Coupling terrestrial and marine datasets for coastal hazard assessment and risk reduction in changing environments

DURATION: 2012 – 2013

TARGET COUNTRIES: Euro-Mediterranean countries

PARTNERS INVOLVED:
Coordinating Centre: ICoD La Valletta, Malta
Other Centres: CERG Strasbourg, France
Other Partners: Università di Modena e Reggio Emilia (UNIMORE, Italy), Université de Caen Basse-Normandie (UNICAEN, France), Consiglio Nazionale delle Ricerche: Istituto di Scienze Marine (ISM, Bologna, Italy); CNR-IRPI (Padua, Italy)

OBJECTIVES OF THE PROJECT

Preliminary note:
The global objectives of this activity fit in priority within the line of action "2.C - Impact of climate change and environment" and secondarily within the line of action "2.B Risk mapping and vulnerability".
Background:
Coastal hazards are a topical issue nowadays which involves scientists and stakeholders trying to define the best procedures to face risks and increase community resilience, either reducing natural hazards or diminishing vulnerability. Coastal environments are particularly sensitive and susceptible to relevant damages in case of both sudden events (e.g., tsunamis, landslides, storm surges) and long-term processes (e.g., sea-level changes).
Coastal instability phenomena which cause heavy socio-economic consequences and fatalities have increased significantly in recent years due to global changes, which determine more frequent extreme meteorological events, and progressive urbanisation of coastal areas, especially in developing countries. Furthermore, if coastlines are located in tectonically active areas, such as the Mediterranean Sea, the situation can be even more problematic.
The study areas are the Normandy coast (France) and the coasts of the Island of Malta, which show different morphoclimatic and tectonic setting, but which have been and are at present affected by significant changes in sea level since the Last Glacial Maximum, when the sea level was some 120 metres lower than present. Previous research carried out in the frame of the "Coastline at risk" project has shown that several landslides along the coastlines of Normandy and Malta are extending well below the sea level.
The Projects involves two specialised centres, CERG and ICoD. The expertise of the academic partners (see above) guarantees the success of the research activities. Co-funding to the research will be made available by each of the partners.

Global objectives 2012 - 2013:
• Delivering an original contribution and new directives for risk reduction in coastal areas taking into account historical and possible future climate changes based on the outputs of the CERG 2009 - 11 Project "Coastlines at Risk: methods for multi-hazards assessment".
• In the absence of documented research aiming at a joint knowledge of 'land and sea' environments and related risks, this project aims to develop a multidisciplinary methodological approach which is capable to integrate terrestrial and marine datasets.
• Focusing on two study areas where significant data have been collected within the "Coastline at Risk" Project with respect to terrestrial processes and related risks. Special emphasis will be devoted to landslides, taking also into consideration the influence of climate change and coastal erosion on sea-level rise, as possible conditioning factors.
• Application of a multidisciplinary geomorphological, engineering-geological and geophysical approach to recognise landforms which are presently under the sea level, but which were not in very recent geological periods and which may be still active (e.g., faults, landslide accumulations, sand bars).
• A better understanding of landslide kinematics through generation of knowledge of their submarine spatial and temporal development. This knowledge would of course enable to provide a more comprehensive picture of landslide hazard conditions.
• Generation of information and knowledge related to risk reduction through pilot studies, with the possibility of extending the methodology to other European coastal areas, improving their environmental resilience.
• The Projects is intended to have a European dimension and a significant impact within the activities of the "European and Mediterranean Major Hazards Agreement".

Specific yearly objectives :

2012:
1) Integration and coupling of existing terrestrial and submarine datasets;
2) Outline of marine level variations since the LGM;
3) Acquiring new data on submarine landforms and processes along the Normandy and Malta coastlines selecting pilot-areas where to conduct multi-beam surveys;
4) Continue the monitoring of coastal processes initiated within the "Coastline at risk" Project.

2013:
1) Integration of newly acquired data (terrestrial and submarine) with the existing ones;

2) Propose a temporal reconstruction of the evolution of the study areas, with particular emphasis on creating maps when the sea levels was below the actual one;
3) Outline a methodology for hazard assessment taking into account climate and sea level changes (thus also focusing on terrestrial and submarine information).
4) Monitoring of coastal processes.

EXPECTED RESULTS

2012 :
Definition and assessment of the relationships between terrestrial and submarine morphological features in relation to landslide processes.

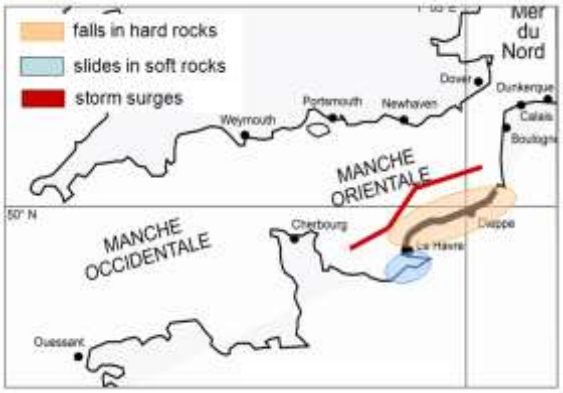
2013 :
1) Improvement of existing hazard maps taking into account issues related to climate change (sea-level, more frequent extreme meteorological events etc.);
2) Acquisition of necessary knowledge to define methods to perform landslide monitoring offshore (on the seafloor);
3) Definition of protocols which can be used in other coastal environments for risk reduction and resilience improvement.
The expected results could be used by others to prepare a guideline on climate change impact and integrate in the BE-SAFE-NET website.

