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REPORT ON PUBLIC AWARENESS AND WIDER SOCIETY IMPLICATIONS OF THE USAGE OF SII

COOPERATION

Project 202798

REPORT ON PUBLIC AWARENESS AND WIDER SOCIETY IMPLICATIONS OF THE USAGE OF SII

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Executive Summary

This report presents the results from two FP7 Projects, MICORE and ConHaz, related to marine storm impacts along European coastlines.

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. As a first step, historical storms that had a significant morphological impact on a representative number of sensitive European coastal stretches were reviewed and analysed in order to understand storm related morphological changes and how often they occur around Europe. 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). Next, an on-line storm prediction system was set up to enable prediction of storm related hydro- and morphodynamic impacts. The system makes use of existing off-the-shelf models as well as a new open-source morphological model (XBeach). To validate the models at least one year of fieldwork was done at nine pilot sites. The data was safeguarded and stored for future use in

an open database that conforms to the OpenEarth protocols. To translate quantitative model results into useful information for Civil Protection agencies the Frame of Reference approach (Van Koningveld et al., 2005, 2007) was used to derive Storm Impact Indicators (SIIs) for relevant decision makers. The acquired knowledge is expected to be directly transferred to the civil society trough partnerships with end-users at the end of the MICORE project.

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.

The present report is structured as it follows. Chapter 1 covers the outcome of the activity of databasing historical storm data and the analysis of the methods for cost estimation used for evaluating the impact of marine storms and the associated coastal hazards. The MICORE approach to quantify for nine field sites the crucial storm related physical hazards in support of early warning efforts and emergency response is described in Chapter 2.

Disclaimer

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

Paolo Ciavola, Oscar Ferreira, Piet Haerens, Mark Van Koningsveld, Clara Armaroli, Quentin Lequeux

1.1 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 in Australia). With these contemporary examples it is clear that a thorough preparation is crucial to maximise the potential for an effective emergency response, minimize 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.

1.2 The MICORE Project

1.2.1 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 a 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.

1.2.2 Existing method 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. (2011) 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 Rjin 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. 1.1), 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 1.1 and on https://www.micore.eu/area.php?idarea=19.

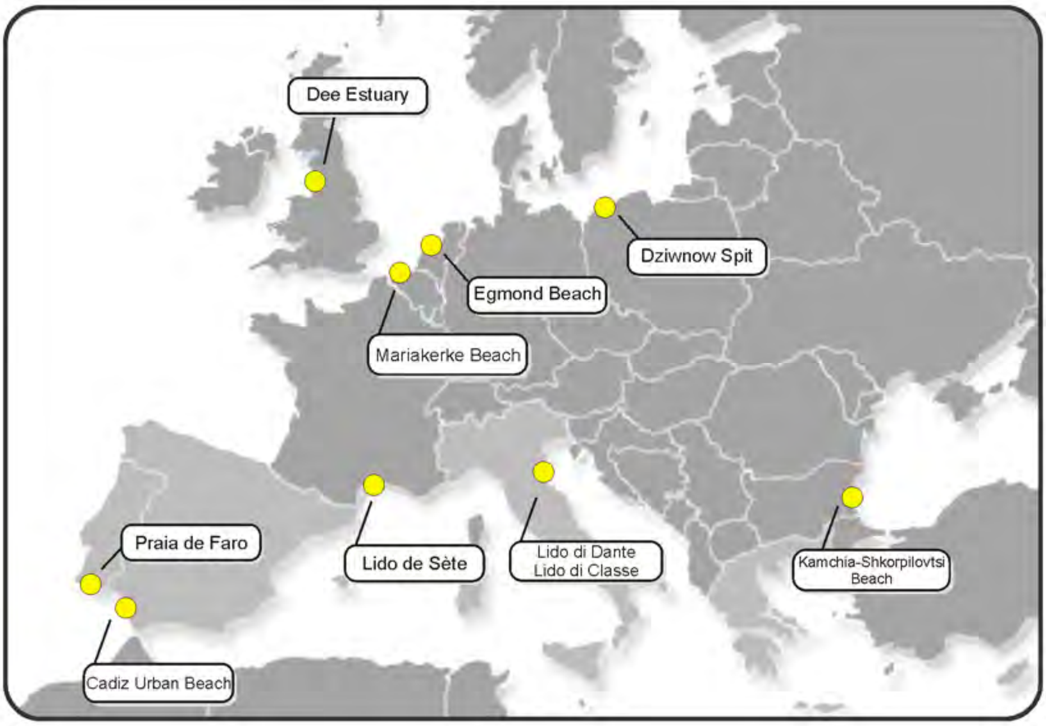

Figure 1.1. Map of the MICORE study sites.

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

Table 1.1. 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	11	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

The procedure adopted by the FEMA to identify an area at risk follows the conceptual scheme shown in Fig. 1.2A. 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. 1.2B) 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).

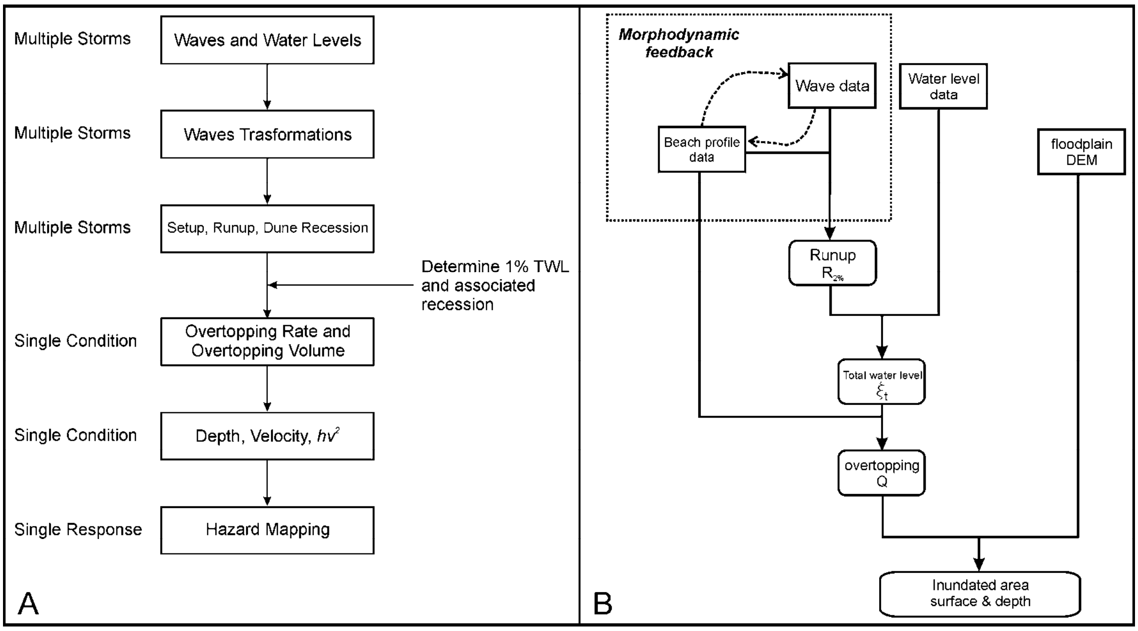

Figure 1.2. (A) The schematic approach adopted by FEMA in the US; (B) the methodology suggested by the FP VI Flood-site Project.

