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List of abbreviations and acronyms

Acronyms as used in this report are defined in the following list:

ARHC: Arctic Regional Hydrographic Commission
AUSV: Autonomous Unmanned Surface Vessels
BDB: Bathy DataBase
BLAST: Bringing Land and Sea Together
BOOS: Baltic Operational Oceanographic System
BSHC: Baltic Sea Hydrographic Commission
CBA: Cost Benefit Analysis
CMEMS: Copernicus Marine Environment Monitoring Service
CMP: Coastal Mapping Planner
CRS: Coordinate Reference System
DG MARE: Directorate-General for Maritime Affairs and Fisheries
DSM: Digital Surface Model
DTM: Digital Terrain Model
EEA: European Environment Agency
EMODnet: European Marine Observation and Data Network
EPSG: European Petroleum Survey Group
ETRS89: European Terrestrial Reference System 1989
ETRS-LAEA: ETRS89 Lambert Azimuthal Equal Area
EU: European Union
EuroGOOS: European Global Ocean Observing System
EVRF: European Vertical Reference Frame
EVRS: European Vertical Reference System
GEBCO: General Bathymetric Chart of the Oceans
GIS: Geographic Information System
GRS80: Geodetic Reference System 1980
HR: High Resolution
ICZM: Integrated Coastal Zone Management

IENWG: IHO-EC Network Working Group
IHO: International Hydrographic Organization
INSPIRE: Infrastructure for Spatial Information in Europe
IOC: Intergovernmental Oceanographic Commission of UNESCO
IODE: International Oceanographic Data and Information Exchange Commission
JECMaP: Joint European Coastal Mapping Programme
LAT: Lowest Astronomical Tide
LiDAR: Light Detection And Ranging
MBES: Multi Beam Echo Sounder
MSL: Mean Sea Level
NHC: Nordic Hydrographic Commission
NOOS: Northwest European Shelf Operational Oceanographic System
NSHC: North Sea Hydrographic Commission
NSHC-TWG: Tidal Working Group of the North Sea Hydrographic Commission
NUTS: Nomenclature of territorial Units for Statistics
OGC: Open Geospatial Consortium
RIS3: Research and Innovation Smart Specialisation Strategies
SAR: Synthetic Aperture Radar
SBES: Single Beam Echo Sounder
SBP: Sub-Bottom Profiler
SDI: Spatial Data Infrastructure
SOLAS: Safety Of Life At Sea
URL: Uniform Resource Locator
WFS: Web Feature Service
WGS84: World Geodetic System 1984
WMS: Web Map Service
WP: Work Package

Glossary

Technical terms as used in this report and its annexes are defined in the following list:

Geodatabase: A geodatabase (or spatial database) is a database that is optimized to store and query data that represents objects defined in a geometric space (i.e. by geographic coordinates).

Hyperspectral imaging: Hyperspectral imaging, like other spectral imaging, collects and processes high resolution information from across the electromagnetic spectrum (very large number of acquired frequencies). The goal of hyperspectral imaging is to obtain the spectrum for each pixel in the image of a scene, with the purpose of finding objects, identifying materials, or detecting processes.

Lidar: An instrument that measures distance to a reflecting object by emitting timed pulses of laser light and measuring the time between emission and reception of reflected pulses. The measured time interval is converted to distance. In survey use, the lidar system usually scans the light pulses across the track of the survey platform (usually an aircraft) so that successive pulses cover a swath either side of the platform's track. Infra-red lasers will reflect off land and water, and are normally used for topographic lidar surveys. Blue-green lasers will penetrate water and are used in hydrographic lidar surveys.

Magnetometer: An instrument for measuring the intensity and/or the direction of the earth's magnetic field.

Multi beam echo sounder: A type of swath sounding system in which the equipment emits a timed pulse of sound that is narrow in the fore-aft direction and wide in the across track direction. The reflected sound is received by several receivers arranged as an array. By use of signal processing of the signal received at combinations of the receivers a much larger number, potentially many hundreds, of acoustic receive beam angles are formed. For each receive beam the time interval between emission and reception of the reflected sound is converted into a range. Geometry is then used to convert each range and receive beam angle to depths and also to position these depths within the swath on the seafloor. MBES systems may also be referred to as beam-formers.

Multispectral imaging: A multispectral image is one that captures image data at few specific frequencies across the electromagnetic spectrum. The wavelengths may be separated by filters or by the use of instruments that are sensitive to particular wavelengths, including light from frequencies beyond the visible light range, such as infrared. Spectral imaging can allow extraction of additional information the human eye fails to capture with its receptors for red, green and blue. It was originally developed for space-based imaging.

Orthophoto: An orthophoto, orthophotograph or orthoimage is an aerial photograph geometrically corrected ("orthorectified") such that the scale is uniform: the photo has the same lack of distortion as a map. Unlike an uncorrected aerial photograph, an orthophotograph can be used to measure true distances, because it is an accurate representation of the Earth's surface, having been adjusted for topographic relief, lens distortion, and camera tilt.

Seabed sampling: The process of taking superficial samples of the seabed.

Secchi disk: A white, black, or varicoloured disc, 30 centimetres in diameter, used to measure water transparency (clarity). The disc is lowered in the water and the depth (in metres) at which it disappears from sight is averaged with the depth at which it reappears. This average value is used to represent sea water transparency.

Side scan sonar: A form of active sonar in which fixed acoustic beams are directed into the water perpendicularly to the direction of travel to scan the bottom and generate a record of the bottom configuration.

Single beam echo sounder: an echo sounder that transmits and receives a sound pulse providing a single spot depth, as opposed to a multi beam echo sounder.

Sub-Bottom Profiler: A form of active, low frequency sonar in which acoustic beams penetrate the bottom. A recorder produces a chart which represents a cross section of the geological structure of the subbottom.

Synthetic aperture radar: A radar with a synthetic aperture antenna which is composed of a large number of elementary transducing elements. The signals are electronically combined into a resulting signal equivalent to that of a single antenna of a given aperture in a given direction.

Vertical datum: Any level surface (e.g., mean sea level, chart datum) taken as a surface of reference from which to reckon elevations or depths. Also called datum level, reference level, reference plane, levelling datum, datum for heights.

Water column sampling: The process of taking samples of water all along the water colum.

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Introduction

The project's strategic objective is to develop an innovative analysis of the needs and means in Europe for the acquisition of marine data in coastal areas, as well as concrete propositions for the development of European strategy for marine data acquisition. This analysis is focused on the characterization of the coastal area, including bathymetry and topography, cover typology information, vegetation and sediment properties, considering also other kinds of data which may be assessed jointly (depending on the operating sensors). To address these objectives, the project Work Plan has been drawn up around 3 work packages (WP).

In the framework of WP1 (Digital Mapping), the project develops propositions concerning an infrastructure enabling partners to prepare, update, aggregate and disseminate data produced by them, as well as tools to prepare and optimize data, provide high performance services disseminating the prepared layers with respect to INSPIRE recommendations, propose an ergonomic web portal and provide training to potential users. This work package proposes an infrastructure enabling partners to autonomously prepare, update, aggregate and disseminate the data they produce through aggregative layers based upon data from several partners resulting in a European layer and specific complementary layers on detailed areas. The work package also aims to provide operating tools to prepare and optimize data with the aim to efficiently disseminate them in order to offer a good user experience and high performance services disseminating the prepared layers with respect to INSPIRE recommendations. These services are available via an ergonomic web portal providing visualization tools and co-visualization with internal and external data (i.e. base layer maps, coastlines, external map co-visualization, etc …). The solution is maintained and supervised and a training for the potential users of the implemented tools as well as support to data creation and manipulation are included in the project.

In the framework of WP2 (Share experience, standards and best practice), the project is assessing consistency of the existing vertical datum, listing and summarizing past experiences and best practices, developing and testing an algorithm for choosing the most appropriate surveying method, and building a technical and economical strategy. This work package develops systems approaches and methodologies for geographic and spatial observations of environmental parameters in coastal areas, producing a heuristic help to assess economic impacts, such as the submersion risks, and socio-economic benefits of successive coastal survey acquisitions. The considered systems and methodologies to assess the geographical coastal information range from the use of classical ship based survey methods like multi beam echo sounder (MBES) to airborne techniques (Lidar) and satellite images at different levels. These are combined with field studies and statistics in geographic information systems. WP2 makes an inventory of the ongoing studies dealing with fusion methodologies for heterogeneous, multi-scale data, simulation models of geographical structures and

the development of formalization based on the concept of fuzzy object localization that leads to define to what extent other surveys have appropriate quality assessment, and could be considered. WP2 focuses on the construction of an algorithm based on past experience and on the development of space-time analysis models of different acquisitions. Moreover, the WP2 works manage heterogeneous data and identify all the existing gaps that need to be filled in order to perform consistent characterisation of the coastal zone. The main task aims to set up the foundation of a set of protocols, organized knowledge and algorithm that helps EU data acquisition plan and to eliminate discontinuities between the national systems for a consistent and homogeneous survey method and strategy.

Finally, in WP3 (Future programme), the project develops a method to draw a Joint European Coastal Mapping Programme (JECMaP) in shallow waters for bathymetric data. The project's partnership directly involves a large number of European Hydrographic Organizations, ISPRA (Institute for Environmental Protection and Research, Italy) having strong experience in coastal mapping from imagery and survey processing for coastal environments, CPMR (Conference of Peripheral Maritime Regions), and the Worldline company, which has an internationally recognized expertise in the field of operational digital mapping and portal design. There is a need to support the data acquisition programme by proposing a governance model between Regions, States and the European Commission over the long term. The main goal is to propose a method to draw a Joint European Coastal Mapping Programme in the shallow waters for bathymetric data, taking into account:

- WP2 outcomes, giving a review of the technical inputs, the possibilities of interoperability and the strategic algorithm;
- The existing data, at European, State and regional levels;
- Organizations like European Environment Agency and programmes like EMODnet and Copernicus;
- The needs of bathymetric data for management of the coastal zones and the connection to be established with the land side;
- The governance of these data in the coastal zone and the economic models in place;
- The financial opportunities offered by the European financial period 2014-2020, for a Joint European Programme.

1 Highlights in this reporting period

- ✓ The portal was opened to the public on 23rd December 2015 with some datasets. Making data available to the portal is a permanent task during the project and it has been continued during the period. So the portal now gives access to several datasets grouped in five categories (Topography & Bathymetry, Coastline – Baseline, Imagery, EMODnet, Additional Layers).

- ✓ A questionnaire linked to the vertical datum issues has been filled in by almost all the partners (all the countries involved in the project are represented). The analysis and some propositions have been produced.

- ✓ Another questionnaire has been defined in order to list and summarize past experiences in terms of coastal mapping. It has been filled in by the relevant partners. The results of this questionnaire have been used to develop an algorithm to help the coast survey planning at regional and transnational level (Coastal Mapping Planner – CMP).

- ✓ The CMP has been developed during this period and implemented in two ways on the portal : geographical and interactive versions. The geographical CMP shows static layers of appropriate technologies computed from statistical datasets. The interactive CMP allows to evaluate the suitability of technologies using values of depth and water clarity inserted by the user.

- ✓ Through the research of the main platform categories, the possible technical synergy effects available today have been evaluated and some recommendations have been produced.

- ✓ Other questionnaires concerning economic models/governance of data and evaluation of the current gaps and ways to fill them has been filled in by most of the partners. The resulting information was used for the production of data acquisition programme proposal.

- ✓ The potential support EU Funds for coastal bathymetric data acquisition have been evaluated by desktop analysis and compilation of information from the partners. This analysis of different funding sources shows that coastal bathymetric data acquisition can be supported by various EU funds. Therefore, the multiplicity of funding sources generates combined with the lack of explicit reference to coastal bathymetric data implies high funding analysis skills and generates complex project development procedure.

- ✓ Coastal zone stakeholders coming from Bologna Charter coordination board has been sollicitated for evaluating their interest in the project work and the tools set up. All regional authorities

expressed their interest in collecting and sharing coastal mapping data if they can use it for the production of thematic maps in the context of integrated coastal zone management.

- ✓ Based on all these results, a strategy for high resolution bathymetric data acquisition has been elaborated. This strategy is based on three axes and should be supported by three pillar actions. Moreover, the consortium produced recommandations for the implementation of this strategy.

2 Results of the main tasks

2.1. Results for task 1(a) (WP1: Digital mapping)

2.1.1. Implementation

A versatile portal to centralize information

The aim of task 1 was to implement a web portal, presenting the available data as digital maps, with the ability to navigate and zoom in the dataset.

The resulting web portal, available at www.coastal-mapping.eu, is a data vizualiser, with a **simple and modern design** that leaves a maximum of space for data, and able to display data from any INSPIRE compliant WMS or WFS server.

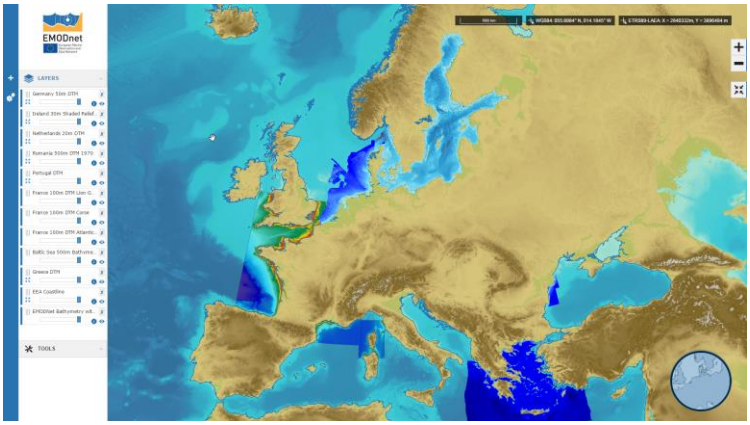

Figure 1: Web portal.

Users can choose data to display from a data catalog, containing all coastal and bathymetric information selected by partners for the Coastal Mapping project. Selected data can be handled through a layer manager, allowing users to order the different layers, and modify their transparency for better data visualization.

Users can also add to the portal data from third parties WMS services, to allow cross comparison between project data and external data.

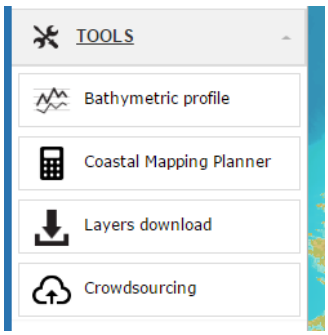

Figure 2: Web portal tools.

Several geographic tools are also available :

- draw a bathymetric profile along a line drawn by the user, for bathymetric data layers
- use the coastal mapping planner algorithme developed in WP2
- download data by drawing a box of interest on the portal
- upload GPS points in order to crowdsource a European coast line

Data Origin

The layers available in the Coastal Mapping portal come:

- either from existing WMS services from the project partners,
- or from built-in WMS and WFS service, from the "DataWarehouse", whose role is to ingest, transform and publish data provided by the partners as data files (GeoTiff, netCDF, gml, XYZ…).

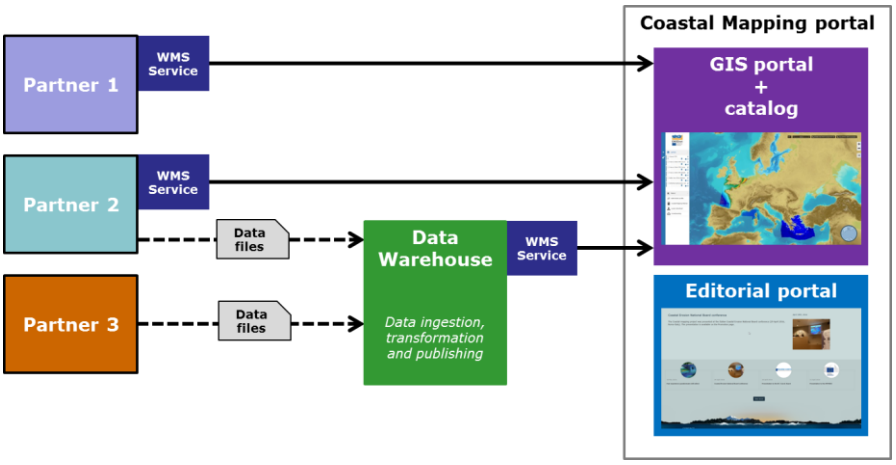

Figure 3: Data workflows.

2.1.2. Data Initialization.

The results are displayed in the different tables of Annex 1.

2.1.3. Maintenance

During the maintenance phase, the portal will be kept available, and project partners can enrich the project data with new data, or update existing data if necessary.

2.2 Results for task 2(c) (WP2.1: Assess consistency of the existing vertical datum)

The aim of WP2.1 is to assess the consistency of vertical datums within the European coastal zone and to recommend a European standard datum for coastal mapping. Within Europe many different vertical reference systems are being used. In the coastal zone the situation is of special interest as, depending on the application, elevations may be referenced to a sea based system, such as MSL or LAT, or to a land based system. The fusion and exchange of land and sea data is a difficult task as the relations between the various systems are not always known with sufficient accuracy. In order to map coastal data from different sources, one unique vertical reference system should be used.

To acquire information on the use of vertical datums in the European coastal zone, a questionnaire was compiled and distributed among partners. Based on this questionnaire and literature study, a vertical datums inventory has been made in the European coastal zone. This resulted in an overview of the height systems on land and a quantification of offsets to EVRF2007. Furthermore, a detailed

analysis of the definitions of Chart Datum, as used by the countries in the European coastal zone, has been given, as well as the relations to the ETRS89-GRS80 ellipsoid.

The implementations of Chart Datum can be divided in three groups as shown in the figure below. For the North Sea and the Atlantic Ocean regions, water levels are mainly determined by tides and hence realizations of LAT are adopted as Chart Datum, following IHO resolution 3/1919 as amended. In the Baltic Sea, where there is no appreciable tide effect, MSL-based surfaces are used as Chart Datum. In the Mediterranean the tidal effect is also small. Because water levels are significantly influenced by surge and temperature, a low water surface is often used for safety reasons.

In this work package three candidates for a European standard are considered: ETRS89-GRS80, EVRS and a harmonized Chart Datum on a maritime basin level. As the actual choice of a vertical datum depends on the application, these candidates can be considered complementary. ETRS89 is the recommended coordinate system by the INSPIRE directive for the horizontal component when sharing geo-information. When a local or regional vertical datum is referenced to the ETRS89-GRS80 ellipsoid, it directly enables ellipsoidal referenced surveying, data combination on land and sea, and comparison of datums between countries and maritime basins. Hence, it is important that the transformations (or separation models) to the ETRS89-GRS80 ellipsoid are defined and available to users.

On land, the INSPIRE guidelines recommend EVRS to express gravity related heights. For countries that are connected to EVRS, it provides the off-sets between national systems and gives the possibility to tie the reference tide gauges to a common datum. However, not all countries in the European coastal zone are connected to EVRS and the relations between sea based systems and EVRS are not always available. In order to use EVRS for marine applications, a next version of EVRF should include a European quasi-geoid as an equal realization of EVRS.

A harmonization of Chart Datum should be done at the level of maritime basins. For areas where tides have a large effect on water levels, it should be LAT, otherwise MSL or level close to MSL could be used, in accordance with the IHO resolution. Care should be taken at the boundaries between basins to establish seamless connections. A harmonization of Chart Datum is already being realized and implemented in the Baltic Sea region. For the North Sea region, the NSHC-TWG aims at the dissemination of discontinuities along the maritime boundaries and the realization of a seamless LAT surface. For the Mediterranean region, there are opportunities when the basin wide marine geoid becomes available as it can form the basis for height system unification.

