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Storm impacts along European coastlines. Part 1: The joint effort of the MICORE and ConHaz Projects

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ABSTRACT

The current paper discusses the topic of marine storm impact along European coastlines, presenting results from two FP7 Projects currently focusing on this topic, one working on the physical aspects of the problem (MICORE) and the other one on the socio-economic implications (ConHaz).

The MICORE Project aims to provide on-line predictions of storm-related physical hazards (hydrodynamic as well as morphodynamic). The ConHaz Project addresses the socio-economic implications should these (or other) hazards actually materialize. Together these projects aim to deliver crucial information for emergency response efforts, while realizing the practical limitations for information processing and dissemination during crisis situations.

The MICORE Project has developed and demonstrated on-line tools for reliable predictions of the morphological impact of marine storm events in support of civil protection mitigation strategies. The project specifically targeted the development of early warning and information systems to support short term emergency response in case of an extreme storm event. The current paper discusses in detail the outcome of an activity of databasing historical storm data. No clear changes in storminess were observed, except for some storm proxies (e.g. surges) and only at some locations (e.g. northern Adriatic, southern Baltic, etc.).

The ConHaz Project undertook a desktop study of the methods normally used for evaluating the impact of marine storms and the associated coastal hazards considering direct costs, costs due to disruption of production processes, indirect costs, intangible costs, and costs of adaptation and mitigation measures. Several methods for cost estimation were reviewed. From the review it emerged that normally end-users only evaluate direct costs after the storms, while the cost of adaptation and mitigation measures is only done strategically in the context of Integrated Coastal Zone Management plans. As there is no standardized method for cost evaluations in this field, it is suggested that clear guidelines should be produced on the basis of simplicity for use by end-users. The integration between historical databases of the physical parameters of storms and detailed cost evaluation information would support the development of a knowledge background in end-users and justify the development of adaptation strategies.

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1. Introduction

Exceptional coastal storm impacts generated by tropical and extra-tropical weather systems cause societal, agricultural and industrial losses and affect at the same time developed and developing nations. For developing nations there is also a potential increase in risk due to the fact that large part of the populations are moving into coastal zones and that new industrial settlements are often located in areas prone to flooding or coastal erosion. For this reason, organizations such as the Intergovernmental Oceanographic Commission have recently delivered guidelines in support of hazard awareness and mitigation (IOC, 2009).

The last ten years were characterised by a large number of coastal disasters around the world (e.g. 2004 – Sumatra tsunami, 2005 – Hurricane Katrina in the US, 2010 – Xynthia storm in France and more recently the 2011 – tsunami in Japan and Typhoon Yasin – Australia). With these contemporary examples it is clear that a thorough preparation is crucial to maximise the potential for an effective emergency response, minimise the impacts under design conditions and promote post event recovery.

At the end of February 2010 a powerful Atlantic storm, named Xynthia, battered Western Europe with hurricane force, causing high waves and exceptional tide levels due to storm surges resulting in flooding. The results were widespread property damage, severe disruption to transport networks and infrastructure. The work by Mercier and Acerra (2011) reviews in a succinct view the event while Garnier and Surville (2010) provide a perspective in the context of the history on flood disasters in France from the Middle Ages to the current days. A recent study (Kolen et al., 2010) concluded that the most important part of the disaster management protocol failed, as the storm surge warning was not understood by the disaster management authorities and the public. As the population prepared for high winds and not for flooding, this was fatal for some of them. The conclusions of the study cited above clearly show the need for an appropriate flood warning system. It is also advisable to point out that the implementation of such a flood warning system is fully efficient on condition that (1) the warning system considers how local communities actually perceive the risk of storm, erosion and submersion; and that (2) the warning system takes into account the public awareness of how to react before the intervention of any emergency service (such as the Civil Protection).

The Xynthia example illustrates the need for new coastal information and warning systems in providing on-line predictions of storm impacts for both frequent and more extreme events. Events like Xynthia also point out the need to have access to standardized methods for post-event appraisal to damage quantification. Often end-users in charge of this activity do not undertake post-event evaluations either because they are not given the statutory responsibility for that or because they are not aware of the existence of standardized socio-economic methods.

The above examples illustrate that at least at European level there is an urgent need to reinforce the knowledge, effectiveness and management of damage control, prevention and response to natural hazards. The efforts made by both the MICORE and the ConHaz Project are resulting in added value to update methodologies, civil protection schemes and even in a prototype tool to predict impact of coastal storms in the future. The results of both projects will allow local governments, decision makers and stakeholders to increase the effectiveness of hazard response and management and climate change adaptation planning.

2. The MICORE Project

2.1. *Goals and objectives of MICORE*

The project involves 16 partners from 9 European countries (for details see www.micore.eu) and its primary goal is to develop and demonstrate on-line tools for reliable prediction of the morphological impact of storm events. The project aims to analyse and map storm related risks in sensitive European regions taking into account intensity, spatial extent, duration and hazard interaction effects. The project started in June 2008 and has duration of 40 months.

The specific scientific objectives of the MICORE Project are:

1. To undertake a review of historical marine storms that had a significant impact on a representative number of sensitive European regional coastlines. A range of coastal regions of the European Union was selected according to wave exposure, tidal regime and socio-economic pressures.
2. To collate data related to occurrence of significant extreme events and socio-economic impacts in a database. Parameters include the characteristics of the storms, the morphological impacts, the socio-economic impacts, an assessment of Civil Protection schemes and competences needed for optimum response strategies.
3. To undertake monitoring of nine European case study sites, collecting new data sets of bathymetry and topography using state-of-the-art technology, and simultaneously measure the forcing agents (wind and waves, tides, surges) that trigger the events.
4. To test and develop reliable methods for numerical modelling of storm-induced morphological changes evaluating the accuracy of off-the-shelf morphological models. Furthermore, to test and develop a new open-source morphological model for the prediction of storm impacts.
5. To set-up early warning systems and to demonstrate their use within Civil Protection agencies. Specific aims are to link morphological models with wave hindcast models, preparing early warning protocols.

