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Morphological Impacts
and COastal Risks induced
by Extreme storm events

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EARLY WARNING SYSTEMS FOR COASTAL STORM RISK

Five key outcomes
from the MICORE project

COOPERATION

MICORE: Morphological Impacts and COastal Risks induced by Extreme storm events

Recent extreme hydrometeorological events in coastal areas have highlighted the devastating effects that can occur from hazards of marine origin. The experiences of Hurricane Katrina that struck the city of New Orleans as well as the two massive tsunamis in the Indian Ocean and Japan tragically demonstrate what can go wrong when engineering design is subjected to forcing beyond its design limits and civil evacuation and management plans fail.

The 1953 storm surge event in the North Sea that resulted in over 2000 deaths and extensive flooding across The Netherlands, England, Belgium and Scotland is a pertinent reminder that Europe is not immune to coastal threats. With approximately 185 000 km of coastline, Europe encompasses a diverse range of coastal environments, including pristine natural habitats, large coastal cities protected by offshore structures, low-lying sandy dune fields, steep rocky cliffs, exposed oceanic coastlines and enclosed sea basins. Each coastal type presents itself with a unique set of issues for coastal managers to deal with.

Due to economic constraints it is simply not possible to design, fund and build engineering schemes to protect vulnerable coastal areas across Europe from every extreme event foreseeable. Indeed in a rapidly-changing global climate there is a considerable degree of uncertainty as to how extreme events will behave in the future, particularly with regards to the intensity, magnitude and duration of coastal storms. Hence there is a pressing need to develop new coastal management systems; ones that can accommodate this uncertainty and minimise the impacts of extreme conditions that fall outside the design limits of both current and future coastal structures.

In this context, the ability to predict the imminent arrival of coastal threats is a valuable tool for civil protection agencies in order to prepare themselves and, if need be, execute the appropriate hazard-reduction measures. Developments in climate modelling have resulted in coastal storm predictions of a level of sophistication to know quite precisely their timing, intensity and other important storm variables up to approximately three days in advance. Building on from this is a way of knowing and communicating in real-time how these storm forcing predictions translate to morphological impacts and risk scenarios in the coastal zone. The work undertaken throughout the MICORE project has been performed to make significant advancements in this area.

THE MICORE PROJECT

The MICORE project (Morphological Impacts and COastal Risks induced by Extreme storm events) was a European initiative comprising 16 different research, commercial and government institutions across nine countries. The overall aims of the project were to set-up and demonstrate an on-line Early Warning System (EWS) for the reliable prediction of morphological impacts due to marine storm events in support of civil protection mitigation strategies. It commenced in June 2008 and had a project duration of 40 months.

The project focused on nine case-study sites (corresponding to the nine European countries involved). At all sites a number of individual work phases were conducted in order to reach the end goal of setting up a prototype EWS for coastal storm risk. These phases included: **01** a review of historical coastal storm events; **02** field monitoring of storm impacts that occurred throughout the project; **03** validating and testing a new as well as existing coastal storm models using the field data results; **04** the development of a prototype EWS; and **05** linking early warnings to civil protection protocols. The use of these nine unique and morphologically diverse sites made the approach developed as generic as possible and demonstrated the robustness of the methodology.

Given that coastal storm predictions are typically provided up to a three-day prediction window, the MICORE project specifically related to short-term emergency response rather than on longer-term strategic objectives. As such it is a clear example of a practice-oriented research programme, providing practical outcomes for coastal management that are useful and applicable to end-users.