RESULTS OBTAINED PREVIOUSLY (if any)

The proposing partners have obtained significant results which can be functional to the development of the present Project within the CERG 2009-11 Project "Coastline at risk: methods for multi-hazard assessment".

RESULTS OBTAINED IN 2012

Study sites in Normandy coast
Along the Normandy coast, the research focuses on landslides and storm surges: the landslides studied are falls in hard rocks (cliff falls, debris fall and boulder and rock falls) and slides in soft rocks.



Location of the main processes in the study sites in Normandy

Two selecting pilot areas are:
The Villerville-Cricqueboeuf Landslides (Lower Normandy Coast, France).
The 12 km long Pays d'Auge coast in lower Normandy is periodically affected by rotational and translational landslide since several centuries. These landslides occurred in marly formations covered by chalks and quaternary deposits. In January 1982, major landslides have caused several damages (roads, destroyed houses). The affected slopes are the Cirque des Graves at the West of the city of Villerville and the Fosses du Macre at the East of the city of Cricqueboeuf.

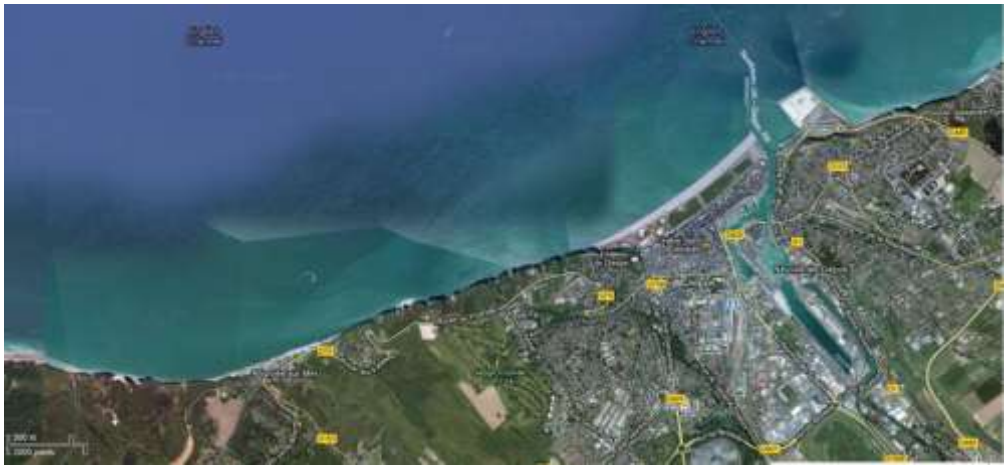

Aerial view of the Villerville-Cricqueboeuf landslide in Lower Normandy

The Pays d'Auge Plateau is bordered on the North by high cliffs of up to 140 m. The topography and geology of the cliffs are various. The main scarp is composed of Cenomanian chalk overlying glauconitic sands. Below, a thick layer of marls is on top of the sandy limestone of Hennequeville which shapes the cliff toe and constitutes a reef flat between Trouville and the Pointe du Heurt. Below the scarp, the slope is more gentle and composed of an accumulation of thick superficial heterogeneous materials (blocks and debris of chalk and flints, loamy sands). These formations have been placed during the Upper Pleistocene period. For coastal risk assessment, the main issues are focused on:

- reconstruction of the long term evolution of the instable slopes;
- definition of the morphology and internal structure of the landslides;
- integration of terrestrial and marine datasets,
- study of the relationship between the predisposal and triggering factors (i.e. the influence of climate change and coastal erosion on sea-level rise),
- definition of the dynamic of the active landslides and the different threshold in order to define a specific 'Landslide Early Warning System'.

Hard rock cliff in Upper Normandy

The other selecting pilot area is located in Upper Normandy along the hard rock cliff subjected to landslides (cliff falls, debris fall and boulder and rock falls) and storm surges, in each part of Dieppe arbour from Cap d'Ailly (Varengeville) at the west part to Puys at the Est part of the study site:



Selecting pilot area in Upper Normandy in each part of Dieppe harbour from Cap d'Ailly (Varengeville) to Puys (Est part).

For coastal hazard assessment, three issues coupling terrestrial and submarine datasets are requiring for:

- definition of the production of debris (flint) from cliff erosion which feeding intertidal sedimentary stock, gravel beach,
- definition of infratidal sandy inputs on gravel beach, which participate to the functioning of these accumulation,
- definition of the impacts of harbor jetty on infratidal sedimentary drift (onshore-off shore and longshore drift).

Study sites in Maltese coast

During this year of research, the existing terrestrial and submarine datasets have been collected through a bibliographic and archive research.

A multidisciplinary approach to integrate and couple terrestrial and submarine datasets has been defined, which foresees contributions from geomorphology, marine geology, geophysics and engineering geology.

The newly acquired submarine data (see specific following section) and the elaboration of a detailed DTM of the seafloor along the north-west coast of the Island of Malta has enabled to outline for the first time the submerged landforms of this stretch of coast. A first attempt to compare terrestrial and submarine landforms has been performed with the aim of producing, during the second year of research, a comprehensive geomorphological map capable to illustrate terrestrial and submarine landforms in the same sheet, which could serve as a useful tool for hazard assessment.