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 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., 2011 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 (EWS) 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.).

1.2.3 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.

1.3 The ConHaz Project

1.3.1 Goals and objectives of the ConHaz Project

The ConHaz Project (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 Rineheart (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.

1.3.2 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 1.2.

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

1.3.4 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 requires 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.

Table 1.2. 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	Good	Yes, through predictive methods	Aerial photographs, structural damage property values, erosion data, coastal development over time	Remote sensing centers, census offices, meteorologica l institutes, previous reports	Medium
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 center	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

1.3.5 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., 2011). 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.

1.3.6 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.

1.3.7 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 maximize 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.

1.3.8 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.

1.4 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.

1.4.1 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 to 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 yr 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 1.3 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.

1.4.1 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.

Table 1.3. 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

1.5 Conclusions

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

2 Storm impacts along European coastlines. Part 2: lessons learned from the MICORE project

Paolo Ciavola, Oscar Ferreira, Piet Haerens, Mark Van Koningsveld, Clara Armaroli

2.1 Introduction

Recent natural disasters in coastal areas have underlined the potential devastating effects of hazards with a marine origin (tsunami, hurricanes, etc). These powerful natural events have raised awareness that the coastal areas can be exposed to natural disasters. Although the processes that generate these events are beyond human control, many lives could be saved in the future if adequate mitigation procedures can be developed. Examples of existing procedures include the warning systems for tsunamis and associated vulnerability mapping, and accurate forecasting of major storms and hurricanes via synoptic weather circulation models. Closely linked to this are civil defence and coastal evacuation plans that aim to reduce the risk to human life and minimise damage to property and infrastructure. An increasing scientific and public concern with natural hazards is currently of interest to environmental policy priorities of the European Union and its member states. Of particular relevance to the protection of coastal areas is to understand if there is an increase in the intensity and frequency of powerful storm events characterised by larger peak wind speeds and consequently larger waves.

Engineering or “pro-action and prevention” has been favoured in the past as the best option for disaster mitigation at the coast. However, most engineering works are constrained by economics, and a compromise must be sought between the potential threat to lives and property and the resources available for design and construction. Furthermore, the design of structures is based on predicted extreme events which themselves are subject to uncertainty, especially in a rapidly changing global climate.

The huge damage to the city of New Orleans by Hurricane Katrina clearly illustrates what can go wrong when engineering design is subjected to forcing beyond its design limits and when civil evacuation and management plans fail. Hurricane Katrina also illustrates that the experience of past storm events can be quickly forgotten and post-event policies of mitigation rather than defence are the norm. For example, although Hurricane Camille in 1969 had a significant impact on coastal Louisiana, post-storm construction criteria aimed at mitigating future flooding were clearly inadequate as damage inflicted by Katrina followed a similar pattern. The threat of hurricane Gustav only three years after Katrina illustrates the additional effects of consecutive storm impacts.

Due to economic limitations it is simply not possible to design, fund and build schemes to protect vulnerable coastal areas from all anticipated events. Indeed, scenarios of climate change impacts from present models are diverse and cannot at present be relied upon to give accurate forecasts of future extreme events around coastal Europe. Therefore, there is an urgent need to develop new coastal management systems to respond to as yet unforeseen extreme events that fall outside the design limits of existing and future coastal structures. In this context, the development of on-line warning systems providing predictions of storm impacts would support civil protection mitigation strategies with an interesting new source of information.

Ciavola et al. (2011) have outlined the joint efforts of the MICORE and the ConHaz projects to make steps in handling storm impact along European coastlines. It was observed that specialist knowledge of coastal behaviour under storm conditions could be useful in improving emergency preparedness.

The MICORE project aimed to set up an on-line warning system utilizing as much as possible already existing open data feeds in combination with already available off–the shelf models and/or the new open source model XBeach (Roelvink et al., 2009). The end result is believed to give a sound basis for emergency response supplying predictions up to 3 days in advance continuously. To notice that this time restriction is due to the reliability of weather forecasts, which are normally issued for a 72 hours scenario. The objective of this paper is to discuss the approaches that are followed and to summarize a number of important lessons learned during the setup and execution of the project. After a brief introduction of the MICORE project, a review of the knowledge on historical storms is discussed, trying to find trends in the studied datasets. Finally, lessons learned on data management, model development and warning system development are described.

2.2 The MICORE Project

The MICORE project (www.micore.eu), funded under the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement 202798, aims to develop and demonstrate on-line tools for reliable predictions of the morphological impact of marine storm events in support of civil protection mitigation strategies. The project has a budget of 4,597,074 € and receives a contribution by the EU for 3,499,954 €. It started in June 2008 and has duration of 40 months, with a partnership of 16 institutions across Europe. The project specifically focussed on emergency response rather than on strategic preparation. As such it is a clear example of a practice oriented research programme towards coastal management. The main implication on the project's development strategy is that, although MICORE aims to further enhance the state-of-the-art in storm impact modelling, the project is supposed to deliver results that are useful/applicable by end users. The project is being developed accordingly with a strong emphasis on the usability of results, following a philosophy of matching research with end user needs (Van Koningsveld et al., 2003). As such, MICORE is building on previous experience developed during previous projects, among others CoastView project (Davidson et al., 2007; Van Koningsveld et al, 2007) and ConScience (Marchand, 2010).

To facilitate the development of a generic approach and promote practical applicability of its end results, MICORE selected nine case-study sites throughout Europe (Ferreira et al., 2009b). Here monitoring was undertaken for a period of at least one year to collect new data sets of bathymetry and topography using state-of-the-art technology (Lidar, ARGUS, Radar, DGPS). The impacts of the storms on living and non-living resources were assessed using DGPS methods and undertaking post-damage assessments. These impacts were afterwards catalogued on local GIS systems and databases and stored on a single repository accessible for all partners. Numerical models of storm-induced morphological changes were tested and developed, using commercial packages and the new open-source XBeach code. The models were linked to wave and surge forecasting models to set-up a real-time warning system and to implement its usage within Civil Protection agencies. The most important end product of the project was the production of an operational warning system with predefined data processing algorithms. Storm Impact Indicators (SIIs) were used for the prediction of major morphological changes and flooding events in relation to predefined management issues.

