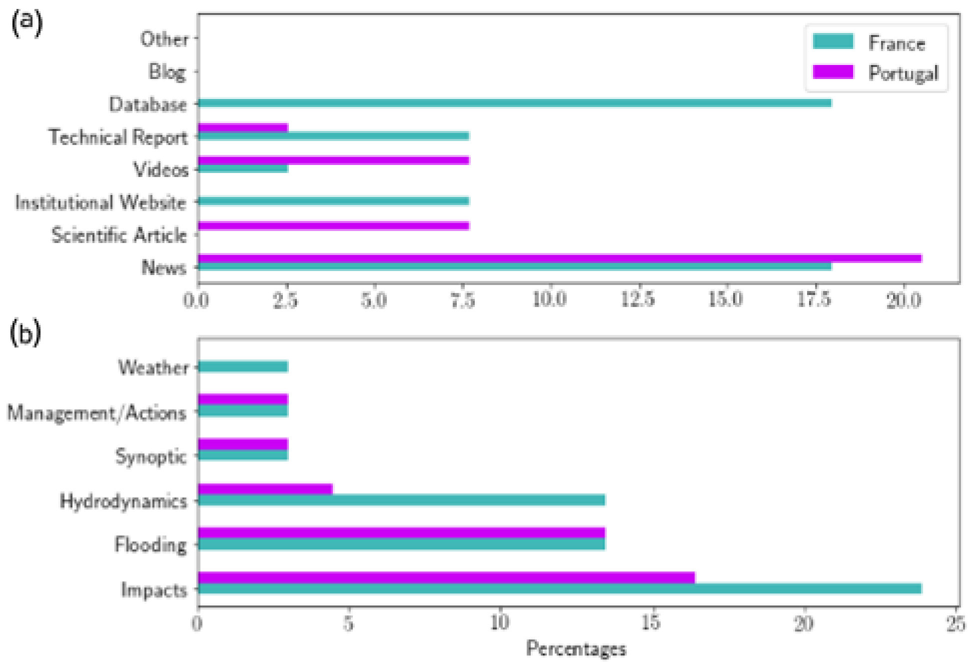

Figure 4. Percentage of occurrence for each type (a) and topic (b) of resources collected after the passage of storm Christina in France (green) and Portugal (magenta).

The differences detected in the types of resources publishing material about the same storm event, but in different countries, might be an indicator of the number and type of institutions covering this kind of information. In Portugal, the event information seems to be provided by academic institutions, while in France, it is provided by government institutions from different levels (e.g., regional, and national). The differences could be due to the amount of coastal assets that are exposed to storm events or to the presence of efficient coastal protections. In countries where the coastline is vulnerable and heavily occupied, storms can generate large impacts and economic damages that are then reported. In addition, there are countries where administrations perform a systematic collection of information on storm impacts for implementing effective coast risk management (e.g., for the Emilia-Romagna Region in Italy, see Armaroli et al. (2012)). The availability of scientific papers could be an indicator of the presence of specialized research teams in universities or research entities that perform a collection of information and the analysis of the effect of extreme events on coastal areas. Regarding the topics published by the resources (Figure 4 (b)), "Weather" is the only topic exclusively addressed in France. All other topics are similar ("Management/actions" and "Synoptic") or more frequently present in the French resources ("Hydrodynamics", "Flooding", and "Impacts").

4 The ECFAS Database of Resources in the framework of the ECFAS Project: an example of application

Impact databases can be used for several purposes, such as, e.g., building statistics, evaluating the level of risk of specific areas, implementing effective protection actions, or reconstructing past events that caused significant socioeconomic impacts (Paprotny et al., 2024). In the framework of the ECFAS project, the DB supported the calibration and validation of coastal flood extent and flood impact modelling at European scale. The in-depth analysis of the information retrieved from the resources (quantitative, qualitative, or visual data) supported the geolocation of flood and impact markers, hereafter called the Database of Markers (DBM hereafter), that were used to generate tailored coastal flood and impact catalogues, that represent (i) a series of flood maps covering most of European coasts and built considering different hazard scenarios; (ii) layers at pan-EU scale with information on the flood impact to population and other assets, such as buildings, roads, etc, produced using the flood maps of the flood catalogue~~.~~ (Duo et al., 2022a; Le Gal et al., 2022b; Montes et al., 2022; Le Gal et al., 2023). The retrieved information on flood markers was used to validate the flood simulations implemented with the LISFLOOD-FP model (Le Gal et al., 2022a; Le Gal et al., 2024) that was then used to build the flood catalogue. The economic losses-related information (i.e., damage to buildings and infrastructure repair costs) and affected people were qualitatively and, where possible, quantitatively compared with the impact estimated with an algorithm for impact assessment developed in the framework of the ECFAS project (Duo et al., 2022b) and that was used to build the impact catalogue (Duo et al., 2023). The DBM characteristics are briefly described hereafter to show how the information collected on flooding events and impacts could be analysed to build a reliable baseline for risk studies and to show the importance of implementing consistent, coherent, comprehensive, and hazard-specific databases (i.e., for coastal flooding).