A detailed report on the consistency of vertical datums in the European coastal zone can be found in Annex 2.

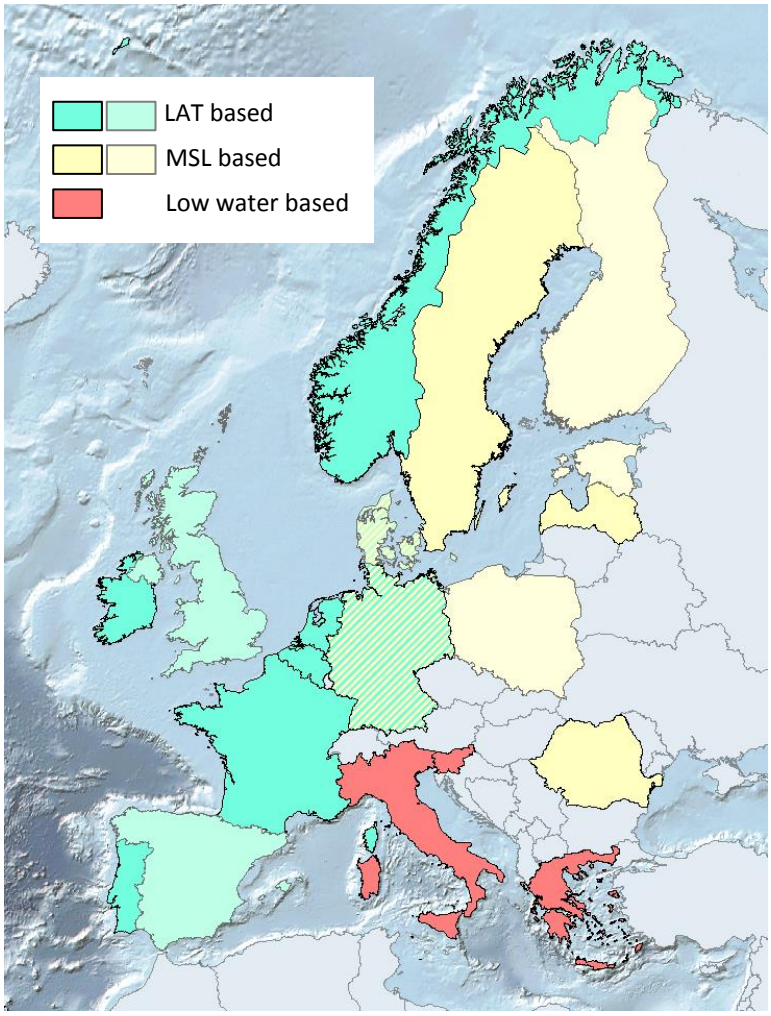

Figure 4: Overview of the type of Chart Datums used in the European coastal zone. Darker hues denote the Coastal Mapping project partners.

2.3. Results for task 2(d)i (WP2.2: Listing and summarising past experience)

The aim of WP2.2 is on the one hand, to collect and analyze different experiences of coastal data acquisitions. On the other hand, to assess and compare the products that can be obtained by means of different technologies in relation with the characteristic of the area to be surveyed and the different purpose of the acquisition (i.e. nautical chart production or scientific product development). The information collected is the benchmark through which the implementation of the algorithm will be developed in WP 2.3.

An online questionnaire was implemented by ISPRA to gain information regarding the characteristics of the surveyed areas, the instruments and the methodology utilized, the purpose and the products obtained.

ISPRA server has hosted the questionnaire and the first release was online on 10 November 2015. Other releases were developed according to the partners' discussions and reviews during meetings (Ostend and Bezons) and on the project portal forum. The final version was online on 22 December 2015 to collect partner responses (http://www.sondaggi.sinanet.isprambiente.it/).

Past experience information concerning coastal data surveys was sent by the partners filling in the online form or the related Excel file. The Excel file was filled, setting up an automated way, by the partners that had a lot of surveys to add.

The questionnaire was structured in three different thematic areas:

- ✓ study site information;
- ✓ survey information;
- ✓ Other information (see below for details).

The "study site information" is related to the extension, the elevation, the morphological characteristics (like EUROSION[1] shoreline classification) and the surveyed area properties (vertical tidal range, turbidity, and Secchi disk value).

The "survey information" concerns the scope of the acquisitions, the type of instrument/sensor and platform utilized.

The "other information" contains the characteristics of the specific products obtained from each survey, the reference system utilized (information useful for the WP 2.1 - vertical datum harmonization), the survey cost estimation and the data availability and repository.

Out of 15 partners that gave feedback on the past experience, 11 partners filled the online form and 4 the Excel form, for a total of 1500 surveys, 645 of which concerning surveys run after the year 2000.

The data handling, managed by ISPRA, has consisted of the following steps: producing the online form and the Excel file, gathering and homogenizing the results from different sources, interpreting answers for specific areas, summarizing and comparing the outcomes.

[1] European Commission, 2004, "Living with coastal erosion in Europe – Sediment and space for sustainability", Luxembourg office for official publications of the European Commission. 40 pp ISBN 92-894-7496-3. (http://www.eurosion.org/index.html).

All the collected data were structured into a geodatabase, with the aim of joining the tabular data with the spatial ones. The results were summarized and analysed according to the aim of the WP 2.2 (the detailed outcomes are reported in Annex 3).

The first results show a broad database of coastal data acquisitions, with information available for the other work tasks of WP2: the vertical datum harmonization (WP 2.1), the algorithm structure (WP 2.3) and the platform sharing (WP 2.5).

The use of NUTS (Nomenclature of territorial units for statistics[2]) for the surveyed area identification is essential to compare the information obtained from the main European statistical indicators.

The online questionnaire is still running on the ISPRA platform but despite the advertising done during international meetings, no more information have been collected.

So were gathered only information from the partner with the limitations already highlighted that could be summarized in:

- ✓ Not all the european coastal regions are represented due to a lack of partners from that regions.
- ✓ The main purpose for data acquisition in coastal area is focused on nautical charting due to the high representative of Hydrographic offices involved.
- ✓ Almost all the surveys have been performed using Multi Beam Echosounder, just few reports about others instruments.
- ✓ Few informations about the survey costs. The provided ones are not homogeneous.

2.4. Results for task 2(d)ii (WP2.3: Develop and test an algorithm)

The aim of WP 2.3 is to develop and test an algorithm for choosing most appropriate surveying method.

The algorithm, called Coastal Mapping Planner (CMP), is designed to give indication about the optimal survey techniques to obtain the main coastal mapping products, playing different scenarios. The final end of the CMP is to be a decision support system for the European and transnational coastal mapping management plans.

The CMP will help to define the best survey methodology and technologies considering:

- the requested coastal mapping final products (navigation charts, habitat maps, morphological maps, etc);
- the physical and quality parameters of the area (depth range and Secchi disk).

The CMP integrates the knowledge gathered from literature, the infield experience of the partners (Hydrographic Offices and research institutes) and the available information.

[2] Regulation (EC) No 1059/2003

The CMP, based on the fuzzy theory, was implemented using R language and free software and it has a scalable structure which permits easily to add instruments and products together with their technical characteristics.

The CMP implement three main survey technologies (Multibeam Echo Sounder; LiDAR, Airborne Hyperspectral sensor) for nine coastal mapping final products (Low resolution DSM, High resolution DSM, High resolution DSM for navigational purposes, High resolution DSM for navigational purposes (Order 1b), Shore line, Vegetation presence map, Vegetation cover type map, Floor Cover Type map, Properties of the Emerged Sediment).

Depending on the characteristics of the survey area, the CMP generates a relevant appreciation of how the different technologies can obtain the products that are selected by the user for the different coastal mapping purposes.

The CMP is availale on the coastal mapping portal (http://coastal-mapping.eu/) under the tools' section in two versions: geographical and interactive.

If the user prefer to use his own data of elevation and water clarity, he can use the interactive version of the CMP and obtain a table with the suitability of the different technologies to acquire the selected product.

Otherwise, in the geographical CMP the user can use the elevation data from the General Bathymetric Chart of the Oceans (GEBCO) dataset and the water clarity data from an elaboration of the Copernicus Marine Environment Monitoring Service (CMEMS) maps of Secchi disck depth. In this case, the output will be a geographical representation that shows which technologies can acquire the selected product and where such instruments can be used.

The detailed description of CMP and its progress are reported in Annex 4.

2.5. Results for task 2(d)iii (WP2.4: Build a technical & economical strategy – WP2.5: Sharing platforms)

2.5.1. Build a technical & economical strategy

Public policy has already begun to implement the principle of integrated management of coastal zones. In 2002, the European Union adopted a Recommendation on Integrated Coastal Zone Management (ICZM), setting out basic principles. These principles are still valid and include: stakeholder involvement, sensitivity of policy to local needs, the adoption of a long-term perspective and the creation of links between all levels of governance, from local to European. The evaluation of the available data and the identification of the gaps of knowledge were the fundamental actions to implement. The analysis shows that the coastal environment is a highly complex system and poses specific challenges for the collection, updating and representation of data due to its dynamic and multi-dimensional nature. Data should represent the temporal dimension and be incorporated into

planning and decision support tools in order to represent different realities of an area at different given times (e.g. seasonal activities).

As a first step we have implemented, based on the availability of data from the consortium, a preliminary cost function analysis using only Lidar (from Shom and ISPRA), MultiBeam and SingleBeam acquisition cost calculated for square meters.

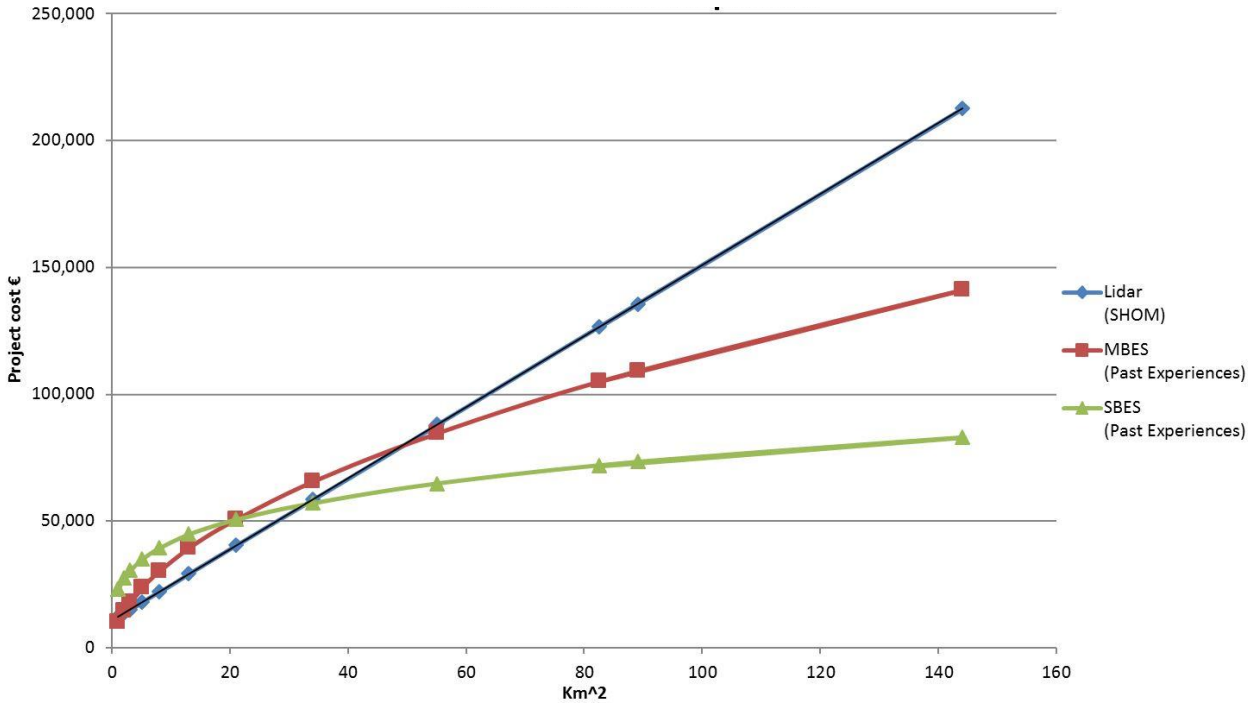

Figure 5: Cost functions comparison.

Issues regarding data and the implementation of a technical and economical strategy include a set of evidence based on the above analysis:

- **Lack of data:** Despite the growing interest and effort put in to developing greater knowledge and understanding of the coastal environment, many gaps still exist and this do put a bias on the analysis showing an increasing cost for square meter using Lidar tehcnology. Different projects point out a lack of data, mainly in coastal regions and regions where fewer human activities take place. This may be explained by the costs of collecting and updating data.
- **Availability:** In many cases, datasets exist but remain unavailable for the public. For example, data collected for scientific research or by private companies are not always available for public use due to academic or commercial sensitivities. Data may also only be available if purchased from its owner, sometimes at prohibitive costs. The longevity of data after the end of a project may be an

issue. These situations may impair the validity and accuracy of the plan or add extra costs if data have to be collected again considering that the only constant acquisition is always related to navigation bathymetry.

- **Quality:** Different methodologies to assess data quality can be used and therefore, the definition of standardised criteria to assess data quality should be agreed upon by the relevant authorities. Factors affecting data quality may be: the data acquisition process, resolution, accuracy, precision, etc. Sometimes, data are available but the quality is not sufficient for planning purposes and therefore cannot be used. The relevant data scale for coastal areas depending on the dataset itself and the planning scope may also affect the quality of the data for the project purposes.
- **Scope:** Data tends to stop at political or administrative borders instead of ecosystem's borders. This may limit the applicability of an ecosystem-based approach. Since environmental processes (e.g. upwelling and sediment transport) and human activities (e.g. maritime transportation) go beyond national borders, the scope of data collection should take into consideration the relevant spatial distribution.

That is to say the past experiences are not sufficient to build a reliable cost function valid on the whole of Europe leading to a very possible development: other environmental variables, together with surface, should be investigated to model a reliable function to quantify the time cost of the survey more than only square meter. It must be developed a market economic model that takes into account the specific needs of stakeholders and characteristics of each area that influence the time acquisition, considering the user segmentation in coastal areas ("scientific users" and "application users").

2.5.2. Sharing platforms

Through the research of the main platform categories, we have evaluated the possible technical synergy effects available today. Further, we have reviewed how sharing platforms through cooperation and combination of efforts may maximize current and future survey potential.

Technical findings

The key goal is to survey once, and to use collected data multiple times and for different purposes. This approach requires high-resolution mapping of different data types simultaneously while keeping induced errors to a minimum.

The approach requires combining different types of sensors, to maximize the number of data types collected, but it does introduce restrictions on how data may be collected. The challenge of close to shore, shallow surveys limits the types of survey platforms that may be used.

- Size matters, and for this work, bigger vessels are not suitable.
- Data collected with LIDAR/Satellite is supplementary at best, since high resolution data cannot be collected with current technology, and collected data are distorted by induced errors.

Mutualisation of means

Combining efforts, through shared planning may result in improved cross border mapping efficiency, but unresolved national restriction on both survey permissions and data distribution, do represent a challenge.

Combining tenders and thus increasing the volume of the work will results in reduced price. It aids in avoiding overlapping efforts, and may give an increased focus on data requirements and standards for such survey operations, resulting in output that is more valuable.

Conclusion

On the maritime part of the coastal areas, survey platform of choice is a surface vessel. The surface is the ideal spot for mapping many data types while keeping induced errors to a minimum and maintaining high position accuracy. On the emerged part of the coastal areas, the surveys must be completed using near surface or orbital platforms.

Figure 6: Examples of AUSV.

Current development of AUSV 'autonomous unmanned surface vessels' will significantly reduce survey cost while greatly increasing efficiency. Combined with new submersible survey instruments, it holds great promises towards our goal of 'surveying once, and reusing many times.'

Various national restrictions limit shared efforts. Permissions required to perform surveys near the shore are difficult or even impossible to obtain. Limitations on who may have access to data surveyed and different policy's on what data resolution that may be freely distributed, continue to be challenges for a necessary transnational cooperation.

Combined tenders is still desirable, and will increase focus on cross border issues that need to be resolved. It will also reduce price for all stakeholders involved.

A detailed report can be found in Annex 5.

2.6. Results for task 3 (WP3.1: Inventory of the current economic models – WP3.2: Financial-transnational programmes – WP3.3: Governance of data – WP3.4: Validation of the proposed programme)

This WP was dedicated to the aggregation of the results of the other workpackages and the realization of complementary studies to propose a future european programme for the management of the acquisition of high resolution coastal bathymetric data.

Five sub-tasks were realized and are described in this section:

- ✓ ***WP3.1 and 3.3, Economic models and Governance of data.***

A questionnaire sent to 15 countries (Lettonia and Estonia joined this work thanks to the Latvia partner), were designed to understand the governance of these data in the countries of the partnership and other for the economic models. Because it became an evidence that the economic models and the governance were totally linked, it was decided to conduce these two studies in common to have an integrated vision of the situation. The Partners of Ireland and Latvia, in charge of these tasks, worked both to this report.

- ✓ ***WP3.2 Financial-Transnational Programmes.***

The partner of CPMR, studied the opportunities offered by different EU programmes for the acquisition of high resolution (HR) bathymetric data and designed a web tool to better access to the operational programmes and the most efficient axes of them for acquisition of data. They examined the Research and Innovation Strategies of more than 100 maritime regions to evaluate the level of taking into account of the maritime policies in the EU regions.

The CPMR will organize on 7th of February 2017 two stakeholders meetings; one with their member regions, the other with the EU parlementaries of the Seas, Rivers, Islands and Coastal areas Intergroup. The objective is to promote the results of the coastal mapping project and prepare the next step.

- ✓ ***WP3.4 Validation of the proposed programme.***

The Lazio Region organized the information of the Bologna Charter network, a memorandum of understanding were signed with the Facecoast cluster, the project and first result were presented to the Italian national board for the erosion with maritime regions and representatives of Environment Ministry, and a test of the algorithm was realized with a stand in the Ferrara Remtech 2016 Event.

- ✓ ***WP3.5 Data acquisition programme proposition.***

To complete the picture with the reality of the necessities for the HR bathymetric data acquisition in the 13 partnership countries, a questionnaire was sent to the partners to evaluate the gaps and the possibilities to fill them.

Connecting all the results, a proposition of EU Strategy was produced. It was approved by all the partners and presented to the Directorate-General for Maritime Affairs and Fisheries (DG MARE).

2.6.1. Inventory of the current economic model – Governance of data

Introduction

This chapter deals with both WP3.1 and WP3.3 which have many overlapping themes in an inventory of current economic models and the governance of data.

A questionnaire was compiled and sent to all partners in November 2015. There were 18 responses from 15 countries (Estonia and Lithuania joined this work thanks to the Latvian partner). The combined answers are submitted in Appendix 6. The questionnaire was sub divided into six themes as follows.

The spatial extents of the coastal zone.

Only two countries uses the exact same definition for the coastal zone. The two main parameters are either a depth contour or a seaward distance. Some countries have no definition but refer to the coastal zone in terms of the type of survey required to map it.

The International Hydrographic Organisation does not specifically define a coastal zone and this was a subject discussed at the GEBCO Future of Ocean Floor Mapping Forum in Monaco in June 2016. The coastal zone definition depends on the requirement for the definition in terms of its use for hydrographic surveying, coastal zone management or determining a scale for study. Many attempts have been made to look for seamless onshore/offshore data integration and a determination of the data density required by various stakeholders. No 'one size fits all' approach has been agreed.