2.2. *Existing methods and new developments*

In the United States, a Federal approach supported by the government through NOAA (http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwEvent~Storms), classified storm events and assessed their effects on property and infrastructure. We believe that such level of public access to storm information is of utmost importance at a European level and MICORE has contributed actively to build a proper historical archive for Europe, adding data for recent storms carefully measured at the 9 case study sites described herewith. Similar databases like that of Lamb (1991) and Pfister et al. (2010) can be found in the literature but the MICORE one is the first at a European scale.

In MICORE it was intended that all datasets compiled or measured by the project should be databased satisfying a requirement of accessibility and standardization. It was decided to adopt the OpenEarth environment (www.openearth.eu), developed as a free and open source alternative to the current often ad-hoc approaches to deal with data, models and tools. Van Koningsveld et al. (2010) describe the OpenEarth philosophy, its infrastructure and main workflow protocols, while Ciavola et al. (this issue) detail its application in the MICORE Project.

Coastlines suffering from long-term erosion are particularly susceptible to the impact of high energy events. The main factor limiting scientific progress in this area is the availability of representative datasets usable to investigate processes and to calibrate, validate and verify morphological models (Southgate, 1995). This view is supported by the conclusions drawn by the EU-COAST3D project (http://www.hrwallingford.co.uk/projects/COAST3D/COAST3D), which found that the predictive capability of existing morphological models remains limited to short-term time-scales. Owing to an incomplete understanding of 3D coastal processes, models cannot yet simulate the beach recovery processes on the post-storm time scale (Van Rijn et al., 2003). This severely limits their application in a range of coastal defence management strategies.

The coastal impact of subsequent storms occurring on a short-time scale has recently received attention in the scientific literature (Houser and Hamilton, 2009). In these cases, the coastline is exposed to the cumulative effect of several medium-energy events that can produce a morphological response corresponding to a single high-energy event with a long return period (Ferreira, 2006). If one looks at the impact on coastal morphology (e.g. beach and dune evolution), a significant role is played by the joint occurrence of storm waves and surges. These events elevate the high water levels on the beach profiles, promote dune erosion and overwashing of natural barriers or overtopping of sea defences. They may produce a range of potentially catastrophic morphological responses determined by the relation between the dune elevation and the maximum water level (Sallenger, 2000; Stockdon et al., 2007).

The accurate definition of storm thresholds above which important morphological changes or damages to man-made structures occur is not consistently described in the scientific literature. It is often only found the definition of a wave height limit above which is considered that a storm occurs, with or without causing damage or important morphological changes. One main goal of MICORE was to assess coastal vulnerability during storms by linking events of major morphological change and damage, with hydrodynamic forcing and identifying indicators of critical thresholds for the latter. The MICORE Project is bringing about advancement in the understanding of morphological changes induced by storms by developing high-quality and innovative process-based modelling. Indeed flood forecasting is nowadays done without morphological model coupling.

The chosen sites (Fig. 1), that are the test areas where field measurements were undertaken, are representative of the range of morphological variability found across European coastlines, being exposed to different wave energy level, tidal ranges and with variable degree of human occupation. Further details on site-specific characteristics can be found in Table 1 and on https://www.micore.eu/area.php?idarea=19.

In response to the long-standing problem of obtaining detailed vulnerability assessments for the coastline, the Federal Emergency Management Agency (FEMA) in the United

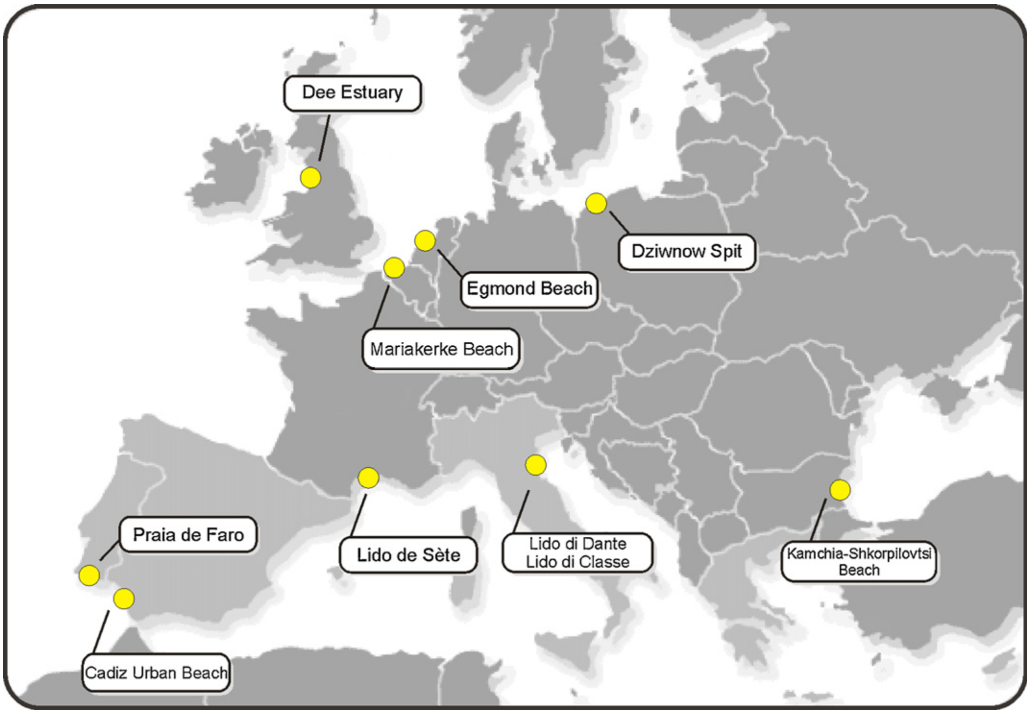

Fig. 1 – Map of the MICORE study sites.