4.1 From the database to impacts identification.

The methodology adopted to generate the DBM is illustrated in Figure ~~4.1~~5. The resources in the ECFAS DB spreadsheets were filtered by the test case and analysed, searching for all the information related to the floods and impacts caused by a specific storm at a specific site. Each resource was deeply analysed in terms of contents and quality of the information. Flooded areas and impacts are identified and geolocated when possible. If a specific location is not identified, a generic location in the area of interest is assigned. Each georeferenced flooded area and impact constitutes a marker. All the identified markers are stored in shapefiles, and the related information is stored in an Excel spreadsheet. In addition to the coordinates' position, some extra information to describe and characterise the markers is retrieved from the resources, incorporating it as attribute fields in the shapefiles. Each marker is classified by: (i) an impact category and subcategory following the ones adopted in the RISC-KIT project (Viavattene et al., 2015); (ii) quality indexes and additional information regarding (iii) flood presence and (iv) economic damages; (v) resource identifier from where the information was retrieved; and (vi) any other information which could be helpful to describe the marker.

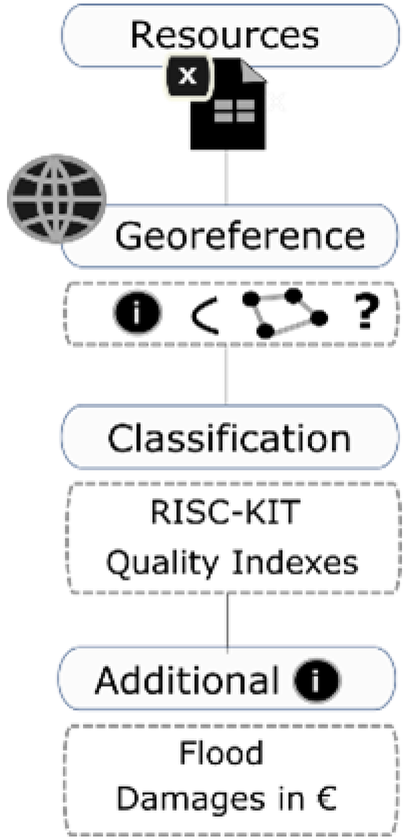

Figure 5. Methodology employed to generate the coastal DBM.

Quality indexes were adopted to control the temporal and spatial precision of each marker, as the information provided from different resources may not always be precise. The uncertainty affects the accuracy of the geolocation and the associated information's reliability. Each quality index follows a 3-score classification, 1 being the maximum quality and 3 the minimum. The criteria adopted to assign the categories are shown in Table 6. The overall reliability of the retrieved information was evaluated during the search and collection phase while building the database of resources.

Table 6: Description of the quality indexes.

Quality index	Values and description
Spatial quality index	1- High confidence. The marker position is clearly traceable from the videos/images/news resources. 2- Medium confidence. The marker position does not refer to a specific location but to an area, city, country etc. 3- Low confidence. The marker is storm-related, but it is not possible to obtain a specific position.
Temporal quality index	1- High confidence. The marker is attributable to the coastal storm analysed. 2- Medium confidence. The marker is related to a period or a cluster of storms.

3- Low confidence. The marker cannot be temporarily located.

In addition, in the attribute table, a field for economic damage is added, providing, when possible, the damage costs (in euros) caused by the event. Finally, when it was possible to assign specific information on the characteristics of the flood, fields were included providing: (i) a flag indicating the availability of specific flood-related information; (ii) the reported or assessed flood depth in metres; and (iii) the level of confidence on the evaluation of the flood depth (low, medium, or high). When not directly reported, the flood depth evaluation was conducted by analysing pictures, videos, or any material that could support the analysis. A few examples are shown in Figure 6. Next, the confidence level of the evaluation was applied depending on the presence of a reference scale (e.g., a person standing in the picture). Finally, the data description information was associated ~~to~~ with the DBM to indicate additional information that could not be described in the other fields.