Work package 1 (prepared by CERG, IcoD, Università di Modena e Reggio Emilia, Université de Caen Basse-Normandie, Consiglio Nazionale delle Ricerche: Istituto di Scienze Marine; CNR-IRPI):

Description:
Integration and coupling of existing terrestrial and submarine datasets;
Associated deliverables:

Normandy case study

For the two sites, all existing terrestrial and submarine datasets have been integrate in a GIS platform (Arcgis 10). The main efforts have been focused in the research and the integration of the submarine datasets (bathymetric characteristics, sedimentary characteristics of sea floor (Figure 3), beach's sedimentary stock evolution on the beaches and at the cliffs foot). This information is very important especially to assess the sandy exchanges between near shore zone and sub-aerial beach.

Several maps, DTM (Digital Terrain Model) at the different scales and resolutions, meteorological data and hydrodynamic conditions (wave climate, tide regime, storm sea level …) have been collected from the bibliography and previous researches. Also, historical census events allow to know (1) the types of atmospheric circulation (2) meteorological conditions (thresholds), and (3) flood extension.

The quality and the density of information are very diverse for the test sites. In example, for the Villerville-Cricqueboeuf landslides, the bathymetric data are relatively low and incomplete. A multibeam sonar survey has been carried out by the SHOM (French Hydrographic Office) but the area covered by the survey stopped at the West part of the Villerville town. At the East part, only information provided by the submarine paper map is available (Figure 4).

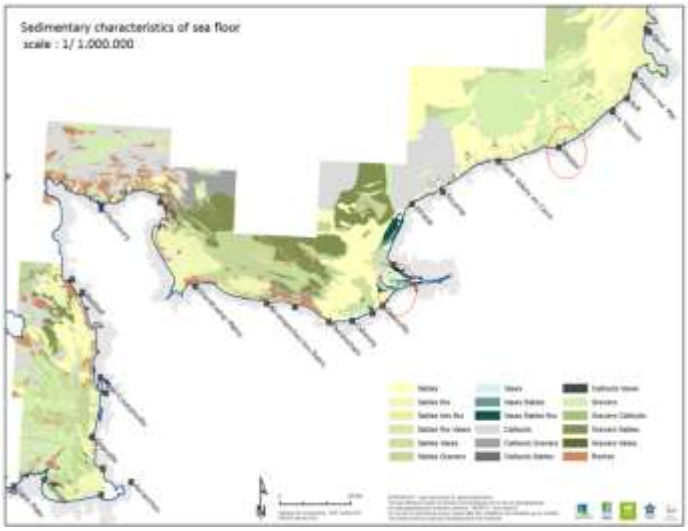


Figure 3. *Sedimentary characteristics of sea floor of the Channel at the scale of 1/1.000.000. (from SHOM, 2011)*

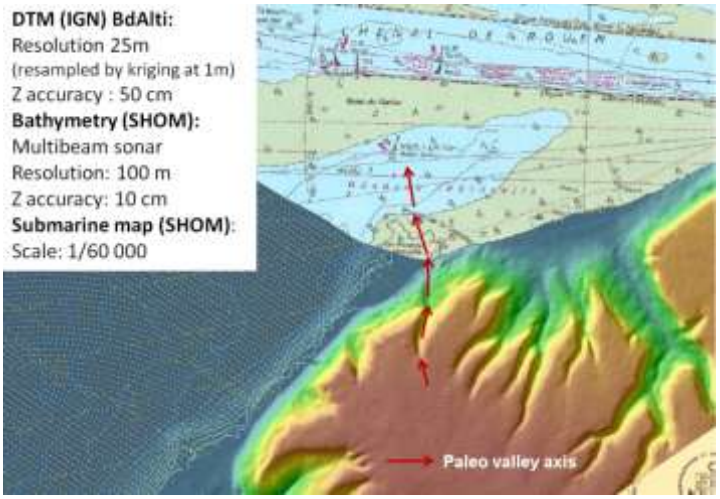
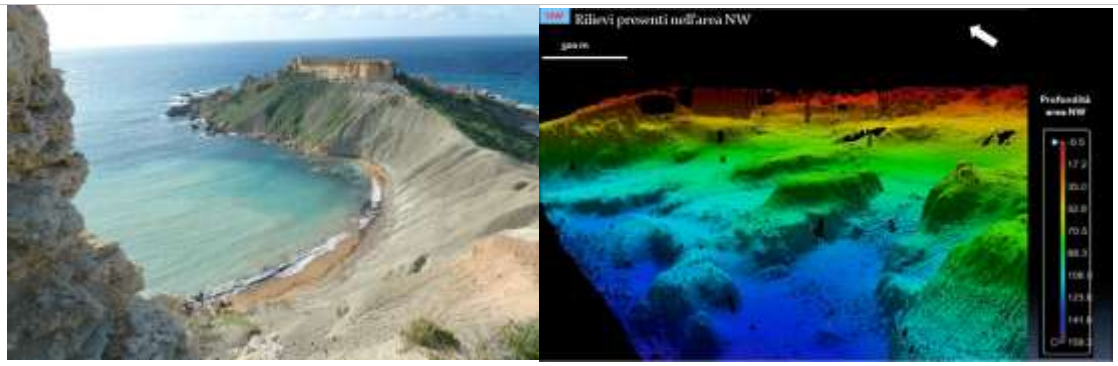


Figure 4. *Example of merged different submarine and terrestrial datasets under the GIS platform for the Villerville-Cricqueboeuf landslides test site.*

Malta case study

During this year of research, the existing terrestrial and submarine datasets have been collected through a bibliographic and archive research. A multidisciplinary approach to integrate and couple terrestrial and submarine datasets has been defined, which foresees contributions from geomorphology, marine geology, geophysics and engineering geology.