The management issues for which SIIs were defined and the uncertainty involved in their use were a sensitive issue that was discussed with decision-makers. The MICORE project employed the Frame of Reference method to assist in the process of defining relevant SIIs for each of the field sites. Just as in CoastView (Van Koningsveld et al, 2005; Van Koningsveld et al, 2007), the MICORE project found it was necessary to distinguish between variables, that describe physical aspects of the coastal system, and Storm Impact Indicators (SIIs), that provide a quantification of the coastal system in a form suitable for decision making. Given the focus on storm-related impacts, common variables that were calculated for each site included: wave height, run up levels, flow velocities, beach and dune erosion (volume/rate), overwash discharge, extent of inundation area, inundation depth, etc. The notion that maps of flow velocities, for example, would not be seen as adequate information to support decision makers per se, a lesson learned already in the CoastView project, still served as an eye-opener to many of the researchers involved. The focus on developing SIIs, the use of the Frame of Reference approach and the associated interaction with end users, revealed another interesting benefit from practice-oriented research: additional inspiration from suggestions by end users.

2.3 Analysis of Historic Storms

One of the MICORE objectives was to undertake an analysis of changes in storm occurrence and to consider possible future variability in the context of climate change. This analysis included the study of trends in meteorological data (e.g. changes in storminess proxies) and intended to provide guidance for the understanding of the response of coastlines to potential changes in the forcing agents. The analysis presented hereafter is based on the study of existing databases available at national and European level for different forcing agents. The full MICORE report on historical storms (Ferreira et al., 2009b) is publicly available on the project's website. The considered driving factors included storm waves, wave energy, winds and surge levels, depending on data availability and on the specific conditions of exposure of each coastline. Further information can be found in Ciavola et al. (2011).

The use of 58 proxy analyses for 12 coastal regions of Europe, including modelled and measured data and the most important storminess indicators (surges, winds and waves), could have given indicative values about storminess trends in Europe (cf. Ferreira et al, 2009b). However, it must be stated that there was no general trend of storminess change in Europe, based on the studied coastal regions, used proxies and datasets. For some coastal regions, specific trends were found (Fig. 2.1). Notice that here only trends that were statistically significant are presented.

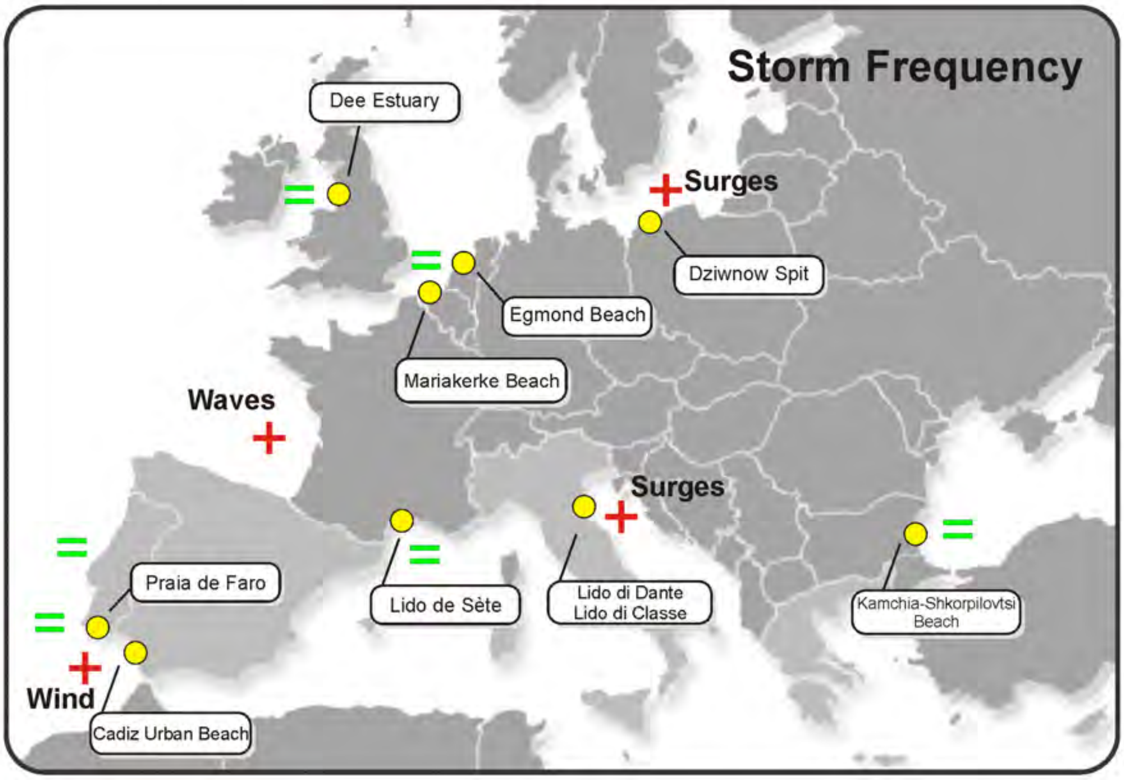

Figure 2.1. Summary map of the presence of changes in storm frequency identified by the MICORE storm review. Only statistically significant trends are presented here with positive (increase) sign. The equal sign means that no trend was present in the data.

At present storminess variability is much higher than the observed trends at the time scale of the performed analysis (records longer than 3 decades). Some analyses (e.g. France - Aquitaine, Spain – Andalusia) indicated a direct relationship between storminess and the NAOI (North Atlantic Oscillation Index). It was however not possible to observe any clear association between storminess changes and global climate change. This does not imply that global climate change consequences (e.g., sea temperature increase, sea level rise) will not have an influence on European storminess and storminess impacts. It mainly means that for the existing and available data sets, those impacts have not been detected or do not have a visible and strong signal at European level.

The inventory of generically applicable thresholds for storm impact showed that each site has its own specific physical features influencing how offshore waves, wind, pressure fields and tides affect the coast. This warrants the setup of a warning system that is based on process models as this is the only way to come up with one generic approach that may be applied to various locations with such variability in physical characteristics like European coastlines.

2.4 Open Earth Data and Knowledge Management

The MICORE project adopted the OpenEarth approach to data and knowledge management (Van Koningsveld et al., 2010). OpenEarth provides a project superseding approach to handling data, models, tools and information. Traditionally, large R&D programmes with partners from various organisations and countries approach the setup of supporting knowledge management infrastructures one project at a time. While this is apparently attractive from a budget management perspective, it also results in grave inefficiencies in developing and archiving the basic elements that are invariably involved: data, models and tools.