Table 1 – Characteristics of the MICORE field sites.

Country	Field laboratory sites	Main characteristics	Km	Background knowledge on storm events
Italy	Lido di Dante – Lido di Classe	Natural with dunes, river mouths – defended coastline, infrastructures, high touristic value, *microtidal*	8	Storm classification, T1, 10, 100 max level
Portugal	Praia de Faro	Barrier-islands, dunes, overwashes, inlets, high touristic value, infrastructures, *mesotidal*	8	Beach changes, impacts, hazard maps
Spain	La Victoria – Sancti Petri	Urban beach, high touristic value, defended coastline, infrastructures – natural sand spit with dunes, overwashes, river mouth, salt marsh, touristic value, *mesotidal*	10	NPA-DB online, historical DB
France	Lido of Sète to Marseillan	Low barrier island, dunes, high touristic value, defended coastline, infrastructures, *microtidal*	13	Intensive campaigns, observations of impact
UK	Dee Estuary	Estuarine site with high occupation and hard engineering, defended coastline, infrastructures, sand dunes, tidal flats, mud flats, salt marsh, high touristic value, river mouth, *macrotidal*	10	Radar observing system, historical storms
NL	Egmond	Nourished beach, dunes, high touristic value, *mesotidal*	5	Many information from end-users
Belgium	Mariakerke	Wide dissipative urban beach regularly nourished, infrastructures, defended coastline, dunes, high touristic value, *macrotidal*	3	Protection for T1000 storm
Poland	Dziwnow Spit	Sand spit with low dunes; river mouth, protected coastline, nourishments to protect infrastructures, high touristic value, *non-tidal*	15	Statistics storm T100
Bulgaria	Kamchia – Shkorpilovtsi	Open beach on the Black Sea, dunes, river mouths, touristic value, *non-tidal*	13	Data for 52 storms and post-storm beach surveys

States played an important role in the identification of risk areas through the provision of Flood Insurance Rate Maps (FIRMs). These maps assist citizens seeking to obtain comprehensive flood insurance policies that accurately reflect the effective risk for a given area. The procedure adopted by the FEMA to identify an area at risk follows the conceptual scheme shown in Fig. 2A. Here all relevant factors are considered including forcing terms (waves, tides, surges) and coastal resilience (man-made or natural). The methodology suggested instead at European level by the EU FP VI Flood-site Project (Fig. 2B) illustrates the importance of the interaction between the beach profile, wave data and run-up level. Without improving the knowledge on this morphodynamic feedback, early warning systems for coastal flooding would only be useful for extreme events, whereas such a system has large potentiality in day by day coastal management (see for example Alvarez-Ellacuria et al., 2009).

To advance vulnerability evaluation methods, Storm Impact Indicators (SIIs) were developed within MICORE. These have an application on a range of natural and artificial coastlines in Europe subjected to variable degrees of wave energy, different tidal regimes and contrasting socio-economic

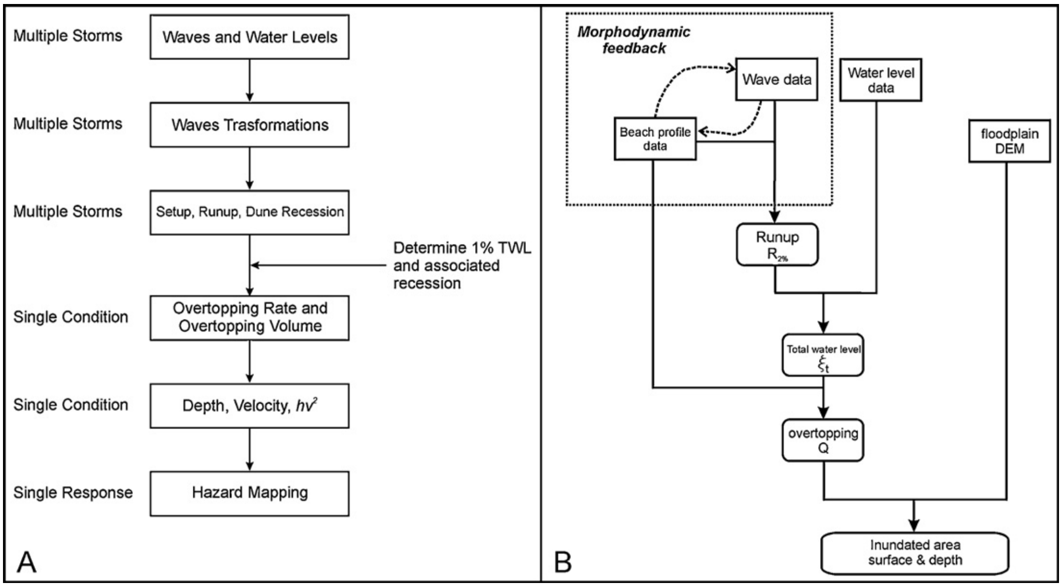

Fig. 2 – (A) The schematic approach adopted by FEMA in the US; (B) the methodology suggested by the FP VI Flood-site Project.

and ecological value. These indicators are intended to be used by competent Civil Protection agencies for organizing evacuation of people, send staff to monitor dike failure at vulnerable locations, locate emergency measures like sand bags or temporary dykes, delimit safe areas where people can move to in case of overwash events, etc. (see Ciavola et al., this issue for further details). The SIIs were developed using the Frame of Reference approach, which was also used in the Coastview Project (Davidson et al., 2007).