Figure 6. Examples of the level of confidence associated with the flood depth: (a) and (b) high level of confidence (clear spatial references in the pictures), (c) medium level of confidence (some reference in the picture) and (d) low level of confidence (no clear reference in the picture).

4.2 Flood and impact markers at the ECFAS case studies

A total of 213 markers were retrieved for 28 test cases using the currently available 211 resources. The number of markers recovered from each type of resource is shown in Table 7.

Table 7. Marker occurrences per type of resource.

Types of resources	Nr. of markers
News	70
Scientific articles	34

Institutional Websites	17
Videos	45
Technical reports	32
Databases	0
Blog	15
Others	0

The type of resource which proportionally resulted in more marker occurrences is “Blog” (from 5 “Blogs” reported in Table 4, 15 markers were obtained), followed by “Technical reports” (32 markers were established from the 17 “Technical reports” reported in Table 4) and “Videos” (45 markers were established from the 21 “Videos” reported in Table 4). Neither “Database” nor “Other” types of resources generated markers. The analysis of markers’ spatial and temporal quality indexes is presented in Figure 7 (a) and (b). The resources mainly produced georeferenced points with high spatial and temporal confidence; the points with low confidence are less frequent.

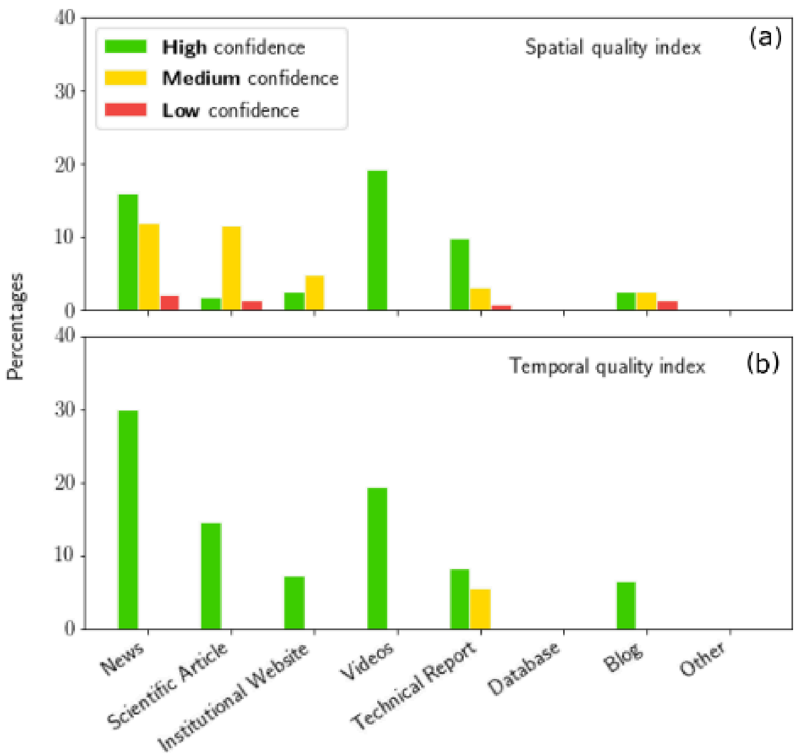

Figure 7. Percentage of occurrence of the high (green), medium (yellow), and low (red) confidence values for the Spatial quality index (a) and the Temporal quality index (b) per type of resource.

The markers retrieved from "Scientific article" mostly show medium spatial confidence (Figure 7 (a)). Scientific articles about coastal storm events usually study the generation of the event and the associated hydrodynamics, which infrequently produces georeferenced information (e.g., wave height/wind velocity from a given buoy/station). In the case of articles publishing information about coastal storm impacts and/or storm damage assessment, the images and information provided focus on the processes rather than on their precise location. The "Technical report" type of resource shows that the geolocations are relatively less defined in time than the other types of resources. Private companies usually produce technical reports by request of regional or national authorities following one or several damaging events. However, such consultancies imply costs, and the damages are assessed after a (long) period of bad weather. Therefore, the markers retrieved from the technical reports are precisely localised in space but less in time. The most reliable resource type is "Video", which shows high confidence in spatial and temporal quality indexes. The markers retrieved from "Blog" and "Institutional website" are of high, medium, and low spatial confidence (Figure 7 (a) and (b)), which may be due to the use of common local names to identify the position of the damages and flood extent, and therefore it is difficult to interpret for a user not familiar with the area.