contents *five key outcomes*

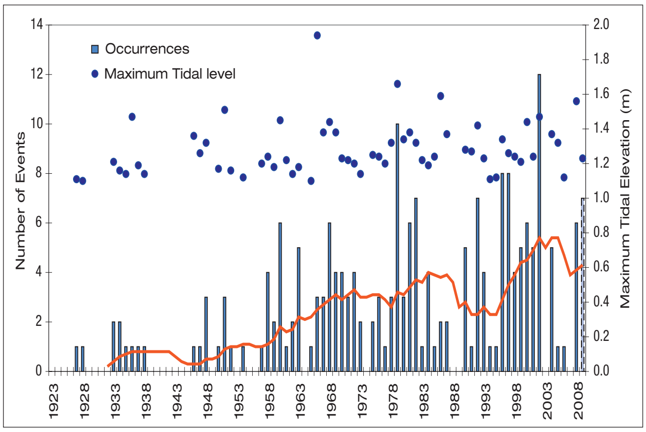
For a more detailed explanation of the methodologies used and results obtained for all work packages of the MICORE project, please see the project's website at **www.micore.eu.**

01 Understanding past coastal storm trends across Europe

1	Italy	Lido di Dante Lido di Classe	Natural with dunes, river mouths - defended coastline, infrastructure, high touristic value, microtidal	8 km
2	Portugal	Praia de Faro	Barrier-islands, dunes, overwashes, inlets, high touristic value, infrastructure, mesotidal	8 km
3	Spain	La Victoria Camposoto Beach	Urban beach, high touristic value, defended coastline, infrastructure - natural sand spit with dunes, overwashes, river mouth, salt marsh, touristic value, mesotidal	10 km
4	France	Lido of Sète to Marseillan	Low barrier island, dunes, high touristic value, defended coastline, infrastructure, microtidal	13 km
5	United Kingdom	Dee Estuary	Estuarine site with high occupation and hard engineering, defended coastline, infrastructure, sand dunes, tidal flats, mud flats, salt marsh, high touristic value, river mouth, macrotidal	10 km
6	The Netherlands	Egmond	Nourished beach, dunes, high touristic value, mesotidal	5 km
7	Belgium	Mariakerke	Wide dissipative urban beach regularly nourished, infrastructure, defended coastline, high touristic value, macrotidal	11 km
8	Poland	Dziwnow	Sand spit with low dunes; river mouth, protected coastline, nourishments to protect infrastructure, high touristic value, non-tidal	15 km
9	Bulgaria	Kamchia Shkorpilovtsi	Open beach on the Black Sea, dunes, river mouths, touristic value, non-tidal	13 km

To gain an understanding of past coastal storm trends across Europe, a total of 58 long-term (i.e. the past 30+ years) time-series of various storminess indicators were assembled and analysed at 12 unique sites. These indicators included elevated water levels, large waves and strong wind speeds, with their selection depending on data availability as well as the specific exposure conditions of each site.

Significantly, while some localised trends were observed (see above and right), **no European-wide trend of past coastal storminess was evident.** This however is not to say that global climate change consequences (e.g., sea temperature increase, sea level rise) will not have an influence on European storminess and storminess impacts in the future. Rather, for the existing and available datasets, shorter-term (i.e. year-to-year) fluctuations in storminess dominate over any potential longer-term signal.



Occurrences of storm surge events (1923-2008) in Venice Italy. Red-line represents a 10-year running average of surge events occurring per year and highlights a general pattern of events becoming more frequent.

02 Demonstrating new data and knowledge sharing protocols: the OpenEarth approach

A common problem for multi-institutional/multi-national R&D programmes is that a significant part of the budget is often spent on setting up some basic infrastructure for data and knowledge sharing. Not only is this project-by-project approach inefficient, it also means that data and knowledge developed over the course of a programme can become either difficult to access, indecipherable or, at worst case, lost over time.

To overcome these issues, the MICORE project adopted a new protocol for managing data and knowledge known as OpenEarth. Instead of existing specifically for a single project, OpenEarth (www.openearth.eu) is a project-transcending database whereby multiple projects can store and actively manage their data, model systems and/or analysis tools. It is 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. By being a common database for many projects OpenEarth promotes project collaboration and skill sharing, for example this generic data-visualisation tool using Google Earth (right). The many different stakeholders involved in the database also provide a way of guaranteeing its sustainability into the future.