The Frame of Reference approach is a methodology aimed at structuring the end user-specialist interaction in application-oriented knowledge development settings. An effective interaction is needed to prevent or postpone the seemingly inevitable divergence of end user's as well as specialist's perceptions on what is relevant knowledge (Van Koningsveld et al., 2003). A key element in this methodology is to use the end user's information need as an explicit starting point for knowledge development and to continually match specialist research with information requested by end users. Van Koningsveld and Mulder (2004) showed that successful policy development is related to a ''basic'' Frame of Reference, comprising explicit definitions of a strategic objective, an operational objective and a decision recipe containing a foursome of elements, viz., a quantitative state concept, a benchmarking procedure, an intervention procedure, and an evaluation procedure confronting the operational as well as the strategic objective. An important lesson learned from the applications of the Frame of Reference approach is that information on the physical system is not useful information for decision makers *per se*. It should be supplied in such a form (accurate, reliable as well as sufficiently aggregated) that a decision can be taken based upon it.

At present Early Warning Systems (EWSs) applied to coastal areas are restricted to predicting impacts from strong winds, tsunamis and storm surges. On the other hand, Early Warning Systems to predict river flooding are for example operational in different EU countries and at European level. The European Flood Alert System (COM(2002)-481) is being developed at the Joint Research Centre in close collaboration with the National flood forecasting centres in the member states as well as several meteorological services. In parallel, in the U.S. NOAA provides flood alerts for the American coastal areas. However, in none of the existing warning systems the morphodynamic feedback is explicitly included in the model train.

The prototype Early Warning Systems that are being developed in MICORE will be able to address mainly operational early warning type risk assessment. In the Guidelines on Coastal Flood Hazard Mapping (Jiménez et al., 2008), delivered by the Floodsite consortium, it was concluded that one of the major sources of uncertainties in coastal flood hazard mapping has been identified as the coastal response or the coastal changes that occur during an event. In MICORE *state-of-the-arts* modelling techniques are used for morphological modelling, based on an open source approach using the Xbeach model (www.xbeach.org/), which has undergone extensive testing at a variety of sites inside (Van Dongeren et al., 2009) and outside (Roelvink et al., 2009) the MICORE scientific community. Most likely the end users of such a system are people who have to decide on taking emergency measures given a storm forecast (e.g. evacuating people, etc.).

2.3. *Main results obtained by the MICORE Project on historical storminess*

The theoretical approach to obtain critical storm thresholds was based on the collection of data on significant morphological changes recorded in the past decades. That included the use of historical sources, topography, bathymetry, aerial photographs, reports, etc. Storms having reported impacts were identified and an analysis of their hydrodynamics was made to produce the thresholds. Data from overwash events, storm erosion, storm damages, coastal flooding, overtopping, dune erosion and impacts on coastal developments were used to characterise the storm threshold that triggered their occurrence.

The described approach was, however, not easy to apply to all study areas within MICORE, due to the wide range of available and representative datasets, as well as the coastal typology among countries (e.g. natural areas versus urban fronts). It was therefore impossible to establish a universal approach, or similar criteria for all study areas. It was however possible to define simple variables that should be used as the most important proxies or parameters. The wave height or the associated wave energy were used as proxy/criteria for the morphological/damage threshold definition for all analysed areas. The storm surge/water levels were used as threshold criterion for the majority of the studied coasts (Belgium, Italy, Netherlands, Poland, Spain – Andalusia, and UK), while not considered for Bulgaria, France, Portugal and Spain – Catalonia. For some coastal regions storm duration, peak period, storm direction, run-up, return periods, tidal levels and joint probabilities were used as complementary approaches. This approach can be recommended for future studies in areas where enough information exists on the hydrodynamic parameters, as well as historical data on the associated beach behaviour.

3. The ConHaz Project

3.1. *Goals and objectives of the ConHaz Project*

The ConHaz Project (ConHaz Project, 2011; www.conhaz.org), standing for ''Costs of Natural Hazards'', is a two-year project funded under the VII Framework Programme. The project has been initiated in February 2010, and its main purpose is to compile and evaluate the state-of-the-art methods enabling the cost assessment of natural hazards. Cost assessments of damages, prevention and responses to natural hazards supply crucial information to decision support and policy development. Significant diversity in methodological approaches taken and terminology used in costs assessments of different natural hazards and impacted sectors makes it difficult to establish comprehensive, robust and reliable costs figures, and to compare costs across hazards and impacted sectors. ConHaz will synthesise current cost assessment methods and strengthen the role of cost assessments in the development of integrated natural hazard management and adaptation planning.

The effect of a coastal storm is normally perceived by society as related to the direct damages if the selected event happens. This can be quantified involving engineering aspects like cost of reconstruction, cessation of activities during the storm, closure of coastal roads (important for the crisis management), cost of emergency actions during the event (to reinforce a seawall, etc.), loss of recreational beach in touristic areas, etc.

The impact of storms has a cost for society, not only as compensations costs, but also has a cost to the insurance market, as Pompe and Rinehart (2008) have recognised for the US market. In the UK concern for increased coastal flooding is now supported by the work done in the context of the Tyndall Simulator (Nicholls et al., 2005). The ConHaz Project is providing the knowledge necessary to assess the present day risks and to study the economic and social impact of future severe storm events. Together, these elements have an important strategic impact on the safety of the people living in coastal areas and upon decision processes aimed at minimising the economic consequences of extreme events. The ConHaz Project is also investigating with stakeholders and end-users the possibilities of producing EU-wide guidelines for a viable and reliable risk mitigation strategy. ConHaz is using information directly derived from MICORE to access cost datasets and then to define the best practices.