Le Gal et al. (2023) implemented a pan European catalogue of flood maps (water depth and velocities) in the framework of the ECFAS project, considering different storm scenarios. To build the catalogue, the flood model, and the simulated floods obtained using the LISFLOOD-FP model (Bates and De Roo, 2000; Bates et al., 2010) forced with hindcasts of Total Water Levels (Melet et al., 2021), was validated using the information included in the ECFAS database, considering 12 test cases for which observations of the actual extent of storms impact was available, i.e., satellite-derived flood maps and in situ flood markers from the DBM (refer to Figure 1 and Table 1 of Le Gal et al., 2023). Depending on the availability of satellite imagery, satellite-based mapping in CEMS is carried out some times after the peak of the event and therefore it is not always able to capture the maximum extension of the flood. This limitation may produce a bias in the estimation of the accuracy of the model. However, a satisfactory agreement was found between the model results and the observed flooded areas and markers, showing the value of measured/observed flood information for model validation. For validation purposes, Le Gal et al. (2023) defined a “hit” when the model was able to flood the grid cell(s) enclosing the identified marker(s). The hit ratio was defined as “the number of markers that were hit compared to the total number of markers available for the test case”. Among the analyzed test cases, five have a marker hit ratio of 100%. For the other test cases, one has a hit ratio of 94.11% and the remaining show values of 50%, 25% and 0%. For only two test cases no flood markers could be obtained from the resources of the DB to perform the validation.

The DBM was also exploited to validate the impact assessment implemented in the ECFAS project on the basis of the flood catalogue by Le Gal et al. (2023). The impact assessment methodology combines object-based and probabilistic evaluations to give uncertainty estimates for damage assessment (Duo et al., 2023). The approach was applied to 16 test cases of the ECFAS DB representing 10 extreme events able to considerably affect 15 European coastal sites (refer to Table 1 and Figure 1 of Duo et al., 2023). Three reference cases were then selected for validation purposes, i.e., to compare the modelled impacts with reported damages (Xynthia in France, 2010; Xaver in UK, 2013, Emma in Spain, 2018). The findings demonstrate that the ECFAS DB provides valuable information to retrieve flood and impact markers for model's validation. Specifically, the information retrieved from the DB was georeferenced and characterized by analyzing the different sources of each event and categorized according to several impact categories. The information contained in the DB also made it possible to assign quality indexes in relation to the type of resource. The type of information retrieved was flood and impact markers, local damage in euros and other additional information that could be significant for the validation of the models (Le Gal et al., 2023; Duo et al., 2023). These data supported the findings that the impact model from Duo et al. (2023) is more accurate compared to traditional grid-based approaches.

5 Discussion and conclusive remarks

A properly designed database provides access to up-to-date and accurate information that the users should be able to easily consult. An appropriate database design is, therefore, essential to achieve the objectives. Users are more likely to use a database that meets their needs and can quickly adapt to changes. A database of resources such as the one presented in the paper is coastal-specific, follows defined rules and definitions, and can be easily improved and/or updated by adding new information. Furthermore, the resources are provided without data manipulation, so the user can apply different methodologies and criteria to extract and use the data. Ideally, a database for the assessment of the impact of extreme events should include all the information associated ~~to~~ with risk definition, from the hazard characteristics to exposure and vulnerability/coping capacity/resilience of the affected area, and the information on impacts and recovery actions. ~~It is very difficult to collect, catalogue and keep updated~~ The implementation of a comprehensive database could be challenging, ~~also~~ because it should include a large amount of information and ~~can~~ be designed according to different purposes (e.g., insurance, risk assessment, emergency management, etc.) ~~objectives and users' needs~~. Furthermore, a standardization for data definition and collection, and a common classification scheme and terminology, might not be available or applied (Koç and Thieken, 2018). The ECFAS awareness system for coastal floods at pan-EU scale was designed through a bottom-up approach, and a large consultation of users was carried out to design the system. The ECFAS DB has a temporal and hazard type bias (Gall et al., 2009) due to its characteristics, but it was not built filtering the information according to pecuniary losses (accounting bias) or to the severity of the event (threshold bias). However, given that it is defined as a DB that collects information only if there is a coastal flood, it could over-represent densely populated, built-up and easily accessible areas (geography bias) (Gall et al., 2009).