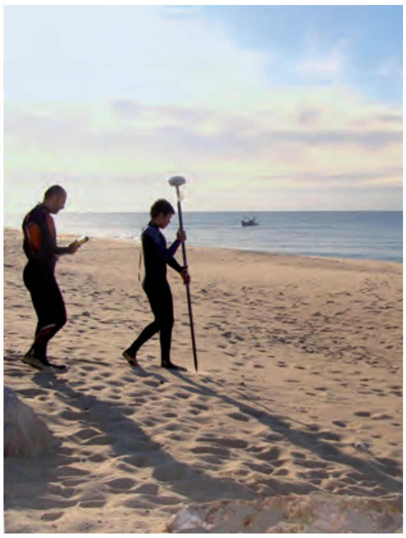
The MICORE project demonstrated that it is advantageous to store and exchange data from various organisations and countries in a multi-project database like OpenEarth. By taking this approach a lot of time and money was saved in the development of such infrastructure. Perhaps its greatest benefit however is that the abundance of quality-controlled data collected throughout the project, such as field measurements of storm impacts (see below) and historical storm data (previous page) will be available for easy use in future R&D programmes, something that is not often the case when projects come to a close.

A data-visualisation tool using Google Earth that is available for use in the OpenEarth database. This example illustrates beach profile and shoreline measurements collected on the coastline of The Netherlands

MEASURING STORM IMPACTS IN THE FIELD

In order to have confidence in the storm impact modelling and the Early Warning System as a whole, model simulations need to be validated against real-world events. Over the course of two winter storm periods (2008 – 2010), MICORE partners undertook a series of pre- and post-storm field measurements whenever a major event occurred. This consisted of a variety of beach measurement techniques, including topographic and bathymetric surveys (using GPS equipment, echo-sounders and high-resolution LiDAR flights), surf-zone current velocity measurements, coastal video imaging technology and sediment sampling.

One particularly large event to take place was a cluster of five storms that occurred over the 2009/2010 new-year period in southern Portugal. Eighteen days of persistently large swell waves of up to 4 metres resulted in substantial erosion of the coastline and the destruction of several seaside houses. Three-dimensional GPS beach surveys (see right) were performed almost daily over this period by MICORE researchers in order to fully capture the rapidly-changing beach response. This event was then simulated using the XBeach model, with the simulation showing a reasonable comparison to the measured beach change.



Three-dimensional beach surveying using GPS at Praia de Faro, Portugal.

03 Expanding and validating a new open-source model of coastal storm impacts

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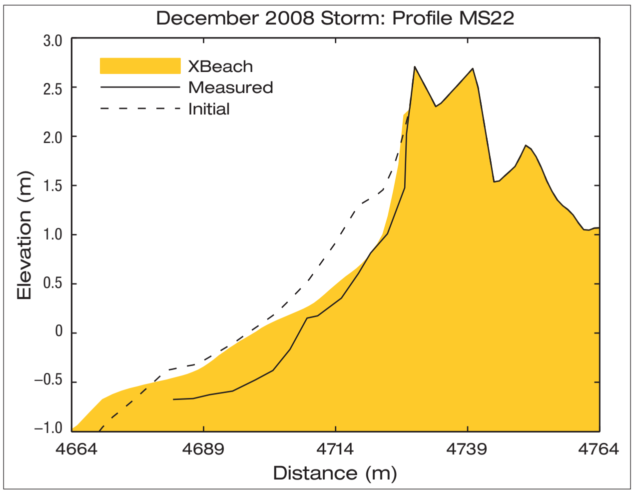
An integral part of an Early Warning System for coastal storm risk is the morphological (coastal erosion and overflow) forecast module. As shown in the diagram on the following page, this module translates forecasts of offshore forcing parameters (e.g. surge and wave forecasts) into information about storm impacts in the coastal zone. For the MICORE project this has been performed using the numerical model XBeach, an open-source, freeware program initially developed for use by the US Army Corps of Engineers.