Hardly any project is by itself of sufficient scale to develop easy-accessible and high-quality data archives, state-of-the-art modelling systems and well-tested analysis tools under version control. Research institutions, consultancy as well as major construction projects commonly spend a significant part of their budget to set-up some basic data and knowledge management infrastructure, most of which dissipates again once the project is finished. Institutions generally employ internally intranet services and internal networks to collaborate and exchange information. However, due to increasing complexity, large projects nowadays are regularly executed by consortia. The internal services of individual institutions do not allow for external collaboration due to technical limitations or simply denial of permission for security reasons. As a result, the way data, models and tools are currently managed, while presumably aimed at protecting the knowledge capital of organizations, in fact also inhibits progress (individual as well as collective).

In MICORE the solution to the fragmentation and difficulty of data access, typical of large-scale, multi-partner projects, was solved adopting an open database approach, without having to rely on commercial proprietary packages and/or onto the local approach normally taken by end-users. The view of the Consortium was that the database should not “die” with the end of the project but rather be maintained and possibly expanded with internal resources of after bidding for new EU funds.

OpenEarth (www.openearth.eu) was developed as a cloneable, free and open source alternative to the project-by-project and institution-by-institution approaches to deal with data, models and tools. OpenEarth rather transcends the scale of single projects In its most concrete and operational form, OpenEarth facilitates collaboration within its user community by providing an open ICT (Information and Communication Technology) infrastructure, built from the best available open source components, in combination with a well defined workflow, described in open protocols and based as much as possible on widely accepted international standards.

The MICORE project showed that it is possible to store data from various partners residing in various countries in one project superseding database, overcoming problems of data format, data exchange capabilities and management effort by the relevant workpackage leader. As a result, the data from MICORE will be available for easy use in future R&D projects. This is a significant improvement to current approaches, where databases are set up specifically for one project often resulting in accessibility problems after the project has finished. The MICORE project also showed that it is possible to share and collaboratively develop generic tools between project partners from different countries, but also interaction with other projects. The project superseding character of the OpenEarth tools repositories also ensures that those developed by MICORE will be available to other projects for further use and refinement.

Applying the OpenEarth approach reduces the time needed in a project to set up ICT infrastructures as these are made freely available. To make the OpenEarth approach work in practice, the required effort shifts towards providing sufficient support and training to assist researchers in making the unavoidable (usually minor) changes in their normal workflow. The setup selected in MICORE was to arrange sufficient support and training at the beginning of the project, including the identification of one dedicated person from the workpackage leader to provide any required support.

An important lesson learned is that data archives should be made available in an easily usable form as soon as possible in the project, i.e. immediately after data collection rather than at the end of the project only. The former approach makes sure that the efforts put into database setup are immediately of use to the project itself, whereas the latter approach only benefits future projects. The interest to the project expressed by end-users invited to attend local dissemination workshops and the final conference (see project's website for details) greatly enhanced the quality of the data archive stimulating users to possibly add their own data. This is particularly true for National Institutions (e.g. Meteorological and Hydrographical Services) that provided data but could not give authorization for data release outside the project. In this case the information is only present in the database in the form of metadata information but it was used in the review of historical storms discussed in the current paper. To notice that all data in the database follows closely the Inspire Directive (2007/2/EC). The problem of open data access to meteorological and oceanographic information which is far beyond the competence of MICORE but possibly must be taken at EU level and discussed with member states.

2.5 XBeach Open Source Model

In MICORE modelling techniques used for morphological modelling are based on an open source approach using the XBeach model, which has undergone extensive testing at a variety of sites (Roelvink et al., 2009; Van Dongeren et al., 2009). As described in Roelvink et al., 2009, the model solves coupled 2DH equations for wave propagation, flow, sediment transport and bottom changes, for varying (spectral) wave and flow boundary conditions. It resolves the wave-group and infragravity time scales, which are responsible for most of the swash and overwash processes, which thus can be modelled explicitly. The model was further developed inside MICORE adding algorithms for groundwater dynamics inside the beach and 2-D hydrodynamics around offshore breakwaters. The code is particularly suited for studying dune erosion, overwashing and breaching as it can represent complex geometries and contains essential physics related to the swash motions during storms. It is open source and freely available at www.xbeach.org, where every change to the code is logged through version control systems.

The MICORE project has demonstrated that a community model can indeed be effectively applied within R&D programmes. All field site modellers set up a dedicated version of the model capturing the specifics of each coastline and producing useful and reasonably accurate results. The application of one generic process model to a vast number of field sites proved to be a great advantage to test the model thoroughly. The fact that the open source model could immediately be improved if any bug or problem would emerge, meant that the model was improved significantly throughout the project.

An automated testbed was set up and each change in the source code was automatically tested on a large number of datasets. The testbed proved to be a great tool in checking the models robustness and their range of applicability. The automated test runs, accompanied with an automated test report that was mailed to all model users weekly, proved to be a great quality assessment tool enhancing the users' confidence to apply the model.

2.6 Indicator based Early Warning System

Building a fully operational regional Early Warning System (EWS) is a very ambitious plan and far beyond the scope of the MICORE project. The set-up of such a system would require at least 5 to 10 years and the support of end-users on a national and European level. It was found that at present end-users are not ready to develop a EWS on a regional scale, although they are indeed interested in applications that demonstrate the capabilities of an operational tool. MICORE therefore focused on providing end-users with a prototype operational chain of models that could demonstrate the capabilities of an early warning system for each test site.

The fact that, with the selected approach, predictions would be available approximately three days in advance only, limited the kind of decisions for which the information could potentially be used. The Frame of Reference approach developed by Van Koningsveld and Mulder (2004) was used to help researchers from different field sites to use one method generically applicable to embed their highly specialized model results in a practical decision context. The SIIs are the base for the EWS as the thresholds of these indicators control if, and at what level, a warning should be issued. Table 2.1 shows the elaboration of a number of management approaches developed within the MICORE project expressed in terms of the Frame of Reference.

Table 2.1. A summary table of some example of the MICORE Frames of Reference. The greyed table row represents the quantitative building block that should be derived from models or measurements. This building block is used in the quantification of the SII. The surrounding table cells provide the practical context in which the SII is relevant. Notice how the structured approach enables cross-comparison between different Frames of Reference.