The first objective of ConHaz is to compile state-of-the-art methods and terminology as used in European case studies considering droughts, floods, storms, and alpine hazards, as well as various impacted economic sectors such as housing, industry and transport, and non-economic sectors such as health and nature. The project is also considering single and multi-risk hazards, leading to direct, indirect and intangible costs. Moreover, ConHaz looks at costs and benefits of risk-prevention and emergency response policies, and the extent to which they can be used in economic assessments of natural hazard policies. The second objective of ConHaz is to evaluate the compiled methods by addressing theoretical issues such as principal assumptions of cost assessment methods, as well as practical issues, such as availability and quality of data. ConHaz also looks at the reliability of the end results by considering the accuracy of cost predictions and best-practice methods of validation, and will identify any gaps in assessment methods. The third objective of ConHaz is to give recommendations according to current best practice, knowledge gaps and identify resulting research needs.

ConHaz aims to develop a strategy that takes into account basic steps which should be implemented in all locations (regardless of the socio-economic differences between coastal countries) and also to look at differences in the management approaches that varied socio-economic/development levels might require. The ConHaz project is addressing the issue of encouraging and facilitating exchange of information on storm impacts produced by nationally funded projects in Member States; establishing robust data management and data quality control and engaging with stakeholders and end users to optimise dissemination strategies. End-users are involved in the project through national project delegates to improve knowledge on topics regarding Civil Protection schemes.

3.2. *Existing methods for cost assessment*

The different cost categories related to coastal storms include (1) direct costs, (2) costs due to disruption of production processes, (3) indirect costs, (4) intangible costs, and (5) costs of adaptation and mitigation measures. Each type of cost is defined as follows:

1. *Direct costs* are costs of damages to property due to the physical contact with the disaster, i.e. physical destruction of buildings, stocks, infrastructure or other assets at risk.
2. Costs due to *disruption of production processes* in industry, commerce and agriculture occur in areas directly affected by the disaster. For example, business interruption takes place if people are unable to carry on their work activities because their workplace is destroyed or unreachable due to the disaster. In the literature, such losses are sometimes referred to as "direct" costs, as they occur due to the immediate impact of the disaster. On the other hand, they are often referred to as "primary" indirect damages, because these losses do not result from physical damage to property but from the interruption of economic processes. However, the methods to evaluate losses due to business interruption are different from those used for direct and indirect damages respectively. For this reason, and in order to avoid definitional misunderstanding, "disruption of production processes" must be used as a separate category.
3. Consequently, *indirect costs* are only those resulting from either direct damages or losses due to business interruption. This includes induced production losses of suppliers and customers of affected companies, the costs of traffic disruption, the costs of emergency services, etc.
4. *Intangible costs* are costs of damages to goods and services which are not, or at least not easily measurable in monetary terms because they are not traded in a market. The intangible effects of the natural hazards include: environmental impacts, health impacts and impacts on the cultural heritage.
5. The *costs of adaptation and mitigation measures* provide an overview of approaches for storm surge risk prevention and their associated costs.

In this section, we briefly present some examples of methodologies for assessing the costs of storms and coastal hazards. To notice that we do not consider the cost of adaptation, as this is related to a "strategic approach" to coastal risk, according to the definition of Van Koningsveld and Mulder (2004). As we are trying to show the applicability of economics approaches to post-event evaluation, the nature of the data made available by MICORE must be kept in mind. A summary of all methods, including data requirements is presented in Table 2.

3.3. *Multivariate model*

A multivariate model is principally based on multiple regression analysis. In the context of coastal storms, under such an approach, many independent variables must be used, e.g. measuring meteorological, socio-economic, and physical conditions related to a specific storm. Physical parameters related to specific storms can be based on results from projects such as MICORE which provides information on the impacts of storm events in the form of morphological changes or impacts on coastal infrastructures. These can be correlated to total direct damage costs and used in a predictive multivariate model to estimate future economic losses resulting from potential future coastal storms. If datasets on historical storms are available,

Table 2 – Overview of the main characteristics of cost assessment methods for the impact of coastal storms and/or associated flooding.

Method	Type of coastal hazard	Type of cost addressed	Expected precision	Considered risk dynamics	Data needed	Data sources	Effort and resources
Multivariate model	Hurricane	Direct and indirect costs	Reasonable	Yes, through probabilistic risk analysis	Historical disaster data, public expenditures, meteorological data, physical and socio-economic variables	Statistics (land planning agencies, weather services, previous research)	Low
Event-based Loss Estimation	Hurricane	Direct costs	Good	Yes	Natural hazard data, general building stock, land-use data, insurance loss data	Census offices, weather services, land-use offices, insurance companies	High
Zone-based Damage Estimation	Storm	Direct costs	Medium	Yes, through predictive methods	Aerial photographs, structural damage property values, erosion data, coastal development over time	Remote sensing centres, census offices, meteorological institutes, previous reports	Low
Input-Output Models	Hurricane	Indirect costs	Good	Yes	Input-output tables; production capacity; adaptation and demand parameters, disaster data	Economic analysis, statistical and census offices	Medium
Contingent Valuation Method	Flood	Intangible costs	Reasonable	Yes	Coastal flood characteristics, stated willingness to pay, environmental conditions, socio-economic data	Surveys, environment agencies, flood hazard research centre	High
Hedonic Pricing Method	Flood	Intangible costs	Good	Yes, through the determination of flood risks	Coastal flood characteristics, revealed willingness to pay from environmental conditions, insurance and housing market data	Housing market data services, national flood insurances programs, previous research	High

this approach requires a low effort and can be applied to both direct and indirect costs with reasonable precision.