The ECFAS Database is a collection of resources. Currently the most similar database is the French Base de Données Historique sur les Inondations (BDHI). The BDHI lists and describes flood events from different sources (river, coastal, etc.), which have occurred on the French territory over the past centuries and up to the present day. The archived documents can be in the form of a press article, hydrological report, meteorological report, historical study, etc. However, the BDHI is a national tool and can only be accessed by authorized users. The ECFAS DB covers instead different European countries and is an open-access tool that can be exploited as it is by any user, updated or complemented with new events according to the interest of different users' communities and purposes (e.g., coastal flood risk management, EWS and emergency, model validation, etc.). Through labelling with unique identifiers, the ECFAS DB allows for a quick and consistent retrieval of all the resources associated with an event and with the test cases. Another relevant characteristic is that the ECFAS DB groups the resources per storm event, so that it is possible to immediately know if the same storm affected more than one country/location. This characteristic of the ECFAS DB is especially important if supranational/trans boundaries studies (e.g., at pan-EU level) have to be carried out.

The ECFAS DB has been built to minimize the biases that could affect databases (Gall et al., 2009). Although intrinsic biases may be present in the sources, these are not amplified or newly introduced in the DB considering the method used for its implementation and the inclusion criteria. Therefore, given the very limited data interpretation, it can be easily scaled and updated using information from different countries (European and beyond) and storms with different extents. The process requires a certain amount of time because the resources have to be retrieved, and quality checked. Additionally, the guidelines will support the future update and use of the DB.

The countries with the lowest number of retrieved resources are Greece, Germany, and Poland and this could be due to . This finding might be a language-related issue or could be due to the different names given to the same storm events. This might introduce biases, affecting the geographical coverage and completeness of the DB. Language barriers can be addressed through, e.g., collaboration with translation services or local institutions/research centers/universities working on coastal flood risk and that could support the identification and consequent translation of local information.

The distribution of the types of resources per country seems to indicate that in France and the UK more resource types were observed with a higher presence of "Technical reports", "Scientific articles", and "Institutional websites". The differences between the types of resources can also be observed by comparing the ones provided for storm Christina, which affected Portugal and France. Therefore, the higher presence of these resource types could be related to a broad awareness on of coastal flooding events or to the significance of their impacts at a national level. For example, it is worth noting that in February 2010, France experienced one the most critical coastal flood events in Europe of recent years (Kolen et al., 2013), in terms of damages and casualties, certainly raising people's consciousness, and the UK is significantly and frequently exposed to such events (Haigh et al., 2016) which supports investment on national and regional initiatives. The ECFAS DB could allow performing other evaluations such as, e.g., to investigate if an "awareness pattern" exists across different countries in relation to national and European policies. The advantages and applications of the database were assessed during the ECFAS project. Georeferenced points (markers) for each test case were retrieved from its correspondent resources, following a specific and replicable methodology to use the information to validate the results obtained from impacts and flood models. The same dataset and its application to identify flood markers could be useful to improve the available flood damage curves at the pan-EU scale (Jongman et al., 2012, among others) or build new ones for specific cases/countries. However, the identification of georeferenced markers from the database is not always possible due to the description of the impacts provided in the resources that can be too generic and without clear pictures or the use of jargon names of the localities/assets affected.

Data availability. The ECFAS Database, including the Guidelines and the GeoJSON files, are available for download in Zenodo at the following link https://zenodo.org/records/7488643 (Souto-Ceccon et al., 2021).

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References

Amores, A., Marcos, M., Carrió, D. S., and Gómez-Pujol, L.: Coastal impacts of Storm Gloria (January 2020) over the north-western Mediterranean, Natural Hazards and Earth System Sciences, 20, 1955–1968, 2020.

Armaroli, C., Ciavola, P., Perini, L., Calabrese, L., Lorito, S., Valentini, A., and Masina, M.: Critical storm thresholds for significant morphological changes and damage along the Emilia-Romagna coastline, Italy, Geomorphology, 143, 34–51, 2012.

Bates, P. and De Roo, A.: A Simple Raster-Based Model for Flood Inundation Simulation, J. Hydrol., 236, 54–77, https://doi.org/10.1016/S0022-1694(00)00278-X, 2000.

Bates, P. D., Horritt, M. S., and Fewtrell, T. J.: A Simple Inertial Formulation of the Shallow Water Equations for Efficient Two-Dimensional Flood Inundation Modelling, J. Hydrol., 387, 33–45, https://doi.org/10.1016/j.jhydrol.2010.03.027, 2010.

Cavaleri, L., Bajo, M., Barbariol, F., Bastianini, M., Benetazzo, A., Bertotti, L., Chiggiato, J., Davolio, S., Ferrarin, C., Magnusson, L., et al.: The October 29, 2018 storm in Northern Italy–an exceptional event and its modeling, Progress in oceanography, 178, 102 178, 2019.