Management issue	**Dike and dune monitoring (extreme marine forcing conditions)**	**Protection of beach property Safeguarding immobile goods (extreme marine forcing conditions)**	**Protection of beach property Safeguarding mobile goods (moderate marine forcing conditions)**	**Coastal Safety – Conservation of natural areas (EU Council Directive 92/43/CEE)**	**Swimmer safety (average marine forcing conditions)**
Strategic objective:	Guarantee an efficient as well as an effective response to coastal threats during major storms	Protection of as much property as possible during storm conditions in an economic optimal way	Sustain recreation entrepreneurs by preventing storm-related damage	Guarantee sustainable safety of natural heritage	Prevent injuries or casualties for recreational beach-goers during everyday conditions.
Operational objective:	Personnel responsible for monitoring the development of natural threats to a coastal resort should be deployed timely to the proper locations	Allocation of the (limited) last minute protection measures to limit economical damage as much as possible	Timely warn recreation companies to put movable goods in a safe place in case of run-up events	Reduce impact of flooding behind the beach and/or dunes	Prevent the unsupervised presence of swimmers in areas in the surf zone where hazardous currents occur
Quantitative State Concept	Likelihood map with most probable locations for coastal flooding developed to unambiguously identify the location as well as the timing of most threatening High Water events	Risk maps (time and space) with expected economical damage in the coastal strip (that contains houses, shops, etc)	Run-up timeseries (e.g. extracted from beach morphodynamic model, e.g. XBeach results)	Run-up and maximum flooding cross-shore and longshore extension (marine water ingression limit)	Space-time map of areas that are unsafe for swimming, covering at least the most used areas.
Benchmark desired state	**Reference state:** Water levels from the model results should not reach beyond a predefined acceptable level.	**Reference state:** No (minimum) economical damage	**Reference state:** Seaward edge of the beach recreation land-use zone as indicated in spatial planning regulation	**Reference state:** Safety is guaranteed as long as the sum of run-up+set-up+surge+tide is below the max berm-beach and dune elevation	**Reference state:** Define areas that are “deep”, “safe”, “unsafe” and “dry”
Benchmark current state	**Current state:** Synoptic results from the model on development of water levels in space and time represent the current state.	**Current state:** Expected economical damage in a coastal strip from inundation maps and socio economical data	**Current state:** The first exceedance of the benchmark level as predicted by XBeach	**Current state:** Weather, wave and surge forecasts. Warning advice transmitted to local authorities	**Current state:** Velocities from the model results, combined with the latest measured water temperature, represent the current (or predicted) state in space and time.
Intervention procedure	According to a comparison between computed water levels and the predetermined acceptable level a map with different colours indicating different flooding probabilities can be constructed based on which dike monitoring personnel could be deployed	Use available protection measures to put up local barriers (sandbags or other) at inundation bottlenecks locations to minimize economical damage	When the SII indicates impact on private properties then a warning should be issued to the beach property owners (as soon as possible but at least one day ahead of time)	Protection of natural areas if the predicted overtopping discharges are high enough to generate consistent flooding (x m3/sec); build up of temporary protections	Flagging of hazardous conditions and locations and evacuation/rescue of people in hazard zones by life guards.
Evaluation procedure	**Operational objective:** After a major storm evaluation of the operational objective may point out that significant high water events occurred on other places than it was foreseen **Strategic objective:** Evaluation of the strategic objective may suggest that a combination of inspectors and video monitoring could be more effective and maybe even more efficient	**Operational objective:** With emergency response measures the damage to property is likely to be prevented / minimized in the most economical way. **Strategic objective:** It remains to be seen however if flooding is the only physical parameter of interest to estimate the economical damage.	**Operational objective:** Related to the operational objective this procedure will assist entrepreneurs to avoid damage to beach beds in case of run-up. **Strategic objective:** Related to the strategic objective we notice that other storm related hazards (wind) are not covered.	**Operational objective:** Natural areas are safe below the critical run-up+set-up+surge+tide value and protected with emergency defences when higher overtopping discharges are expected. **Strategic objective:** Set-back strategies may be considered	**Operational objective:** Determine if there are actual offshore currents occurring. If not refine the model. Determine if the people are aware of the flagged areas. **Strategic objective:** Evaluation of the strategic objective may suggest that a combination of inspectors and video monitoring could be more effective and maybe even more efficient

The MICORE project intended to prove that based on a predicted storm and sufficient information about the state of the coastal zone and its infrastructures (e.g. bathymetry, topography of beach and dunes, dyke characteristics), accurate predictions of storm impact in support of civil protection mitigation strategies could be made. Hereto a generic concept of an Early Warning System (EWS) was developed, consisting of five essential modules (illustrated in Fig. 2.2):

- An observation module, including weather, wave, surge measurements;
- A forecast module, including weather, wave, surge and morphological forecasts (XBeach);
- A decision support module, including Storm Impact Indicators and hazard maps;
- A warning module, including warning at different levels which are site-specific;
- A visualisation module including on-line GIS based maps.

To provide on-line warnings of coastal hazards, the EWS preferably should be able to rely on real time measurements of the driving forces (waves, water levels, wind and currents) and on the receptor characteristics (the coastal area, characterised by the morphological status of the nearshore, the beach characteristics, the presence of infrastructures on the beach and in the hinterland). Some EU members already have an operational monitoring network for offshore oceanographic parameters (e.g. waves and tides) and are willing to integrate their data into a EWS. The morphological status is also frequently measured along the coastal area in different EU member states. What is often missing is the link between all these observations and an operation, robust, forecasting system.

In order to convert predicted weather forecasts (i.e. wind and pressure fields) into a wave field and/or a surge level, a number of numerical models should be combined in the forecast module (cf. Baart et al, 2009). This module should foresee the translation of weather forecasts into a morphological forecast that predicts the morphological status of the coastal area. In the case of areas protected by flood protection structures, the latter provides essential input for the dyke breaching and flood forecast modules. Within the MICORE project the morphological forecast module used the XBeach model and was set-up to translate the physical parameters into Storm Impact Indicators (SIIs). These SIIs relate physical parameters to strategic and operational objectives and to actions, if required (Table 2.1). For each SII a forecast will be issued by each warning system at each demonstration site, linking the outcome to the decision support module. Based on pre-defined thresholds within the SIIs different levels of warnings can be issued, distinguishing no risk, medium risk and high risk. The warning system concept can be easily visualised using an online web interface based on open source software like Google Fusion Tables and Google MAPS that can be implemented within almost any existing website maintained by end users.