The newly acquired submarine data (see specific following section) and the elaboration of a detailed DTM of the seafloor along the north-west coast of the Island of Malta, has enabled to outline for the first time the submerged landforms of this stretch of coast (see figure below). A first attempt to compare terrestrial and submarine landforms has been performed with the aim of producing, during the second year of research, a comprehensive geomorphological map capable to illustrate terrestrial and submarine landforms in the same sheet, which could serve as a useful tool for hazard assessment.



Comparison of emerged and submerged structural landforms susceptible to landsliding along the NW coast of Malta

Work package 2 (prepared by the CERG, IcoD, Università di Modena e Reggio Emilia, Université de Caen Basse-Normandie, Consiglio Nazionale delle Ricerche: Istituto di Scienze Marine; CNR-IRPI):

Description:
Outline of marine level variations since the LGM for selected coastal areas in Normandy and Malta;
Associated deliverables:

Normandy case study
An outline of sea-level variations since the Last Glacial Maximum (LGM) has been produced based on literature and recent researches (Figure 5). This has to contributed to reconstitute the general environmental conditions since Wurm period (- 30 000 year BP, maximum of Wurm), in the Channel, with periglacial conditions, and the estimated positions of sea level for several dates with a lower sea level ca. 130 metres lower than today.

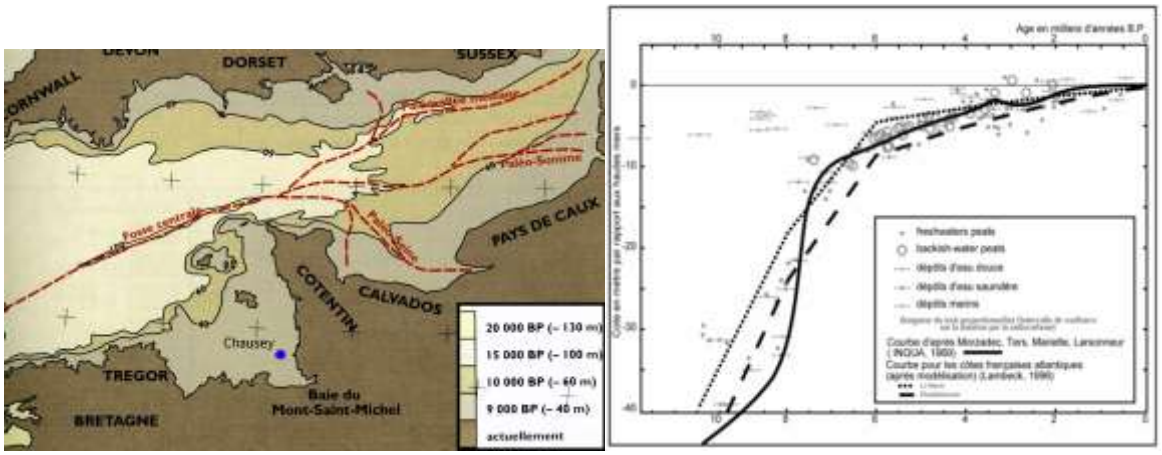


Figure 5. *Position of the shore (level) since the Wurm period (left image) and Curves of relative sea level rise during the Holocene for the N-W of France (right from Morzadec et al., 1969 & Lambeck, 1996).*

During the Holocene (last 10 000 years), after intensive increase of the sea level (between 10 000 to 8 000 year BP) with a rate of 6-7 cm per year, the rate decreased with a value of 3-4 cm per year, and at 5 000 year BP, the sea level reached more or less the actual sea level. It is not really well observed on Figure 5 (right), because the curve is an average for the N-W of France for tidal range different than tidal range observed in study sites (the Channel is a macrotidal and megatidal sea and it is very difficult to determine precisely the sea level). But for the Lower Norman study site, our observations and measures conducted during this project allowed to determine the position of the low tide cliff (at the altitude of -1 m NGF) which is the limit of the reef flat. This would correspond to the position of the shoreline at 6000-5000 year BP located at a distance of 290-330 m in front of the actual shoreline (Figure 6 & Figure 7).

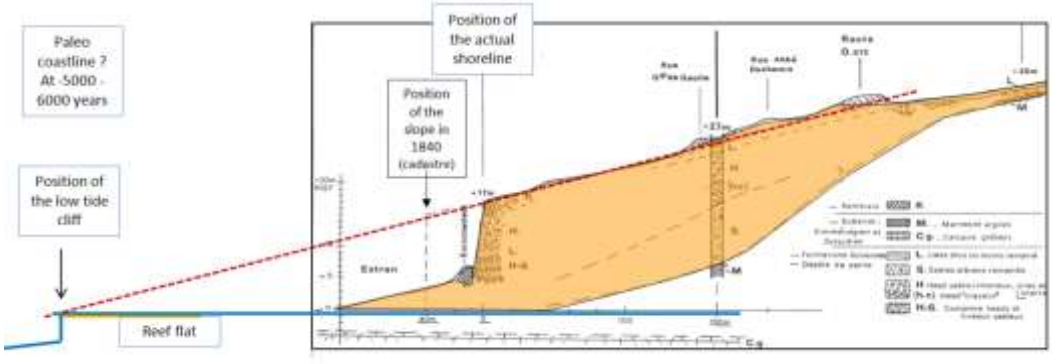


Figure 6: *Cross section of the paleo-valley fulfilled by colluvial-alluvial materials and different position of the shoreline during the last 6000 years at Villerville town, France*

Figure 7: *Position of the shoreline at 5000-6000 years BP in front of the Villerville-Cricquebeouf slope, France.*

The progressive sea erosion during the last 6000 years reach a value of 300 m: the rate of erosion is approx. 5 cm per year for this sea level. But for the future, we have to take into account the relative sea level evolution. On the base of monthly and annual mean sea level measured between 1950 to 2011 at the Dieppe harbor and Le Havre harbor located close to the study sites, the rate of Sea Level Rise (SLR) is respectively 0.53mm per year and 0.18 mm per year since 1960's (Figure 8).