Similarly the length of coastline can be analogous to measuring a piece of string whereby scale and purpose need to be defined.

The population of the coastal areas is also difficult to define without agreed onshore boundaries. Human activities requiring good data in the coastal zone are well understood however it is apparent that the broad range of activities are almost common to all countries as shown in Table 2-Annex 6.

The responsibility for onshore and offshore data is usually divided at the water's edge and sometimes the inter-tidal zone is a no-man's land. The use of different vertical and horizontal datums is a significant obstacle in creating a seamless data set and it would be difficult to get any one country to harmonise datums and a major challenge for EU harmonisation.

Recommendation*: Future EMODnet effort should seek to form a working group to define a set of standard definitions that can be used to measure the coastal extents with a view to establishing comparative effort required for data acquisition in the 'coastal zone'. The definition should be innovative taking into account the sustainable coastal management and the specificities of the different basins, and not only choosing physical caracteristics.*

Governance of Data

The EMODNET Coastal Mapping consortium is predominantly comprised of National Hydrographic Authorities or proxies thereof. Details of these institutions and their legal frameworks are in Appendix 6 Section 3.1. The legal frameworks are either set with roots in a Military, Environmental or Transportation background or combination thereof. Most of the partners have a responsibility for producing products for the safety of navigation as the primary reason for data acquisition. It is important to understand that these products are derived from much denser data that is archived and not always available to the general public. The governance of the core data is generally held at a national level but in some countries regional authorities are responsible for some data sets - details in Appendix 6 Section 3.2.

Various budget scenarios are connected to both data acquisition and data management. In general all funding is through central exchequer funding at the state level. Some projects utilise regional and/or local funding. WP3.2 deals with this in more detail.

Data Sharing Tools

All partners except IIM, IHPT, DDNI, GeoEcoMar and GIS have a web presence where data is available to download in various resolutions. Data has also been incorporated into the EMODnet portal at low resolution.

Very high resolution or raw data are not as readily available either through data policy or possibly lack of resources to host data. Most partners do offer a consultative process to allow stakeholders to engage in negotiation for access to data but surprisingly only a few actively search out engagement with stakeholders to find out their needs. However in many cases this is mitigated by engagement in public media, social media and industry events.

The questionnaire showed some common tools between data holders and users but not always on a formal basis. The most common tool for sharing data is through a WMS/WFS for bringing data into a GIS environment and this probably negates some of the needs for formal agreements.

We would prevent the use of WMS/WFS data without the technical knowing and the intelligence attached to the data

Transnational Governance

All countries except Slovenia indicated some involvement in at least one of the following networks or organisations: International Hydrographic Organisation (IHO), North Sea Hydrographic Commission (NSHC), Baltic Sea Hydrographic Commission (BSHC), Arctic Regional Hydrographic Commission (ARHC), Nordic Hydrographic Commission (NHC), General Bathymetric Chart of the Oceans (GEBCO), Intergovernmental Oceanographic Commission of UNESCO (IOC), International Oceanographic Data and Information Exchange Commission (IODE), EuroGOOS, European Marine Observation and Data

Network (EMODnet), SeaDataNet, OSPAR, HELCOM, Infrastructure for Spatial Information in Europe (INSPIRE), Bologna Charter.

Data Policy

All countries are funded through central state funds with some regional and EU funding for specific projects. Romania DDNI and Sweden SMA are the only organisations that rely mostly on internal funding.

The cost of bathymetric data acquisition is high and especially in the coastal zone but warranted by the need to provide safe navigation data under the Safety Of Life At Sea (SOLAS) Convention. The fact that the data is also useful to a number of stakeholders then raises the problem of cost recovery for data storage and dissemination. Another factor is whether the data is considered to be classified, predominantly for military reasons.

In the Coastal Mapping consortium there is general agreement that a free data policy would be beneficial to many users and some countries do provide free access but most have some restrictions. See Table 1 below.

Data Policy	Partners	% (x/18)	Cost Benefit Analysis
Free access to all data	GERMANY (BSH)	31	No
	IRELAND (INFOMAR)		Yes – Pcw
	ITALY (Lazio Region, ISPRA)		No
	FRANCE (Litto3D),		No
	ESTONIA (MAE)		No
	SLOVENIA (GIS)		No
Open access to all data with some costs	ITALY (IIM)	26	No
	NORWAY (NHS/NMA)		Underway
	FRANCE (SOME DATA)		

Table 1: Data access policy

Cost Benefit Analysis

Table 1 shows that Ireland is the only partner to have published (2008) a Cost Benefit Analysis with a 5 year evaluation completed in 2013 by Price Waterhouse Coopers

(http://www.infomar.ie/publications/Reports.php). **This report confirmed that INFOMAR data is a key enabler of national marine policy with a *cost to benefit ratio of 4-5:1***. This CBA ratio is deemed to be conservative in relation to similar evaluations done in the USA (35:1), Cameroon (8:1) or Philippines (5.5:1). The Evaluation report analysis several European countries organisations engaged in similar undertakings to underpin the analysis.

Two other countries (Norway and Lithuania) are in the process of doing a CBA evaluation and results should be available in 2017. The Irish analysis gives positive indications which are very useful to justify the expenditure by the state where the private market is not able to sustain the cost of data acquisition.

It should be important, to realize a "Coast-benefit" analysis at the European level to promote the evolution of the situation in the European member states.

2.6.2. Financial-transnational programmes

In the Framework of the Work Package 3 of the project, the CPMR analysed the potential support EU Funds for coastal bathymetric data acquisition. This survey mixed two approaches combining desktop analysis and compilation of information from the project partners.

The following funding opportunities were analysed:

- ✓ Horizon 2020 and previous Research Framework Programmes;
- ✓ European Maritime and Fisheries Fund;
- ✓ LIFE Programme;
- ✓ Connecting Europe Facility (CEF) and TEN-T Programme.
- ✓ European Regional Development Fund through Transnational and Cross-Border Interreg Programmes and through the Research and Innovation Smart Specialisation Strategies and Operational Programmes of a selected panel Regions.

The work on the Interreg Programmes lead to the development of two interactive maps compiling information related to opportunities offered for coastal bathymetric data acquisition.

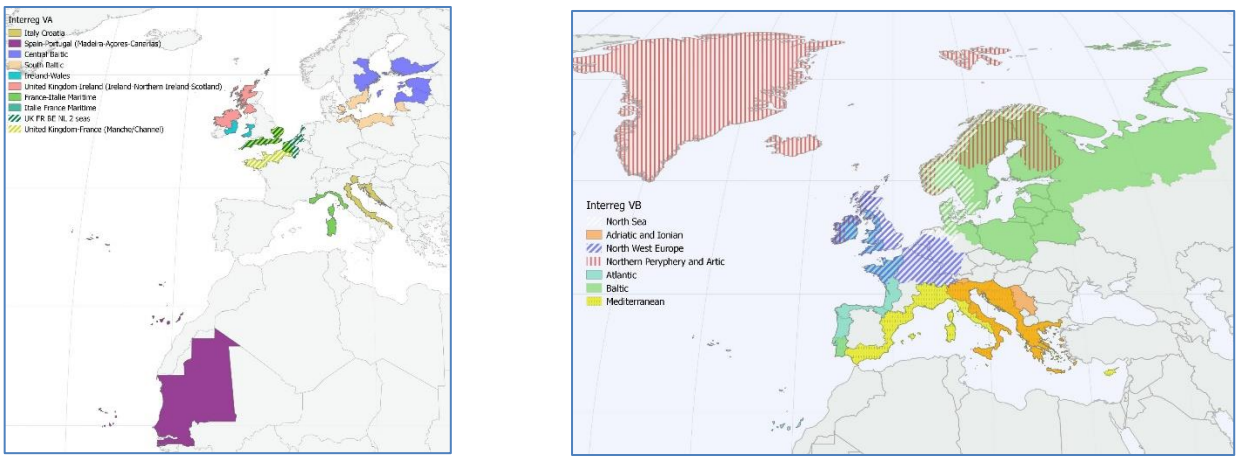

Figure 7: Maps of Interreg VA and VB.

This analysis of different funding sources shows that coastal bathymetric data acquisition can be supported by various EU funds. Every Interreg programmes offers funding possibilities while some bathymetric data projects are funded by the LIFE Programme, the CEF or the TEN-T Programme. However, most of those opportunities are implicit. The Operational Programmes offering a potential to support coastal bathymetric data acquisition actually refer to other activities such as "transport efficiency" for example.

Therefore, the multiplicity of funding sources combined with the lack of explicit reference to coastal bathymetric data, implies high funding analysis skills and generates complex project development procedure.

This situation demands:

- Acknowledgement of coastal bathymetric data by EU funds supporting it;
- Coordination of EU's efforts to support coastal bathymetric data acquisition through its funding programmes.

2.6.3. Validation of the proposed programme

ICZM-Monitoring Center of Lazio Region[3] has high cooperation and project management experiences already acquired in the framework of projects co-financed by the European Regional Development Fund also as lead partner, and it is a component of Bologna Charter coordination board[4]. Since year 2015, Lazio Region is one of the Working Group coordinator of the National Board on Coastal Erosion[5] promoted by the Ministry of the Environment and Protection of Land and Sea of Italy (MATTM).

[3] www.cmgizc.info
[4] www.bolognacharter.eu
[5] www.isprambiente.gov.it/it/news/istituito-il-tavolo-nazionale-sull2019erosione-costiera

During Coastal Mapping initiative, with the aim of suggesting the more sustainable and useful Joint Programme at the European scale, Lazio region has solicited coastal zone stakeholders coming from Bologna Charter coordination board, for being as exhaustive as possible with description of the situation in the EU Member States.

A set of EU initiatives has been promoted by Lazio Region in order to give visibility to Coastal Mapping products and results such as:

- ✓ the official adhesion of Coastal Mapping Project to the European Cluster Facecoast[6] with the signature of the Memorandum of Understanding between the representatives of Coastal Mapping project and Medsandcoast[7] project;
- ✓ the promotion of the Coastal Mapping Portal[8] during the Bologna Charter Coordination Board meeting of April 28th 2016 in Rome;

Figure 8: Ferrara Remtech2016.

- ✓ the promotion of the Coastal Mapping Algorithm during the "National guideline on coastal erosion" Conference of Ferrara Remtech2016[9] on September 21-23, 2016. During this initiative several regional public authorities with competences on coastal zone management have been involved for testing the Coastal Mapping tools and some feedback and suggestions have been collected thanks to the realisation of the "tools interest interview" realised in the face to face modality during the test tools experience.

The main feedback are:

The evaluation of the proposed tools quality was positive for all interviewed. They were partially interested because of the geographic scale. More detailed geographic scales for local uses would have been appreciated. They suggested that the Algorithm should take into account the survey costs and be able to compare them too. They also suggested use of some other technology (like Single Beam Echosounder) in the case of beach profile monitoring for the evaluation of very shallow water morphology. All regional authorities expressed their interest in collecting and sharing coastal mapping data if they can use it for the production of thematic maps in the integrated coastal zone management context.

A detailed report can be found in Annex 8.

[6] www.facecoast.eu
[7] medsandcoast.facecoast.eu
[8] www.coastal-mapping.eu
[9] www.remtechexpo.com

3 Data acquisition programme proposal

To complete the picture with the reality of the necessities for the acquisition of high resolution (HR) bathymetric data in the 13 countries of the parnership, a questionnaire was sent to the partners to evaluate the gaps and the possibilities to fill them. A detailed report of the results of this survey can be found in Annex 9.

Connecting all the results, a proposition of EU Strategy were realized, approved by all the partnership, presented to the European Commission and specifically to its DG MARE, DG Research and innovation, DG Growth and DG Environment.

To present an operational prospective to the DG MARE, the partnership of “Coastal mapping” project carried out an evaluation of the gaps of high resolution bathymetric data in the EU that we would have to fill for a sustainable development of our coastal zones. These results are complementary of the report done on WP2.5 “sharing platforms”.

The HR bathymetric data can be considered as fully complementary with the data managed by Copernicus program and in EMODnet projects. These data offer the opportunity to refine the circulation models along the coast, and the marine flood risk areas. It allows to present to the stakeholders the fine reality of their coastal seabed and, added to the fauna and flora layers, these data can help to decide more relevant strategies of coastal management.

All the EU maritime basins were considered in this evaluation.

Because each maritime basin, and bordering countries, represents specific situation and have specific definition of the "coastal zone", we preferred not to impose a definition which would not correspond to the reality of the uses, environmental characteristics, risks, economical possibilities of development, for all coastal areas. It is a recommendation of the “coastal mapping” project partnership, *that it is necessary to take into account the specificities of the maritime basins in the future acquisition strategy for coastal data.*

The results concerning the gaps and the possibilities of common acquisition are presented by “maritime basins”, defined by the International Hydrographic Organization involving all the EU maritime countries. Some partners gave illustrations of their coastal situation.

The gap analysis, carried out with 13 EU countries, embracing all the EU maritime basins, gives a first result of the European situation. This picture should be completed with other EU countries and the governance of a *EU Strategy for High resolution coastal bathymetric data acquisition* should be designed to progress significantly toward our goal of a knowledge of coastal areas, adapted for all kind of activities. This report represents a basic tool for this strategy.

The different basins and Member States which situation was evaluated were:

- *Mediterranean and Black Sea* with: Italy, France, Greece, Slovenia for Adriatic,.
- *Baltic* with: Sweden, Latvia, Germany
- *North* with: Germany, Netherlands, Belgium
- *Atlantic* with: Ireland, France, Portugal.

This panel represents more than 50% of the EU maritime member states.

The second part of the report summarizes the information received from the partners to describe the needs of data in shallow waters. The definition of the coastal zone used is given, the potential technologies to use and the capacity to share means are described by sea basin.

The main questions of the query were;

1) How many km2 of coastal zone, in shallow waters, would it be necessary to cover with high resolution data in your area of responsibility ?

2) What technology(ies) would be most efficient? "Multibeam, Lidar, Satellite, other.."

3) Do you have means to share, at the level of your maritime basin; vessels, planes, Multi Beam, bathymetric Lidar head..satellite images ?

4) What would be the priorities for a campaign strategy?

5) How to organize transnational campaigns for data acquisition ?

How could run a Joint European Coastal Mapping Programme?

It appears that the need for high resolution bathymetric data is important in the EU basins.

Important efforts must be done to ensure a safe navigation in the EU coastal zones, that is the basic condition to develop activities and permit to all EU countries to implement the agreements signed with global maritime organizations. All the EU member states have to comply with the SOLAS convention, that implicates the responsibility for a coastal State, to ensure the safety of navigation along its coasts.

However, the implementation of maritime policies in shallow waters, requires precise and validated data to answer to the juridical situation of the coastal management by the national and local authorities that have to take decisions concerning the planification.

The partners re-affirm that *standardized and high resolution data is the condition of re-usability of data by all the stakeholders for the maritime policies*. Using standard procedures would allow to give to the data a quality assurance. *The IHO rules must be used, no data should be gathered without an assessment about their uncertainty*.

It is strongly recommended that the use of these standards should be mandatory when bathymetric data is acquired with EU funds in the context of maritime policies and research.

Using standards is necessary to save money and energy, the processing and qualification of the data is a key part of the work to deliver valuable, safe, authoritative data, usable by the stakeholders to implement integrated maritime policies.

To be used by the authorities for the coastal management, the planification documents, the impact studies, the data must be legal data. This implies that it must be certified data.

The Hydrographic offices are in charge of the training of hydrographers, based on standards delivered by IHO. They are qualified, in their countries, to certify the data with high level of confidence and the data delivered are enforceable.

As a consequence, the experiences and the survey means can be shared, the acquisition and the processing of data can be done with means of another country, but the final certification must remain, to the responsible organization for the considered country.

It appears as a condition for ingestion of these data in all the maritime policies implementations and a condition for stakeholders to download from EMODnet portals.

In this study, we did an evaluation of a high resolution data acquisition which cover 175 000 km2. This one is indicative and relies only on the inputs from the countries involved in the "coastal mapping" project. It will be necessary to complete this study with the needs from the other EU maritime countries.

The needs are not the same in the different basins:

-Considering the depth, the needs of acquisition of data are for a 50m depth in the Mediterranean and 10-20 or 30m depth in the other basins, due to the configuration of the basins and the obligation to have the best knowledge of the presence of the protected species and habitats in a very busy area.

-Concerning the technologies of acquisition and in particular the possibility of sharing platforms for the bathymetric data, the suggestions shall be re-evaluated on a regular basis to follow their evolution.

The maximum resolution useful for the evaluation of activities is 0.50m, the actual MBES can deliver 0.20m in good conditions.

The evaluations of the most interesting technology are directly linked to the transparency of the waters and the *algorithm is calibrated to analyze this parameter*.

Among the different technologies discussed: Bathymetric Lidar, MBES, satellite derived bathymetry, photogrammetry, on UAV , *the LIDAR*, in all basins, *when the transparency of the water permits it*, represents an interesting solution to obtain data usable for the sustainable coastal management, with reasonable duration and costs. The example given by the Swedish partner is enlightening; "*An evaluation for 0-10 m using Bathymetric LIDAR is 34 M€ and could be achieved in a 5 year period using 4 months per year and two airplanes. Estimation for the secondary multibeam surveys for the areas 3-*

10 m gives between 92.5 and 114 M€ and the survey time between 81 and 100 years using only one boat (20-25 years using 4 boats)".

To complete the depth profile, Multibeam Echosounders should be used.

EU joint program dedicated to LIDAR acquisition of High Resolution Bathymetric data should represented a high step forward for coastal areas knowledge. It should be organized by basins and rely on a global strategy for the development of capacities, the sharing experiences, to support evolution of the technologies in function of the needs, to stimulate the research around these results, to help to develop learning tools for the stakeholders.

For the multibeam echosounder surveys; the partners recommend the sharing of their vessels per basin.

However, the time required for the organization of the campaigns must be taken into account. The campaigns must be designed one or two years in advance at least. They would mainly concern neighbor countries or sub-basins in maritime basins.

Satellite derived technology; This technology presents an important potential for the coverage of large areas but is still limited in terms of accuracy. Where no data exist, satellite can provide a first guess and help to design the strategy of acquisition. In the areas where the transparency is very weak, the satellite could be useful to detect more favorable situation to realize LIDAR campaigns.

Other Technologies, like *photogrammetry*, or LIDAR on UAV can allow the coastal managers to update, complete or realize surveys in special areas. Some partners use it (GSI Ireland) and can share their experience to develop it in the other countries.

Sharing platforms to do acquisition of different types of data:

As discussed in the W2.5 report, the panel of actors to coordinate in each country and at the EU level to built a partnership for organizing common campaigns of acquisition of bathymetry, sharing means among different countries, is a challenge as important than the technical one.

Sharing means for different parameters seems difficult, and a lot of energy has to be spent to coordinate different types of actors, depending on different Ministries, but would be useful for the "maritime community".

However, it could be useful to involve specialists of other types of data or local stakeholders in the preparation of the campaigns to take into account their needs and insure the future use of the data.

Moreover, it seems indispensable that specialists of the bathymetry to be involved in the preparation of EU programs with maritime goals. This would facilitate the use of standards, the IENWG can be associated.

How to organize the campaings, what could be the next steps?

It appears to the partners that filling the gaps of these key data useful for all the EU actors in charge of coastal management, ***should be considered as a public service***.

In numerous Directives concerning the maritime policies, the EU considers that the data must be as open as possible, that implicates a common effort of mutualization of technical, administrative and financial means to create the common basic knowledge for the implementation of the EU Directives in a sustainable and transnational way.