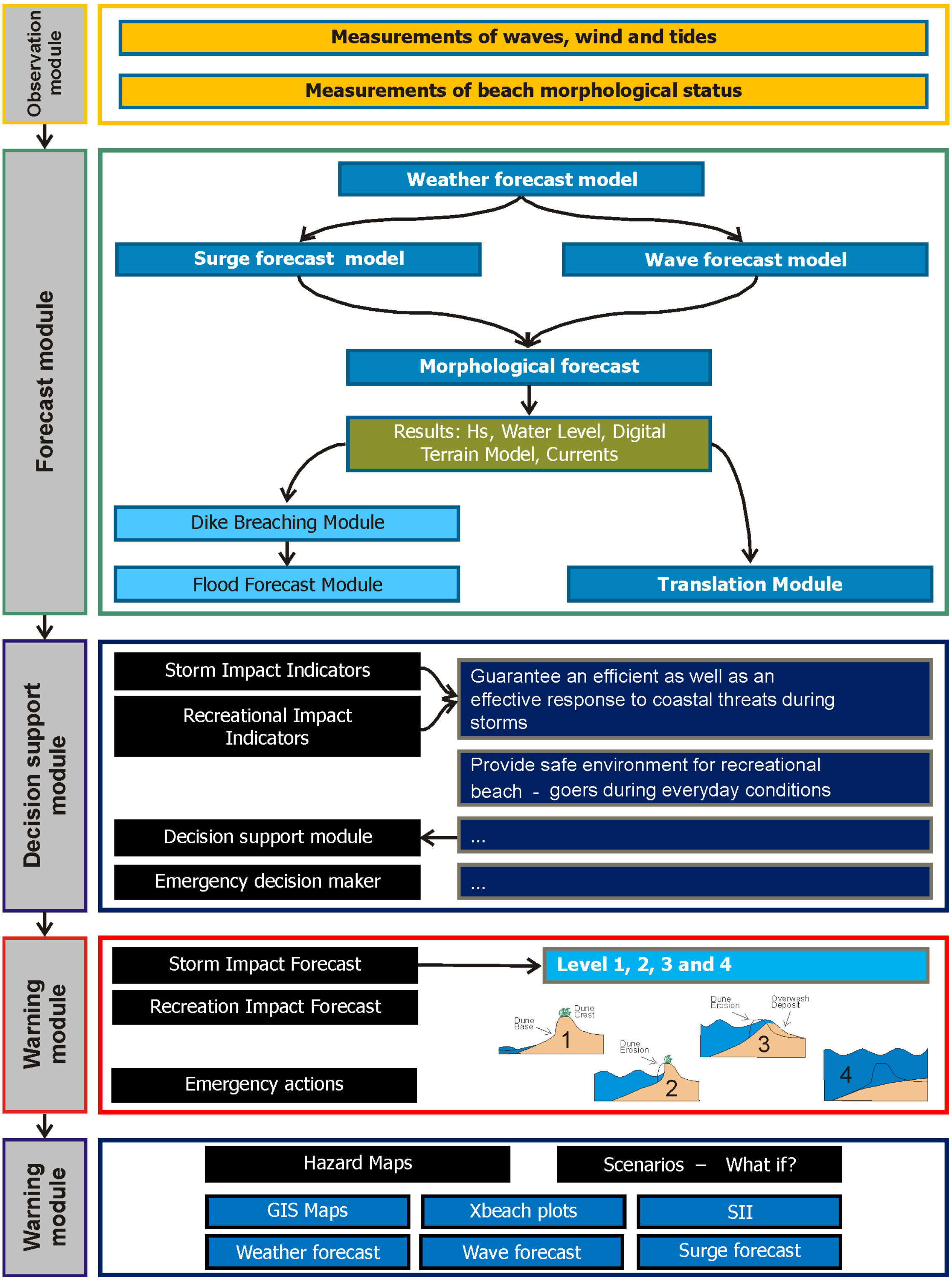

Figure 2.2. Generic concept of the MICORE Early Warning System prototype. The Storm Impact Level builds on the scale proposed by Sallenger (2000).

Within the MICORE project, the Dutch (cf. Baart et al, 2009) and Belgian (Fig. 2.3) test cases were set up at an early stage as examples for other partners within the consortium. In the example of

Fig. 2.3 the wave and water level predictions were provided by the Flemish Government and taken from an ftp-site or equivalent. Together with sediment data and the most recent bathymetric and topographic measurements, the input data for the XBeach model is kept up to date. The collected data is automatically transformed into the standard input format for XBeach that calculates the morphologic evolution of the coastal stretch for the given hydrodynamic conditions. The Storm Impact Indicators (SIIs) are derived from the XBeach model results by applying dedicated algorithms. Routines are set-up to automatically determine the most critical locations within a coastal section (Fig. 2.3a). The SIIs are calculated for each profile, during the entire simulation (Fig. 2.3b). The test case for the Belgian coastline visualizes (i) the status of all predefined SIIs, (ii) the dry beach width (DBW) of the profiles, merged into a line, (iii) time series of some output parameters of XBeach and (iv) the strategic objectives described in the SIIs.

An important lesson learned in the MICORE project is that once it becomes operational, the EWS should be running all the time with minimal intervention by operators. This is crucial to thoroughly test the systems robustness and ensure its stable operation in the event of an extreme storm. When the EWS predicts the exceedance of a predefined SII related threshold, a warning should be sent automatically to the competent end-user, e.g. the Civil Protection, which would then decide how to act accordingly. Informing the general public could be done by SMS and Internet interfaces but it is important to carefully consider the desired public response. Finally, it could be imagined that the end-users at the bottom scale of the safety chain, e.g. Fire Brigade, dyke inspectors, local police, may use portable GIS systems or even a Smartphone to visualize the areas where erosion and flooding are predicted to occur. One important point that must be always remembered during EWS development is simplicity. Not all users of the EWS may be competent in GIS technology and warning levels must be easy to understand (e.g. clear colour coding).