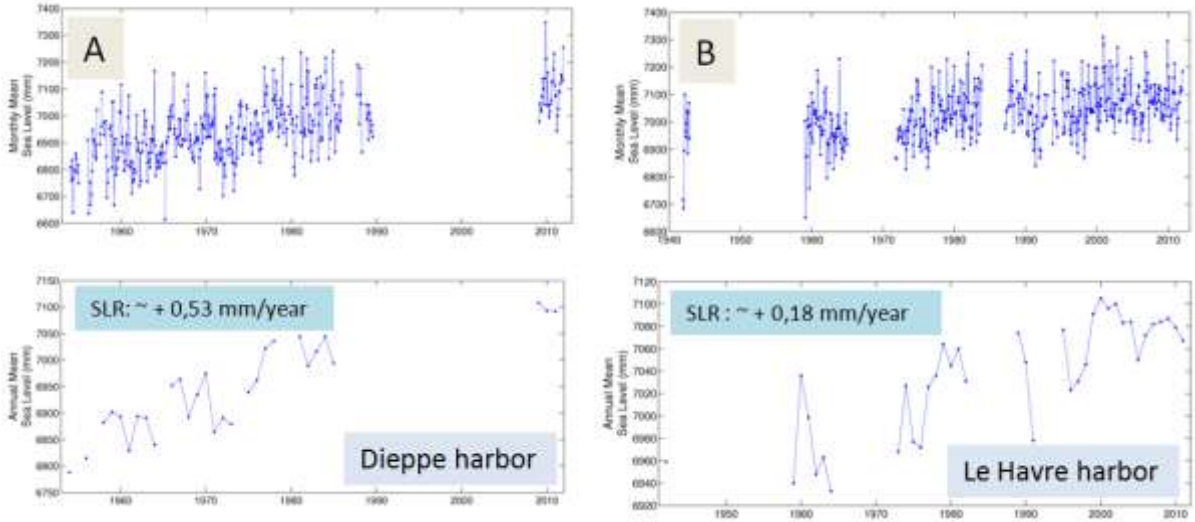


Figure 8: *Monthly and annual mean sea level measured and rate of Sea Level Rise (SLR) between 1950 to 2011 for the Dieppe harbor (A) and Le Havre harbor (B) (from Pirazzoli et al., 2002 and PSMSL, 2011).*

Malta case study

Based on recent literature (Lambeck et al., 2011; Carroll et al., 2012; Furlani et al., 2012; Marriner et al., 2012), an outline of sea-level variations since the Last Glacial Maximum (LGM) has been produced. This has contributed to confirm the hypothesis that the large-scale landslides located along the north-west coast of Malta were triggered in different morpho-climatic conditions, which foresaw more humid conditions and a sea level ca. 130 metres lower than today (Figs. 2 and 3). This means that the onset of the numerous block slides at present observable along the coast probably affected valley slopes rather than coastline areas. The progressive increase of the sea level during the Holocene would have then caused the partial submersion of the lower parts of the landslide accumulations.

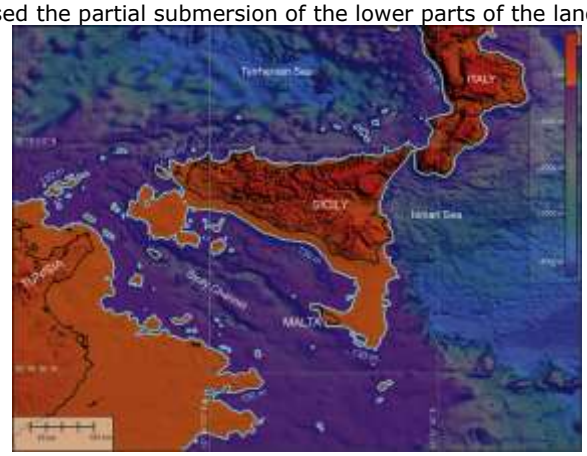


Fig. 2 – Paleogeography of the Central Mediterranean Sea during the LGM (sea level ca. 130 m below present level; after Furlani et al., 2012)