Within the MICORE project the XBeach model was expanded and validated using the extensive collection of storm impact field data gathered at each of the nine sites (see box on previous page). Since each field site represents unique topographic and environmental conditions, this enabled the functionality of the model under various circumstances to be tested for greater use throughout Europe and worldwide. Some results are shown below for the Italian and Bulgarian study sites. For the Italian site, the performance of the model focused on how well it simulates dune erosion during storms and for this particular storm event in December 2008 the results below show that the post-storm eroded dune face is well-replicated by the model. The focus in the Bulgarian case meanwhile was on wave run-up and for this large storm in March 2010 the model results also closely match the measured wave run-up levels.

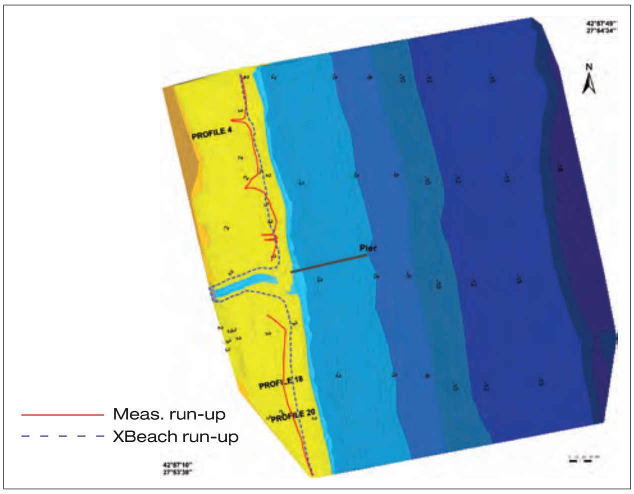
Important knowledge transfer took place over the course of the project between geoscientists that have knowledge about local and regional coastal conditions and numerical model developers. The end result is that this has ultimately led to a model that has been incorporated in all of the prototype Early Warning Systems.

A storm event in December 2008 at Lido di Classe, Northern Italy.



XBeach modelling and validation of dune erosion from that event.

Wave run-up during a storm event in March 2010 at Kamchia Shkorpilovtsi, Bulgaria.



Validation of wave run-up estimations using 2D XBeach modelling of the same event.