Ciavola, P., Harley, M. D., and Den Heijer, C.: The RISC-KIT storm impact database: A new tool in support of DRR, Coastal Engineering, 134, 24–32, 2018.

Di Baldassarre, G., Nohrstedt, D., Mård, J., Burchardt, S., Albin, C., Bondesson, S., Breinl, K., Deegan, F. M., Fuentes, D., Lopez, M. G., et al.: An integrative research framework to unravel the interplay of natural hazards and vulnerabilities, Earth's Future, 6, 305–310, 2018.

Duo, E., Montes Pérez, J., Le Gal, M., Souto Ceccon, P. E., Cabrita, P., Fernández Montblanc, T., and Ciavola, P.: ECFAS Pan-EU Impact Catalogue, D5.4 – Pan-EU flood maps catalogue - ECFAS project (GA 101004211), www.ecfas.eu (1.2), https://doi.org/10.5281/zenodo.6951527, 2022a.

Duo, E., Montes-Pérez, J., and Souto-Ceccon, P. E.: ECFAS Impact Tool, D5.3 – Algorithms for impact assessment - ECFAS project (GA 101004211). Zenodo, https://doi.org/10.5281/zenodo.7489035, 2022b.

Duo, E., Montes, J., Le Gal, M., Fernández-Montblanc, T., Ciavola, P., and Armaroli, C.: Validated probabilistic approach to estimate flood direct impacts on the population and assets on European coastlines, Nat. Hazards Earth Syst. Sci. Discuss. [preprint], https://doi.org/10.5194/nhess-2023-197, in review, 2023.

Fernández-Montblanc, T., Vousdoukas, M., Ciavola, P., Voukouvalas, E., Mentaschi, L., Breyiannis, G., Feyen, L., and Salamon, P.: Towards robust pan-European storm surge forecasting, Ocean Modelling, 133, 129–144, 2019.

Ferrarin, C., Valentini, A., Vodopivec, M., Klaric, D., Massaro, G., Bajo, M., De Pascalis, F., Fadini, A., Ghezzo, M., Menegon, S., et al.: Integrated sea storm management strategy: the 29 October 2018 event in the Adriatic Sea, Natural Hazards and Earth System Sciences, 20, 73–93, 2020.

Gall, M., Borden, K. A., and Cutter, S. L.: When do losses count? Six fallacies of natural hazards loss data, Bulletin of the American Meteorological Society, 90, 799–810, 2009.

Guzzetti, F. and Tonelli, G.: Information system on hydrological and geomorphological catastrophes in Italy (SICI): a tool for managing landslide and flood hazards, Natural Hazards and Earth System Sciences, 4, 213–232, 2004.

Haigh, I. D., Wadey, M. P., Wahl, T., Ozsoy, O., Nicholls, R. J., Brown, J. M., Horsburgh, K., and Gouldby, B.: Spatial and temporal analysis of extreme sea level and storm surge events around the coastline of the UK, Scientific Data, 3, 1–14, 2016.

Haigh, I. D., Ozsoy, O., Wadey, M. P., Nicholls, R. J., Gallop, S. L., Wahl, T., and Brown, J. M.: An improved database of coastal flooding in the United Kingdom from 1915 to 2016, Scientific Data, 4, 1–10, 2017.

Hall, J., Arheimer, B., Aronica, G. T., Bilibashi, A., Boháˇc, M., Bonacci, O., Borga, M., Burlando, P., Castellarin, A., Chirico, G. B., Claps, P., Fiala, K., Gaál, L., Gorbachova, L., Gül, A., Hannaford, J., Kiss, A., Kjeldsen, T., Kohnová, S., Koskela, J. J., Macdonald, N., Mavrova Guirguinova, M., Ledvinka, O., Mediero, L., Merz, B., Merz, R., Molnar, P., Montanari, A., Osuch, M., Parajka, J., Perdigão, R. A. P., Radevski, I., Renard, B., Rogger, M., Salinas, J. L., Sauquet, E., Šraj, M., Szolgay, J., Viglione, A., Volpi, E., Wilson, D., Zaimi, K., and Blöschl, G.: A European Flood Database: facilitating comprehensive flood research beyond administrative boundaries, Proceedings of the International Association of Hydrological Sciences, 370, 89–95, 2015.