The EU countries and regions try to put in common means and budget to do some acquisitions ***but it is not sufficient and don't allow an ecosystem based approach for the EU coasts***.

The EU Commission could help to fill the gaps, participating to the organization of a EU board, bringing together the representatives of the Member States and Regions, and the different Directions of the EU commission concerned by coastal and maritime activities, under the umbrella of the DG MARE and EMODNET. This organization could manage: the global strategy, the coordination of the common budget for the campaigns, the public calls for tender to be organized if necessary, the agenda of the acquisitions, the basin's strategies, the communication, the mutualization of experiences..

The partners decided to arrange the presentation of the gaps by hydrological basins, in the objective to promote the possibility of the organization of strategies of acquisition of data in common conditions of technologies, sea characteristics, uses, species and habitats, governance of financial sources.

As a consequence, in addition to the EU level board, it must be put in place *basin scale sub committees* to organize the campaigns and decide priorities.

The majority of the partners are used to work in common, through the IHO organization and can share technical, administrative and financial tasks. Different examples of common activities demonstrate the capacity of synergy at basin's scale or between neighbor countries: IHO Hydrographic commissions, HELCOM re-survey plan (EU project FAMOS), EuroGOOS. There are already regional bodies BOOS (Baltic Operational Oceanographic System) and NOOS (Northwest European Shelf Operational Oceanographic System).

Bilateral surveying projects are running between neighbor countries like Denmark (gst.dk) and the Netherlands (Rijkswaterstaat). These were developed to perform efficient surveying across the boundary lines . In the EU project BLAST (Bringing Land and Sea Together), an InterReg4 project, financed concrete lidar measurements on the Belgian coast and in Denmark.

What coud be the priorities?

Giving priorities seems difficult; Dealing separately with the safety of navigation, coastal urban zones, ports, economic areas (marine energy, aquaculture, transport, nautical activities, tourism..), or marine protected areas, doesn't allow to develop an integrated maritime policy and put in place ecosystemic strategies, the preservation of habitats, sustainable protection against climate change.

Toward a European strategy for high resolution bathymetric data

Connecting all the results, a proposition of EU Strategy was produced. It was approved by all the partners and presented to the DG MARE. This Strategy is based on three axes and should be implemented by three pillar actions.

THREE AXES

- AXIS 1: Set up coordinated programmes for data acquisition at maritime basin scale;
- AXIS 2: Seize opportunities for bathymetric data acquisition in the framework of the EU operational programmes and funds; and ensure that those data are standardized and capitalized;
- AXIS 3: Promote good practices for the production of bathymetric data from multiple sources, standardized for re-use by all coastal stakeholders for maritime policies.

THREE PILLAR ACTIONS IN SUPPORT OF THE STRATEGY

- Design a European organization for steering the Strategy;
- Design digests of standards and hydrographic practices for all potential contributors to acquisition of these data;
- Design a better partnership with the coastal stakeholders for the use of high resolution bathymetric data in Europe.

Recommandations from the "Coastal Mapping Partnership" which represents 13 countries, 160 Maritime Regions, on all the EU maritime basins:

- ✓ By stakeholders experiences in coastal zone, all the maritime policies, their integrated management and ecosystemic approach need, standardized and validated, high resolution bathymetric data. Each maritime planification begins with the acquisition of HR bathymetric data and it should be considered as a public service.

- ✓ The coastal area is a key zone for blue growth, ecosystems and habitats, high-risk climate change area, but due to different conditions, it is necessary to take into account the specificities of the maritime basins in the future acquisition strategy for coastal data.
- ✓ Standardized, safe, authoritative, and high resolution data is the condition of re-usability of data by all the stakeholders for the maritime policies. The IHO rules must be used, no data should be gathered without an assessment about their uncertainty, the final certification must remain, to the responsible organization for the considered country
- ✓ It is strongly recommended that the use of standards should be mandatory when bathymetric data is acquired with EU funds in the context of maritime policies and research. It seems mandatory that specialists of the bathymetry be involved in the preparation of EU programmes with maritime objectives. This would facilitate the use of standards, the IENWG can be associated.
- ✓ The partnership promotes the pooling of these data in the EMODnet products, to permit the implementation of all EU maritime Directives particularly for the transnational cooperation needed for the ecosystemic approach.
- ✓ Coastal mapping project has produced different tools that it recommends to use and develop further; the coastal mapping portal, the algorithm for choosing the technology of acquisition of data and a tool for better fund the acquisition of data using European programmes in relevant areas.
- ✓ A cost-benefit study could demonstrate the interest for Europe of a secured mechanism of acquisition and sharing of coastal bathymetric data, and the "coast benefit" of the Strategy proposed.

In conclusion, for the partnership, since an integrated maritime policy needs an integrated vision, and since coastal areas are a major stake for blue growth but also highly sensitive from an environmental point of view, a strong action must be taken to progress significantly on the knowledge of these areas.

*For that reason, the coastal mapping project strongly recommends that a **European Strategy with the above 3 axis and 3 pillars actions** be implemented. For the sake of efficiency the project team recommends platform sharing and/or organizing common campaigns for data acquisition, systematic requirement that any EC funded project including data acquisition must respect standards and ensure data capitalization and promotion of good practice to maximize the benefits of community/crowd sourced data.*

4 Challenges encountered during the reporting period

4.1. Specific challenges encountered in preparing portal

Impacts of the choice of projection

The project team made the choice to present the data in the portal ETRS89-Lambert Azimuthal Equal Area (EPSG:3035) for 2 main reasons :

- Compliance with INSPIRE recommandations for pan-European spatial analysis and reporting
- Preservation of areas, especially in northernmost regions, compared to WGS84 - Geographic projection (EPSG:4326) used by the existing EMODnet portals.

It was also chosen to allow users to choose the projection in which they want to display data. The WebGIS viewer supports the 3 following CRS and can be changed using the settings tools :

- ETRS89 - LAEA (EPSG:3035), which is the default CRS
- WGS84 Geographic projection (EPSG:4326)
- WGS84 Web Mercator (Auxiliary Sphere) (EPSG:3857).

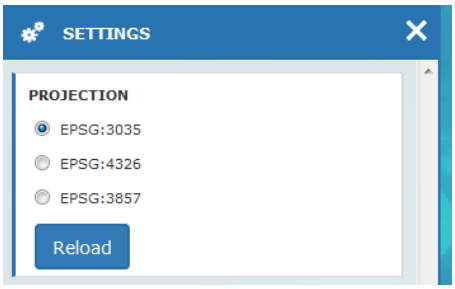

Figure 9: Web portal settings.

Reprojection artifacts issue

The support for the on-the-fly reprojection brings issues due to the GeoServer main library for GIS operations: GeoTools. The reprojection produces visual artifacts (grey borders) on the bounding box of existing data.

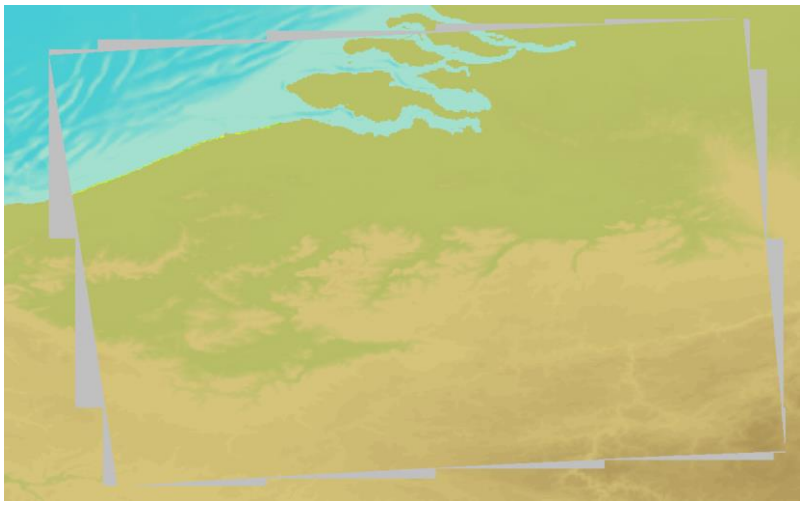

Figure 10 : Example of reprojection artifacts in GeoServer.

The project team hoped that this issue would be fixed by the GeoServer development team before the final release of the portal, however no fixed date is known up to now, and this issue will be present in the final version.

Compatibility with other EMODnet projects

The project team decided to switch the basemap used as default when opening the portal from GEBCO to EMODnet Bathymetry map, for a better data resolution.

As Bathymetry project source projection is EPSG:4326, it does not provide a full coverage of the rendering zone in the Coastal Mapping Portal, when reprojected in EPSG:3035.

In order to benefit from higher resolution of EMODnet bathymetry data, and coverage and land data from GEBCO, it was decided to merge the data into one base layer in the portal, as shown below :

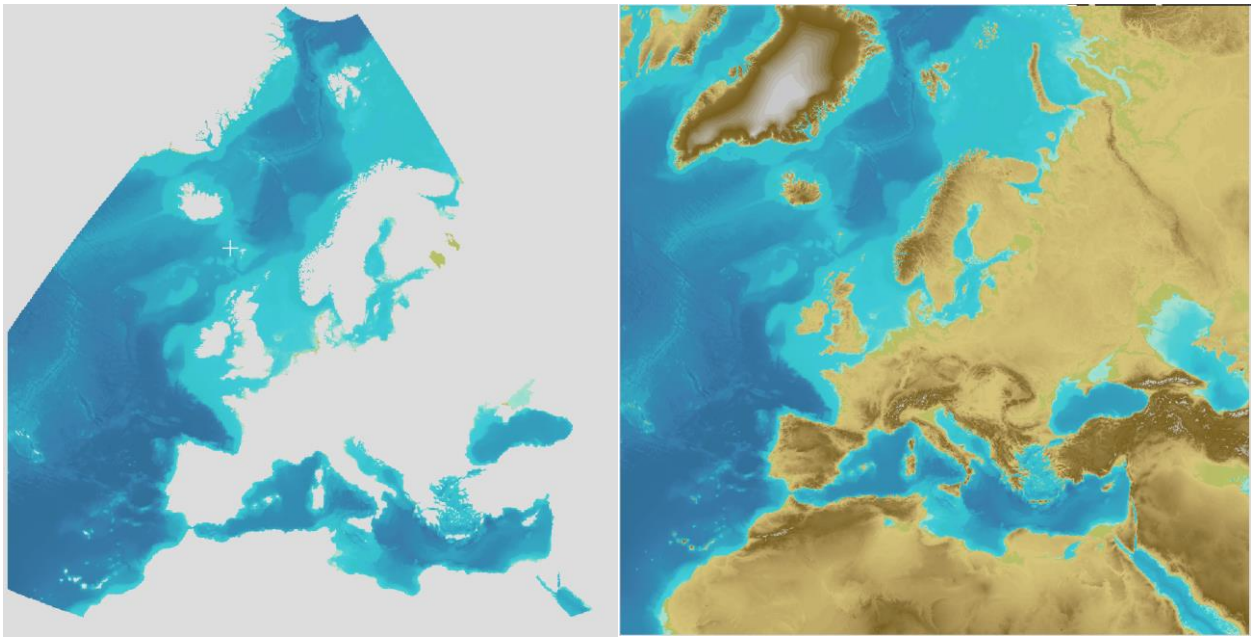

Figure 11: Left: EMODnet Bathymetry map, as projected in EPSG:3035; Right: final version of the Coastal Mapping portal basemap

No standardized EMODnet registration process

The implementation of EMODnet registration process has been judged non priority by the project team for two reasons.

- **Technical** : during the time when the main effort of implementation of the portal was done, there was no standard registration process defined among EMODnet project. Discussions in the

EMODnet Technical Working Group in October 2015 concluded to the need for more testing to choose the best authentication mechanism, without further information.

- **Functional** : the project team thinks not relevant to have a registration process for a portal supposed to propose data freely downloadable, if it covers only statistics purpose.

Integration of map of suitability for survey from geographical algorithm

One of the aim of the project is to propose a map of best suitable survey technique depending of local parameters (bathymetric, water clarity, survey cost). The initial objective was to propose a single map of all sea basins, colored depending on the best suitable survey technique, defined by the Coastal Mapping Planner algorithm.

The main challenge here is the computing time required to generate such a map : the Coastal Mapping Planner algorithm has not been designed for extensive use for high resolution map on the whole sea surface, the estimated generation time is expressed in month.

The first solution has been to generate a low resolution map of suitability for each survey technique for all sea basins. The next step is to generate high resolution map of suitability, only for coastal zone, in order to focus on the main goal of the project, and keep computing time within acceptable limits.

Data initialization

The first challenge we encountered was that the data required from the partners is not necessarily available under an open license thus not available for displaying on the portal.

For the bathymetry layers we tried to use a common colormap for all layers without success. Data were too heterogenous in quality. Then, we chose to leave them with their own colormap depending of the range of depth value and add a legend.

From this many layers from as many different partners we had to establish a standard for naming the layers.

As partners with already existing standard OGC services we had the possibility to let the portal use our services without re-delivering everything. But as it is the layers form, external services are not dowloadable through the portal. Only those delivered to and processed by the portal are.

Concerning external data from EEA or other EMODnet communitys there were two challenges. The first was to find the WMS URLs. And secondly, we could not display them because of the triple projection of the portal. Most WMS don’t offer all three CRSs and it is necessary that they offer them for displaying on the portal. To skirt this issue, we directly downloaded and published the EEA coastline and EMODnet Bathymetry on the portal.

4.2. Other challenges encountered in achieving the tasks

Main challenge	Measures (to be) taken
SHOM: filling of the past experiences questionnaire (1155 surveys in the scope of the questionnaire)	Set up of an automated way : 1) Extraction of surveys from Caris BDB : 1 shape file by survey with attributes values 2) Intersection with EUROSION data and NTU rasters from MERIS 3) Export of the compilated and deconflicted data into an Excel file with a Python script
BSH: 1. Filling of the past experiences questionnaire	Some fields were filled by extracting data from existing DB-logfiles. Some fields were generated in ArcGIS using semi-automated procedures. Some calculations were necessary based on the information in the report.
2. Providing data for the portal	BSH provided Worldline with high resolution coastal data .There were issues with the metadata, which did not have a File Identifier field filled in. Land- and seabed-information based on different zero-levels and have been transformed before delivering. Delivery first failed due to the size of the data and was managed by cutting the data in several files.
3. Questionnaire on economic models	To prepare all answers for the questionnaire, it was necessary to handle different information from regional governments and convert it into comparable statements.

IHPT: Calculating in a uniform and consistent way the cost of the surveys conducted in different years and using different techniques	Consulting the report of each survey and calculating the ratio between the surveyed area and the effective number of days surveyed. This procedure had to be made case by case, without being able to be automated.
HNHS: 1. Filling of the past experiences questionnaire 2. Filling the Vertical datum issues questionnaire	Retrieving the metadata and reports of survey, summarizing them to an Excel file, to fill in the questionnaire. This had to be done separately for each survey. Different people were assigned to gather manually the needed information and data for each survey and calculating the referenced cost, according to the estimated cost for each vessel for each day surveying or idle. Then all the information and data were summarized to an Excel file referenced to the questionnaire and finally for each survey a full list of questions was answered. Consulting different services as HNHS is not responsible for vertical datum. The questionnaire was answered after discussing about vertical datum with Hellenic Army Geographical Service (HAGS) and National Technical University of Athens (NTUA) specialists.
IIM: 1. Filling of the past experiences questionnaire	1. Dividing all surveys conducted into different classes, based on the kind of vessel and equipment used;

2. Filling the Vertical datum issues questionnaire	2. Fixing the price of every kind of survey using the cost tables available For each Survey we extrapolate the metadata attribute as GDI file from BDB Database. Coordinating the reply with other Authorities involved in the activities connected with datum.
GIS: 1. Filling of the past experiences questionnaire 2. Filling the Vertical datum issues questionnaire 3. Considering the strategic question 4. Legal issues 5. Considering method - purpose of data collected	Looking at all surveys reports, extracting metadata, finding all the information needed for questionnaire, determining ratio of survey areas for each survey, trying to find costs for each survey. Consulting different agencies responsible for specific topics, since GIS is not responsible for vertical datum. Above all considering the best possible survey method to be used, considering cross-border influence of hydrographic activities; neighbouring countries conducting joint surveys . Legal issues, especially regarding if all data should come to HO to be used for all other purposes; different countries - different obligations Different methods and purpose for collecting the data for using it in one platform - use of same standard and quality control (if needed).
RWS: 1. Getting information on the vertical datums used in Europe and their definitions	A questionnaire on vertical datum issues was composed and distributed among partners.

2. Providing data for the portal	The filled in questionnaires provide a good overview of the topic and of the complexities related to vertical datums on sea. Information about countries that were not represented in the consortium was acquired through an extensive literature study. For internal purpose, the original data was available in centimeter only and conversion to meter was necessary. Metadata was not yet available and had to be created. The upload required installing third-party software which was not possible due to internal policies; software was installed on a stand-alone pc.
GSI: 1. Filling of the past experiences questionnaire (187 surveys in the scope of the questionnaire) 2. Providing data for the portal 3. WP3.2 Questionnaire on economic	Some fields were filled by extracting data from existing shape files. Some fields were generated in ArcGIS using semi-automated procedures. A large number of fields were filled by consulting each individual survey report and entering the information in the spread sheet. Some calculations were necessary based on the information in the report. GSI provided Worldline with data in several formats in order to test the system. XYZ, Geotiff, ESRI ASC, BAG, .shp and also five WMS. The only issue with data format was the XYZ format which was not supported by the warehouse. There were issues with the metadata, which did not have a File Identifier field filled in. Compiling one questionnaire to reflect a lot of

models	cross over with WP3.1. This process allowed partners to only answer one set of questions but this required close coordination with Latvia. A good response was received but good analysis will now be required which will involve help from our INFOMAR project partners.
DDNI: Extracting coastal data form database	1. Building a coastal database from archives; 2. Extracting bathymetric data (still working) from historical charts (semi-automated procedure); 3. Some data is prepared to be uploaded on the portal (31700 EPSG) and we are still waiting for the interface to be available (credentials and methodology – as discussed in Rome at ISPRA).
SMA: 1. Filing of the past experience questionnaire 2. Discovered unfunctional metadata in the portal	Our metadata is not structured in a way that makes it possible to fill out the questionnaire. We will try to extract some samples from on-going surveys. The Metadadata service at SMA had to be corrected/reorganized.
MDK 1. Export 8 files for LIDAR and 8 files for Single Beam from our Bathymetric Data Portal.	Both surveys Lidar and Single Beam are splitted in 8 zones along the Belgian coast. Those files were delivered through the Flemish government Drop Server (VOBO). The metadata of the survey project is described in the GML and XML files with the corresponding file name. The GML file

2. The processing of an update of the LiDAR data. The old LiDAR data of 2015 has to be replaced by the new LiDAR data of 2016.	includes the surrounding polygon of the survey together with S-57 attributes of the survey. Every year around May there will be an update of the 16 zones for the CM (Coastal Mapping) Portal. A WMS service with the baseline and coastline is set up for integration in the CM Portal. For each survey we define a project name as described in the CM meeting in Dublin: COUNTRY TYPE RESOLUTION YEAR AREA. The metadata of the survey project is described in the CDI xml files with the same file name as the GeoTIFF files. CDI stands for Common Data Index that gives users a highly detailed insight in the availability and geographical spreading of marine data sets, that are managed by the SeaDataNet data centers. In those files you will find the surrounding polygon of the survey together with the CDI attributes.
LAZIO: 1) Filling in the past experience questionnaire 2) Understanding the better way to attract the attention/interest of "Bologna Charter" network to the Coastal Mapping products/results	Creating an excel database of past experience on coastal monitoring taking into account all the information requested by the WP2 past experiences questionnaire. A specific public event has been organised by Lazio Region in the context of the Bologna Charter Coordination Board and of the Italian National Board on Coastal Erosion in order to show the potential of Coastal Mapping products to the coastal Administrations

	participants. Nevertheless the main feedback from stakeholders got in touch, pointed out the need of a stronger link between the morphology of shallow waters and the morphology of the coastal zone, which indeed includes the former. The most of administrative actions on coastal zones need the continuity of the morphological survey between submerged and emerged zones. To face this challenge, a demonstrative implementation on the portal of specific data is scheduled, envisaging a further involvement of the stakeholders in order to collect their advice.
NHS: 1. Including data from high north (Svalbard) 2. Detailed information about past surveys 3. Enough manpower to manage a contribution beyond the minimum	Worldline has modified the area covered by the portal. Too much work to compile information for all surveys compared to the value added. The suggested algorithm has to take into account the extensive use of MBES. We have tried to allocate more capacity, but this was not possible due to lack of available resources.
ISPRA: 1. processing the results from the past experience questionnaire	1) Collection and homogenization of the results both from the online questionnaire and from the excel table. 2) Importing the data into a geodatabase. 3) Joining the tabular data with spatial data. 4) Comparing and summarizing the results.