04 Operating on-line prototype Early Warning Systems for coastal storm risk

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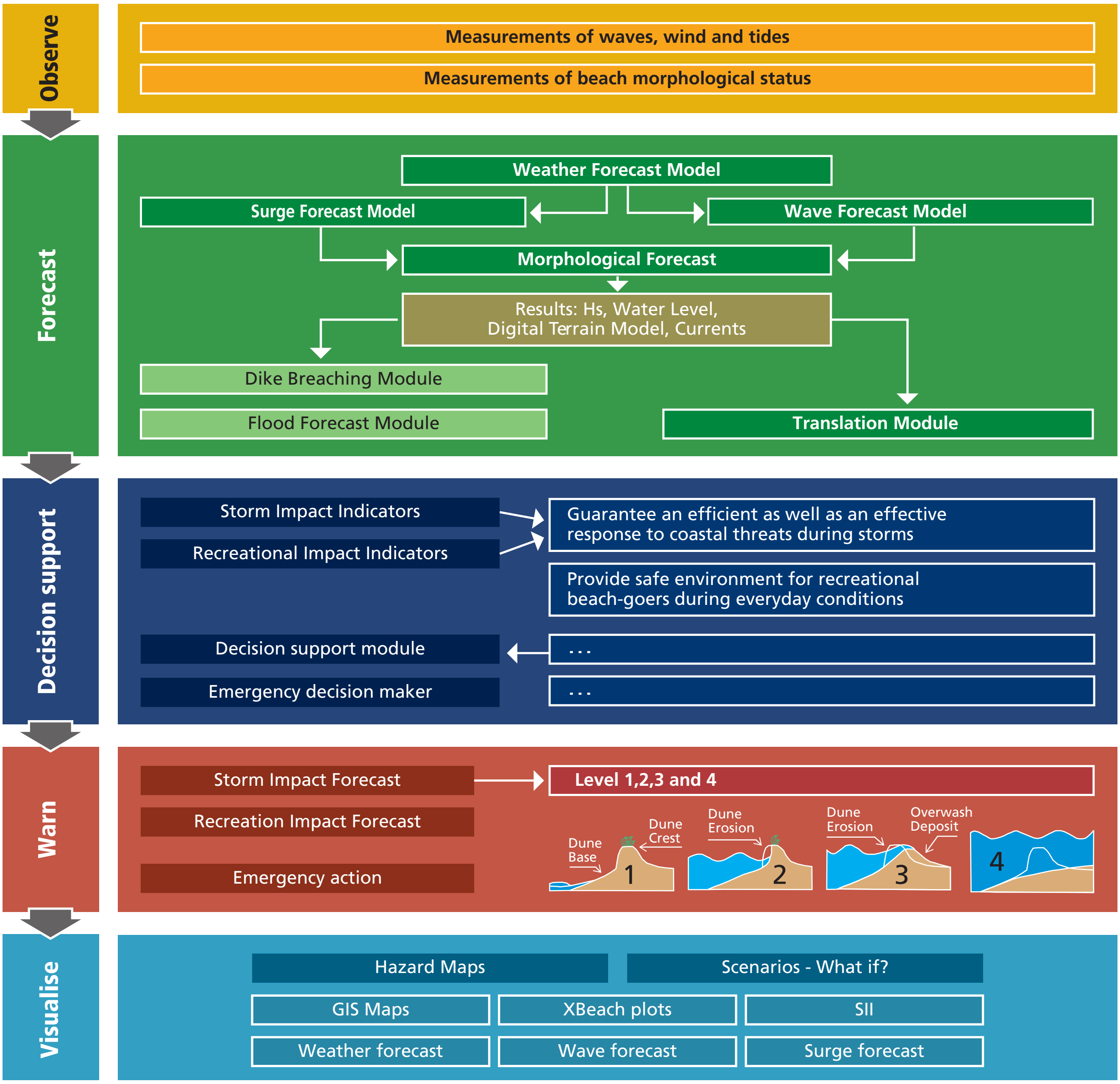

A generic structure for an Early Warning System of coastal risk (above) was developed and found to be adaptable to each of the nine prototype systems. This structure is based on five essential modules:

- An **observation module**, where weather, wave, surge and initial beach profile measurements necessary for numerical modelling are collected
- A **forecast module**, consisting of the numerical model forecasts of weather, wave, surge and morphology (i.e. XBeach)
- A **decision support module**, containing tools (i.e. Storm Impact Indicators and hazard maps) to assist decision making
- A **warning module**, where warnings are issued according to various site-specific thresholds
- A **visualisation module**, displaying on-line information to assist end-users.

Each prototype EWS was operated in on-line mode, executing this chain of modules daily. Running the EWS in daily mode, instead of only during extreme offshore conditions, was found to be crucial in testing the system's robustness and gaining additional confidence by end-users in its overall performance. It also expanded the applicability of the EWS to more day-to-day functions such as beach safety.

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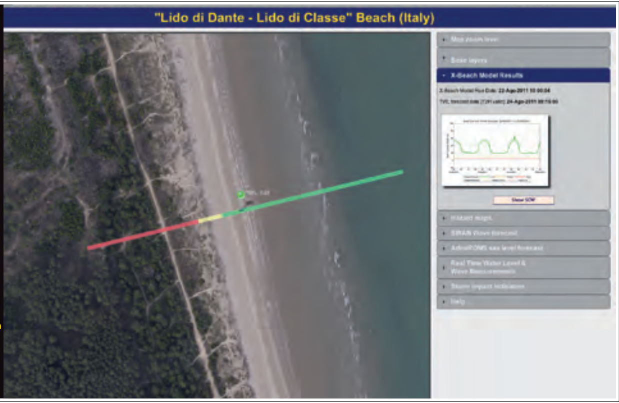
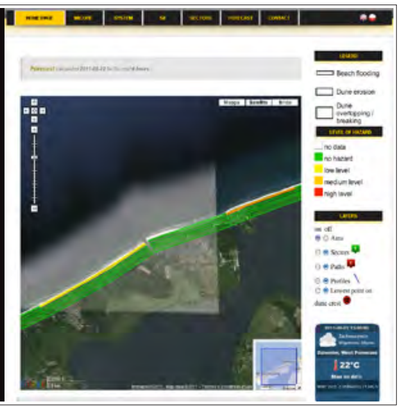
Early Warning Systems