Hilker, N., Badoux, A., and Hegg, C.: The Swiss flood and landslide damage database 1972–2007, Natural Hazards and Earth System Sciences, 9, 913–925, 2009.

Irazoqui Apecechea, M., Melet, A., and Armaroli, C.: Towards a pan-European coastal flood awareness system: Skill of extreme sea-level forecasts from the Copernicus Marine Service, Frontiers in Marine Science, 9, 1091 844, 2023.

Jones, R. L., Guha-Sapir, D., and Tubeuf, S.: Human and economic impacts of natural disasters: can we trust the global data?, Scientific Data, 9, 1–7, 2022.

Jongman, B., Kreibich, H., Apel, H., Barredo, J., Bates, P. D., Feyen, L., Gericke, A., Neal, J., Aerts, J. C., and Ward, P. J.: Comparative flood damage model assessment: towards a European approach, Natural Hazards and Earth System Sciences, 12, 3733–3752, 2012.

Koç, G. and Thieken, A. H.: The relevance of flood hazards and impacts in Turkey: What can be learned from different disaster loss databases?, Natural Hazards, 91, 375–408, 2018.

Kolen, B., Slomp, R., and Jonkman, S.: The impacts of storm Xynthia February 27–28, 2010 in France: lessons for flood risk management, Journal of Flood Risk Management, 6, 261–278, 2013.

Kotroni, V., Lagouvardos, K., Bezes, A., Dafis, S., Galanaki, E., Giannaros, C., Giannaros, T., Karagiannidis, A., Koletsis, I., Kopania, T., et al.: Storm naming in the eastern mediterranean: Procedures, events review and impact on the citizens risk perception and readiness, Atmosphere, 12, 1537, 2021.

La Red: The challenge of information sources. Project DesInventar, http://www.desinventar.net/data_sources.html, 2013.

Lang, M., Coeur, D., Audouard, A., Oliver, M. V., and Pène, J.-P.: BDHI: a French national database on historical floods, in: 3rd European conference on flood risk management (FLOODrisk 2016), vol. 7, p. 04010, 2016.

Le Gal, M., Ciavola, P., Gastal, V., Fernandez-Montblanc, T., and Delbour, S.: Validated LISFLOOD-FP model for coastal areas, Deliverable 5.2 – ECFAS Project (GA 101004211). Zenodo, https://doi.org/10.5281/zenodo.5809290, 2022a.

Le Gal, M., Fernández Montblanc, T., Montes Pérez, J., Duo, E., Souto Ceccon, P. E., Cabrita, P., and Ciavola, P.: ECFAS Pan-EU Flood Catalogue, D5.4 – Pan-EU flood maps catalogue - ECFAS project (GA 101004211). Zenodo, https://doi.org/10.5281/zenodo.6778807, 2022b.

Le Gal, M., Fernández-Montblanc, T., Duo, E., Montes Perez, J., Cabrita, P., Souto Ceccon, P., Gastal, V., Ciavola, P., and Armaroli, C.: A new European coastal flood database for low–medium intensity events, Natural Hazards and Earth System Sciences, 23, 3585–3602, 2023.

Le Gal, M., Fernández-Montblanc, T., Montes Perez, J., Duo, E., Souto Ceccon, P., Ciavola, P., and Armaroli, C.: Influence of model configuration for coastal flooding across Europe, Coastal Engineering, 192, 104541, 1-17, https://doi.org/10.1016/j.coastaleng.2024.104541, 2024.

Magnan, A. K., Oppenheimer, M., Garschagen, M., Buchanan, M. K., Duvat, V. K., Forbes, D. L., Ford, J. D., Lambert, E., Petzold, J., Renaud, F. G., et al.: Sea level rise risks and societal adaptation benefits in low-lying coastal areas, Scientific Reports, 12, 10 677, 2022.

Mazhin, S. A., Farrokhi, M., Noroozi, M., Roudini, J., Hosseini, S. A., Motlagh, M. E., Kolivand, P., and Khankeh, H.: Worldwide disaster loss and damage databases: A systematic review, Journal of Education and Health Promotion, 10, 2021.

Melet, A., Irazoqui Apecechea, M., Fernández-Montblanc, T., and Ciavola, P.: Report on the Calibration and Validation of Hindcasts and Forecasts of Total Water Level along European Coasts, Deliverable 4.1 – ECFAS project (GA 101004211), Zenodo, https://doi.org/10.5281/ZENODO.7488687, 2021.