2. building an algorithm able to collect the expertise from different operators in coastal mapping	Choice of a Fuzzy rule based system model that is well suited to convert the operational knowledge in computing language.
3. collecting the knowledge from the different partners on specific acquisition technologies	1) Presentation and discussion among the partners at the project meetings. 2) Discussion on the coastal mapping forum.
4. developing the geographical version of the algorithm to provide to the portal high resolution maps of technologies' suitability all over Europe, due to the high computation time of the task.	1) the interactive algorithm was rewritten to optimize the processes and to parallelize the computation on multiple CPUs. 2) the maps were produced by running the geographical CMP on a server that used 6 CPU's for the task.
5. Gathering the information needed to define the cost functions associated to each acquisition technology, products and surveyed area properties.	1) Presentation and discussion among the partners at the project meetings. 2) Establishment of a specific working group.
6. Providing data for the portal	Organize the data to upload in the portal, prepare legend image and compile metadata.
GeoEcoMar:	
1. Work package 2: "Share experiences, standards and best practices".	Data management and processing in accordance with the project specifics and requests.
2. Future programme: how to be defined in order to keep pace with the local needs and challenges.	Accommodation of local rules and practices with new EU rules and future expected developments
MAL:	
1. Very shallow water (less than 5m) hydrographic surveys along shoreline	Possibility of use new hydrographic measurement technologies (remote control

with unknown depths and underwater objects.	equipment, LIDAR technologies etc.). The very beginning of planning stage at the moment. There are no resources and equipment available.
2. Development and implementation of Hydrographic information system (HIS)	Creation of complete survey data and cartographic information system. In progress. Expected completion time – end of 2018.

Table 2: List of other challenges encountered

5. Allocation of project resources

The following table gives an indication of the efforts in % of the total project efforts for the various work packages during the first 18 month period:

- WP1 : Digital mapping
- WP2 : Share experience, standards and best practice
- WP3 : Future programme
- WP4 : Management

Country	Partner	WP1	WP2	WP3	WP4	Total
Belgium	Afdeling Kust, Division Coast, Vlaamse Hydrografie, Fleminsh Hyd. Adm Centrum	21.00	39.00	28.00	6.00	94.00
Germany	BSH - Bundesamt für Seeschifffahrt und Hydrographie	21.43	40.00	26.50	6.00	93.93
France	SHOM - Service hydrographique et océanographique de la marine	45.00	30.00	15.00	5.00	95.00
France	Worldline Company	94.14	1.56	1.04	0.26	97.00
France	CRPM - Conférence des Régions Périphériques Maritimes	0.00	4.82	61.08	1.50	67.40
Greece	HNHS -Hellenic Navy Hydrographic Service	21.00	41.00	27.00	5.00	94.00
Ireland	GSI - Geological Survey of Ireland	6.00	13.00	73.00	2.00	94.00
Italy	Istituto Idrografico Della Marina	21.43	40.00	26.00	6.00	93.43
Italy	ISPRA - Istituto Superiore per la Protezione e Ricerca Ambientale	3.00	80.00	1.50	0.30	84.80
Italy	Lazio	8.00	20.00	48.00	2.00	78.00
Latvia	Maritime Administration of Latvia	8.19	16.35	67.06	2.42	94.02

Netherlands	Rijkswaterstaat - Dutch Ministry of Infrastructure and the Environment	6.50	78.00	8.00	2.00	94.50
Norway	Norwegian Mapping Authority - Hydrographic Service	7.00	76.47	8.00	2.00	93.47
Portugal	Instituto Hidrográfico	21.43	41.50	26.00	6.00	94.93
Romania	GeoEcomar	21.00	42.00	28.00	6.00	97.00
Romania	Danube Delta National Institute	21.43	42.86	28.57	4.14	97.00
Sweden	Sjöfartsverket - Swedish Maritime Administration	10.00	75.00	9.00	2.00	96.00
Slovenia	GIS - Geodetic Institute of Slovenia	19.00	37.00	30.00	5.00	91.00
Totals per WP (%)		96.40	91.27	84.19	85.56	92.07

Table 3: Efforts in % of the total project efforts

6. Meetings held since last report

Date	Location	Topic	Short Description
23/06/2015	St-Mandé (FR)	WP1 meeting	[project] Identification of first actions for WP1.
24/06/2015	St-Mandé (FR)	Kick-off meeting	[project] KO with the project team.
30/06/2015	Ispra (IT)	EMODnet-INSPIRE workshop	[external] Exchange of information between the two initiatives.
01-02/07/2015	Ispra (IT)	Steering Committee	[external] Fourth EMODnet steering Committee.
02/07/2015	Ispra (IT)	Seminar at JRC	[external] Information on EMODnet for Joint Research Center staff.
02/07/2015	Ispra (IT)	Kick-off meeting	[external] Official KO with DG MARE/EASME.
05/08/2015	Web conf.	WP1 meeting	[project] Presentation of project tools and structure of portal specification.
19/10/2015	Ostend (BE)	MODEG	[external] 23rd MODEG meeting.
21-22/10/2015	Ostend (BE)	Portal Specification Review	[project] Progress meeting including WP2 and WP3 state actions.
22/10/2015	Ostend (BE)	Bathymetry progress meeting	[external] Identification of synergies between the two projects.
23/10/2015	Ostend (BE)	Technical working group	[external] Harmonization of

			portals and web services.
1-2/12/2015	Bezons (FR)	Portal	[project] Progress meeting including WP2 and WP3 state actions.
7-8/12/2015	Brussels (BE)	EMODnet-INSPIRE workshop	[external] Exchange of information between the two initiatives.
8-9/12/2015	Brussels (BE)	EMODnet-MSFD coordination	[external] Coordination and synergies between the two initiatives.
9-10/12/2015	Brussels (BE)	Steering Committee	[external] 5th EMODnet steering Committee.
18-19/01/2016	Saint Mandé (FR)	4th IENWG	[external] Presentation of the project update.
2-4/03/2016	Roma (IT)	Algorithm	[project] Progress meeting including WP1, WP2 and WP3 state actions.
21/04/2016	Brussels (BE)	23rd MPMSEG	[external] Maritime Policy Member State Expert Group meeting
28/04/2016	Roma (Italy)	BC Coord. Board	[external] Bologna Charter Coordination Board meeting
7-8/06/2016	Stockholm (SW)	Progress meeting	[internal] Progress meeting.
21-22/06/2016	Brussels (BE)	Steering Committee	[external] 6th EMODnet Steering Committee meeting
14-15/09/2016	Dublin (IRL)	Progress meeting	[internal] Progress meeting
13/10/2016	Brussels (BE)	European Week of Regions and Cities	[external] Workshop
13-14/10/2016	Brussels (BE)	IENWG5	[external]

			Presentation of the project update.
08/12/2016	Brussels (BE)	Final meeting	[external] Presentation to DG MARE/EASME

Table 4: Meetings held since last report

7 Outreach and communication activities

Date	Media	Title	Short description and/or link to the activity
02/07/2015	Presentation	EMODnet Coastal Mapping	Information on the project for Joint Research Center staff (Ispra, IT).
20/10/2015	Presentation	The European Marine Observation and Data Network	Presentation of the project (1 slide) by the EMODnet Secretariat.
18/01/2016	Presentation	EMODnet Coastal Mapping	Update on the project to the IENWG.
21/04/2016	Presentation	Coastal Mapping project	Presentation at the MPMS expert group.
25/05/2016	Presentation	Towards a standardized European vertical datum	Presentation at the EUREF 2016 symposium.
21/09/2016	Presentation	Coastal Mapping	Presentation of the project to the (Italian) National Table on Coastal Erosion – Ferrara (IT)
08/12/2016	Presentation	Coastal Mapping	Presentation of the results at a DG MARE conference

Table 5: Outreach and communication activities

8. Portal user statistics

The statistics start from 4th February 2016.

8.1. Website global statistics

The statistics are more detailed in Annex 10.

Table 6: Users' visits of the website (general)

Period	Unique visitors	Number of visits	Pages
04/02/16-25/12/16	2105	3181	6259

Table 7: Users' visits of the website (by country)

Country	Sessions	Pages/session
France	884	1.86
Italy	391	2.16
United Kingdom	325	1.63
Belgium	194	2.19
Spain	166	2.22
Russia	165	1.95
United States	100	1.51
Germany	96	1.92

Sweden	94	2.18
Ireland	78	1.78

Table 8: Users' visit of the website (by service provider)

Service Provider	Sessions	Pages/session
service hydrographique et oceanographique de la marine	360	1.58
worldline france hosting	203	2.43
(not set)	117	1.57
istituto superiore per la protezione e la ricerca ambientale	94	1.85
comfortel ltd.	88	1.97
national maritime administration	74	2.38
commission europeenne	58	2.00
voxility.net	54	1.00
wind telecomunicazioni s.p.a	48	2.98
flanders marine institute	41	2.63

Annex 1: Datasets available through the portal

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List of acronyms

BSCD2000	Baltic Sea Chart Datum 2000
BSHC	Baltic Sea Hydrographic Commission
CD	Chart Datum
CRS	Coordinate Reference System
EPSG	European Petroleum Survey Group
ETRS89	European Terrestrial Reference System 1989
EVRS	European Vertical Reference System
GBVP	Geodetic Boundary Value Problem
GNSS	Global Navigation Satellite System
GOCE	Gravity field and steady state Ocean Circulation Explorer
GRACE	Gravity Recovery and Climate Experiment
GRS80	Geodetic Reference System 1980
HAT	Highest Astronomical Tide
IERS	International Earth Rotation and Reference Systems Service
IHO	International Hydrographic Office
INSPIRE	Infrastructure for Spatial Information in the European Community
IOPG	International Association of Oil & Gas Producers
ITRS	International Terrestrial Reference System
LAT	Lowest Astronomical Tide
LLW	Lowest Low Water
MDT	Mean Dynamic Topography
MLLW	Mean Lower Low Water
MLWS	Mean Low Water Springs
MSL	Mean Sea Level

NAP	Normaal Amsterdams Peil
NSHC	North Sea Hydrographic Commission
TWG	Tidal Working Group
UELN	United European Leveling Network
VORF	Vertical Offshore Reference Frame
WGS84	World Geodetic System 1984

1 Introduction

The aim of WP2.1 is to assess the consistency of vertical datums within the European coastal zone and to recommend a European standard datum for coastal mapping. Within Europe many different vertical reference systems are being used. In the coastal zone the situation is of special interest as, depending on the application, elevations may be referenced to a sea based system, such as MSL or LAT, or to a land based system. The fusion and exchange of land and sea data is a difficult task as the relations between the various systems are not always known with sufficient accuracy. In order to map coastal data from different sources, one unique vertical reference system should be used.

To acquire detailed information on the use of vertical reference datums, a questionnaire was compiled and distributed among partners. Based on this questionnaire and literature study an inventory is made of vertical datums in the European coastal zone. This study focuses on both the vertical datum on land and at sea, including the definition of Chart Datum, and the methodologies used for its realization. Furthermore, an overview is given of the relations of national systems to the ETRS89-GRS80 ellipsoid and EVRS, and developments with respect to new realizations and harmonization between neighboring countries are discussed.

A harmonized vertical datum enhances wider and easier use of the data in accordance with the INSPIRE directive. The actual realization of a harmonized vertical datum is beyond the scope of this project. Such a realization is a long process that requires the involvement and the commitment of all stakeholders. For data exchange and fusion it is important that the transformations (or separation models) to a common reference, such as the ETRS89-GRS80 ellipsoid are defined and available to users.

In this report various candidates for a European standard are analyzed and, depending on the application, advantages and disadvantage of each system are considered. The report is structured as follows. In chapter 2 a short review of coordinate reference systems and vertical datums is given. Chapter 3 gives an overview of developments in Europe with respect to the definition of new datums and transformations as well as the harmonization of vertical datums. The inventory of vertical datums on both land and at sea within the European coastal zone is presented in chapter 4. Chapter 5 deals with the analysis of INSPIRE requirements with respect to vertical referencing of coastal data. Additionally other relevant standards are discussed. Finally, the candidates for an European standard that could serve as a common reference for bathymetric mapping are elaborated in chapter 6.

2 Definition of vertical datums

A vertical datum is defined as any level surface taken as a surface of reference from which to reckon elevations or depths. On land, geodetic vertical datums are generally used to express elevations. At sea, however, elevations are generally referred to a datum defined by a certain phase of the tide (see figure 1). In this chapter the concepts of the principal coordinate reference systems and vertical datums are discussed.

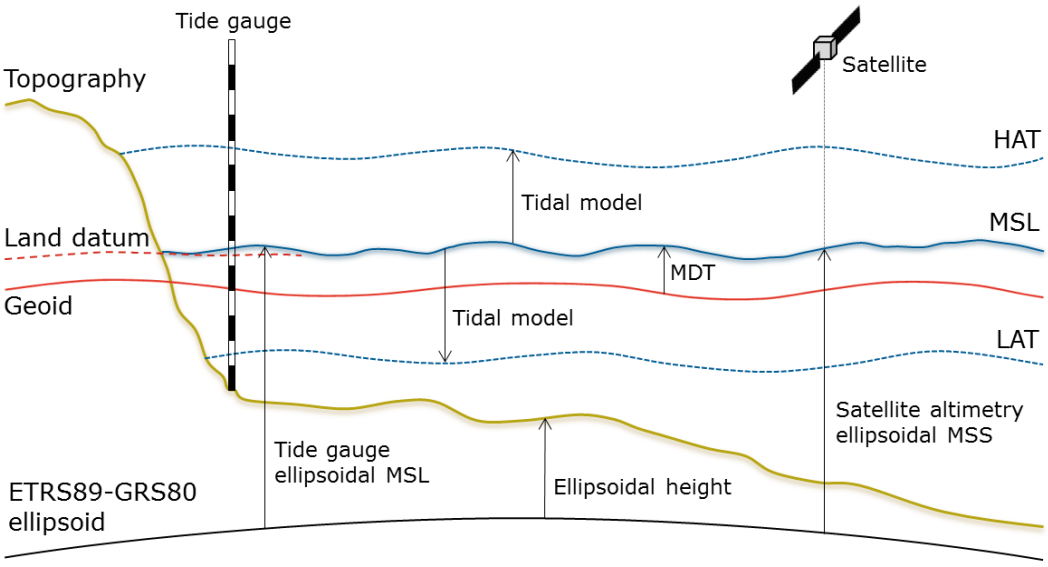


Figure 1: A schematic overview of vertical datums in the coastal zone. Based on Keysers et al. (2015).

2.1 International coordinate reference systems

To describe the position of a point on the Earth's surface a mathematical framework is required. This framework is provided by a coordinate reference system (CRS). In Europe the principal international CRS are the World Geodetic System (WGS84), the International Terrestrial Reference System (ITRS) and the European Terrestrial Reference System 1989 (ETRS89). These systems differ in level of accuracy and are therefore used for different applications.

The most well-known system is WGS84, which is the reference system being used by GPS. As described in FIG (2006), many users claim to be working in WGS84, for instance in positioning at sea and nautical charting. However, WGS84 is primarily a US military system; for civilian users the only WGS84 realization available is through the GPS broadcast satellite orbits, limiting the accuracy of WGS84 coordinates for civilian users to a few meters.

However, new WGS84 realizations are coincident with ITRS realizations at about 10-centimeter level. For these realizations there are no official transformation parameters. Thus ITRF coordinates can be considered equivalent to coordinates expressed in WGS84 at 10 cm level. The most recent WGS84 realization (G1674) adopted ITRF2008 coordinates for more than half of the reference stations and velocities of nearby sites for the others. This means that ITRF 2008 and WGS84(G1674) are likely to agree at the centimeter level (ITRS, 2016 (website)).

The International Terrestrial Reference System (ITRS) is a global reference system co-rotating with the Earth. Its realizations, called International Terrestrial Reference Frames, are achieved by a set of physical points with precisely determined coordinates (Petit and Luzum, 2010). These coordinates are obtained using the observations of several space geodetic techniques: GNSS, VLBI, SLR, LLR and DORIS[1]. Due to longer timespans of observations, improved models, discontinuities in time series and newly added (or discontinued) stations, the realization of ITRS is updated regularly. The latest realization is ITRF2014, published by the International Earth Rotation and Reference Systems Service (IERS) on 22 January 2016. ITRF coordinates can be transformed between realizations using a 14 parameter transformation; a 7-parameter similarity transformation involving a scale factor, three rotations and three translations, and 7 parameters involving their rates.

When expressed in ITRS, coordinates of European stations are found to slowly change in the order of about 2.5 cm/year as the result of plate tectonics. Therefore, the IAG sub-commission Regional Reference Frame for Europe (EUREF) designed the European Terrestrial Reference System 1989 (ETRS89) in such a way that it is based on the ITRS except that it is tied to the stable part of Eurasian Plate.

ETRS89 is coincident with ITRS at the epoch 1989.0. Like ITRS, realizations are called frames and for each ITRS realization a corresponding frame in ETRS89 can be computed (labelled $ETRF_{yy}$).

The EUREF Technical Working Group (TWG) recommends to use ETRF2000 as a conventional frame of the ETRS89 system (Boucher and Altamimi, 2011). Both ITRS and ETRS89 use the Geodetic Reference System 1980 (GRS80) ellipsoid as the reference ellipsoid. At present the two systems differ by about 60cm. Hence, only for practical applications where coordinates with an accuracy at the one meter level are sufficient, ITRS and ETRS89 (and 'WGS84') may be considered equivalent.

2.2 Geodetic datum and height systems

A geodetic (vertical) datum is a reference surface of zero elevation to which heights are referred to. Traditionally, this reference surface is taken as mean sea level, often locally realized through the measurements at a selected tide gauge or as the average of multiple tide gauges. However, due to currents, winds, temperature and salinity, mean sea level is not an equipotential surface of the Earth's

[1] GNSS: Global Navigation Satellite System, VLBI: Very Long Baseline Interferometry, SLR: Satellite Laser Ranging, LLR: Lunar Laser Ranging, DORIS: Doppler Orbitography and Radio positioning Integrated by Satellite system.

gravity field. Hence, two points at equal mean sea level do not necessarily have the same height when defined rigorously with respect to the gravity potential. The equipotential surface that closely approximates mean sea level is called the geoid. It can be proven to be perpendicular to the direction of the gravity vector at all points. Due to the inhomogeneous mass distribution of the Earth, the geoid has an irregular shape with variations of about ±100m compared to the GRS80 ellipsoid.

Local geoid models are generally computed from a combination of a global gravity model, (high resolution) gravity measurements, GNSS/spirit leveling and other techniques, such as satellite altimetry. Since the dedicated gravity space missions such as GRACE and GOCE[2], global gravity models have improved significantly. As a result, many countries are developing a new national geoid model and updating the height system.

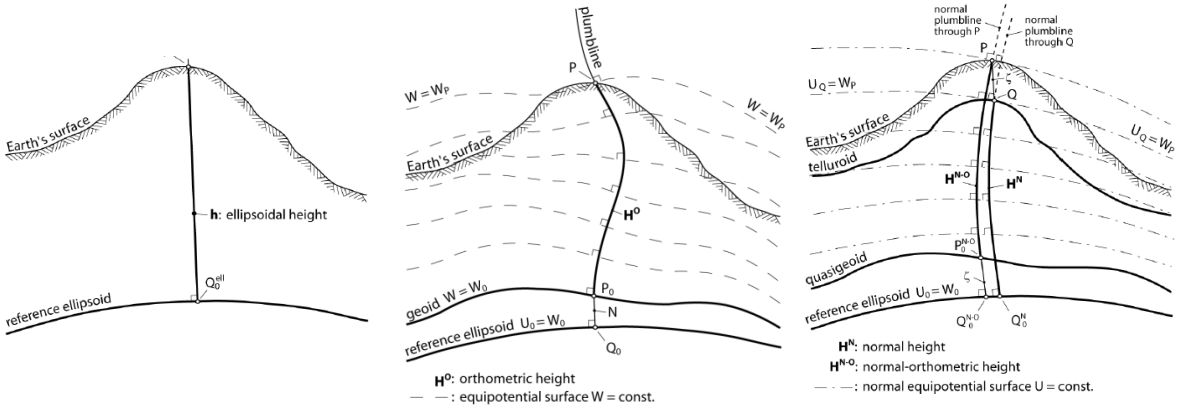


Figure 2: An overview of height systems; ellipsoidal heights h, orthometric heights H^O, normal heights H^N and normal-orthometric heights H^{N-O} (Featherstone and Kuhn, 2006).

Height systems

A height system depends on the choice of datum surface, but also on how the distance between that surface and a point of interest is defined. Height systems may be divided in geometrical and physical height systems. The most common geometrical heights are ellipsoidal heights, defined as the straight-line distance along the ellipsoidal normal from the geometrical surface of a reference ellipsoid to the point of interest (Featherstone Kuhn, 2006). Ellipsoidal heights are not (directly) related to gravity and as such do not follow the intuitive interpretation of height that water flows from 'high' to 'low'.

Physical heights are defined by the gravity potential difference between a point on the Earth surface and the potential at the local height system reference point. These potential differences, called geopotential numbers, are converted to heights by dividing them by the gravity acceleration. The kind

[2] GRACE: Gravity Recovery and Climate Experiment, GOCE: Gravity field and steady state Ocean Circulation Explorer

of physical height depends on the kind of gravity value used in this conversion. (Rummel et al. 2014). A schematic overview is given in figure 2.2.

Commonly used physical heights are orthometric heights, normal heights and normal-orthometric heights. Below, short definitions of these systems are given based on Featherstone and Kuhn (2006) and Rummel et al. (2014).

The o*rthometric height o*f a point on the Earth's surface is the distance from a point to the geoid along the plumb line. It is obtained by dividing the geopotential number by the mean value of gravity along the plumb line. This requires gravity variations or mass-density distribution to be accurately known inside the topography. Therefore, an approximation of the mass-density is often used in practice instead.

The normal height is the curved-line distance along the normal gravity plumbline from

the surface of the reference ellipsoid to the point of interest on the surface of the telluroid. The latter is the theoretical approximation of the Earth's surface. These heights are obtained by replacing the real gravity acceleration along the plumb line by the normal gravity in the conversion of the geopotential numbers. This way the assumptions on the mass-density or gravity inside the topography is circumvented.

Both orthometric and normal heights require gravity observations to determine geopotential numbers. When normal-orthometric heights are used the actual geopotential numbers are replaced by differences in the corresponding normal potential and actual gravity is replaced by normal gravity. Geometrically, the normal-orthometric height is the distance along the normal gravity plumbline from a point on the surface of the quasigeoid (which is not a equipotential surface but coincides with the geoid at cm level at low altitudes) to a point on the Earth's surface.

Traditionally heights are measured by spirit leveling. With this technique both instrument and leveling rod are aligned with the direction of the gravity vector. However, due to irregular mass distribution the resulting heights depend on the leveling route taken. In other words, leveled heights do not take into account that equipotential surfaces are not parallel and the distance between these surfaces is changing. To obtain orthometric heights or normal heights from leveling, corrections are required for the gravity-related misalignment of the instrument and leveling rods.

EVRS

The European Vertical Reference System (EVRS) is a gravity related height system that is based on the United European Leveling Network (UELN). It is realized as a network of benchmarks with given geopotential numbers and normal heights (with GRS80 as reference gravity field) in the zero tidal system. The datum is defined as the equipotential surface with a constant Earth gravity field potential at the Normaal Amsterdams Peil (NAP) level (Ihde et al. 2008).

The first realization of EVRS was EVRF2000, which was based on a single datum point (Amsterdam). For the latest realization, EVRF2007, 13 datum points on the stable part of the Eurasian plate were used, with their geopotential numbers held fixed to EVRF2000. Since the last realization, updated leveling data and new data from countries originally not part of the UELN have become available, a new realization may be expected in the next years/ near future.

2.3 Tidal datums

In hydrography the traditional surface to refer depths to is Chart Datum (CD). It is the reference level that is used in nautical charts and tables produced by hydrographic offices. For areas where tides have dominant effect on the water level, Chart Datum is generally a low water (or tidal) datum. A tidal datum is a vertical reference surface that is defined by a certain phase of the tide (e.g. Mineta et al., 2000). Due to the variety and complexity of tidal characteristics many implementations of Chart Datum are being used. Examples are Lowest Astronomical Tide (LAT), Lowest Low Water (LLW), Mean Lower Low Water (MLLW), or Mean Low Water Spring (MLWS). Chart Datum is often not a seamless reference surface as it may vary from location to location.

The International Hydrographic Office (IHO) recommends that LAT, or a surface as closely equivalent to this level as is practically acceptable by hydrographic offices, is adopted as Chart Datum for areas where tides have an appreciable effect on the water level (IHO, 2015). IHO defines LAT as the lowest tide level that can be predicted to occur under average meteorological conditions and under any combination of astronomical conditions. Such a prediction can be done by a harmonic analysis of water level observations spanning a period of at least 19 years.

For areas where water levels are not dominated by tidal movement, the resolution of the IHO is less clear. The tidal working group of the Baltic Sea Hydrographic Commission (BSHC) have proposed to use Mean Sea Level as Chart Datum which is currently being implemented (see section 3.2). MSL is the average level of the sea surface measured over a long time span (generally 19 years). As discussed in the previous section MSL at different locations refers to different height levels with respect to the geoid. The difference between the geoid and MSL is given by the Mean Dynamic Topography (MDT). The IHO resolution is currently being revised to include a unambiguous definition of MSL and guidance for Chart Datum in areas not affected by tides.

Slobbe et al (2013) assessed the safety of LAT as a chart datum. One of the main motivations to use LAT as CD is that LAT provides an indication of the minimal water depth that can be expected under average meteorological conditions and hence provides a sense of safety. However, in their study Slobbe et al show that the actual water level in the eastern part of the North Sea drops below LAT (during periods of tidal minima) once per month to once per week. Therefore, they propose a probabilistic design of Chart Datum. That is, Chart Datum is defined as a level which is exceeded with a given fixed probability.

2.4 Vertical datum unification

The harmonization or unification of heights has been the subject of many studies; an overview of various approaches is given in Sansò and Venuti (2002) and in Rummel et al. (2014). In the latter the following three methods are listed for the connection of different datum zones:

1) Geometric leveling and gravimetry
2) Geodetic Boundary Value Problem (GBVP) approach
3) Ocean leveling

The first approach is straightforward but can only be applied on continents. ERVS is based on this approach; by combining leveling data of various countries (corrected for gravity) in one adjustment, offsets between datums can be determined directly. A disadvantage of this approach is that it cannot be used to connect islands or separate continents as (datum) points need to be directly connected via a leveling network.

The GBVP approach to height unification involves the determination of the gravity potential through a selected datum point from local gravity data combined with a satellite gravity model. In this approach bias effects introduced by height offsets of the input data (eg. local gravity measurements) can be estimated or may be neglected depending on the required accuracy. Offsets between two datum zones can then be determined using the basic relation h-N=H between ellipsoidal heights h, orthometric heights H and geoid heights N (Gerlach and Rummel, 2013), see figure 3.

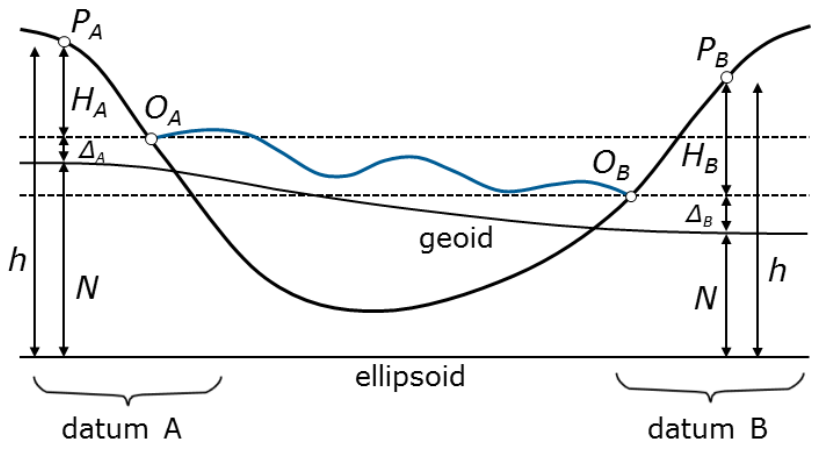


Figure 3: Schematic overview of the connection between two datums A and B (based on Gerlach and Rummel, 2013).

The ocean leveling approach uses oceanographic data and/or models to determine the difference in the height of the ocean surface (relative to a level surface or geoid) between different locations. The mean dynamic topography (MDT) denotes the difference between mean sea surface and the geoid, thus if the MDT is known with sufficient accuracy at tide gauges in different datum zones, it would directly give the datum offsets between those zones (Gerlach and Rummel, 2013). The MDT can be derived from ocean models, but the accuracy of this approach depends on the availability, the quality and resolution of the oceanographic data used. Alternatively it can be determined from a combination of satellite altimetry and a gravimetric geoid. However, the quality of the estimation is limited by the quality of satellite altimetry data near the coast, just where tide gauges are located.

3 Description of previous and ongoing work

In the past decade several projects that focus on the realization of a vertical datum in the coastal zone have been carried out or are ongoing. In section 3.1 a description of the BATHYELLI project in France, the VORF project in the UK and the NEVREF project in the Netherlands is given. Other initiatives focus on the harmonization of vertical datums. These are discussed in section 3.2

3.1. Realization of vertical datums and transformations

3.1.1 BATHYELLI

The BATHYmetry referenced to the ELLIpsoid (BATHYELLI) project is an ongoing project that started in 2005 and is led by the French Hydrographic Office (SHOM). The goal is to establish a set of models of reference surfaces at sea around the French coasts and to develop a software tool to be able to transform data from one vertical datum to another (Pineau-Guillou and Dorst, 2011; BATHYELLI, 2012).

In the first phase of this project the surfaces MSL, LAT and CD have been determined with respect to the ETRS89-GRS80 ellipsoid. The methodology is based on the computation of MSL; the LAT and CD surface are derived by tidal modeling and the defined relations between LAT and CD.

The MSL surface is determined by a combination of three techniques. Far off the coast MSL is determined from altimetry measurements, along the coast observations from tide gauges have been used. To fill the gap between open sea and the coast, SHOM carried out several GNSS surveys at selected locations.

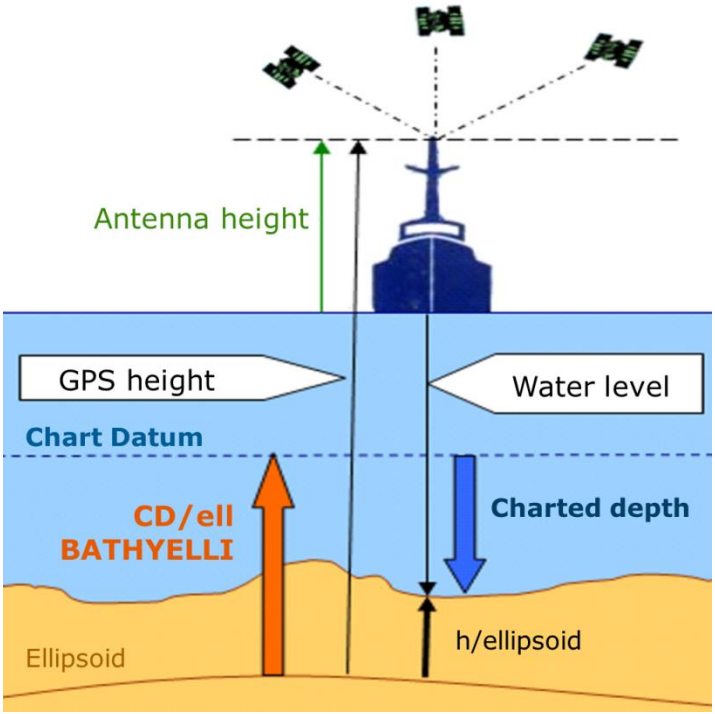


Figure 4: The concept of BATHYELLI (modified from BATHYELLI, 2012).

The second phase started mid-2011 and focused on the validation and improvement of the vertical datums by including additional GNSS measurements, as well as the development of the transformation software. Furthermore, relating the vertical datums at sea to the ellipsoid enables the use of GNSS for ellipsoidal referenced surveying (see figure 3.1), which may make tidal and meteorological corrections unnecessary.

3.1.2 VORF

The Vertical Offshore Reference Frame (VORF) project is an ongoing collaboration between University College London and the United Kingdom Hydrographic Office (UKHO) (VORF, 2016). The aim of VORF is to relate both onshore and offshore datums in the UK and Ireland to a consistent reference frame (ETRS89) (Adams et al., 2006).

Heights on land in the UK are referred to about a dozen different datums, while depths at sea are given with respect to over seven hundred Chart Datums. To allow the creation of seamless coastal data sets from existing data or to enable real-time bathymetric data reduction without tidal information, the relationships between the vertical datums and to ETRS89 must be known.

The two most significant steps in the VORF modelling process are the modelling of mean sea level (at reference epoch 2000) and the determination of LAT with respect to this. Similar to the modeling of MSL in the BATHYELLI project, the MSL is derived using altimetry measurements at open sea and tidal information. However, the gap between these data sources is filled by interpolating the sea surface topography (equivalent to MDT in open sea) and adding those values to the geoid to obtain mean sea level. As well as modelling LAT and MSL referenced to the ETRS89-GRS80 ellipsoid, tidal surfaces have been created for Mean Low Water Springs (MLWS), Mean High Water Springs (MHWS) and Highest Astronomical Tide (HAT) (see figure 5). More details on the methodology used for deriving the tidal level surfaces can be found in Turner et al. (2010).

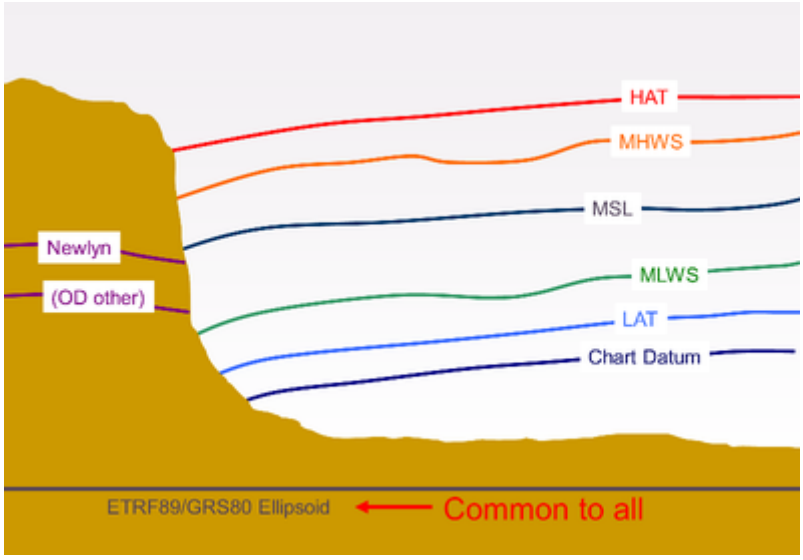


Figure 5: Reference surfaces included in the VORF project.

The VORF solution for UK and Ireland was completed in 2008 and has become an essential tool in operational hydrography. In addition to providing digital models of the reference surfaces, VORF also provides a software to transform between the various datums. Current focus of the project is on extending the concept globally for the offshore zone beyond 12 nautical miles from land (Turner et al., 2013).

3.1.3 NEVREF

The Vertical reference frame for the Netherlands mainland, Wadden islands and continental shelf (NEVREF) project is a STW Technology Foundation project that started in 2014 and will end in 2018. The goal of the project is the realization of a vertical reference for the Dutch continental shelf, including transformations between the derived surfaces and commonly used land and sea datums. The main reference surfaces computed within this project are a new quasi-geoid with an accuracy of 1 cm and a LAT surface with 1 dm accuracy in relation to the geoid. Furthermore, the project will provide a

quantification of the chance that water levels will be below LAT and a methodology to connect the Wadden Islands and offshore platforms to the land datum (NAP).

In contrast to modeling of Chart Datum (LAT) with respect to MSL the quasi-geoid is used as an intermediate surface to derive CD. The advantage of this approach is that interpolation or additional GNSS surveys are not required to fill the gap between altimetry and tide gauges. Instead, a regional hydrodynamic model is used (see figure 6), which, after vertical referencing, provides water levels relative to the quasi-geoid (Slobbe et al., 2014). The hydrodynamic model is also used to improve the estimation of the dynamic sea surface topography, required to obtain the quasi-geoid from radar altimetry measurements. This coupled problem of referencing the hydrodynamic model to the quasi-geoid and the estimation of the quasi-geoid itself is solved in an iterative manner. The ellipsoidal heights of LAT are obtained by adding quasi-geoid heights to the modeled LAT values.

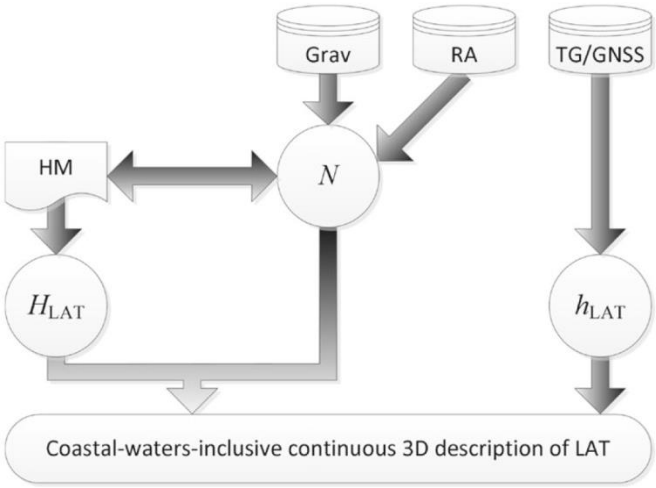


Figure 6: Schematic representation of the methodology used in the NEVREF project (Slobbe et al., 2014). Here, N is the quasi-geoid height, H_{LAT} and h_{LAT} are the heights of LAT with respect to the quasi-geoid and the ellipsoid, respectively; HM=hydrodynamic model; Grav=gravimetry; RA=radar altimetry; TG=tide gauges.

3.2. Harmonization of vertical datums

3.2.1 North Sea

In the North Sea region several initiatives have been carried out or are still running aiming at a harmonized Chart Datum. Here an overview of the BLAST project and the work done by the NSHC-TWG is given.

BLAST

BLAST (Bringing Land and Sea Together) was a regional project for better integration of information across the coastal margin in the North Sea region. Over three years, 17 partners from 7 countries, including governmental organizations, universities and private companies, collaborated on the harmonization and integration of land and sea data. BLAST was funded by the European Union as part of the Interreg IVB North Sea Region Programme (BLAST, 2010). The project started in 2009 and was completed in 2012.

Two work packages were directly related to the vertical datums in the coastal zone. Work package 3.5 focused on the development of a vertical reference frame for the North Sea area, as well as a transformation tool that can convert data in the near coastal areas between land height datums and marine vertical datums (Strykowski et al., 2011). The analysis on existing CD in the North Sea region and the creation of a shared vertical reference frame was done jointly with the North Sea Hydrographic Commission Tidal Working Group (NSHC-TWG).

The other BLAST work package on vertical datums was work package 3.11. This activity dealt with the development and application of a new methodology for the unification of chart datum in the North Sea and connection to the onshore height systems . The developed methodology formed the basis for the approach used in the NEVREF project discussed in the previous section. The output surfaces (LAT and MDT) created as part of this work package were incorporated into the BLAST Height Transformation Tool.

NSHC-TWG

The North Sea Hydrographic Commission (NSHC) tasked its Tidal Working Group (TWG) to coordinate the introduction of LAT in its member states, which led to an action item to create a common seamless LAT-level for the North Sea. The first results, incorporated in the BLAST project, included a detailed analysis of the national vertical datums at sea and the differences between those realizations. Furthermore, grids were created that represent the MSL, LAT and CD levels of the North Sea in relation to the ellipsoid. The merged surfaces are not seamless; differences at the maritime boundaries are equal or less than 0.6m for MSL and LAT, and equal or less than 0.8m for the CD surface (NSHC-TWG, 2010).

The NSHC-TWG has continued to work on combining existing national models in order to develop a common reference surface for tidal reduction to Chart Datum in the North Sea. Since 2010, new LAT-ellipsoid data has become available from Denmark, Germany, United Kingdom, France and the Netherlands. An analysis of discontinuities along the maritime boundaries is currently in progress (see also section 4.3).

3.2.2 Baltic Sea

In 2005 the Baltic Sea Hydrographic Committee (BSHC) established the Chart Datum Working Group to investigate and facilitate the harmonization of vertical reference systems in the Baltic Sea region. The

various national systems are principally based MSL, but as discussed in section 2.2, MSL can be at different height levels from one location to another. This situation may be inconvenient for navigation and data exchange. Furthermore, there were several realizations of MSL in use, relating to different epochs (see figure 7), because post-glacial rebound causes changes of depth of up to 1 cm per year (Mononen, 2014).

After a preparatory phase the CDWG proposed to the BSHC to use EVRS as a harmonized vertical reference system for the Baltic Sea. This proposal was accepted by the BSHC and there is a good commitment among the member states to adopt this harmonized datum. Implementation of the harmonized datum, Baltic Sea Chart Datum 2000, is estimated to be completed in 2020. Until then several actions need to be addressed, such as technical and legislative issues, data transfer methods, water level information, publication of nautical products and communication to users.

Related to the harmonization of a vertical reference, the BSHC-CDWG is cooperating with the FAMOS (Finalising Surveys for the Baltic Motorways of the Sea) project to develop a common geoid model for the Baltic Sea. To achieve this, marine gravity measurements, by means of running a gravity meter onboard the survey vessels, are carried out to collect additional gravity data on an opportunity basis during hydrographic surveys (FAMOS, 2016).

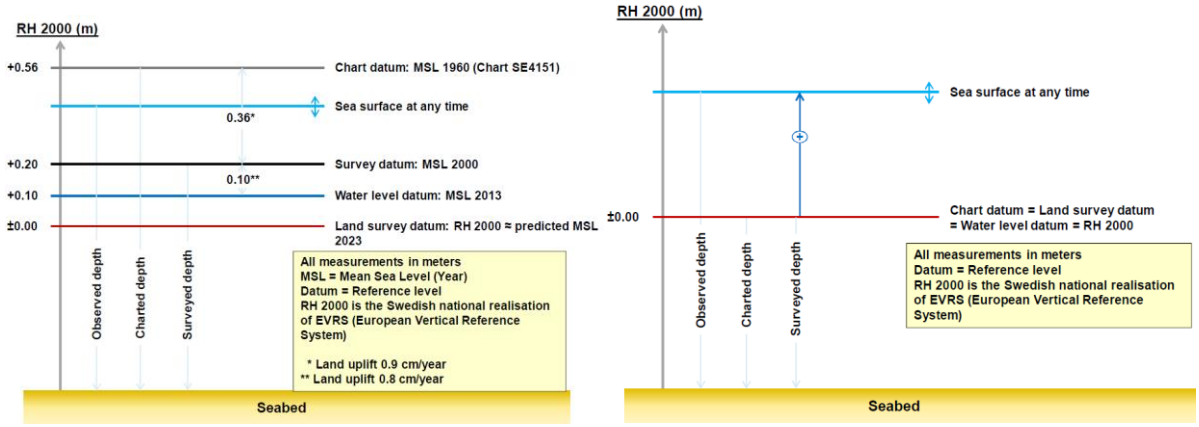
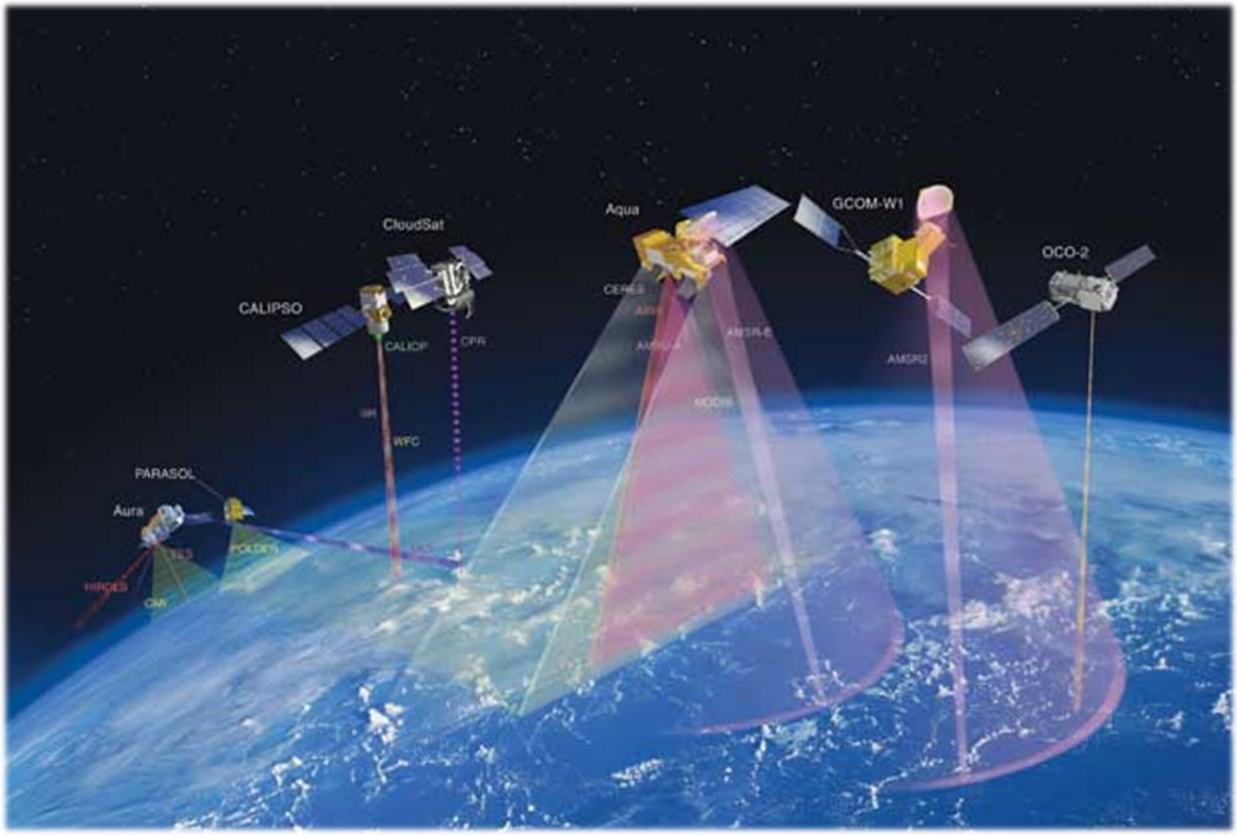


Figure 7: Current and future relationships between vertical reference systems as used within the Swedish nautical chart SE4151. After harmonization depths are referred to RH2000, which is the Swedish national realization of EVRS (from Mononen, 2014).

3.2.3 Mediterranean Sea

Within the Mediterranean region several research initiatives related to vertical datums and sea level variations are ongoing. A basin wide project is the GEOMED-2 project (Barzaghi et al., 2016), which is carried out by a large consortium of research institutes, mapping agencies and hydrographic offices. The GEOMED-2 project aims at the determination of a high-accuracy and resolution marine geoid for the Mediterranean Sea. The modeling is based on the availability of satellite gravity data from GOCE,



The Swedish Maritime Authority (SMA) did a study for satellite derived bathymetry some years ago using experts in the field. The outcome was shortly that it was hard to determine if an area was too dark to give any detection or simply too deep for the light to penetrate. Some quite shallow rocky bottom and very dark vegetation was impossible to detect.

When we had good reflectivity of the seafloor, the depth could be determined with an estimated accuracy of better than 1m.

The most unexpected outcome was that it was easier to estimate the depths in the Baltic Sea where more humus and other particles were present than on the west coast where the water was much clearer. In the clearer waters, all colorbands disappeared almost at the same depth whilst in the Baltic it was a much clearer possibility to determine the depth based on what depth the separate colorbands disappeared.

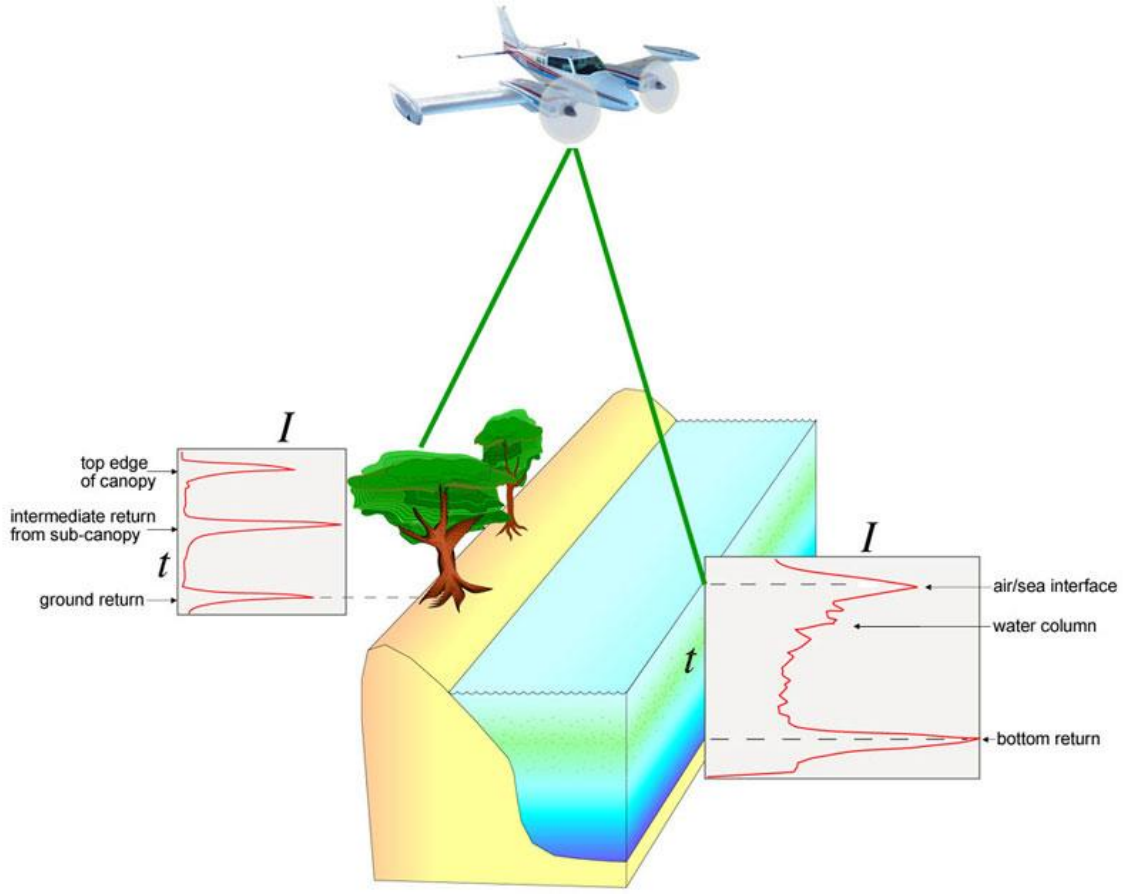
Satellite derived bathymetry (SDB) is a useful reconnaissance tool that can be used to map near-shore bathymetry, characterize a coastal area and to monitor seafloor change, which has been in use since the 1980's . Multispectral satellite imagery is most commonly used for SDB products because it is an available resource from freely available sources and commercial satellite platforms.

Irish multi-sector collaboration has explored over the last 5 years methods for improving SDB accuracy in a number of case studies around the Irish coastal waters. Building on established image processing methodologies for calculating satellite derived relative depths and employing local spatial regression models, aiming to improving accuracy when calculating water depth and subsequently decreasing prediction errors in deep or turbid waters.

Compiling a catalogue of the existing SDB case studies in European waters, understanding the models employed and quantifying depth uncertainties are challenges that have not been yet fully accomplished at the European level. Standardisation and best practices for SDB in the European level are also challenges lying ahead

3.2 Near surface based

Performing Airborne LiDAR Bathymetry (ALB) surveys is associated with strenuous logistic operations. The results are characterised by medium efficiency, medium resolution, and variable accuracy. ALB surveys have been summarized in several reports e.g.: (TopoBathy project p.36.) Data acquisition using high resolution photography, multispectral, and hyperspectral imaging may be combined with ALB.



3.2.1 Planning

The survey Level of Effort (LOE) analysis involves the standard line planning based on identified information available. It is of importance that one is able to provide detailed data layers that facilitated the preparation work that usually is required to start a line plan estimate, such as base maps, definitive survey areas, exclusion polygon and various others.

At the same time, analysis from other common factors that affect the LOE, such as airport locations and characteristics, and most importantly the presumed airborne operations schedule, which would dictate productivity rates in terms of flight hours per day.

3.2.2 Airports

Basic research needs to be made on airports at close range from survey areas that, on initial assessment, appear to fullfill requirements for regular airborne operations of small aircraft (King Air A90, Cessna 404 or similar). Certain airport characteristics are requirements for proper operations, such as airstrip length (minimum 1,220 m), regular fuel service (jet A), and aircraft shelter. Geographic location of airports in relation to the survey areas are also important to minimize transit time; the less transit time the more productive a flight can be.

3.2.3 Ground Control

One of the operational requirements in a LIDAR survey is maintaining high accuracy positioning trajectory solutions across the entire survey area. Standard operating practice dictates that a ground hold within 10 km of a fixed ground station (typically established at the airport) allows for a 70 km baseline range during flight, however, baseline ranges can be extended even further if a network of GPS base stations is maintained throughout the whole aircraft trajectory. This network can consist of base stations from permanent or temporal active networks from which data can be retrieved every day without restrictions.

3.2.4 Limitations

The maximum depth of penetration of any LIDAR system depends on a number of factors, including the clarity of the water during acquisition and the power of the system being used for data acquisition. Full powered ALB systems (SHOALS, LADS, HawkEye, CZMIL) have a theoretical penetration of two to three times (depending upon bottom reflectivity) the Secchi depth, up to a maximum depth. Water clarity rather that depth is the main criterion to look for to forecast successful laser penetration and bottom detection.

From preliminary knowledge offered by SMA/NMA and researched elsewhere, it is known that water clarity can decrease dramatically during certain months of the year mainly due to rain runoff and primary productivity in the water. In order to investigate this phenomenon further, NASA's Aqua-MODIS/SeaWIFS satellite imagery may be used to analyze diffuse attenuation coefficient of light at 490

nm (K490) which is in the blue-green region part of the spectrum. Diffuse attenuation values can be used to estimate the expected penetration in the water of green laser wavelength through the direct relationship 3/K490.

Another derivation that can be made from such images is that diffuse attenuation has a spatial variation component, meaning that the analysis should be made at the regional level, clustering areas where conditions are more or less similar.

For the purpose of evaluating climate conditions over a project area, sample sites should be chosen to represent general regional trends. By better understanding the variance between regions it will allow for more strategic planning and execution of acquisition to maximize efficiency.

For LIDAR operations adverse weather can negatively impact operations: rain, fog, hail, snow and high winds. Historical patterns of these conditions must be taken into account during the climate analysis.

Cloud cover associated to non-precipitating systems, and specifically the ceiling altitude, can affect LIDAR operations at 400-500 m altitude AGL (above ground/sea level). This means the ceiling for cloud, haze or fog must be at least this high. Ceiling statistics from various regional airports should be researched for average ceiling altitudes per month.

What SMA have seen so far, is that it is very hard to get a good object detection based on LIDAR measurements. The recent German Report also indicates that the systems does not really live up to order 1A. At the same time, it is almost the only thing you can get depths from in very shallow areas.

3.2.5 Drone data acquisition

Recent developments of small autonomous airplanes or drones opens up for new areas of low cost data acquisition. Though LIDAR instruments still are too heavy for drone use, georeferenced photography does offer high accuracy terrain models in the coastal zone. The advantage of drones is much lighter logistic wise than regular airplane LIDAR operations.

3.3 Surface based

Surveys based on surface vessels equipped with Multi Beam Echo Sounders (MBES) are characterized by relatively low efficiency, but delivers high resolution and high data accuracy. The surface is actually the 'sweet spot' for bathymetric surveys. Sub surface is plagued by high operation costs and sub optimal position accuracy. Airborne bathymetric surveys are hampered by lack of penetration effectively limiting the use of Lidar below 5 meters depth.

Though surface based surveys traditionally lack effectiveness, recent advances in technology do increase efficiency, and significantly reduce operational cost in near shore operations.

3.3.1 Planning

All planning aims at controlling risk. Low cost, efficient data collection requires sufficient knowledge of the operations to be performed, including tradeoffs related to equipment and operational procedures. The main goal is always to collect the required data, with as little effort as possible and with the correct quality. Though requirements may differ significantly, there are common needs and challenges that the surveyor has to deal with.

Planning for a project based survey effort with limited time window, will be inherently different from planning for a national all year around survey effort. Important operational parameters that do affect planning are:

- Weather
- Depth
- Seabed characteristics and sediment types
- Types of vessels
- MBES Sensor limitations

A survey area designated by a polygon, gives some indication of the work to be performed, but how may one calculate the effort involved in performing the survey? The Norwegian Mapping Authority (NMA) has developed a normalizing function based on all collected data from a specific type of vessels. Most areas already have some depth information available. The normalizing function allows us to consider this depth information and actually calculate the effort cost wise and timewise for a planned project. Extensive research have shown that the cost and effort grows exponentially as one get near shore. In any project, but especially if a specific time window is given, available weather data will be considered and used to indicate uncertainty.

3.3.2 Autonomy

The choice of platform is an important factor that do affect both cost and time of a specific survey. Traditionally MBES surface based surveys have high cost due to the labor intensiveness and logistic cost of the operation. At the same time efficiency is limited by daylight, size of crew, fatigue etc.

Unmanned Surface Vehicles (USV) are currently being developed, and tested by many different companies. NMA is currently cooperating with Maritime Robotics to further the development of one such concept called the 'Mariner'. Field-testing show very promising results, with operations being conducted in both autonomous and semi-autonomous mode.

The fact that traditional vessel based near shore surveys are the most cost intensive surveys, leads us to consider alternative survey methods. We know from experience that airborne bathymetric Lidar surveys are costly as well, and does not yield high quality data below 5 meters of depth. These factors indicate that USV could be the optimal survey platform for near shore surveys.

3.4 Sub surface based

Very low efficiency, very high resolution, medium position accuracy

Very near sensing: MBES, SAS, and imaging.

NMA has limited operational experience using AUV and therefore we have not researched this platform further.

Mareano AUV assessment report. (Not available yet)

4. Combining sensors

4.1 Data value matrix

It seems obvious that no one platform may produce all data types by itself. We do need both the overview and the details. But if forced to choose, one would need a better understanding of the prioritized data type needs of the stakeholders.

The matrix below lists all relevant data types that the partners may collect. The focus is to locate those types which have a high data value (DV) and then evaluate how these may be collected the most efficient.

Legend of table:

Data type: The type of data that is collected

Limitations: Expected range of use in water

Sensor type: Classification of sensor

Platform: Type of system that carry the sensor

Quality: Defined by the sensor specification (low-medium-high)

Density: Points pr. square meter (low-medium-high)

Issues: Inherent problems related to the use of the sensor or the treatment of the data

DV comm.: Estimated commercial value of data (1-10)

DV public: Estimated public value of data (1-10)

DV multiuse: Estimated multiple application use of these data (1-10)

Data type	Limitations	Sensor Type	Platform	Quality	Density	Issues	DV comm.	DV public	DV multiuse
Depth xyz	-	MBES	Surface vessel	high	high	-	10	10	8
Water column	-	MBES	Surface vessel	High	-	Data storage	1	0	1
Backscatter	-	MBES/SBP	Surface vessel	High	Medium	Data storage?	7	5	7
Salinity	-	MVP	Surface vessel	High	low	-	3 Oceanography	2	3
Temperature	-	MVP	Surface vessel	High	low	-	3 Oceanography/ Meteorology	4 fishing	3
Turbidity	0-10m	Turbidity meter	Surface Vessel	Medium	low	-	5	2	4
Acceleration xyz	-	Gravimeter	Surface vessel	High	medium	-	2	1	8 Geoid models
Height xyz	-	LIDAR	Plane	High	High	-	7	4	7
Height xyz	0-100m	Ortho images	Drone	High	High	-	9	9	8
Depth xyz	0-5m	Ortho images	Drone	Medium	Medium	Operate at low tide	6	8	5
Depth xyz	0-10m	LIDAR	Plane	Low	Low	Classification of	7	10	8

						data			
Depth xyz	0-10m	Multi/Hyper sp. imaging	Plane	Low	Low	Classification of data?	3	4	4
Turbidity	0-10m	Multi/Hyper sp. imaging	Plane	?	?		4	2	3
Surface current	0-20m?	ADCP?	Satellite	High?	High?	-	2	1	2
Acceleration xyz	-	Altimetry	Satellite	Low	Low	?	2	1	8 Geoid models
Spectral signature (calibration)	0-20m	Spectroradiometer	Field	High (radiometric resolution 1nm)	Low (point sampling)	Cloud hampered			
Sediment mineralogy (emerged)	0-20m	Hyperspectral Spectroradiometer	Plane	High	Medium (2 m - 5 m)	Cloud hampered, need of calibration measurements			
Sediment grain size (emerged)	0-20m	Hyperspectral Spectroradiometer	Plane	High	Medium (2 m - 5 m)	Cloud hampered, need of calibration measurements			
Sediment moisture	0-20m	Hyperspectral Spectroradiometer	Plane	High	Medium (2 m - 5 m)	Cloud hampered, need of calibration measurements			
Seabed mapping	0-20m	Multispectral Spectroradiometer	Plane	Medium	Medium (0.5 m - 5 m)	Cloud hampered, classification of data			
Seabed mapping	0-20m	Hyperspectral Spectroradiometer	Plane	High	Medium (2 m - 5 m)	Cloud hampered, classification of data			
Seabed mapping	0-20m	Multispectral Spectroradiometer	Satellite	Medium	Low (0.5 m - 30 m)	Cloud hampered, acquisition dependent on satellite operational revisit time, classification of data			
Seabed mapping	0-20m	Hyperspectral Spectroradiometer	Satellite	Medium	Low (30 m -100 m)	Cloud hampered, acquisition dependent on satellite operational revisit time, classification			

						of data			
Turbidity	0-20m	Multispectral Spectroradiometer	Plane	Medium	Medium (0.5 m - 5 m)	Cloud hampered, need of calibration measurements			
Turbidity	0-20m	Hyperspectral Spectroradiometer	Plane	High	Medium (2 m - 5 m)	Cloud hampered, need of calibration measurements			
Turbidity	0-20m	Multispectral Spectroradiometer	Satellite	Medium	Low (0.5 m - 30 m)	Cloud hampered, acquisition dependent on satellite operational revisit time			
Turbidity	0-20m	Hyperspectral Spectroradiometer	Satellite	High	Low (30 m -100 m)	Cloud hampered, acquisition dependent on satellite operational revisit time, need of calibration measurements			
Height xyz	Land	Dual Multispectral Spectroradiometer (nadir + offnadir camera)	Satellite	Low	Medium (15 -30 m)	Cloud hampered, acquisition dependent on satellite operational revisit time, processing time			
Depth xyz	0-20m	Multispectral Spectroradiometer	Plane	Low	Medium (0.5 m - 5 m)	Cloud hampered, need of calibration measurements, experimental algorithm for retrieval			
Depth xyz	0-20m	Hyperspectral Spectroradiometer	Plane	Low	Medium (2 m - 5 m)	Cloud hampered, need of calibration measurements, experimental algorithm for retrieval			
Depth xyz	0-20m	Multispectral Spectroradiometer	Satellite	Low	Low (0.5 m - 30 m)	Cloud hampered, acquisition dependent on satellite operational revisit			

						time, need of calibration measurements, experimental algorithm for retrieval			
Depth xyz	0-20m	Hyperspectral Spectroradiometer	Satellite	Low	Low (30 m -100 m)	Cloud hampered, acquisition dependent on satellite operational revisit time, need of calibration measurements, experimental algorithm for retrieval			
Surface variation	Land	SAR	Satellite	High (mm)	Medium (dependent on cover type)	Data storage, processing time, dependent on land cover type, need of long time series			
Surface mean sea level	0 m	Altimeter	Satellite	High (mean error 3 cm)	Low	Acquisition dependent on satellite operational revisit time			
Surface current	0 m	SAR	Satellite	Low	Low (several km)	Acquisition dependent on satellite operational revisit time, experimental algorithm for retrieval			

4.2 Operational limitations

Survey planning is always related to the type of sensor being utilized. In this section we will try to review operational limitations that may restrict the combination of different sensor types.

Bathymetric LIDAR:

Depending on type of system (type of laser) and power of system (including size of footprint), the operational height is significantly lower than traditional land based Lidar systems. Typically, these systems operate at 400-700 meter altitude. Operating at lower altitudes could be desirable, but is

usually not allowed due to potential damages that the laser may cause to human sight. Extensive research indicate that the technology does not yield dependable high quality data below 5m depth.

MBES:

The minimum detectable depth is normally a slant range from the center of the transducer of 0.5 to 1m. At the same time to have the transducer on a depth shallower than 0.5m can cause surface noise to affect the bottom detection.In the shallow waters the opening angle of the detected beams is actually much larger than specified as the minimum footprint on the seafloor is equal to the transducers physical width.

In the system specifications the opening angles is specified for the center part of the swath, perpendicular to the transducer face. For a circular transducer this is true for all angles but for a flat transducer the opening angle doubles already 60 degrees from nadir. This means that the physically detected beam for a 0.5 degree system at 60 degrees from nadir is 1.0 degree and at 70 degrees from nadir is 1.5 degrees.

Interferometric Sidescan:

Interferometric systems is actually sidescan systems that have one or two additional rows of receiver elements. This makes it possible to determine the angle of the received signals and hence to detect depths from the backscatter signal.

Interferometric systems normally has a much narrower along track beam width than a traditional MBES and because of this, a somewhat lower survey speed in order to achieve a full bottom coverage. The density of detected depths for a single swath can be as high as one detection every 2.5cm. As the transducers of these systems are angled far away from nadir the number of detections in the near nadir region of the swath is low. Some manufacturers have tried to solve this by advanced signal processing and/or addition of single beam channels to fill this poorly covered section of the swath. When it comes to beam width the opposite rule than for traditional MBES applies, as the nadir part of the swath is the one furthest away from perpendicular of the transducer face.

The high number of detected depths makes the data volume to be many times higher than from a traditional MBES and post processing of these data volumes is normally very time consuming and the percentage of erroneously detected depths is much higher than from a traditional MBES.

4.3 Sensor crosstalk

The inherent nature of the different instruments may limit the sharing of platforms. Generally, this is not an issue as far as passive instruments are concerned, but active instruments may interfere with each other.

Lidar: Can be combined with any other passive sensors. May also be combined with other active sensors as long as instruments do not operate at the same bandwidth/frequency.

MBES/ Interferometric Sidescan: Can be combined with any other passive sensor. If different type of echo sounding instruments are to be utilized at the same time they have to be sufficiently placed apart, or they have to transmit intermittently in order to avoid disturbances.

SAR: Can be combined with any other passive sensor. If different type of echo sounding instruments are to be utilized at the same time they have to be sufficiently placed apart, or they have to transmit intermittently in order to avoid disturbances.

5. Mutusalisation of means

5.1 Combining efforts

Survey efforts today tend to focus on the needs of single nations or specific sectors of private industry. Experience from other survey disciplines may bring a new approach to the table. Currently, research vessels across Europe exchange information about planned operations and capacity on available vessels through national expedition planning meetings. This approach applied to the bathymetry survey platforms would allow for a better utilization of the combined capacity.

Opportunities

Facilitation of cross border survey efforts that meets the needs of several stakeholders. This presupposes a communicated plan for surveys, and may result in shared efforts when it comes to collection and use of data.

More predictable income/budget situation for every vessel. Closing budgets or financing investments in platforms is a challenge without a predictable income. Sharing platforms may yield confidence in the survey industry, as well as fine-tune the type of platforms available for different survey tasks.

Challenges

Differing regimes for classifying bathymetric data limits the sharing of both platforms and data. National security imposes restrictions on not only data publishing and use, but also access to the actual survey platforms and data processing systems. This issue should be addressed and if possible be resolved.

5.2 Combining tenders

Increasing scope of work to lower price. It may be obvious that operational overhead accounts for less of the survey cost when the scope of work increases. Still it seems difficult to coordinate survey efforts in order to lower the actual survey costs.

It seems combined survey efforts at the national level are complex. The planning phase involves different sectors of government, and planning is an issue. Budgets needs to be combined, which is time consuming. Finally the requirements for and use of data differ. We expect these issues to multiply when international means, plans and budgets are to be synchronized.

Even so, the advantages will be significant. Contracts awarded by the Norwegian Mareano program show decreased cost, and increased data quality. Combined tenders will further ensure that the different stakeholders receive adequate data according to specifications.

6. Recommendations

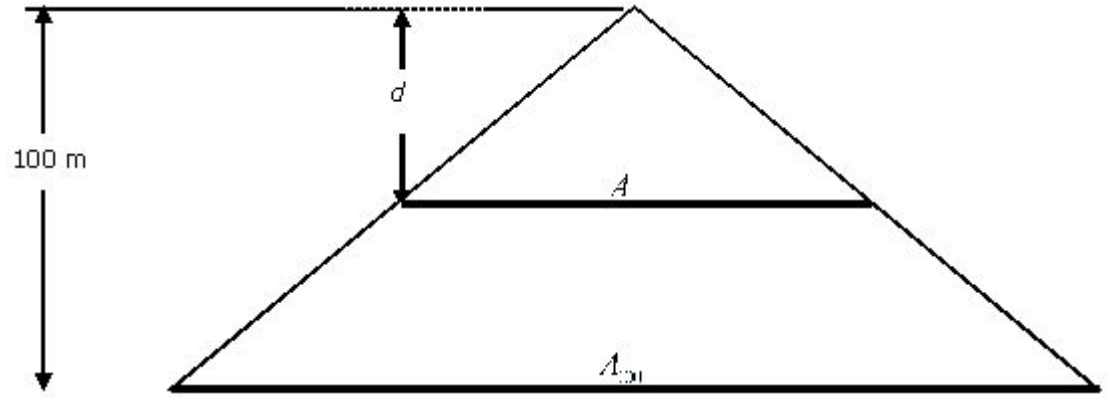
Firstly, the inherent problem related to making any recommendations is this: do we agreed upon the definition of the underlying factors that define the scope of work. If we say that we are to survey 1km coastline, what does it mean? The area may be 2.4 km^2, but what effort is needed to survey such an area?

For years, this issue has plagued the NMA both when we are faced with the task of reporting status of actual work that has been performed, and when trying to estimate cost and effort required to perform a specific survey. What we have found is that it does not make sense to talk about square kilometers as a factor to indicate either cost or effort, nor the type of instrument to be utilized. Instead, we have put into use what we call normalized square kilometers.

The normalizing is based on inverted depth.

$$A_{100} = \frac{100}{d} A$$

The area is A, and A_{100} is the normalized area at 100 meters depth and d is the actual depth. This is deducted from considering the figure below:

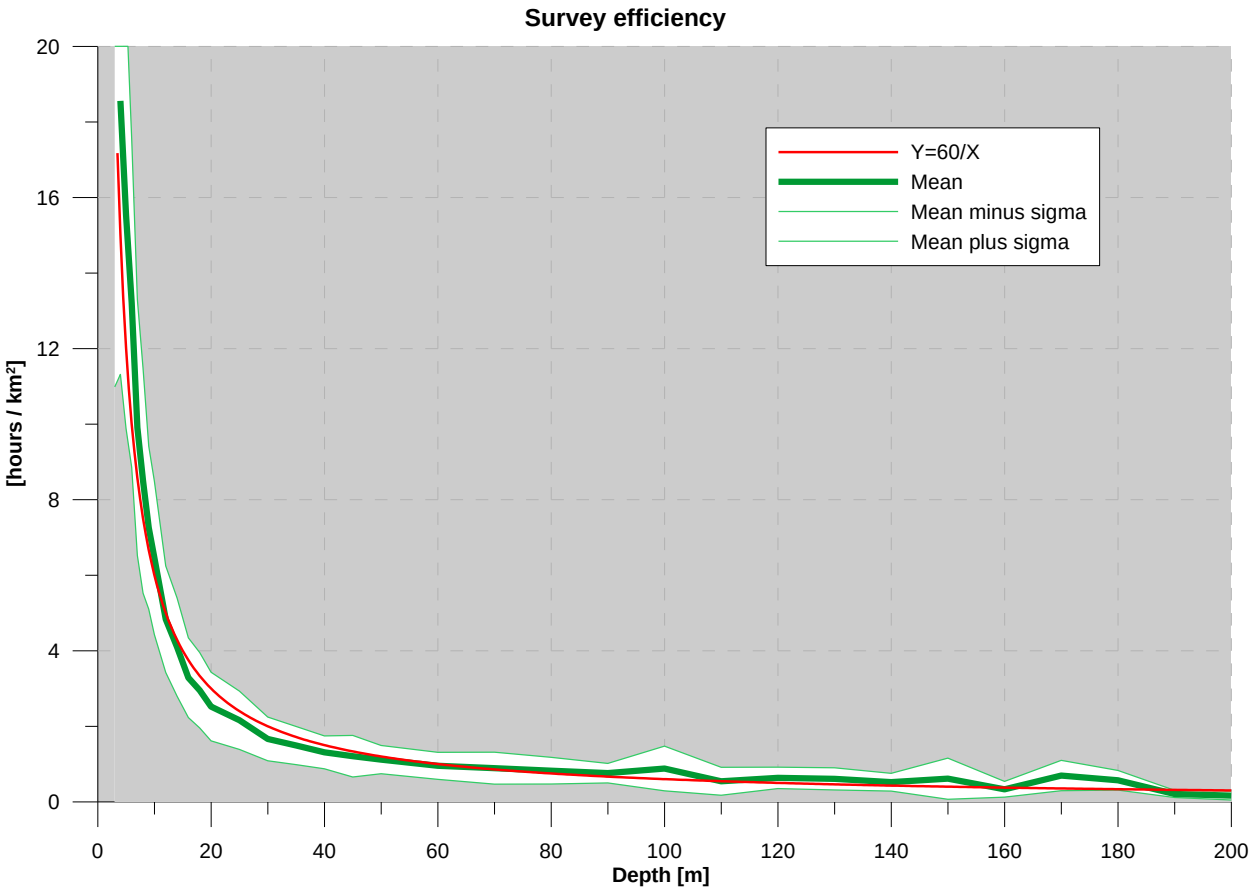


Normalized square kilometers is based on the analysis of actual surveys performed covering a wide array of terrain types as well as depth conditions. This estimation technique yields several benefits:

- -all surveys performed are automatically calculated to produce normalized square kilometers. When we talk with our stakeholders, they may be confident that cost and effort related to surveys in different areas and under different conditions are comparable.
- -when new areas are planned, we may give good estimates on cost and effort related to perform a specific survey with our vessels.

We assume that this challenge will be the same when faced with the task of calculating cost and effort of surveying EU coastal waters, and therefore suggest that the normalizing function should be developed further to yield two main results:

- Actual cost and effort for other types of sensors and platforms than MBES.
- Indications of optimal type of sensors to be combined and platforms to be utilized under different conditions.



Our results do indicate that when the difference between actual square kilometers and normalized square kilometers deviates exponentially, this is a firm indicator of a need to switch sensor type or platform. The breakoff for effective use of MBES is around 5 meters resulting in depths of 1 meter and deeper.

Secondly, we do recommend further research into the use of autonomous vehicles for surveying. Both airborne and surface based surveys can be significantly more effective by applying autonomy to the actual performance of the survey. The size of the platform can be reduced thus reducing cost, and the survey length significantly increased thus reducing operational overhead.