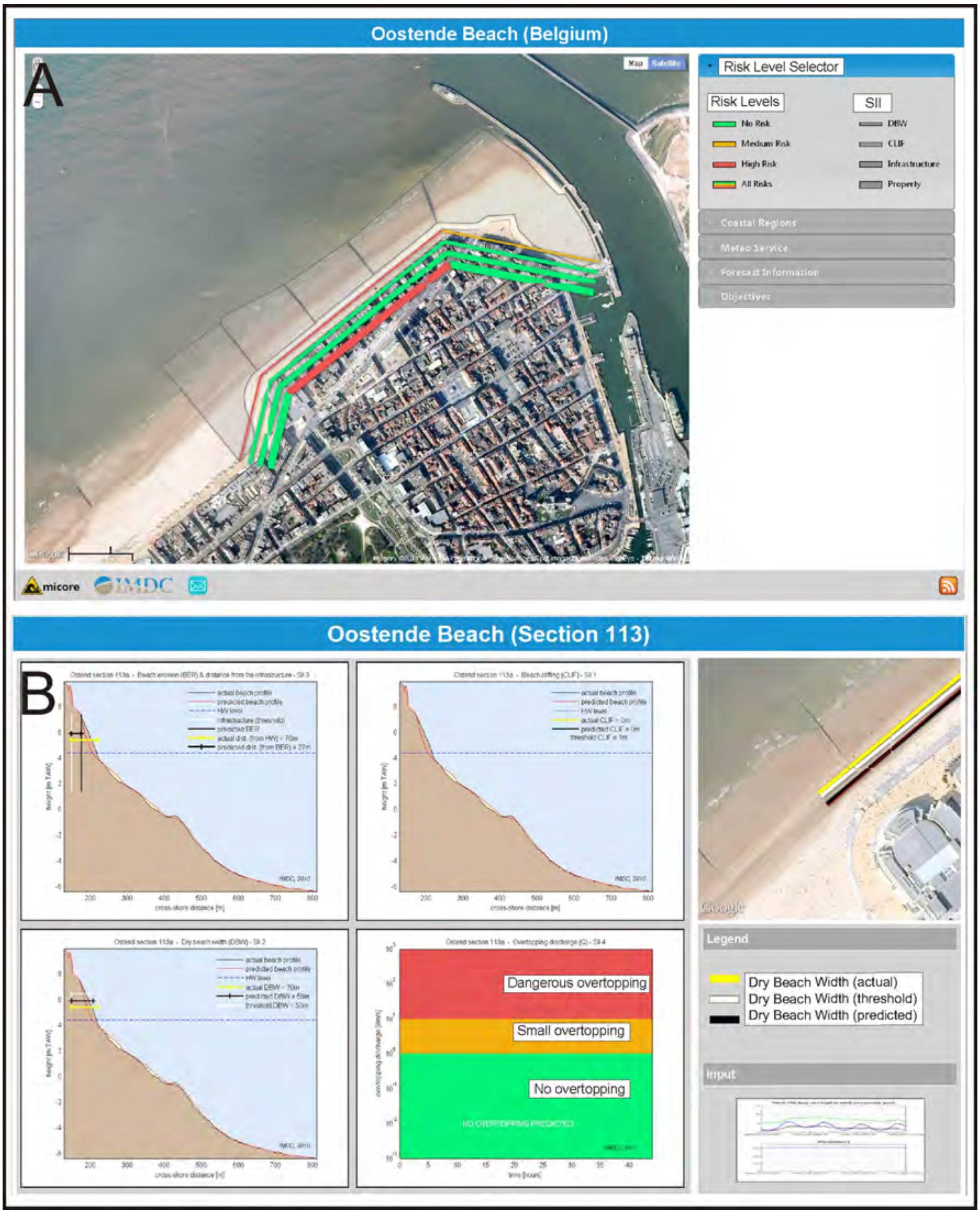

Figure 2.3. (a) Example of visualization of the Early Warning System in the test case for the Belgian coastline at Oostende Beach; (b) Example of details on the Early Warning System visualization on beach profiles. The system is accessible on http://gis.hostoi.com/oostende/.

2.7 Conclusions

Economic limitations mean it is simply not possible to design, fund and build schemes to protect vulnerable coastal areas from all anticipated events. Indeed, scenarios of climate change impacts from present models are diverse and cannot at present be relied on to give accurate forecast of future extreme event around coastal Europe. Therefore, there is an urgent need to develop new coastal management systems to deal with as yet unforeseen extreme events that fall outside the design limits of existing and future coastal structures. MICORE addressed this by revisiting historical extreme storm events and evaluated closely their impact on the human occupation of the coastal zone. It was found that an obstacle to database building is the freedom of access to meteorological and marine (waves, tide level) datasets.

It is recommended that a policy of free access is implemented at national and supranational level. It is also recommended that the database on storm impacts should be extended at EU level. The database initially set-up by MICORE should be maintained and continue to use an open-source approach like the OpenEarth one.

MICORE has addressed the problem of predicting morphological storm impacts and provided innovation through the development of a storm early warning system based on real-time data acquisition and assimilation into a range of state-of-the-art hydrodynamic and morphological models. This will initially only be available for the case study sites, but will be further exportable to the whole National coastline whether national governments may decide to adopt it. The Early Warning System developed within MICORE is providing the answers to the feedback loop of morphological changes that a beach undergoes during storm events. The outcome of the EWS should be coupled to other models to forecast flood and dyke breaching.

An important point to support the robustness of the Early Warning System is validation, which implies a certain continuity of morphological monitoring programme. It is recommended that EU member states start a national programme of coastal monitoring after high energy events using accurate and rapidly deployable methods like plane based Lidar. Additionally, for specific sites other more localized approaches must be sought (e.g. videomonitoring or X-band radar). Data access to this information must be at no cost for research purposes as this would underpin numerical model calibration.

One of the main reasons to start the MICORE project was to enhance the emergency response effectiveness of civil protection authorities in the case of a severe coastal storm; an objective that was thought to become even more relevant in the light of predicted climate change (including sea level rise). With the development of state-of-the-art real-time prediction systems, which would quantify storm impact including the process of erosion, an important new source of information would be available. It is recommended that national and regional government stimulate the setting up of these warning systems as well as support ancillary research development of the codes to make them more stable and reliable.

The MICORE project provided demonstration Early Warning System for rapid visualization of storm impacts. How and if this information will/should be used in actual crisis situations was outside the MICORE scope. It is however recommended that at the level of Civil Protection in member states marine storm risk becomes one of the considered hazards with appropriate safety and response plans. Post-event surveys of economical damages should be undertaken to justify future investment in adaptation strategies.

3 References

Alvarez-Ellacuria, A, Orfila, A., Olabarrieta, M., Gómez-Pujol, L., Medina, R. and Tintoré., J., 2009. An Alert System for Beach Hazard Management in the Balearic Islands. Coastal Management, 37, 569-584.

Baart, F., van der Kaaij, T., van Ormondt, M., van Dongeren, A., van Koningsveld, M., Roelvink, J. A., 2009. Real-time forecasting of morphological storm impacts: a case study in the Netherlands. J. Coastal Res. SI 56, 1617 – 1621.

Ciavola, P., Ferreira, O., Haerens, P., Van Koningsveld, M., Armaroli, C., 2011. Storm impacts along European coastlines. Part 2: lessons learned from the MICORE project. Environ. Sci. and Policy 14, 924-933. doi:10.1016/j.envsci.2011.05.009.

Ciavola, P., Ferreira, O., Haerens, P., Van Koningsveld, M., Armaroli, C., Lequeux, Q., 2011. Storm impacts along European coastlines. Part 1: the joint effort of the MICORE and ConHaz projects. Environ. Sci. and Policy 14, 912-923. doi:10.1016/j.envsci.2011.05.011.

Coastal Wiki, 2008. Socio-economic evaluation, accessed 30 March 2011, [http://www.coastalwiki.org/coastalwiki/Socio-economic_evaluation].

ConHaz Project, 2011. ConHaz – Costs of Natural Hazards, accessed 30 March 2011, [www.conhaz.org].

Davidson M.A., Van Koningsveld M., De Kruif A., Rawson J., Holman R.A., Lamberti A., Medina R., Kroon A., Aarninkhof S.G.J., 2007. The Coastview Project: developing video-derived coastal state indicators in support of coastal zone management. Coast. Eng. 54, 463-475.

Ferreira, O., 2006. The role of storm groups in the erosion of sandy coasts. Earth Surf. Process. Landforms, 31, 1058-1060.