Italy

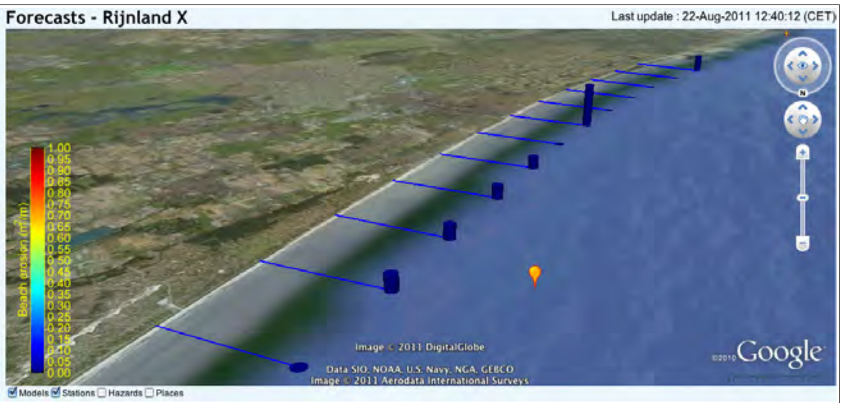
Belgium

France



Poland

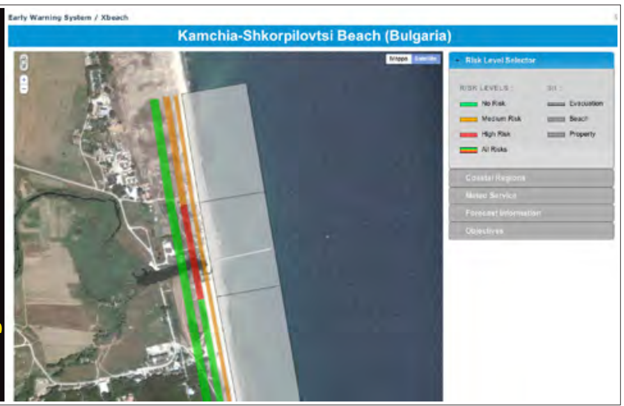
Spain



The Netherlands

United Kingdom

Portugal



Bulgaria

Example EWS: Ostend Beach, Belgium

http://gis.hostoi.com/oostende

Located in the middle of the Belgian coastline, Ostend Beach is a densely-populated coastal town featuring a promenade and numerous apartment blocks built on a dyke protected by a seawall.

The EWS at this site focuses on advising civil protection authorities on the predicted state of four vital Storm Impact Indicators:

1. The width of dry beach available for **recreational activities**
2. The existence and height of **potentially-hazardous beach scarps**
3. The distance between the waterline and **vulnerable infrastructure**
4. The overtopping discharge of any sea water over the dyke as an indication of **flood risk to property**.

The predicted levels of risk associated with each indicator (**red** = high, **orange** = medium, **green** = no risk) are visualised for different coastal sections and simply presented as four cross-shore bands overlaid onto an interactive Google Maps display. In this way civil protection authorities can quickly identify the whereabouts and type of any potentially hazardous situation along Ostend Beach. More detailed information about the indicators and the predicted change in the entire beach profile are also accessible through the website. In the future, this way of visualising the EWS can be expanded to cover the entire Belgian coastline and beyond.