3.4. *Event-based Loss Estimation*

Event-based Loss Estimations have been used in the US by the Federal Emergency Management Agency (FEMA) under an applicable standardized methodology called HAZUS-MH (Multi-hazard Loss Estimation), and performed through different models for estimating potential losses resulting from earthquakes, hurricanes, and floods using GIS applications (Scawthorn et al., 2006). Potential losses include physical damages, economic losses, and social impacts. Estimation models require specific data that depend on the characteristics of the study region and the type of disaster. In the context of coastal storms, the HAZUS-MH Hurricane Wind Model can be applied to hurricanes, while the HAZUS-MH Flood Model can be applied to coastal flooding and related damages. Mainly based on physical damage to building structures and contents (repair and replacement costs), loss estimates include primarily direct economic losses, but can also calculate losses due to the disruption of production processes (e.g. on the basis of income losses). The method is accurate but requires a high effort in data collection.

3.5. *Zone-based Damage Estimation*

In coastal areas, damages and losses of built capital are very much related to the location of the buildings, and especially to their distance to the shoreline. West et al. (2001) implemented the distance-dependent damage concept in a probabilistic approach where the probability of damage decreases linearly with the distance of the structure from the shoreline. The definition of vulnerability zones is therefore fundamental to estimate the costs of coastal storms. MICORE can help to provide information and means on how to define such vulnerability zones, identifying dune and shoreline retreat during storms. Indeed, some of the typical SIIs chosen in the project are dealing with these issues (see for details Ciavola et al., this issue). The positive aspect of this method is that it can be applied using compilation of data and remote sensing observation, thus the effort is lower compared to the previous method.

3.6. *Input-Output Model*

Input-Output Models (or I-O models) are models used to evaluate indirect economic losses due to business interruption resulting from a shock such as a natural disaster. An Input-Output Model enables the evaluation of how the disturbance (e.g. an extreme storm event) affects the economic system through changes in consumption and demand, generally at national or regional level. More precisely, the model assesses the changes in the interrelations between different economic actors such as industries and consumers. The model is actually based on the principle that an industry uses inputs that are produced by other industries, while the production of this industry will serve as input to other economic sectors. The methodology, consisting in determining the flows of goods and services between the different industries, is applied for determining the economic response over a certain period of time, usually for yearly based economic calculations. Although the methodology is generally simple, the use and calibration of data sources can require a consistent effort, especially when the standard framework of the model is modified (e.g. by including specific variables in order to improve the model), or even extended (Jonkman et al., 2008). A drawback of this approach is the fact that the physical characteristics of the event are not accounted for, thus information like that contained in the MICORE database is not properly exploited.

3.7. *Contingent Valuation Method*

The premise of the Contingent Valuation Method (CVM) is that people have preferences in relation to all kinds of goods, including goods and services that are not traded in the market, and therefore have no market value. A CVM study can estimate “intangible values” such as economic values of ecosystem services and environmental goods. By using questionnaires, the surveys consist in asking people the maximum amount of money they would be willing to pay for a specific environmental service (or change in the availability of a good). This technique is also referred to as a “stated preference method”, because survey respondents are asked to directly state their values. Based on return periods of events, one advantage of having information like the MICORE datasets is that the expected loss can be estimated in advance. One could therefore estimate what is the expected cost of the disaster before it happens, and use these data when designing the questionnaires in order to maximise the reliability of the surveys. The application of this method using the MICORE database would enable the prediction of losses and costs associated with coastal storms for given return periods. The effort in data collection is high as questionnaires and interviews are required.

3.8. *Hedonic Pricing Method*

The Hedonic Pricing Method (HPM) is also used to evaluate intangible environmental effects. The method is essentially related to the variation in property prices (land or house prices) in a disaster-affected area. The fundamental principle of the methodology resides in the fact that property prices depend on the characteristics of a particular environmental effect (Coastal Wiki, 2008); conversely, this environmental effect can be given a price on the basis of changes in house prices. To the contrary to stated preference methods (e.g. CVM), a Hedonic Pricing Method is based on revealed preferences because it relies on actual transactions. In the context of changes in coastal areas, Hamilton (2007) studied the role that coastal and other landscape features have on the attractiveness to tourists. This study evaluated, among other things, the impact on revenue caused by changes in the attractiveness of the coast, such as changes due to adaptation measures to sea-level rise (e.g. from the conversion of open coast to dikes) and thus illustrates how intangible effects can be estimated. Data collection requires a large effort, mainly of socio-economic information.

4. Implications of new findings on EU emergency response policies

The Directive 2007/60/EC on the assessment and management of flood risks entered into force on 26 November 2007. This Directive requires EU member states to assess if water courses and coastal areas are at risk from flooding, to map the flood extent and assets and humans at risk in these areas, to take adequate and coordinated measures to reduce this flood risk. The Directive also reinforces the rights of the public to access this information and to have a say in the planning process. The flood hazard maps should include historic as well as potential future flood events of different probability. The results of the EU Directive are typically GIS-based flood hazard and flood risk maps that give a static result and are produced to support the strategic objectives of a coastal region. We outline below the policy implications of our findings in support of the Directive.

4.1. *Evaluation of storminess evolution in Europe*

A main factor limiting the MICORE study was the unavailability of representative (mostly measured) data sets for the last 40 years or more As a consequence, it was decided to focus the study mainly on the last decades (generally 40–50 years datasets) where the available data was found to have good quality standards.