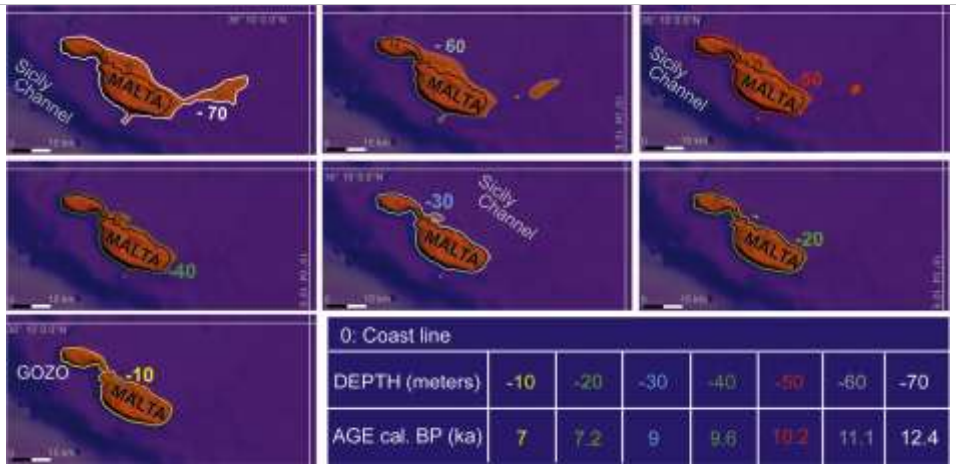
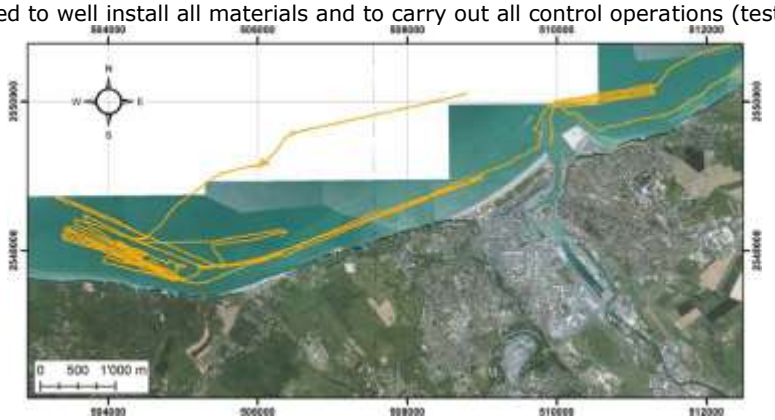


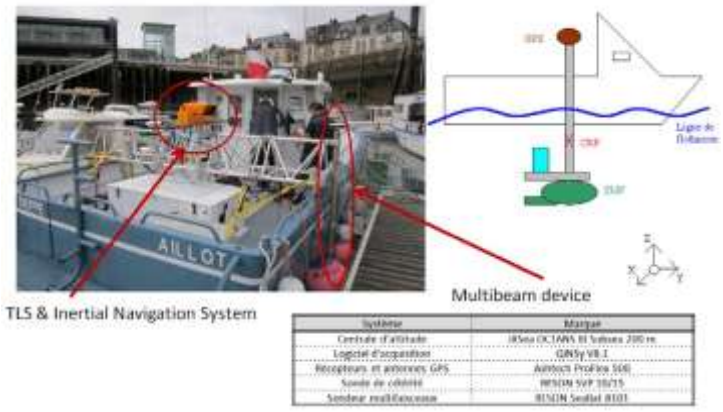
Fig. 3 - Palaeoshorlines during the post-glacial sea-level rise, from 12,400 to 7000 years ago; after Furlani et al., 2012

Work package 3 (prepared by CERG, IcoD, Università di Modena e Reggio Emilia, Université de Caen Basse-Normandie, Consiglio Nazionale delle Ricerche: Istituto di Scienze Marine; CNR-IRPI):
Description:
Multi-beam survey of selected Normandy and Malta coasts.
Associated deliverables:

Normandy case study
The selecting pilot area is located in Upper Normandy along the hard rock cliff subjected to landslides (cliff falls, debris fall and boulder and rock falls) and storm surges, in each part of Dieppe arbour from Cap d'Ailly (Pourville) at the west part to Puys at the East part of the study site.
For coastal hazard assessment, three issues coupling terrestrial and submarine datasets are requiring for:
• definition of the production of debris (flint) from cliff erosion which feeding intertidal sedimentary stock, gravel beach,
• definition of infratidal sandy inputs on gravel beach, which participate to the functioning of these accumulation,
• definition of the impacts of harbor jetty on infratidal sedimentary drift (onshore-off shore and longshore drift).
The different devices (MLS coupling with Multibeam) were installed on the boat:
• 1. Mobile Laser Scanning (MLS) is using the same principles than aerial devices. It is constituted by 2 GNSS (GPS) antennas in order to localize the laser source, 1 Inertial Measurement Unit (gyroscope to orientate the Line of Sight of the laser) and 1 TLS (Terrestrial Laser scan) that produces laser pulses and records the time of flight. Also, by this way, we could well know the laser's position, orientation and time of flight, and obtain spatial registration of points (cloud points).
• 2. Multibeam: Bathymetric measurements were acquired by the multibeam sounder high-resolution SeaBat 8101 manufacturer RESON. This system operates at frequency 240 kHz. The geometry of emission and reception antennas to get an opening angle (of the beam) transverse and longitudinal 1.5 by 1.5 ° °, and therefore a beam footprint well resolved on the bottom of the sea. The multibeam is also
associated with GPS antenna and to attitude station OCTANS Subsea manufactured by iXSea which is used to compensate the movement of the boat and provide the vessel's heading.
• One full day is required to well install all materials and to carry out all control operations (test and calibration).