The Early Warning System for Ostend Beach, Belgium. The example presented is for a design storm event with a 1000-year return period. As can be seen by the red colour bands in the Google Maps display, this hypothetical extreme storm event suggests "High Risk" scenarios in terms of the dry beach width available for recreational activities (the "DBW" colour band) and property flooding due to large amounts of sea water overtopping the dyke (the "Property" colour band).

05 Building better bridges between coastal experts and end-users

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A critical point discovered by the MICORE project was that very few European countries currently have in place civil protection schemes for coastal storm risk. For the few countries that do, these schemes are based on meteorological warnings that do not necessarily take into account the vulnerability of a certain coastal area and its site-specific characteristics (i.e. the type of morphology and the degree of urbanisation). A reason for this lack of schemes when it comes to coastal storms (as opposed to protection schemes for flooding for example) is in part due to the gap that exists between end-users making decisions about civil protection on the coast and coastal experts with a deep understanding about complex coastal processes.

MICORE actively sought to encourage more co-operation between coastal experts and end-users. One of the main ways of achieving this was by adopting the "Frame of Reference" method, a generic decision-making approach aimed at matching coastal science output with end-user needs through the use of use of Storm Impact Indicators (see box below). Regular meetings were held between the two groups to decide upon the most suitable indicators for each site according to its site-specific issues. It was found that simply discussing these issues helped raise awareness on both sides of how the important problem of coastal storm hazard mitigation can be better managed in the future.

STORM IMPACT INDICATORS (SIIs)

Physical parameters such as dune erosion volumes, flow velocities, wave run-up levels and dyke overtopping discharges are used frequently by coastal experts to quantify the impacts of storm events. From an end-user perspective however these parameters are difficult to use operationally, where quick decisions have to be made based on the available information. The forecast and decision support modules for the Early Warning System therefore focused on delivering output of so-called Storm Impact Indicators (SIIs). SIIs are a quantification of the coastal system in a form suitable for decision making.

Linked to these SIIs are pre-defined threshold levels that trigger various degrees of action by authorities.

One such example of an SII is the Safe Corridor Width (below), which is used in the Italian EWS as a measure of how much dry beach width exists between the dune foot and waterline to allow for safe passage by beach users. If this width becomes too narrow, then people on the beach could be putting their lives at risk by having no means of escaping the hazardous marine conditions. In this case the appropriate action is to close the beach using beach signage.

Strategic Objective	Operational Objective	Quantitative State Concept	Benchmarking Desired State	Benchmarking Current State	Intervention Procedure	Evaluation Procedure
Prevent loss of life due to hazardous maritime conditions	Signal that the beach is closed in hazardous conditions	**Safe Corridor Width** (SCW), defined as the distance between the dune foot and the total water level	**Low hazard**: SCW is greater than 10 metres; **Medium hazard**: SCW is between 5 and 10 metres; **High hazard**: SCW is less than 5 metres.	Time-series of predicted SCW	Place signage on the beach to indicate the beach is closed	Check that signage was placed and that no loss of life occurred.

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Conclusion and recommendations

The work of MICORE has made significant innovations in the area of coastal storm risk management and coastal civil protection schemes. The development of nine fully-operational Early Warning Systems for coastal storm risk show that such an on-line tool based on real-time data acquisition and using a range of state-of-the-art hydrodynamic and morphological models is feasible for vulnerable areas across Europe. These prototype EWSs lay the foundation for a greater roll-out across Europe, by adopting the following principles:

- Using a generic structure adaptable to a range of different coastal environments
- Using free and open-source software without the need for commercial licenses
- Catering the functionality of the EWS to the needs of end-users.

It is therefore recommended that resources be placed into the development of larger-scale Early Warning System schemes for coastal storm risk, at regional and national levels as well as European wide. These schemes could be merged with existing schemes, such as those already in existence for tsunamis and terrestrial flooding. Furthermore, continued monitoring of future coastal storms using accurate and rapidly-deployable survey methods is crucial to gaining additional understanding as to the changing nature of storm systems across Europe and for further EWS testing.

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Further Information

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