One major problem found by the MICORE partners was the difficulty in accessing long time-series of measured data. For several countries meteorological databases are not publicly available or have restrictions of use, which impede a free distribution of the data. In several cases datasets do not extend further than few years or, at the most, few decades. Data available from few years to a couple of decades are not useful to determine long-term trends that can be assumed to overcome interannual variability or cyclical behaviour. The solution to minimise this problem was found extending the existing databases of measured data by integration of results from hindcast models (mainly for waves, see for example the HIPOCAS database in Guedes Soares et al., 2002). The two main differences between the datasets assembled by the partners are therefore the data source (measured versus hindcast) and the size of time series (from 4 years up to 105 years depending on data availability for each regional coastline).

Datasets with less than 30 years were not considered as indicators of relevant climatic trends. Even so, three decades may be insufficient to exclude long-term cycles (e.g. 18 years lunar cycles). Thus, the results presented in this paper should be considered with caution, considering the limits of the information on which they are based.

The different European coastal regions are subject to distinct storminess, which can be mainly expressed by surge levels and/or waves. Both are directly related to wind as a forcing agent, although surge levels are extremely dependent on changes on atmospheric pressure (e.g. low pressure systems) and, at a different time-scale, on changes induced by global sea-level rise. For some coastal regions storm impacts are mainly related with surge levels (e.g. Belgium, Netherlands, Poland, Italy) while for others waves seem to be the most important factor (e.g., Portugal, Spain). Therefore, the use of a single proxy for all coastal regions was not possible, given the particular characteristics of each case. As a consequence, each partner defined specific proxies, based on the available data and on the nature of the studied coastal area. Wind was used as a proxy for Belgium, Bulgaria, Italy (Northern Adriatic), Netherlands, Spain (Atlantic Andalusia) and UK (Eastern Irish Sea). Surges or water levels were used for Belgium, Italy (Northern Adriatic), Netherlands, Poland and UK (Eastern Irish Sea). Waves were used at all coastal regions with the exception of the Netherlands.

Almost all wind analyses were based on measured data, e.g. Belgium, Italy, Netherlands, Andalusia (Spain), Eastern Irish Sea (UK). For the Bulgarian Black Sea the wind characteristics were reconstructed from reanalysis of hindcasted data and for Catalonia (Spain) hindcast and measured data were used together. All surge and water level analysis were based on measured data. On the contrary, wave analysis for datasets covering more than 30 years was mainly based on hindcasting (e.g. Bulgaria, France – Aquitaine and Mediterranean, Poland, Portugal – West Coast, Spain – Andalusia, and UK – Eastern Irish Sea). Measured data were only used for Belgium, Portugal (South Coast) and Catalonia (Spain) but in the two latter cases validated hindcast data were also used to complement the dataset. The periods considered for wind analysis range from 46 years (Netherlands) to 105 years (Andalusia – Spain), for surge analysis range from 45 years (Poland) to 100 years (Netherlands), while for wave analysis range from 30 years (Belgium) up to 60 years (Bulgaria). For Italy the wave analysis was not included in this summary because only 18 years of wave records were available.

All partners performed an evaluation of data quality and defined which type of analysis could be made for each data set. Ideally all proxies should provide results on storm duration, storm intensity and storm frequency trends. It was however not possible to analyse storm duration trends for Belgium and Spain (Atlantic Andalusia), storm intensity trends for Spain (Atlantic Andalusia) and storm frequency trends for Belgium. For all other coastal regions it was possible to analyse trends for at least one proxy and in several cases for more than one. In the overall analysis interpretations based on averaged data (water levels/surges, wave heights or winds) were rejected and only values above a given and well defined threshold were used. A total of 54 proxies analyses were made, using surge/water levels, wave height and wind above a defined threshold for the 12 considered coastal regions.

Table 3 is a synthesis of the performed and incorporates, among other information, the storm threshold for each proxy, together with the trend analysis on the parameters. The main conclusion derived from the table is that a clear trend of storminess change at European level is not evident. Most of the used proxies (62%; 36 in 58) showed ''no trends''. About 19% (11 in 58) showed an increasing trend on storminess with only 3 proxies (5%) having a statistically significant increase (for $p < 0.05$). Circa 19% (11 in 58) of the proxies showed a decreasing storminess trend, although none of them were statistically significant.

There is a need to develop regional models and analysis and test their validity against the thresholds. It is recommended that wave threshold are defined using well defined and unambiguous parameters, e.g. significative wave height, wave energy, etc. to be able to integrate data from different datasets (e.g. buoys, oil rigs, observation towers, etc. Likewise, when maximum water levels due to surge processes are used, special attention should be devoted to reference levels of tide gauges, as this may change over time due to processes like subsidence. Joint probability analyses should also be explored to achieve an integration between proxies/variables.

4.2. *Cost evaluation of impacts*

Considering the methods reviewed in the previous sections, we recommend the following approaches to evaluate direct costs related to marine storms: A Multivariate Model using correlations between different variables, such as population and wind speed can, for example, explain a certain percentage of the variance in total costs resulting from a wind storm. For large magnitude coastal storms, e.g. hurricanes, wind is certainly a very representative proxy for damage on buildings, but other factors like the nearshore wave height and the maximum surge level play a primary role. This method requires a low effort, but historical datasets, like the one assembled by the MICORE Project, must be available.

As in end users there is a tendency to only estimate direct costs, the two best methods seem to be the Event-based Loss Estimation or the Zone-based Damage Estimation, especially in the context of post-event appraisal. For coastal storms in particular, the latter is possibly easier to be applied than the former. Both methods can be applied using archives and GIS systems of storm impacts like those developed under the MICORE umbrella.