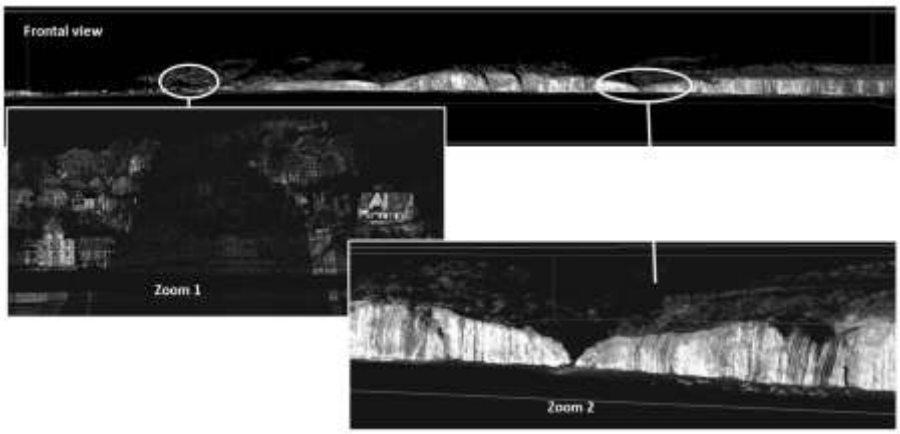


Example of vessel trajectory during bathymetry and MLS acquisitions for one single day in September 2012 from Cap d'Ailly (Pourville) to Puys (Upper Normandy).



General view of the different devices (MLS coupling with Multibeam) installed on the boat for simultaneous survey (September, 2012). (by R. Cancouet, E. Augereau, C. Delacourt, IUEM-DO, Brest).

First results:
Once all instruments set up on board, topographic and bathymetric measurements can be done quickly. If weather conditions is good (not too windy and rainy), we could obtain information on approx two linear km per hour.
For the MLS (Figure xx.3), on the example of frontal view, we obtained a very good general aspect of the landforms. In high density areas (Zoom 1), the resolution is better than 10 cm (cf. house). The morphological parameters (Zoom 2) can be well observed, even on intertidal areas. Surfaces processes, such as collapse talus, can be observed and quantified in few seconds.



Cloud points obtained by MLS (Mobile Laser Scan) from Dieppe to Pourville (Upper Normandy, September 2012) (by C. Michoud, D. Carrea, M.-H. Derron, M. Jaboyedoff, UniL CRET)

For the multibeam survey, the preliminary results allow to well observe the bathymetry with a very good resolution (around 20 cm): In example, an important accumulation of blocks on the lower shore platform is well detected at the cape d'Ailly. These blocks of sandstone are in relation with the retreat of the cliff by large old rock falls (the blocks are arranged in the shape of crown or curved belt); also, near the jetty of Dieppe, an important sandy accumulation progress towards the tip of the jetty.

Malta case study
In the frame of this project a new marine survey along the north-west coast of the Island of Malta was commissioned to AquaBioTech Limited, which performed it in May 2012. It consisted of a Multi Beam and a Sub Bottom Profiler survey to obtain a high resolution bathymetry of the shallow water and to assess the internal structure of the submarine landslides. An inteferometric echosounder Swathplus was used which is made up by two transducers with a frequency of 117 kHz that can reach a depth of 350 m.

The survey carried out has investigated an area of about 7.5 km in length (north/south orientation) and a maximum distance from the shore of 1.6 km in width (east/west orientation). Preference has been be given to shallower areas, close to the coastline to better support the integration of terrestrial and marine datasets. The survey area extends from the south point of Cirkewwa to Ras il-Pellegrin point as seen on the map (Figs. 4 and 5).

The detailed bathymetry, achieved by means of analysis carried out in collaboration with CNRISMAR, has provided useful information on the seafloor morphology, including submerged landslide accumulations. The elaboration enabled the production of a DTM of the seafloor of the investigated area with a resolution of 2 m and a vertical exaggeration of 5x (Fig. 5). Worth of note are the profiles achieved for Anchor Bay, where extensive landslide monitoring is ongoing. The observation of the first metres under the seafloor enable to identify buried collapsed blocks related to the landslides affecting the north side of the bay.

The Sub Bottom Profiler analysis, to be carried out in the next year, will show the internal seafloor layers and a more in depth view of landslide deposits buried by marine sediments.

Long WGS84	Lat WGS84
14°18'40.0490"	35°54'15.7742"
14°18'37.9081"	35°58'22.3723"
14°20'47.2283"	35°58'23.0960"
14°20'49.2576"	35°54'16.4961"
14°18'40.0490"	35°54'15.7742"

Fig. 4 – Coordinates of the marine survey area along the NW coast of Malta

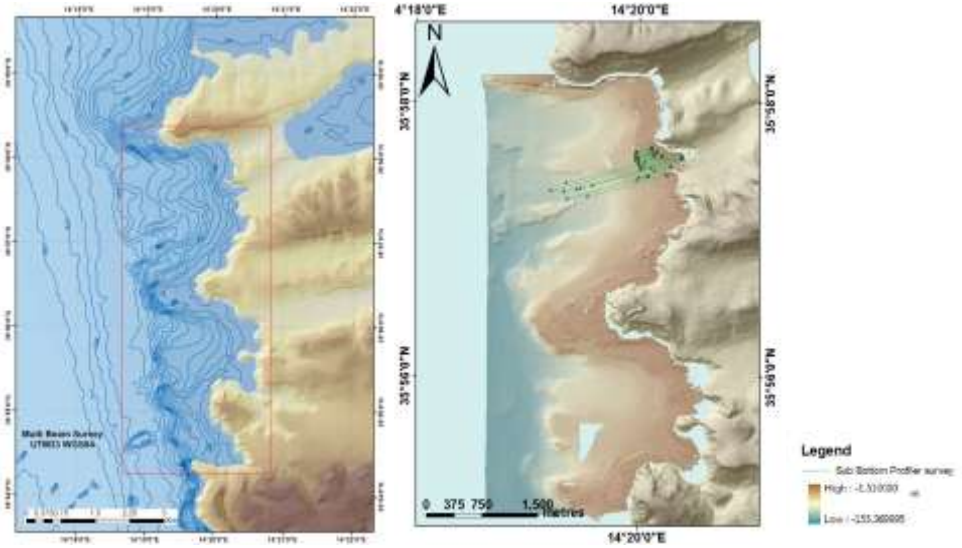


Fig. 5 – Extension of the marine survey area (left) and DTM of emerged and submerged areas along the NW coast of the Island of Malta (right)