Montes, J., Duo, E., Souto, P., Gastal, V., Grigoriadis, D., Le Gal, M., Fernández-Montblanc, T., Delbour, S., Ieronymidi, E., Armaroli, C., and Ciavola, P.: Evaluating coastal flood impacts at the EU-scale: the ECFAS approach, in: EGU General Assembly Conference Abstracts, pp. EGU22–11 295, 2022.

Morucci, S., Coraci, E., Crosato, F., and Ferla, M.: Extreme events in Venice and in the North Adriatic Sea: 28–29 October 2018, Rendiconti Lincei. Scienze Fisiche e Naturali, 31, 113–122, 2020.

Paprotny, D., Morales-Nápoles, O., and Jonkman, S. N.: HANZE: a pan-European database of exposure to natural hazards and damaging historical floods since 1870, Earth System Science Data, 10, 565–581, 2018a.

Paprotny, D., Sebastian, A., Morales-Nápoles, O., and Jonkman, S. N.: Trends in flood losses in Europe over the past 150 years, Nature Communications, 9, 1–12, 2018b.

Paprotny, D., Terefenko, P., and Sledziowski, J.: An improved database of flood impacts in Europe, 1870–2020: HANZE v2. 1, Earth System Science Data Discussions, 2023, 1–37, 2023.

Paprotny, D., Rhein, B., Vousdoukas, M. I., Terefenko, P., Dottori, F., Treu, S., ´Sledziowski, J., Feyen, L., and Kreibich, H.: Merging modelled and reported flood impacts in Europe in a combined flood event catalogue, 1950–2020, EGUsphere, 2024, 1–47, 2024.

Pascual, G. and Bustamante, A.: Catálogo Nacional de Inundaciones Históricas, Dirección General de Protección Civil y Emergencias. Ministerio del Interior español, 2014.

Sancho-García, A., Guillén, J., Gracia, V., Rodríguez-Gómez, A. C., and Rubio-Nicolás, B.: The use of news information published in newspapers to estimate the impact of coastal storms at a regional scale, Journal of Marine Science and Engineering, 9, 497, 2021.

Santos, Â., Mendes, S., and Corte-Real, J.: Impacts of the storm Hercules in Portugal, Finisterra, 49, 2014.

Sanuy, M., Rigo, T., Jiménez, J. A., and Llasat, M. C.: Classifying compound coastal storm and heavy rainfall events in the north-western Spanish Mediterranean, Hydrology and Earth System Sciences, 25, 3759–3781, 2021.

Souto-Ceccon, P. E., Duo, E., Ciavola, P., Fernandez-Montblanc, T., and Armaroli, C.: Database of extreme events, test cases selection and available data, Deliverable 5.1 – ECFAS Project (GA 101004211). Zenodo, https://doi.org/10.5281/zenodo.7488643, 2021.

Svetlana, D., Radovan, D., and Ján, D.: The economic impact of floods and their importance in different regions of the world with emphasis on Europe, Procedia Economics and Finance, 34, 649–655, 2015.

Tschoegl, L., Below, R., and Guha-Sapir, D.: An analytical review of selected data sets on natural disasters and impacts, Centre for Research on the Epidemiology of Disasters Louvain, 2006.

Van Dongeren, A., Ciavola, P., Martinez, G., Viavattene, C., Bogaard, T., Ferreira, O., Higgins, R., and McCall, R.: Introduction to RISC-KIT: Resilience-increasing strategies for coasts, Coastal Engineering, 134, 2–9, 2018.

Viavattene, C., Jimenez, J., Owen, D., Priest, S. J., Parker, D. J., Micou, P., and Ly, S.: Coastal risk assessment framework guidance document, Tech. rep., Middlesex University, 2015.

Vousdoukas, M. I., Voukouvalas, E., Annunziato, A., Giardino, A., and Feyen, L.: Projections of extreme storm surge levels along Europe,Climate Dynamics, 47, 3171–3190, 2016a.

Vousdoukas, M. I., Voukouvalas, E., Mentaschi, L., Dottori, F., Giardino, A., Bouziotas, D., Bianchi, A., Salamon, P., and Feyen, L.: Developments in Large-Scale Coastal Flood Hazard Mapping, Natural Hazards and Earth System Sciences, 16, 1841–1853, https://doi.org/10.5194/nhess-16-1841-2016, 2016b.

Vousdoukas, M. I., Mentaschi, L., Hinkel, J., Ward, P. J., Mongelli, I., Ciscar, J.-C., and Feyen, L.: Economic motivation for raising coastal flood defenses in Europe, Nature Communications, 11, 1–11, 2020.