Ferreira, Ó., Ciavola, P., Armaroli, C., Balouin, Y., Benavente, J., Del Río, L., Deserti, M., Esteves, L.S., Furmanczyk, K., Haerens, P., Matias, A., Perini, L., Taborda, R., Terefenko, P., Trifonova, E., Trouw, K., Valchev, N., Van Dongeren, A., Van Koningsveld, M.,Williams, J.J., 2009b. Coastal Storm Risk Assessment in Europe: Examples from 9 study sites. J. Coastal Res. SI 56, 1632 – 1635.

Ferreira, Ó., Vousdouskas, M., Ciavola, P., 2009a. Review of climate change impacts on storm occurrence. MICORE Report D.1.4, 123 pp. Available at https://www.micore.eu/file.php?id=4

Garnier, E. and Surville, S. F., 2010. La tempête Xynthia face à l'histoire. Croît Vif, Saintes, 2010, ISBN 978-2-36199-009-1, 176 pp.

Guedes Soares, C., Weisse, R., Alvarez, E. and Carretero, J.C., 2002. A 40 Years Hindcast in European Waters, Proceedings of the 21st International Conference on Offshore Mechanics and Arctic Engineering (OMAE 2002), Paper OMAE2002-2860.

Hamilton, J.M., 2007. Coastal landscape and the hedonic price of accommodation, Ecological Economics, 62, 594-602.

Houser, C. and Hamilton, S., 2009. Sensitivity of post-hurricane beach and dune recovery to event frequency. Earth Surf. Process. Landforms, 34, 613–628.

IOC, 2009. Hazard awareness and risk mitigation in integrated coastal area management. In: Manuals and Guides Number 50. ICAM Dossier Number 5, Intergovernmental Oceanographic Commission, UNESCO, Paris.

Jiménez, J., Kortenhaus, A., Anhalt, M., Plogmeier, C., Panayotis, P. and Wojciech, S., 2008. Guidelines on Coastal Flood Hazard Mapping. Floodsite Project report T03-08-02, 64 pp.

Jonkman S.N., Bočkarjova M., Kok M., Bernardini P., 2008. Integrated hydrodynamic and economic modelling of flood damage in the Netherlands, Ecological Economics, 66, 77-90.

Kolen, B., Slomp, R., van Balen, W., Terpstra, T., Bottema, M., Nieuwenhuis, S., 2010. Learning from French experiences with storm Xynthia - Damages after a flood. Ministry of Transport, Public Works and Water Management, Rijkswaterstaat, Centre for Water Management, 89p.

Lamb, H.H., 1991. Historical Storms of the North Sea, British Isles and Northwest Europe, Cambridge University Press, Cambridge, 204p.

Marchand, M. (Ed.), 2010. Concepts and Science for Coastal Erosion Management. Concise report for policy makers. Deltares, Delft. 2010.

Mercier, D., and Acerra, M., 2011. Xynthia, une tragédie prévisible. Place Publique, ISBN 978-2-84809-169-3.

Nicholls, R,. Mokrech,M., Richards, J., Bates, P., Walkden, M., Dickson, M., Jordan, A. and Milligan, J., 2005. Assessing coastal flood risk at specific sites and regional scales, Tyndall project T2.46 Technical Report.

Pfister, C, Garnier, E., Alcoforado, M..J., Wheeler, D., Luterbacher, J., Nunes, M. F., Taborda, J. P., 2010. The Meteorological framework and the cultural memory of three severe winter-storms in early eighteenth century Europe Climatic Change 101, 281-310.

Pompe, J.J. and Rinehart, J.R., 2008. Mitigating damage costs from hurricane strikes along the southeastern U.S. Coast: A role for insurance markets. Ocean and Coastal Management 51, 782–788.

Roelvink, D., Reniers, A., Van Dongeren, A., Van Thiel de Vries, J., McCall, R., and Lescinski, J., 2009. Modelling storm impacts on beaches, dunes and barrier islands. Coast. Eng. 56, 1133-1152.

Sallenger, A.H., 2000. Storm impact scale for barrier islands. J. Coastal Res. 16, 890-895.

Scawthorn, C., Blais, N., Seligson, H., Tate, E., Mifflin, E., Thomas, W., Murphy, J., Jones, C., 2006. HAZUS-MH flood loss estimation methodology. I: Overview and flood hazard characterization. Natural Hazards Review, 7, 60-71.

Southgate, H., N., 1995. The effects of wave chronology on medium and long term coastal morphology. Coastal Engineering, 26, 251-270.

Stockdon, H.F., Sallenger, A.H., Holman, R.A., Howd, P.A., 2007. A simple model for the spatially-variable coastal response to hurricanes. Marine Geology, 238, 1-20.

Van Dongeren, A., Bolle, A., Vousdoukas, M., Plomaritis, T., Eftimova, P., Williams, J., Armaroli, C., Idier, D., Van Geer, P., Van Thiel de Vries, J., Haerens, P., Taborda, R., Benavente, J., Trifonova, E., Ciavola, P., Balouin, Y., Roelvink, D., 2009. Micore: dune erosion and overwash model validation with data from nine European field sites. Proceedings of Coastal Dynamics 2009: Impacts of Human Activities on Dynamic Coastal Processes, pp. 1-15, doi:10.1142/9789814282475_0084.

Van Koningsveld, M., Davidson, M.A., , Huntley, D.A., Medina, R. , Aarninkhof, S.G.J., Jimenez, J., Ridgewell, J. , de Kruif, A., 2007. A critical review of the CoastView project: Recent and future developments in coastal management video systems. Coast. Eng. 54, 567-576.

Van Koningsveld, M., Davidson, M.A., Huntley, D.A., 2005. Matching Science with Coastal Management Needs; The Search for Appropriate Coastal State Indicators. J. Coastal Res. 21, 399 – 411.

Van Koningsveld, M., de Boer, G.J., Baart, F., Damsma, T., den Heijer, K., van Geer P., de Sonneville, B., 2010. OpenEarth: inter-company management of data, models, tools and knowledge. Proceedings WODCON XIX Conference Beijing, China, 2010.

Van Koningsveld, M., Mulder, J. P. M., 2004. Sustainable Coastal Policy Developments in the Netherlands. A Systematic Approach Revealed. J. Coastal Res. 20, 375-385.

Van Koningsveld, M.; Stive, M. J. F.; Mulder, J. P. M.; de Vriend, H. J.; Dunsbergen, D. W., Ruessink, B. G., 2003. Usefulness and Effectiveness of Coastal Research. A Matter of perception? J. Coastal Res. 19, 441-461.

Van Rijn, L. C., Walstra, D. J. R, Grasmeijer, B., Sutherland, J., Pan, S.and Sierra J. P., 2003. The predictability of cross-shore bed evolution of sandy beaches at the time scale of storms and seasons using process-based profile models. Coastal Engineering, 47, 295-327.

West, J.J., Small, M.J., Dowlatabadi, H., 2001. Storms, investor decisions, and the economic impacts of sea-level rise, Climatic Change, 48, 317–342.

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