5. Conclusions

The objective of this paper was to introduce two European VII Framework research projects that are currently addressing the

Table 3 – Synthesis of storminess trends (duration, intensity and frequency) for each coastal region. For some sites different periods were analysed for different proxies and different trends have been obtained for different proxies. NA – not available.

Study site	Period	Proxy	Storm duration trend	Storm intensity trend	Storm frequency trend
Belgium	1925/1955–2000/2007	Wind, Waves and Surge	NA	No trend	NA
Bulgaria	1948–2008	Waves and Wind	Decreasing	Increasing; No trend	Decreasing
France – Aquitaine	1958–2008	Waves	NA	Increasing	Increasing
France – Mediterranean	1958–2008	Waves	NA	No trend	Increasing
Italy – Northern Adriatic	1923/1960–2008	Wind and Surges	NA	No trend	Wind no trend; surges increasing
Netherlands	1890/1962–1990/2008	Wind and Surge	NA	No trend	Decreasing
Poland	1947/1958–2000/2007	Surge, Waves and Storm Energy	Increasing	Increasing	Increasing
Portugal – West coast	1958–2001	Waves	NA	No trend	No trend
Portugal – South coast	1958–2008	Waves	Decreasing	Decreasing	Decreasing
Spain-Atlantic Andalusia	1902/1958–2007/2008	Waves and Wind	NA	NA	Waves decreasing; wind increasing
Catalonia – N (Tordera)	1958–2008	Waves	No trend	No trend	NA
Catalonia – Central (Llobregat)	1958–2008	Waves	No trend	No trend	NA
Catalonia – S (Ebro)	1958–2008	Waves	No trend	No trend	NA
UK-Eastern Irish Sea – Heysham	1963–2008	Water level	No trend	No trend	No trend
UK-Irish Sea – Princess Pier	1963–1982	Water level	No trend	No trend	No trend
UK-Eastern Irish Sea – Bidston	1929–2002	Maximum monthly wind speed	No trend	No trend	No trend
UK – Eastern Irish Sea	1960–2007	Significant wave height	No trend	No trend	No trend

topic of coastal storm hazards. The MICORE Project aims to provide on-line predictions of storm related physical hazards (hydrodynamic as well as morphodynamic). The ConHaz Project addresses the socio-economic implications, should these (or other) hazards actually materialize. Together these projects aim to deliver crucial information for emergency response efforts, while realizing the practical limitations for information processing and dissemination during crisis situations.

To the knowledge of the authors, Europe still lacks a comprehensive database of marine storm occurrence and their impact on European coastlines. Although in some cases National databases exist or may be under development, there is a requirement for standardization of data collection and protocols across the EU. It is recommended that the production of National Storm Databases be encouraged by national governments. The databases must include simple damage assessments at least for direct costs.

The findings of our work also point towards the need of making available into the public domain all European data sets on storminess indicators, as well as to establish monitoring networks for storminess proxies that should be kept active for decades, integrating both new and historical data. Gaps in existing data should be filled with the most advanced and best validated climatic models in order to diminish uncertainties and increase the accuracy of data analysis.

The threshold values for morphological change and damage identified in MICORE can be used as guidelines for testing storm erosion models. The defined thresholds were, for the most of the analysed cases, based on historical observations and/or available field data. The estimated thresholds should be improved in the future, either by addition of new field data and/or numerical modelling efforts. The defined thresholds are strongly depending on the morphological conditions of each study area and therefore they face geographical limitations. In order to cover larger parts of the European coastline further analysis is needed. In MICORE the development of the thresholds was based on detailed data collection along limited parts of a coastline, at a scale from meters to kilometres. Thus, the obtained thresholds cannot be extrapolated to other neighbouring areas or to other coastal regions (even within the same country) that present different oceanographic and morphological settings. The trends in storm variability are not at all uniform. There is no evidence of a global in storminess at European level but in some places local changes were detected. For example, changes in surge frequency were found in the northern Adriatic and in the southern Baltic Sea. Likewise, an increase in severe wave storms was found in the Gulf of Biscay.

The ConHaz desktop study found that end-users normally evaluate only direct costs after the storms, while the cost of adaptation and mitigation measures is only done strategically in the context of Integrated Coastal Zone Management plans. As there is no standardized method for cost evaluations in this field, it is recommended that clear guidelines should be produced on the basis of simplicity. It is also recommended that national and/or regional governments give a clear statutory role to local institutions for collection of data on damages. Protocols should be prepared based on simple standardized questionnaires which could then be integrated in an archive where physical (e.g. wave height, surge level, wind speed) and qualitative information (pictures, newspaper articles, interviews) could be stored.

In order to evaluate the "secondary" societal losses due to the occurrence of an event, ConHaz suggests to use reconstruction costs, using for example for a given area the value for the type of house that was damaged. Regarding infrastructures (e.g. sea-walls), the cost of fixing a failure. Regarding natural environments (beaches), the cost of a beach replenishment, for example using the cost of a cubic metre of sand from the quarry or dredging pit normally used in the area. Secondary losses due to loss of economic activities are difficult to be quantified, as this implies to access revenue information, which is confidential and often reflects submerged economical activities (e.g. not included in tax declarations) which may be not quantifiable.

An interesting future application of MICORE information could be a desktop evaluation of the impacts of storms with a given return period and the consequent re-evaluation of house values on areas at risk. This dataset may equally be of interest to insurance companies for cost of coverage and to banks for coverage of mortgages. This would lead to an increase in insurances policies or no financing by banks when the asset is at risk. On a longer term, this could reduce cost to society and/or a lower occupation of land at risk.

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