Work package 4 (prepared by CERG, ICoD, Università di Modena e Reggio Emilia)

Description:
Monitoring of coastal processes initiated within the "Coastline at risk" Project.
Associated deliverables:

Normandy case study
As regards the Norman case study in France, the APO-CERG Project "Coastline at risk" focused on coastal instability phenomena occurring on the Lower Normandy where large active landslide occur in the Villerville-Cricqueboeuf municipalities (see description above). Monitoring of coastal landslides has been continued in the frame of this project. Several monitoring campaigns have carried out during 2012, in order to measure the superficial displacements, the water table variations and the climatic conditions. The results' analysis shows that the landslides continue to be active and show horizontal and vertical displacements in agreement with trend of movement shown during the last years of observation.

Maltese case study
As regards the Maltese case study, the APO-CERG Project "Coastline at risk" focused on coastal instability phenomena occurring on the north-western stretch of the Island of Malta where widespread active lateral spreading and block sliding occur due to the presence of rock masses showing different lithological and geomechanical characteristics (Soldati et al., 2011; Devoto et al., 2012). Integrated research methods and techniques were applied with special reference to mapping and monitoring of coastal instability phenomena along the coastlines (Mantovani et al., 2012).

Monitoring of coastal landslides has been continued and strengthened along the north-west coastline of Malta, at Il-Prajjet (Anchor Bay) and Ghajn Tuffieha Bay (Fig. 6). Monitoring techniques include GPS, consisting in 2 reference stations and more than 20 benchmarks spread all over the unstable areas and wire extensometers which have shown that rock spreading phenomena are active with local displacements up to a few centimetres per year. In order to guarantee the repetitiveness of the surveys, this project is meant to continue the GPS measurements. Moreover, this has been accompanied by the installation of wire extensometers to monitor in continuous the displacements along the most active fractures. Additional benchmarks have been placed along the selected fractures and the first measures have been made manually by means of a wire extensometer.
Two monitoring campaigns have carried out during 2012, in April and November. The results' analysis shows that the landslides continue to be active and show horizontal and vertical displacements in agreement with trend of movement shown during the last years of observation. The total displacements recorded at the Anchor Bay site are shown in Fig. 7.

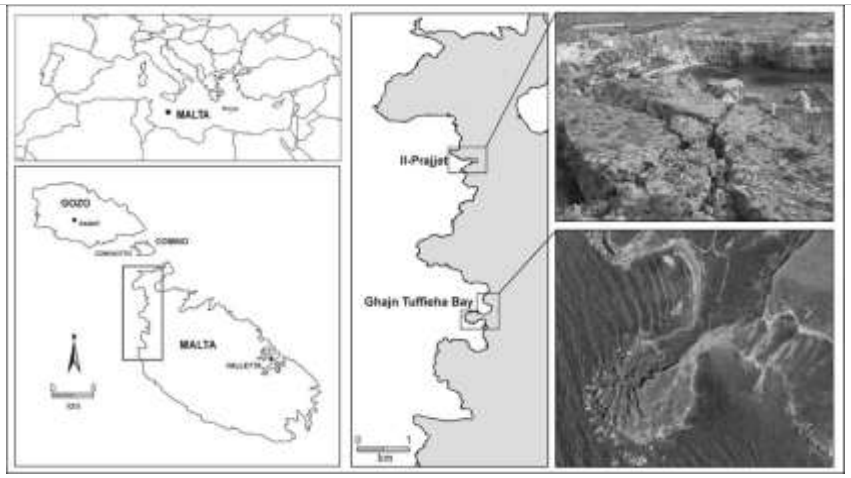


Fig. 6 - Location of the landslide monitoring sites along the NW coast of Malta

Fig. 7 – Displacements measured at the monitoring site of Anchor Bay, NW coast of Malta

ACTIVITIES PLANNED IN 2013

Working package 1 (prepared by CERG, IcoD, Università di Modena e Reggio Emilia, Université de Caen Basse-Normandie, Consiglio Nazionale delle Ricerche: Istituto di Scienze Marine; CNR-IRPI):
Description:
Improvement of existing hazard maps taking into account issues related to climate change (sea-level, more frequent extreme meteorological events etc.);
Associated deliverables:

Work package 2 (prepared by CERG, IcoD, Università di Modena e Reggio Emilia, Université de Caen Basse-Normandie, Consiglio Nazionale delle Ricerche: Istituto di Scienze Marine; CNR-IRPI):
Description:
Acquisition of necessary knowledge to define methods to perform landslide monitoring offshore (on the seafloor);
Associated deliverables:

Work package 3 (prepared by CERG, IcoD, Università di Modena e Reggio Emilia, Université de Caen Basse-Normandie, Consiglio Nazionale delle Ricerche: Istituto di Scienze Marine; CNR-IRPI):
Description:
Definition of protocols which can be utilised in other coastal environments for risk reduction and resilience improvement.
Associated deliverables:

Work package 4 (prepared by CERG, ICoD, Università di Modena e Reggio Emilia):
Description:
Monitoring of coastal processes.
Associated deliverables: