EMODnet Thematic Lot n° 0 – High Resolution Seabed Mapping (HRSM)

EMODnet Phase III

Report on Interoperability and International Collaboration

CONTRACT NUMBER – EASME/EMFF/2015/1.3.1.7/SI2.742125

Call No. EASME/EMFF/2016/005

Date: 22/01/2018

Updated: 18/02/2018

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1. Introduction

The European Union and national states have considered for long time the economic benefit of the use of spatial data to support policy making such as in the context of the Marine Strategic Framework Directive (2008). With the INSPIRE directive, policies have been defined in order to enable the creation of National Spatial Data Infrastructures (SDI), within the context of harmonization across Europe through interoperable datasets and service towards the goal of the European Spatial Data Infrastructure (ESDI). Within this context, since 2009, the European Marine Observation and Data Network, EMODnet, has been focused to design, populate and maintain the mutli-thematic marine infrastructure and the associated organization needed to facilitate the sharing of marine and coastal fragmented data.

In the domain of bathymetry, all the efforts put together since the infancy of EMODnet Bathymetry (2009) have demonstrated to be very successful when generating the compilation of bathymetric data into a European wide bathymetric digital elevation model alongside a detailed description of the filiation of the data sources composing it. This success is largely achieved by implementing key concepts that are, amongst others, common practices, semantic interoperability, standardization of formats and processing, cross-domain and cross-country interoperability.

In this report the actions are described which have been and are undertaken to ensure that interoperability is ensured within the core EMODnet Bathymetry community for the benefit of the generation of the DTM model along with the management of the data cataloguing services. Also it will be illustrated how these efforts are largely benefiting access to the data and metadata as prerequisite for international collaborations.

2. Elements and importance of interoperability within the context of bathymetry

Two main sub-communities of bathymetry data providers globally exist and are present within the EMODnet HRSM consortium:

- Hydrographic Offices. Official bodies such as Hydrographic Offices (HO's), Port & Harbor Authorities as well as state agencies and other bodies in charge of coastal planning collect bathymetric data for the purposes of ensuring the safety of navigation.
- Research institutions. Unlike Hydrographic Offices, research institutions do not have common standards for the collection, processing and delivery of data. The level of processing of the datasets which are made available varies from one organization to another and from one application to another. The data being made available ranges from raw through to fully processed survey data, or may alternatively be provided as DTMs.

In the next sections, it is described how EMODnet Bathymetry, since its early stage, has proposed to overcome this inherent diversity in terms of practices in data management. This description will basically follow the progression of treatment of the bathymetric information from the elementary observation up to product delivery as illustrated by Figure 1. All the elements that will be described are in accordance with the documentation generated by the consortium with respect to the specification of the metadata and data contents shared within the EMODnet Bathymetry detailed in [1] and [2].

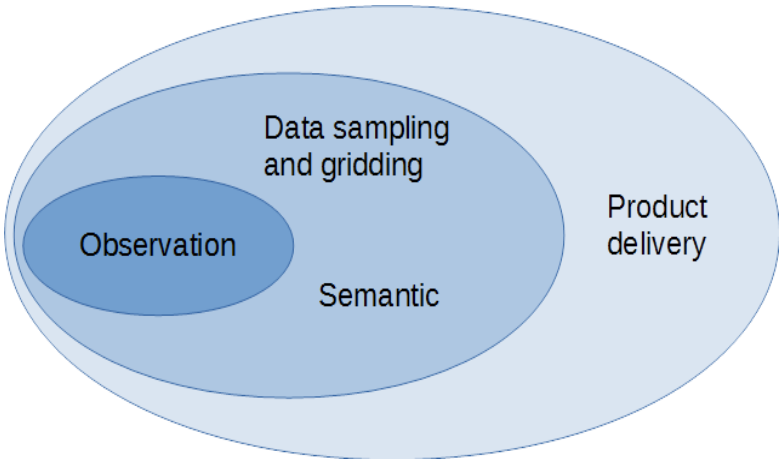


Figure 1 Path of the bathymetric information from the observation to the product delivery, as considered by the EMODnet Bathymetry community

3. Harmonisation and standardization in EMODnet Bathymetry

EMODnet Bathymetry deals with heterogeneous bathymetric data. In order to overcome this diversity and take benefit of each source of information an effective and adapted data management system has been designed in accordance with international standards and common practice. They are components in the EMODnet Bathymetry processing chain illustrated below. Figure 2 reads from the top, where source data are described (metadata production) and sampled using dedicated software (see respectively section 3.2 and 3.3). Metadata are made available for cataloguing while sampled data are made available for compilation in a regional DTM, prior to the integration in the complete DTM and display on the Web portal. With multiple actors (data provider, regional coordinator, web/portal integrator, metadata curators) communication is at the heart of this methodology. Efficient communication is ensured between all these levels as will be explained.

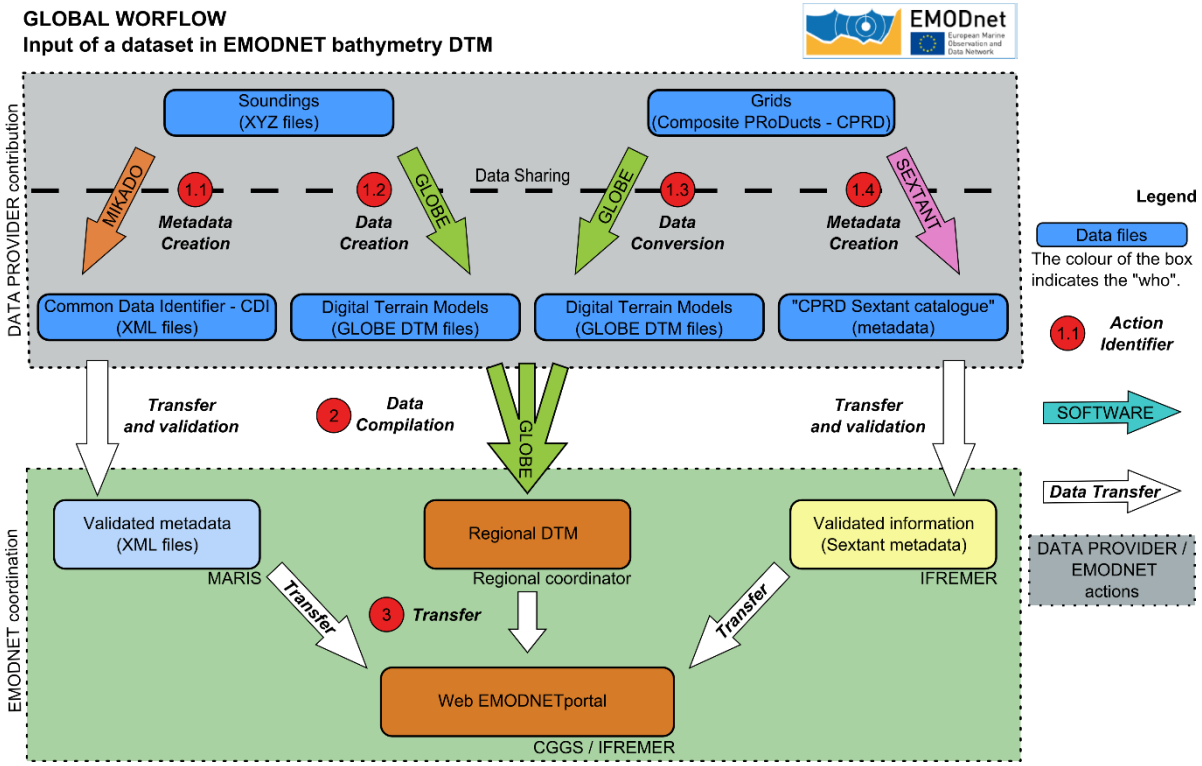


Figure 2 Overall metadata and data workflow illustrating the need for strong interoperability both at the internal level (ensuring understanding between data providers and regional coordinator) and at the external level (as of rendering and serving the product to users)

3.1. Observations

Bathymetric observations are defined as measurements of a depth relative to a moving acquisition unit (more than often a vessel), the position of this unit being referenced within a global worldwide frame. As part of the interoperability effort, at the level of the measured data, a consensus has been found to express the position and depth of the soundings relative to such a unified reference system. This system is composed of a horizontal coordinate reference system and a vertical datum defined as follows.

Co-ordinate reference systems (CRS):

Elevation or bathymetry is positioned with respect to a geodetic datum using a set of coordinates defined as latitudes and longitudes. While ETRS89 is the geodetic system suggested for land measured data in Europe, the WGS84 (World Geodetic system) is being used for EMODNET Bathymetry as the geodetic system of reference because of the following reasons:

- Considering the large extent of the EMODnet bathymetric grid that goes beyond the Eurasian plate (where controlling point of the ETRS89 lies)
- Most organizations conducting marine surveys, are collecting and storing data using the WGS84 coordinate reference system (as their surveys also exceeds the ETRS89 zone of reference).
- Other worldwide or regional projects such as the general bathymetric Chart of the Ocean (GEBCO (REF) and IBCAO) gather datasets and display their product with respect to the WGS84 system.
- Precision accuracy of the WGS84 relative to the ETRS89 system is of the order of the meter to the sub-meter. Considering the resolution of the previous and current bathymetric DEM (~100m), WGS84 remains an acceptable choice with no impact on the precision.

Depth datum

The lowest astronomical tide (LAT) is the vertical datum recommended by the International Hydrographic Organization [3]. This choice is motivated by the practicality, for the user of hydrographic charts, to be able to separate the measurement of the depth from the tide height. In places, essentially where the influence of the tide is negligible, mean sea level (MSL) is used. Practically, in these areas LAT does not differ significantly from MSL. This is also the case for bathymetric measurements acquired beyond the break of the shelf in the deep sea ocean. Also the data from the main data providers operating in shallow water (where vertical precision is requested) areas (HOs, harbours etc.) usually references “Chart Datum” which tends to be consistent with the LAT (at worst with an acceptable difference of 50cm).

Overall, the adoption of LAT enables soundings to be used to generate a consistent surface (provided variations less than 50cm are acceptable) with minimal, if no conversion of vertical datum.

Time dimension

The time dimension is not formally used to geographically reference bathymetric information. However, considering the dynamic aspect the seabed morphology, the time component is of importance, especially considering the ability to generate comparisons between series of data sources at various time intervals from the same geographic area. In order to facilitate it, the rule for data exchange is to use UTC (Co-ordinated Universal Time) and not local time. The format for time dimension is specified in the metadata.

3.2. Semantics

While the previous section was centered on the observation, this section provides elements on the common description of the source data. Describing the source data is a key element for the user of the data to understand the context in which the data has been acquired, how it has been processed, and its expected quality. This is particularly true within the EMODnet bathymetry framework for both the aggregation of individual data sources within the DTM and the interrogation and use of individual data by individual users through the portal.

Since the early stages of EMODnet Bathymetry, strong relations with SeaDataNet have been established. SeaDataNet's primary goal is the development of a standardized, distributed system for managing the large and diverse data sets collected by oceanographic fleets and automatic observation systems across various scientific themes. The key element in the realization of such a distributed system includes common standards for the expression of data ownership, data acquisition and processing, communication and quality assurance. This includes the use of XML and international standards, such as ISO 19115, and more importantly shared (and commonly defined) vocabularies.

These shared, or governed vocabularies, facilitate interoperability between all the stakeholders following the lifecycle of the data (data provider, regional coordinator, final, integration and products users). Giving a detailed description of the SeaDataNet infrastructure is beyond the scope of this report. SeaDataNet has relations with, follows and contributes to international standards committees such as the Open Geospatial Consortium (OGC), International Organisation for Standardisation (ISO) and the World Wide Web Consortium (W3C). It has an active cooperation and tuning with the INSPIRE community, in particular the INSPIRE team of JRC, which has been essential to the definition of the INSPIRE Directive 2007/2/EC aiming at establishing an Infrastructure for Spatial Information in the European Community which is supported through legislation and technical guidelines, such as concerning data models (schemas), metadata and network services [4].

The benefits that EMODnet Bathymetry is getting from this tight collaboration with SeaDataNet reside in the explicit expression of lineage (origin), history and distribution conditions of the data sources. The table below indicates the fields used and commonly accepted by both the EMODnet Bathymetry data providers and the SeaDataNet community. The SeaDataNet Common Data Index (CDI) infrastructure

with its network of distributed data centers has been adopted and adapted by EMODnet bathymetry to provide an integrated and harmonized overview and access to bathymetric survey data sets that are gathered by the project. The CDI metadata files describe bathymetric survey measurements, following the ISO19115 – 19139 metadata standards, and are supported by SeaDataNet controlled vocabularies.

Variable	Typical values/comments	Mapping with discovery metadata of SeaDataNet
ID	A unique local identifier dataset at the distributing data centre to access metadata and dataset.	CDI ID
Data provider reference	EDMO identifier	Originator or distributing Data Centre
Instrument	Depth: Single beam, multibeam, lidar, other. Position : Determines indirectly **the accuracy** of the positioning system	Instrument or gear type used to collect the data and positioning system
Creation of the dataset	Date or year of the survey or gridding	Creation/revision date
Revision of the dataset	Date of the year	Creation/revision date
Start Date	Start date of the survey (single survey) or of the oldest survey used to produce the DTM	Start Date
End date	End date of the survey (single survey) or of the most recent survey used to produce the DTM	End date
Bounding	Bounding box, curve (track line) or surface (seafloor coverage) polygon	Idem
Horizontal CRS	CRS (preferably the EPSG code, see SDN list	Datum coordinate system
Vertical CRS	Vertical datum used for depth (e.g. Mean sea level, Chart datum, Lowest astronomical tide, not applicable, ellipsoid)	Vertical datum
Sampling and gridding method	Sampling and interpolation method used with processing parameters	No appropriate field in CDI (initially designed for observation data : is added in the abstract ("what") for single survey DTM)
Dimensions	Dimensions for grid (eg Time)	
Resolution	Spatial resolution Time resolution	"Track resolution": term not appropriate in CDI but field appropriate for discovery of spatial resolution. Idem for the time dimension

Table 1 (previous page) Metadata describing the bathymetric data (extract of CDI format)

While the CDI is used as the basis for the description of individual bathymetric surveys, the EMODnet Bathymetry team is also conscious that some data providers want to provide gridded product composed

from multiple sources, also known as composite grids. Hence, the EMODnet bathymetry community has adopted and adapted the SeaDataNet Sextant catalogue service, in order for data providers to provide details about Composite DTMs. This is known as the CPRD index. The Sextant metadata files also follow the ISO19115 – 19139 metadata standards, and are supported by SeaDataNet controlled vocabularies. The performance of the indexing undertaken as part of the current EMODnet HRSM project in Work Package 1 is described at length in the accompanying annual report [5].

As part of the previous phases of EMODnet Bathymetry, along with the current one, tools are being developed in order to provide interfaces for the data provider to fill efficiently the metadata when providing their bathymetric information. While Mikado is being utilized to fill the CDI for individual surveys, Sextant allows providing the requested metadata for CPRD. All the fields, except some free fields, are controlled directly by drop-down lists which are sourced in the respective Seadatanet vocabularies. Both interfaces are designed to allow the data provider to enter his information using a human-readable format, such as illustrated by Figure 3. Functionalities of Mikado also have been developed to allow a direct connection on the local database of the data provider and the ability to map the local metadata fields with the corresponding EMODnet/Seadatanet metadata database.

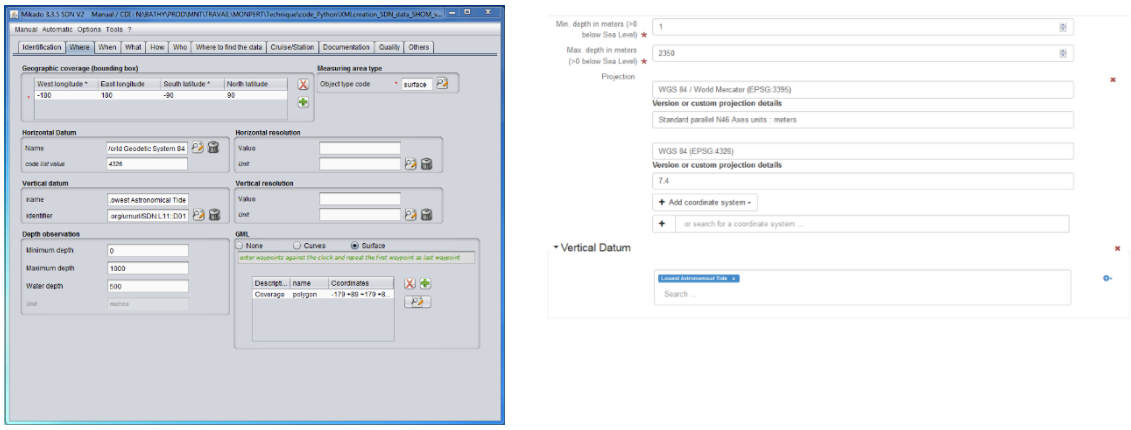


Figure 3 Human readable interface of MIKADO (left) and Sextant (right) used to fill metadata associated with bathymetric data

Mikado and Sextant interfaces both generate metadata files encoded in XML format, using XML tags and values defined to be compliant with ISO191995-ISO19139 standards along with seadatanet vocabularies. The following snippet of metadata file, shown in Figure 4, provides an example. These type of files enable machine-to-machine processing as demonstrated in the section 3.5 concerning product delivery.

```
− <gmd:pointOfContact>
  − <gmd:CI_ResponsibleParty>
    − <gmd:organisationName>
        <sdn:SDN_EDMOCode codeList="http://seadatanet.maris2.nl/isocodelists/sdncodelists/edmo-edmerp-Codelists.xml#SDN_EDMOCode" codeSpace="SeaDataNet" codeListValue="1527">Rijkswaterstaat Central Information Services</sdn:SDN_EDMOCode>
      </gmd:organisationName>
    − <gmd:contactInfo>
      − <gmd:CI_Contact>
        − <gmd:phone>
          − <gmd:CI_Telephone>
            − <gmd:voice>
                <gco:CharacterString>+31 88 797 28 00</gco:CharacterString>
              </gmd:voice>
            </gmd:CI_Telephone>
          </gmd:phone>
        − <gmd:address>
          − <gmd:CI_Address>
            − <gmd:deliveryPoint>
                <gco:CharacterString>Derde Werelddreef 1</gco:CharacterString>
              </gmd:deliveryPoint>
            − <gmd:city>
                <gco:CharacterString>Delft</gco:CharacterString>
              </gmd:city>
            − <gmd:postalCode>
                <gco:CharacterString>2622 HA</gco:CharacterString>
              </gmd:postalCode>
            − <gmd:country>
                <sdn:SDN_CountryCode codeSpace="SeaDataNet" codeListValue="NL" codeList="http://vocab.nerc.ac.uk/isoCodelists/sdnCodelists/cdicsrCodeList.xml#SDN_CountryCode">Netherlands</sdn:SDN_CountryCode>
              </gmd:country>
            − <gmd:electronicMailAddress>
                <gco:CharacterString>did-info@rws.nl</gco:CharacterString>
              </gmd:electronicMailAddress>
            </gmd:CI_Address>
          </gmd:address>
        </gmd:CI_Contact>
      </gmd:contactInfo>
    − <gmd:role>
        <gmd:CI_RoleCode codeList="http://vocab.nerc.ac.uk/isoCodelists/sdnCodelists/gmxCodeLists.xml#CI_RoleCode" codeListValue="custodian" codeSpace="ISOTC211/19115">custodian</gmd:CI_RoleCode>
      </gmd:role>
    </gmd:CI_ResponsibleParty>
  </gmd:pointOfContact>
```


Figure 4 Snippet of ISO-19139 XML data file conveying the metadata of individual surveys (CDI). CPRD metadata are likewise encoded in XML ISO19139 files

3.3. Qualitative assessment of the bathymetric data

The International Hydrographic Organization document S-44 is a document that describes the specification of bathymetric surveys, with respect, essentially, to the precision needed to ensure safety of navigation. Hydrographic Offices members of the EMODNet HRSM consortium provide proof that they are respecting this standard within the metadata description. National standards can also be used as elements of the description of the quality of the bathymetric datasets. Examples of both cases are given in Figure 5.

Conscious that national classifications may differ, and also that several members of the EMODnet HRSM consortium are not Hydrographic Offices, and hence are not subject to use the IHO S-44 Standard as a support for the acquisition and processing of their bathymetric data, the EMODNet High Resolution Seabed Mapping consortium made a further step forward and agreed on a classification of qualitative aspects of the source data. Those aspects basically rely on the precision reached by the individual components of the system, essentially characterized by the horizontal (QI_Horizontal) and the vertical (QI_Vertical). Associated with these elements are the age of the survey (QI_Age) and the purpose of the survey (QI_purpose). Table 2 provides all the elements of this classification. A detailed description can be found in the following reference [6].

QI_horizontal	QI_vertical	QI_age (provider expresses it through	Respect of a standard (abstract)
Unknown or > 500m (That is grossly equivalent to TACAN, OMEGA systems or similar)	0: Unknown, plummet, leadline	> 30 y	Purpose of the survey unknown (historical survey with no associated information).
between 500m and 50m (That is grossly equivalent to LORAN, DECCA systems or similar)	1: SBES Low Frequency, SDB (similar than 2+5%d)	10-30 y	Transit and/or opportunity
between 50m and 20m (That is grossly equivalent to natural GPS systems)	2: MBES low frequency (lower than 100kHz) (similar than 1+2%d)	5y -10 y	Bathymetric/morphologic survey
< 20m (GPS with correction) (That is grossly equivalent to aided GPS system DGPS, RTK …)	3: Lidar, SBES High Frequency	0y – 5y	Hydrographic survey or compatible with hydrographic standards
	4: MBES High frequency (higher that 100kHz) (1+0.5%d)		

Table 2 Definition of the Quality Index components

These four fields and associated values have been implemented in both Mikado and Sextant metadata cataloguing tools. They have been filled by the data providers [5] and can be seen and used as part of the metadata files as demonstrated in Figure 5.

Currently this classification can be considered as an effective and unambiguous way of communication between data providers and regional coordinator, who are consequently supported in their choices to use one dataset compared to another by comparing these indicators. In other words, this can be considered as an internal interoperability effort. Moreover, this classification will be used to provide a representation of the confidence that the user can expect from the overall gridded EMODnet DTM product.

Finally, one can notice that the expression of uncertainty or confidence related to bathymetric grids is sparse. This is particularly the case for an international global compilation such as GEBCO for which lineage of the source of data and expression of associated confidence could be further enhanced. The work undertaken by the EMODnet HRSM and earlier EMODnet bathymetry consortia for management of the lineage of the source data and the recent work on the Quality Index are of potential interest to international groups such as IHO, GEBCO, and others. This will be further discussed in section 4 of this document.

OTHER INFO

Quality info

Name	Date	Comment
Commission Regulation (EU) No 1089/2010 of 23 November 2010 implementing Directive 2007/2/EC of the European Parliament and of the Council as regards interoperability of spatial data sets and services	2010-12-08	See the referenced specification
COMMISSION REGULATION (EC) No 1205/2008 of 3 December 2008 implementing Directive 2007/2/EC of the European Parliament and of the Council as regards metadata	2008-12-04	See the referenced specification
IHO S-44	2017-06-27	IHO S-44 provides a set of standards for the execution of hydrographic surveys for the collection of data which will primarily be used to compile navigational charts to be used for the safety of surface navigation and the protection of the marine environment.
Dutch Standards for Hydrographic Surveys	2009-07-01	This publication has been prepared in accordance with the 5th edition of the IHO S-44. The difference is that this publication is dedicated to hydrographic work as performed by the Dutch government. It therefore contains some important additions and extensions.
Hoofdprocedure Hydrografisch Werkproces HYD-HP-001	2016-04-01	De RWSV's zijn regels voor het nemen van monsters in het kader van het programma Monitoring Waterstaatkundige Toestand des Lands (MWTL). De voorschriften beschrijven ook hoe bemonstering- en meetapparatuur onderhouden moet worden.
QI_Horizontal	2017-06-30	4
QI_vertical	2017-06-30	3
QI_Age	2017-06-30	3
QI_Purpose	2017-06-30	3

Lineage

The data centres apply standard data quality control procedures on all data that the centres manage. Ask the data centre for details.

Figure 5 Example of the expression of the quality of the survey data through national and international standards, and also unified expression of the Quality Index

3.4. Data sampling and gridding

While section 3.1 has been focusing on the source data and section 3.2 and 3.3 have been discussing the description of source data files (surveys), this section discusses briefly what are the elements used for the generation of the bathymetric DEM delivered by EMODnet Bathymetry. The specification of the EMODnet grid is documented in [1], and [2] for the future HRSM release, along with the sampling methodology at the level of the data provider. In the next two sections the focus will be on the technical points that:

- Allow building a coherent bathymetric surface grid
- help the DTM product being easy to access and use with on-the-shelf software
- benefits to other international initiatives devoted to seabed mapping.

For statistical purposes, a reference grid must be regular and simple for users to manipulate. Regular grids are in general use in the ocean community and can be easily handled by all current software and applications. As detailed in [1] and [2], the success behind the generation of the EMODnet DTM has been to use a constrained sampling strategy which relies essentially on the choices of the resolution and the grid origin.

Data sampling resolution

Sampling of the source data (originating from the data providers) have been selected to fulfil the following constraints:

- The density and the resolution of source data collected by sensors in these depth ranges
- The best resolution that data provider are able to deliver, which satisfies their national legislation on data diffusion
- The mechanisms used to bring the compiled data sets up to the resolution expected for the final EMODnet product.

In order to accommodate these various constraints and following the 1st European Workshop on a European reference grid [7] a hierarchical grid system has been defined (see table below). This schema is ensuring consistency in the computation of depth between different levels of resolution, especially when merging datasets from different sources which are at varying resolutions.

Resolution level	Mesh size in fraction of minute of arc	Corresponding value in meter
7	1	1852,00
6	4	463,00
5	16	115,75
4	64	28,94
3	256	7,23
2	1024	1,81
1	4096	0,45

Table 3 Accepted levels of resolution for grid sampling.

As part of the sampling procedure, simple and unified descriptive statistical information is provided at the level of the grid cell. These are used as part of the aggregation of the sources of data. These statistics are the mean, min, max, standard deviation of the soundings, and number of soundings per grid cell. These statistics, associated with the metadata are particularly useful for the regional coordinator while merging the multiple data sources. Moreover, their combination is expected to be used as part of an updated confidence layer (see below).

Note that, despite the fact that the EMODnet consortium, encourages their data providers to sample their source data, some data providers deliver composite grids which are sampled at the resolution of the targeted product (1/16th arcminute in the case of the future EMODnet HRSM delivery).

Cell geometry and origin

In order to achieve consistent and comparable grid cells, the grid system should have a clear and simple relationship to the coordinate reference system in order to facilitate data delivery and exchange.

The chosen grid system is cell based i.e. the thematic attributes are geometrically associated to the centre of a grid cell. In order to avoid the problems of offset between grids of the same resolution or of a resolution being a multiple of the initial level, a convention must be adopted.

The origin of the grid coverage is the SW corner of the bounding box.

To position the bounding box in a unique way, it is proposed to adopt the following convention related to:

- the Greenwich meridian (0°) in longitude

- the Equator (0°) in latitude

If the grid were extended to this point the origin of the cell should have (0,0) and the coordinates of the cell would be (LX/2, LY /2), LX and LY being the dimensions of the cell in X and Y (see Figure 6)

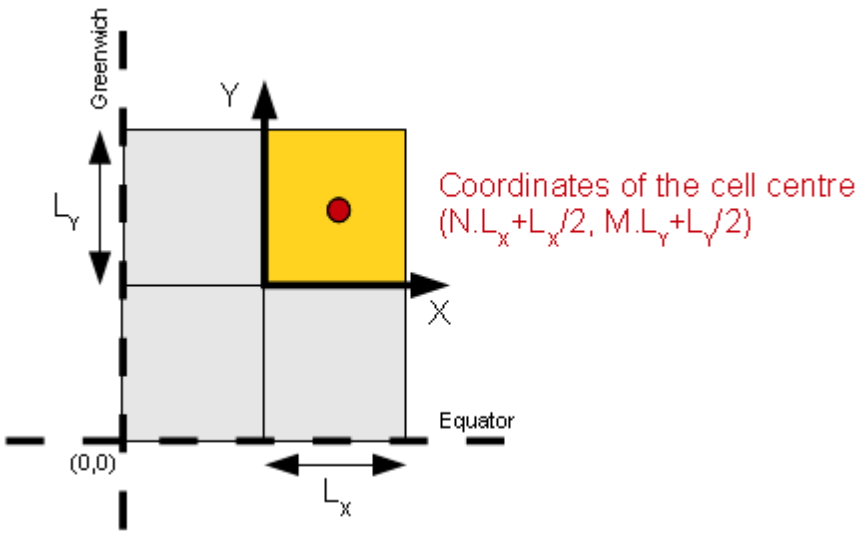


Figure 6 Cell/grid geometry

Note that by adopting this convention relative to the cell geometry and origin of the sampled grid, along with the choice of the data resolution sampling scheme, make 2 by 2 cells of the level 6 exactly fitting one cell of the GEBCO 30 seconds grid.

Globally, all the work undertaken to design this methodology is ensuring an internal interoperability in the gridding process. Moreover it allows data providers to comply with their local data distribution policies by decimating the source data in a simple and homogeneous way before it is delivered to the basin coordinators. Also it is reducing the volume of data that needs to be handled (full resolution multibeam survey can generate Gigabyte to Terabyte volume of data).

The Globe software has implemented in details the tools used for this methodology (see Figure below) and has shown to manage efficiently the multiple sources of data composing the EMODnet grid (preview release). The software is provided to all the members of the consortium, making sure that the methodology is implemented consistently the same way, which in turn enables a robust generation of the DTM.

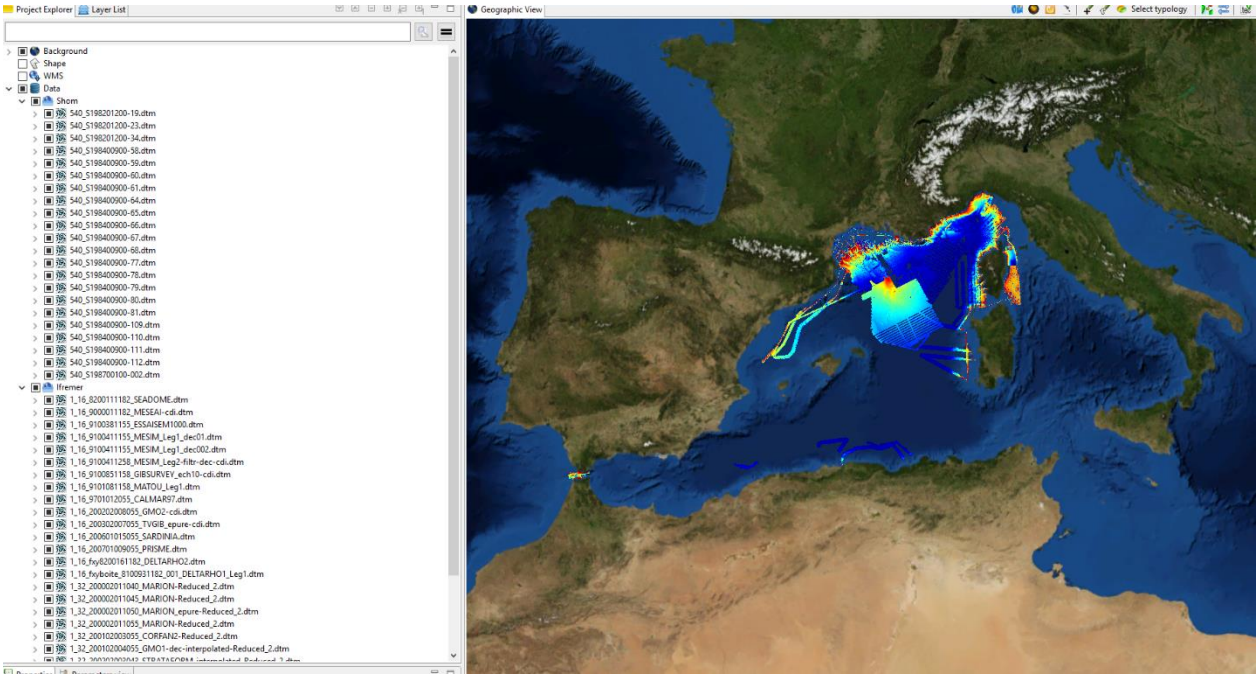


Figure 7 Implementation of the EMODnet bathymetry methodology for producing sampled source grid and associated merging within the GLOBE software used by all the partners of the EMODnet HRSM consortium

File format

Sampled grids and DTM products are internally generated in NetCDF-CF, which is widely adopted in the oceanography community. To users also other formats are delivered such as Ascii Comma Separated Value (known as EMODnet CSV files and detailed in [8]), XYZ file (where only position and depth are provided), Esri ASCII grid and GeoTiff format which are largely implemented by the Geographical Information System industry in their software.

Currently work is undertaken to generate the DTM product also using the BAG (Bathymetric Attributed Grid) format as this is considered by the IHO to be a format compliant with the S-102 standards currently being implemented by the Hydrographic Services community [9], and accepted by INSPIRE, as part of the Data specification on elevation [10].

3.5. Product delivery

Harmonisation involves the use of common access interfaces and resource formats. This includes the EMODnet Bathymetry portal which provides the ability to discover and access the data (both the DTM and its constituents) within a harmonised and human readable interface filled with the information provided as part of the metadata content described in sections 3.2 and 3.3. It also includes Open Geospatial Consortium web services such as Catalogue Service for the Web (CSW), Web Feature Service (WFS), Web Coverage Service (WCS) and Web Map Service (WMS), all supported by metadata standards such as ISO-19115 and ISO 19139 and raster grid format delivery. Figure 8 illustrates the delivery of the

metadata (WFS) and data content (WMS) within any modern GIS software allowing any data users to use the EMODnet results for any desktop analysis.

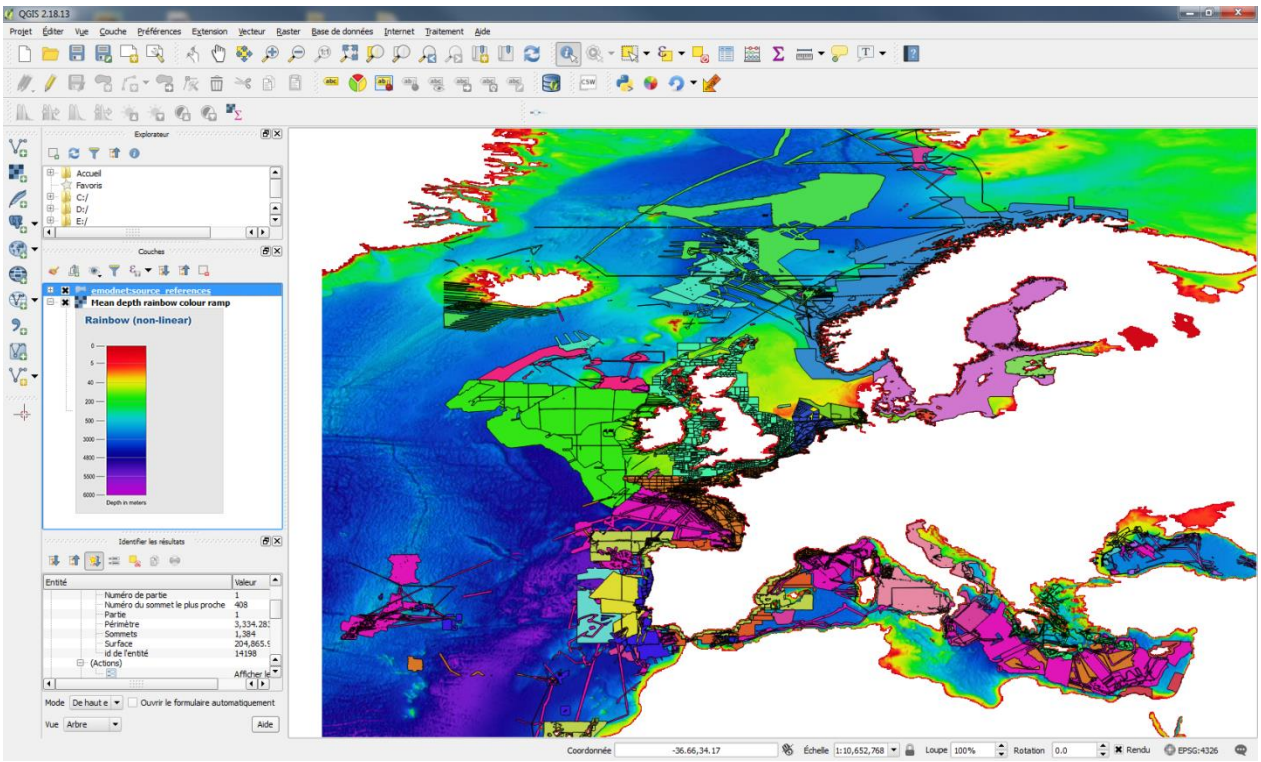


Figure 8 Example of EMODnet data access using OGC web services within on-the-shelf open source GIS software (QGIS). The bathymetric grid (back) is served using WMS. Polygons (front) representing each of the components of the bathymetric grid (except GEBCO left transparent) are served using WFS.

The different OGC services being made available to users (institutional or private) of the EMODnet bathymetry can be found at the following addresses:

WMS: http://ows.emodnet-bathymetry.eu/wms

WFS: http://ows.emodnet-bathymetry.eu/wfs

WMTS: http://ows.emodnet-bathymetry.eu/wmts

WCS: http://ows.emodnet-bathymetry.eu/wcs

Likewise the following snippet of python code demonstrates that the use of these OGC standards enable easy access and use of the EMODnet products in automated processes. A wide range of algorithms can be developed (in other languages than Python) to further use, interrogate, analyse the EMODnet products, which could open the door to unexpected use, such as demonstrated during the EMODnet Open Sea Lab (held in November 2017). The piece of code below simply extracts a region of the DTM, with boundaries specified by the user.

```
# import packages

import os

from owslib.wcs import WebCoverageService

from osgeo import gdal


# define the connection

url = 'http://ows.emodnet-bathymetry.eu/wcs?'

wcs = WebCoverageService(url,version='1.0.0',timeout=320)

wcs.identification.type

wcs.identification.title


# define variables

clipfile = r'..\temp.tif'

requestbbox = (2.097,52.715,4.277,53.935)

layer = 'emodnet:mean_atlas_land'


# get the data

bathyml = 'emodnet:mean'

sed = wcs[layer] #this is necessary to get essential metadata
from the layers advertised

sed.keywords

sed.grid.highlimits

sed.boundingboxes

cx, cy = map(int,sed.grid.highlimits)

bbox = sed.boundingboxes[0]['bbox']

lx,ly,hx,hy = map(float,bbox)

resx, resy = (hx-lx)/cx, (hy-ly)/cy
```

```
width = cx/1000

height = cy/1000


gc = wcs.getCoverage(identifier=bathyml,

         bbox=requestbbox,

         coverage=sed,

         format='GeoTIFF',

         crs=sed.boundingboxes[0]['nativeSrs'],

         width=width,

         height=height)


fn = clipfile

f = open(fn,'wb')

f.write(gc.read())

f.close()

filetiff = gdal.Open(clipfile)

theImage = filetiff.GetRasterBand(1).ReadAsArray()

os.unlink(clipfile)
```

4. Interoperability as prerequisite for international collaboration

Overall, the use of Mikado and Sextant interfaces, along with the controlled vocabularies (for which the governance is ensured by SeaDataNet) and associated training and support are the foundations for explicit description of each of the components (>25.000 sources) of the bathymetric dataset handled within EMODnet Bathymetry. Following prior data conformity checks of the individual sources of data, the efforts put in the detailed description of the source information also enables the harmonization of sampled source datasets during the merging process. More importantly compliance with INSPIRE is ensured as CDI metadata and CPRD metadata profiles are based on ISO 19115 – 19139 standards and marking up is supported by SeaDataNet Common Vocabularies, enabling Discovery – Viewing – Access services for retrieving survey data sets, which are also available through standard OGC web services. Finally Downloadable data sets and data products are available in various commonly used formats.

As a result of all the efforts put into interoperability highlighted in the previous pages of this report, EMODnet bathymetry is able to distribute and share efficiently the bathymetric information that it has generated, along with explicit information on its components, making data providers satisfied and comfortable to display and share their data. Within this context, EMODnet Bathymetry has largely gained in visibility and is now benefiting from this in other international collaborations. These collaborations will be described in this last chapter.

4.1. GEBCO

The General Bathymetric Chart of the Ocean (GEBCO) is the most comprehensive compilation of publically available bathymetric data. The worldwide model is generated at 30 arc-second (~1km grid size) from shipborne systems (singlebeam or multibeam sounders, leadline) or through indirect method based on spatial altimetry (with spatial resolution around 20 kms). Satellite altimetry is only used when no data at better spatial resolution are available. Need for regional contribution, especially in coastal areas (extending to the continental shelf) is crucial for GEBCO, as altimetric extrapolation is only adapted to deep oceanic water depth (beyond the foot of the continental shelf ~2000m water depth).

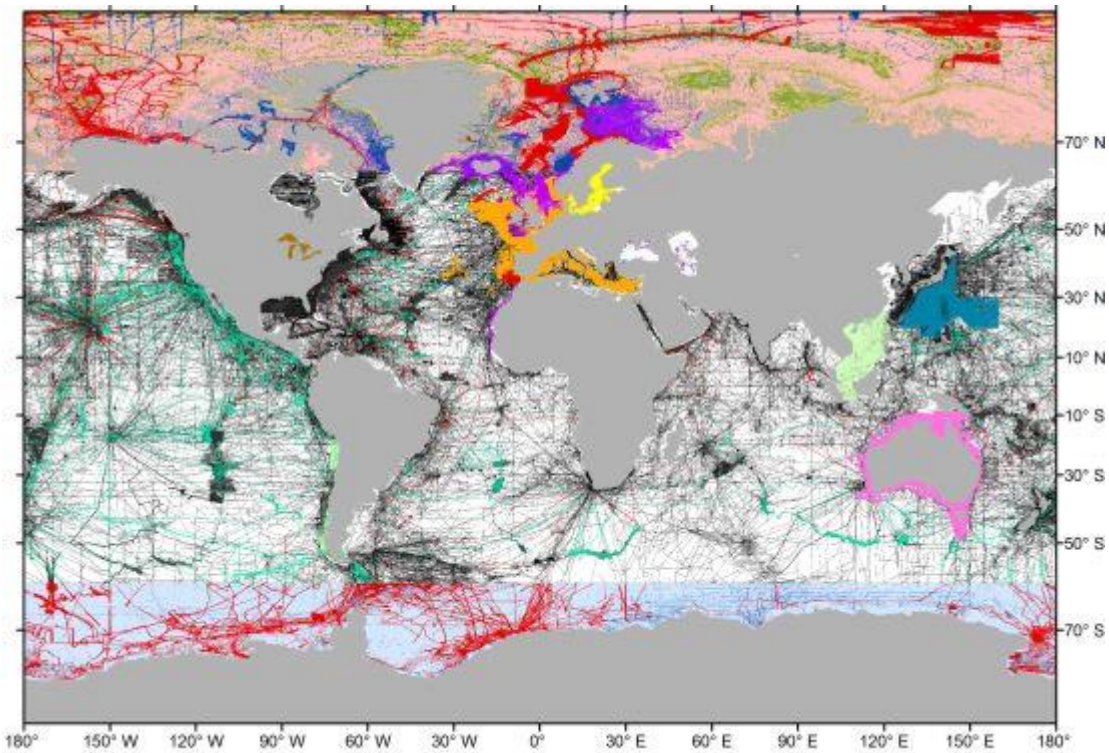
With these considerations, the collaboration between EMODnet Bathymetry and GEBCO is obvious. Since 2014, this collaboration is alive at various levels both within the EMODnet and the GEBCO communities:

- GEBCO members, and more especially, the technical coordinator (BODC) is part of the EMODnet HRSM consortium.
- EMODnet collaborators are part of various sub-committees of the GEBCO. Those are TSCOM

(Technical Sub-Committees on Ocean Mapping) for which the coordinator of the EMODnet HRSM is the Vice Chairman, Scrum (Sub-Committee on Regional Undersea Mapping) for which four EMODnet HRSM collaborators are members, and the GEBCO Guiding Committee in which two EMODnet HRSM collaborators are sitting.

- Relations with other regional efforts are possible especially at the limit of their relative extensions. An example of such synergy is the current effort in the management of bathymetric data from the Arctic Ocean originating from the IBCAO (International Bathymetric Chart of the Arctic Ocean) community which will be integrated in the next release of EMODnet HRSM.

The most obvious proof of efficient collaboration between GEBCO and EMODnet communities is the mutual integration of bathymetric information within both DTM grids. Figure 9 below shows the geographical distribution of the various sources of data composing the recent GEBCO released, in 2014. One can see that EMODnet data (from 2013) are used.



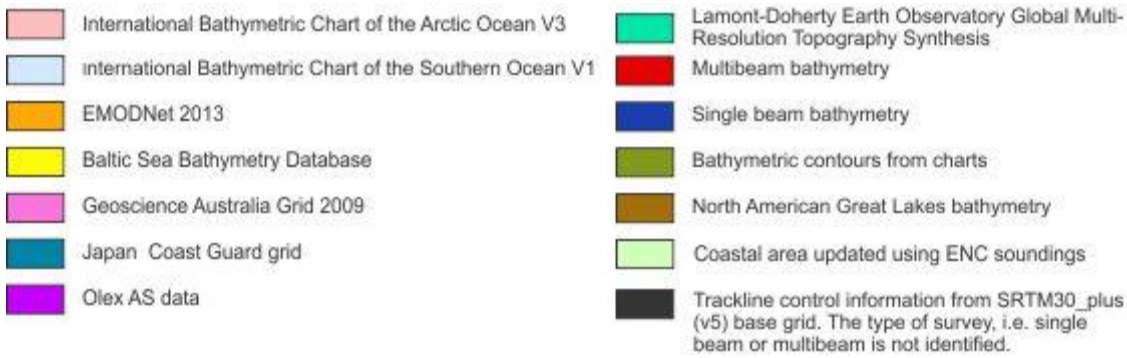


Figure 9 Coverage of the source of data composing the GEBCO 2014 grid (last release) including the EMODnet bathymetry grid

Following the integration of the EMODnet grid in the GEBCO grid, the latter is used in turn within EMODnet to fill the gaps where data are not available (which are therefore essentially filled by the altimetric derived GEBCO component). The mechanism of integration is illustrated in the figure below. This procedure strongly benefits from choices made by the EMODnet community described in section 3.4 taken to facilitate interoperability of both gridded products.

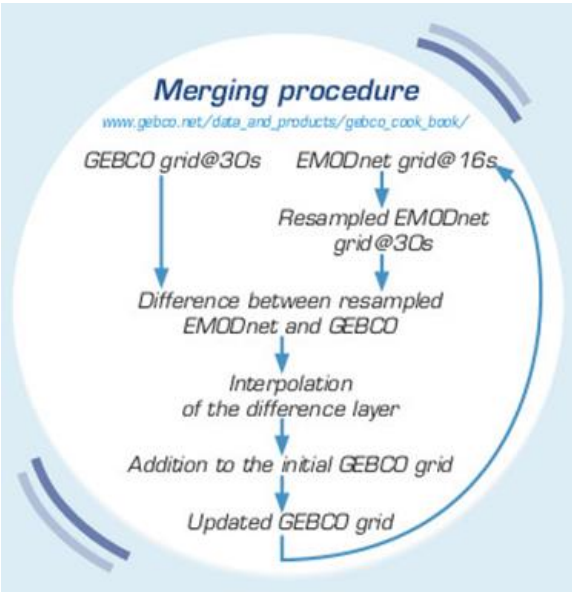


Figure 10 Schematic representation of the GEBCO EMODnet Bathymetry merging procedure

Results of this collaboration and the use of the merging procedures, mainly consist of:

- The convergence of both bathymetric products for the European waters, hence minimizing the confusion for the users
- Smoothing the interface between the areas of pure bathymetry data and the ones issued from altimetry extrapolation, in both products.

Note that despite the fact that the releases of GEBCO and EMODnet DTM products can't really be synchronized, each product uses the most recent (and curated) product from the other part.

4.2. IHO – NCEI

The International Hydrographic Organization, has been mentioned earlier in this document. Its primary goals are to promote hydrography and ocean mapping through the management of Hydrographic Standards (mention of the S-44 [3]), to coordinate mapping efforts and to allow member states to provide authoritative data, primarily used to ensure safety of navigation at sea but also to provide information needed for appropriate decision making processes concerning the marine environment. At present, 16 European national hydrographic services are members of the EMODnet HRSM consortium.

Supporting the GEBCO compilation, mentioned above, is one of the most important contributions provided by the IHO. Member states are regularly asked to provide bathymetric data for this compilation, especially for shallow and coastal areas. With the close interaction described in the previous section between the GEBCO and the EMODnet HRSM community, IHO member states belonging to the EMODnet HRSM consortium are indirectly fulfilling this request.

The other important global contribution to IHO is to support the DCDB (Data Centre for Digital Bathymetry). The DCDB contains oceanic bathymetric soundings acquired by hydrographic, oceanographic and other vessels during surveys or while on passage. Data are publically available and used for the production of improved and more comprehensive bathymetric maps and grids. Physically the DCDB is hosted by NCEI (National Centers for Environmental Information) of the U.S. National Oceanographic and Atmospheric Administration. This data are particularly important to support the GEBCO Programme but is not the only source. Here again, as a result of the efforts put into the interoperability, the implementation of the WFS EMODnet Service allowed a relatively straightforward combination of bathymetric data coverage (and associated metadata) held in the DCDB and in the CDI/CPRD EMODnet HRSM catalogues. The figure below illustrates this combination implemented as part of Data viewers (North Atlantic Data Viewer - http://maps.ngdc.noaa.gov/viewers/north_atlantic/ and Crowd Source Bathymetry Data - https://maps.ngdc.noaa.gov/viewers/csb/). For the Crowd Source Bathymetry viewer, filtering capabilities of the WFS service supported by the appropriate metadata allow to display the multibeam surveys individually from the other type of surveys. More importantly, each of the EMODnet survey identified on these viewers can be interrogated through the direct forwarding from the NOAA/NCEI viewers to the EMODnet Bathymetry CDI/CPRD catalogues, where the interested users can read the entire metadata file, and get access to the data through shopping basket mechanisms.

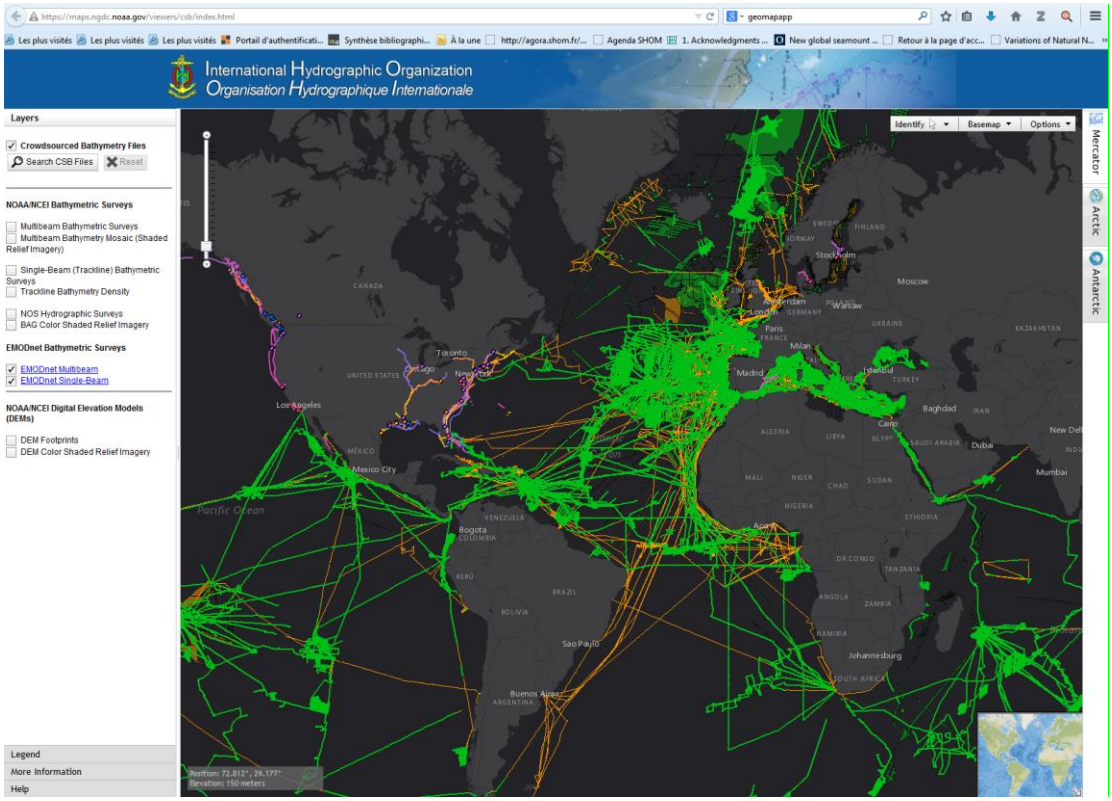


Figure 11 International Crowd Source Bathymetry viewer showing the ability to display bathymetric coverage from the DCDB and EMODnet sources

4.3. Galway Statement - North Atlantic

Alliance (AORA)

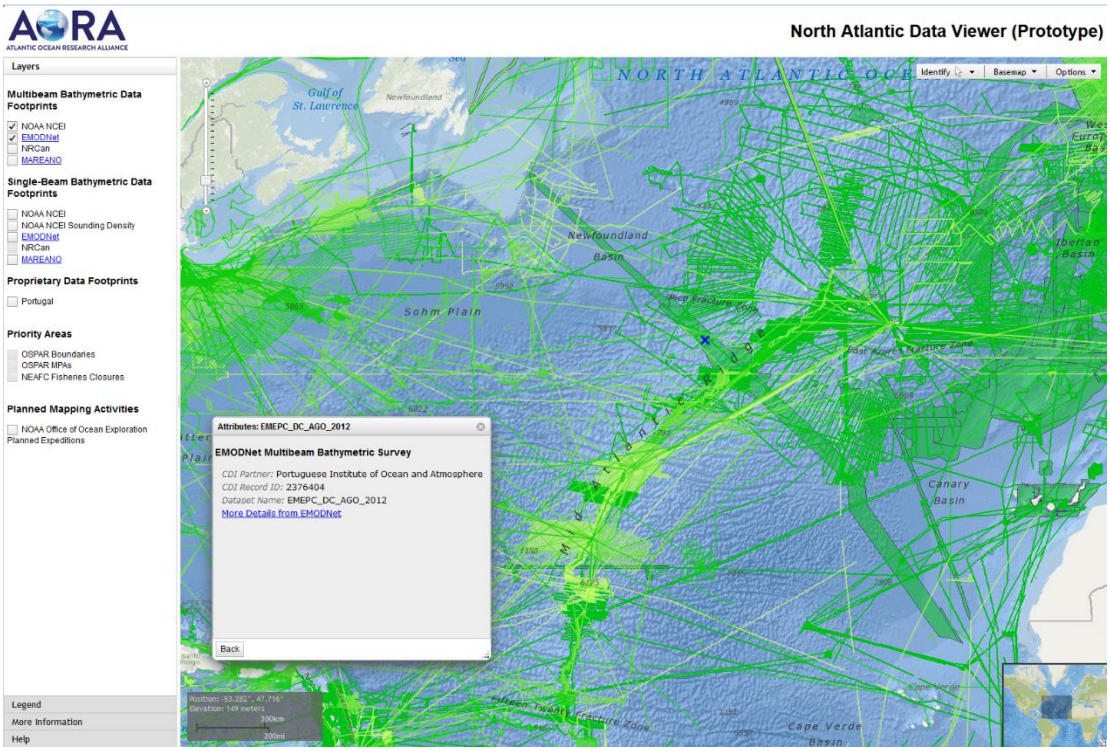


Figure 12 Atlantic Ocean Resarch Alliance viewer illustrating bathymetric coverage from NOAA/NCEI (DCDB) and EMODnet Bathymetry

Overall, the collaboration between EMODnet bathymetry and the NOAA/NCEI is shown to be active and leading to intelligent use of the bathymetric knowledge in decision making processes, such as for the AORA initiative (H2020 Grant Agreement number 652677). The Atlantic Ocean Research Alliance is the implementation of the Galway statement which aims at seeking trans-Atlantic marine research cooperation between the Europena Union, Canada and the United States.

As part of this framework a group of international experts (Atlantic Seabed Mapping International Working Group, ASMIWG) has been tasked to develop and implement a cohesive seabed mapping strategy for the North Atlantic Ocean. Benefiting from the collaboration between EMODnet and the NOAA/NCEI this group of experts have been able to identify lacks of bathymetric coverage (in the international open seas) and prioritize future surveys or transits to be undertaken from the hydrographic and research communities from the EU, USA or Canada. Figure 13, extracted from a recent paper [10], which describes their methodology, highlights the results of this work. This paper also suggests survey priorities over deep sea areas lacking of bathymetric measurments. These priorities are driven by the potential social and economic benefit that precise information would generate (mining exploration, search and rescue, environmental and habitat conservation). Representatives of EMODnet HRSM are in close contact with members of the ASMIWG.

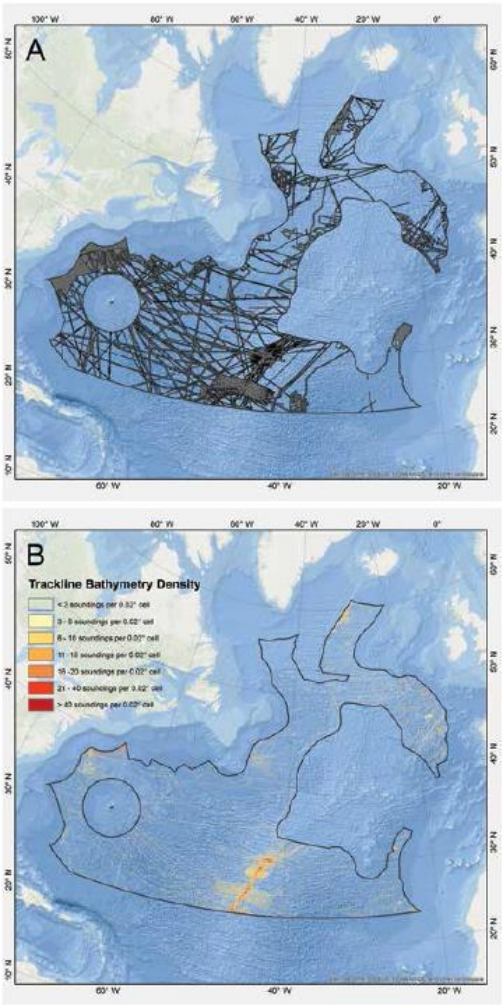


Figure 13 Bathymetric Coverage in international waters (as generated from DCDB and EMODnet Bathymetry repositories through the AORA viewer)

4.4. EMODnet family and Marine Strategy Planning projects

As a matter of fact, international collaborations also originate directly from the global EMODnet family. Indeed, the physical description of the seabed, starting from the bathymetry is of strong importance to other thematic lots. As for any other users, EMODnet Bathymety serves both metadata catalogues and DTM product through the appropriate OGC web services listed above. Hence all the EMODnet thematic portals can freely use them. Likewise, as part of the EMODnet Seabasin CheckPoints can benefit from direct access through the EMODnet Bathymetry portal or throug the web services to the information they need as part of their challenges. Similarly, EMODnet Bathymetry data are also serving ongoing cross-boundary Marine Strategy Planning projects funded by the European Commission (such as SIMCelt, SIMWest Med, …).

The most obvious example of interaction with another EMODnet thematic portal concerns the Seabed Habitat theme. EMODnet Bathymetric product DTM is currently used by this thematic portal to support of the definition of types of habitat. Concerned about the various sources of bathymetric data composing the gridded model, the question of the level of confidence that a user can rely on was asked. As a preliminary answer, the EMODnet Bathymetry group generated a map of confidence based on the age of the data and its density. The generation of this layer of information on the confidence is well documented [11]. This first attempt to express the confidence of our DTM product motivated further work on the definition of QI indexes presented in section 3.3 of this document.

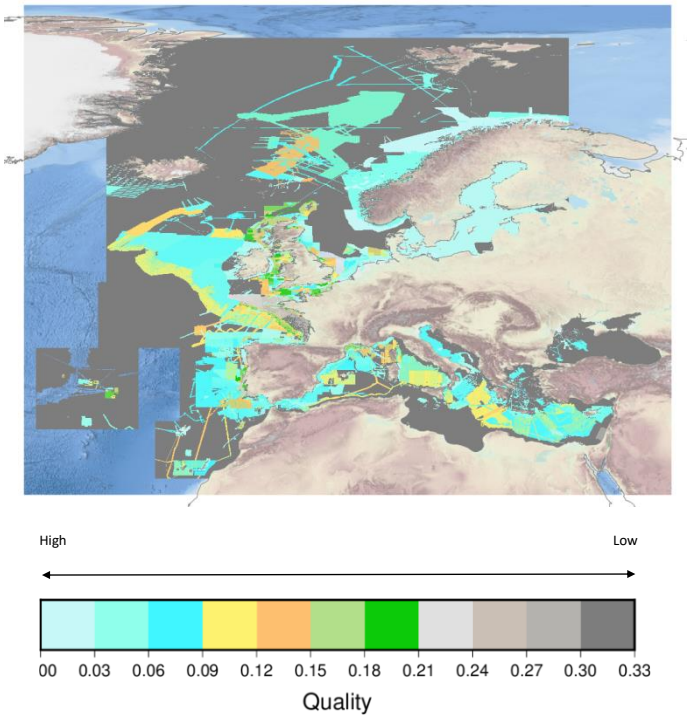


Figure 14 Confidence map generated for the EMODnet Seabed Habitat group. A low value indicate a higher confidence.

4.5. GeoMapApp and other data viewing initiatives

The Lamont Doherty Earth Obervatory of the University of Columbia (USA) is particularly experienced in the field of Ocean Mapping. GeoMapApp is a Geoscience oriented Geographical Information Software in which curated geophysical data are made available. Bathymetric data is one of these geophysical data layers. The last release of the EMODnet bathymetric grid (without the GEBCO contribution) has been made available to this group, as illustrated on the figure 15.

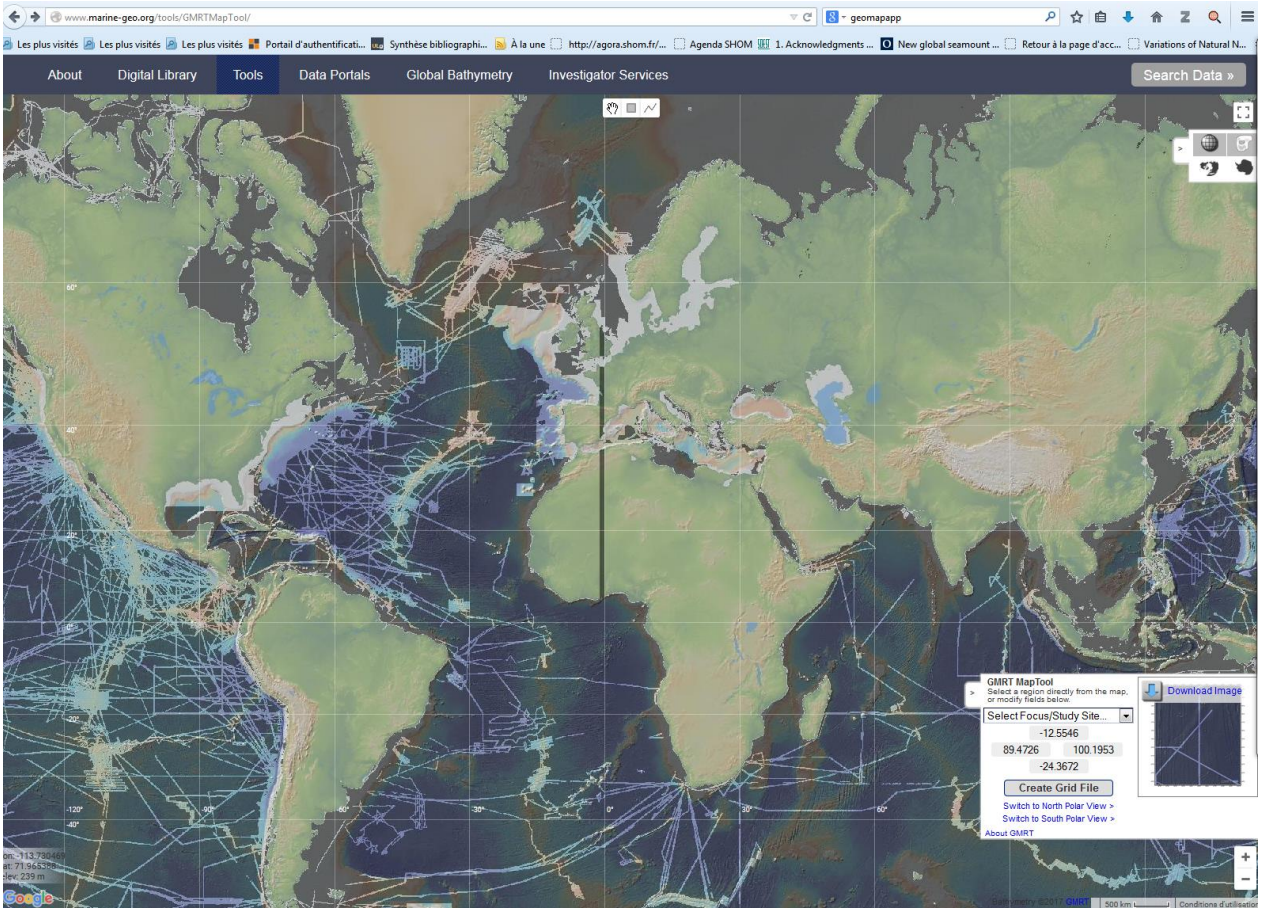


Figure 15 Output of the Geomapap bathymetric coverage. Bright areas indicates measured (as of soundings) bathymetric data

Technical discussions with data centric commercial world wide companies such as Google and ESRI have been recently revitalised for the integration of the EMODnet Bathymetry grid as part of their respective data delivering services (Google Earth and ESRI TopoBathy). Both companies are currently evaluating administrative issues concerning the use of the EMODnet grid (such as credits and other legal aspects). The potential implementation of the EMODnet product within these services are envisioned to be facilitated because, here again strong efforts have been put in the respect of interoperability constraints and respect of international standards since the infancy of the EMODnet Bathymetry initiative.

4.6. Seabed 2030 initiative

In June 2016, the forum for Future Ocean Floor Mapping brought together in Monaco, over 150 representatives from major ocean-related and international organizations from all over the world. A number of EMODnet Bathymetry participants were amongst these representatives. Announced in June 2017, the Seabed 2030 initiative originated from this forum. This initiative envisions producing a map of the world Ocean floor by 2030 for which objects larger than 100 m can be resolved which will be very

challenging for some parts of the world (e.g. Southern Indian Ocean). The GEBCO project is the driver of this initiative which, in turn is run under the auspices of the IHO and the IOC (such as GEBCO is currently). At present, the project is defining its modus operandi (creation of Regional Data Assembly and Coordination Centers, Guiding committee, communication …). The main actions that the Seabed 2030 initiative is aiming at, in order to accomplish its targeted goals, are (as taken from the Seabed 2030 roadmap for future ocean floor mapping [12]):

- Building working relationships with bathymetric data contributors all over the world.
- Aggregating and compile existing data into a widely available digital database.
- Identifying unmapped areas, enabling prioritization of coordinated survey operations in these regions.
- Implementing the latest technology for ocean mapping (e.g. satellite derived near shore bathymetry, crowd sourcing from fishing merchant and recreational vessels).

One must recognize that this list of tasks is largely considered, with actions ongoing and already realized within the EMODnet Bathymetry project (or as part of EMODnet Ingestion for the crowd sourcing). This is indeed recognized by the actors of the Seabed 2030 initiative, who are strongly supporting collaborations between their community and EMODnet Bathymetry. As cited from the Seabed 2030 roadmap [12], “the collaboration with ongoing mapping efforts such as EMODnet covering European waters […], the Baltic Sea Bathymetry Database […] and the North Atlantic initiatives will be key to get the World Ocean mapped by 2030”.

Within this context, EMODnet Bathymetry is promoting the success of its federated infrastructure, opposed to centralized infrastructure, where data providers manage and release their source data at their will (which might be dependent of their national legislation). In this situation only metadata (with originator of the data) is centralized. EMODnet Bathymetry coordinators and members remains fervent advocates of this philosophy, which strongly relies on the strength of all the actions put into interoperability (as presented in the previous section). Recent demonstrations of EMODnet Bathymetry (11/2017 and 12/2017) to members of the GEBCO (Seabed 2030 – GEBCO) technical groups and IHO Directors, suggested that the metadata model and bathymetric classification scheme (section 3.3) developed and used by the EMODnet Bathymetry community is of interest for a wider international use. Members of the EMODnet HRSM consortium will take part in an emerging GEBCO – Seabed 2030 working group on metadata.

5. Conclusions

Before 2009, bathymetric data held by hydrographic organization and research institutes in Europe were sparsely accessible. With the implementation of the INSPIRE Directive and the EMODnet initiative, access to the data has strongly been improved. This can be observed for all the EMODnet thematic portals including EMODnet Bathymetry.

In this report the difficulties of managing heterogeneous bathymetric data originating from multiple sources have been explained, and the ways it is addressed in EMODnet Bathymetry through adoption of the effective data management system for oceanographic data (collecting and processing data, making it available and reusable, etc.) originating from the collaboration with SeaDataNet. This included also adaptation which was needed from the bathymetry community (metadata content and vocabulary, standardized geographic representation of sampled data and composite products, etc.).

Efforts put on the management of the data with a strong focus on their interoperability are clearly beneficial both for:

- The creation of the bathymetric DTM, as specifications respecting the standards enable an effective processing workflow from the data originator, to the regional coordinator and finally to the integration on the portal and the final delivery to end-users.
- The standardization documentation, access and delivery of the overall EMODnet Bathymetric DTM along with each of its components for their use by individuals or international bodies to improve the bathymetric knowledge.

With this approach, the future of the EMODnet bathymetry repository should be facilitated. Indeed, data management is at the basis of our objective to support online geoprocessing services (Virtual Environment), as discussed in the associated annual report. Common definitions and standards enable machine-to-machine communications, allowing us to focus only on the architecture and the implementation of cloud-based solutions.

Finally, both at European and international level, it can be seen that a virtuous circle starts to appear in which data repository curators improve their management systems with the support of the scientific community's researchers, which in turn, need coordination between the institutions that collect and disseminate data. As shown in this report, EMODnet Bathymetry fits in this view and has now become a leading data repository.

6. References

[1] Methodology and Guidelines for integrating data and processing regional DTM, Service Contract No. “MARE/2012/10 Lot 1 Hydrography, EMODnet Bathymetry internal document, 29 pages.

[2] Methodology and Guidelines for processing original input data into DTMs for possible integration in EMODnet Regional DTMs, Service Contract No EASME/EMFF/2015/1.3.1.7/SI2.742125, EMODnet Bathymetry Internal document, 16 pages

[3] IHO Standards for Hydrographic Surveys, 5th edition, February 2008, Special Publication No 44. https://www.iho.int/iho_pubs/standard/S-44_5E.pdf

[4] Directive 2007/2/EC of the European Parliament and of the council of 14 march 2007 establishing an Infrastructure for Spatial Information in the European Community – Official journal of the European Union

[5] EMODnet High Resolution Seabed Mapping first annual report, Service Contract No EASME/EMFF/2015/1.3.1.7/SI2.742125

[6] High Resolution Seabed Mapping WP1: Data provider contribution Completing metadata elements for the generation of the Quality Index for the EMODnet DTM, Service Contract No EASME/EMFF/2015/1.3.1.7/SI2.742125, EMODnet Bathymetry internal document, 22 pages.

[7] Short Proceedings of the 1st European Workshop on Reference Grids, Ispra, 27 - 29 October 2003. http://eusoils.jrc.ec.europa.eu/projects/alpsis/Docs/ref_grid_sh_proc_draft.pdf

[8] DTM exchange format specification Service Contract No. “MARE/2008/03 Lot 1 Hydrography – SI2.531515”, EMODnet Bathymetry internal document, 4 pages.

[9] IHO standards on Bathymetric surface product specification, Edition 1.0.0, April 2012, Special Publication 102, 51 pages. https://www.iho.int/iho_pubs/standard/S-102/S-102_Ed1.0.0_Apr12.pdf

[10] Wölf, A.C., Jencks, J., Johnston, G., Varner, J., Devey, C. (2017) Identifying deep-sea targets areas for a pilot Atlantic seabed mapping project using GIS techniques. The Journal of Icena Technology, Vol 12, No 4, p28-42.

[11] Generating data quality indicator from EMODnet bathymetry, MARE/2012/10 Lot 1 Hydrography, EMODnet Bathymetry internal document, 13 pages.

[12] The Nippon Foundation GEBCO Seabed 2030 road map Mission statement. https://seabed2030.gebco.net/documents/seabed2030_brochure.pdf