EMODnet Bathymetry - High Resolution Seabed Mapping (HRSM2)

Report on Interoperability and International Collaboration

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Foreword

In February 2018, the EMODnet Bathymetry consortium reported on its efforts and strategy to support and benefit from interoperability and international collaborations. Beyond the initial strategy related to the specification of the metadata content and format, along with the gridding geometry, efforts have been made to reinforce EMODnet Bathymetry key role in facilitating the access of bathymetric information at the global scale for all the users. The present document updates the earlier version.

Disclaimer

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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, actions are described which have been and are currently 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, we will document how these efforts are largely benefiting access to the data and metadata as prerequisite for international collaborations.

2. Interoperability within the context of bathymetric information

Two main sub-communities of bathymetry data providers globally exist and are present within the EMODnet HRSM2 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. In our description, we follow the life cycle of the bathymetric information: from the elementary observation (soundings) up to the product delivery (DTM) as illustrated on *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].

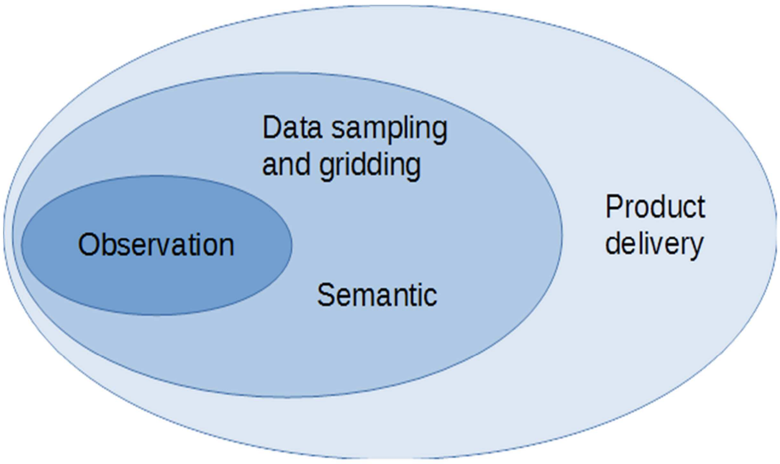

Figure 1: Path of the bathymetric information from the observation to the product delivery, as considered by the EMODnet Bathymetry community

3. Harmonization 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. The process, illustrated below, shows the different steps of the generation of EMODnet DTM and the inventory/distribution of individual sources of bathymetric information. *Figure 2* reads from the top, where source data are described (metadata production) and sampled using dedicated software (see respectively section 3.2, 3.3 and 3.4). 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, based on commonly agreed concepts and methodologies.

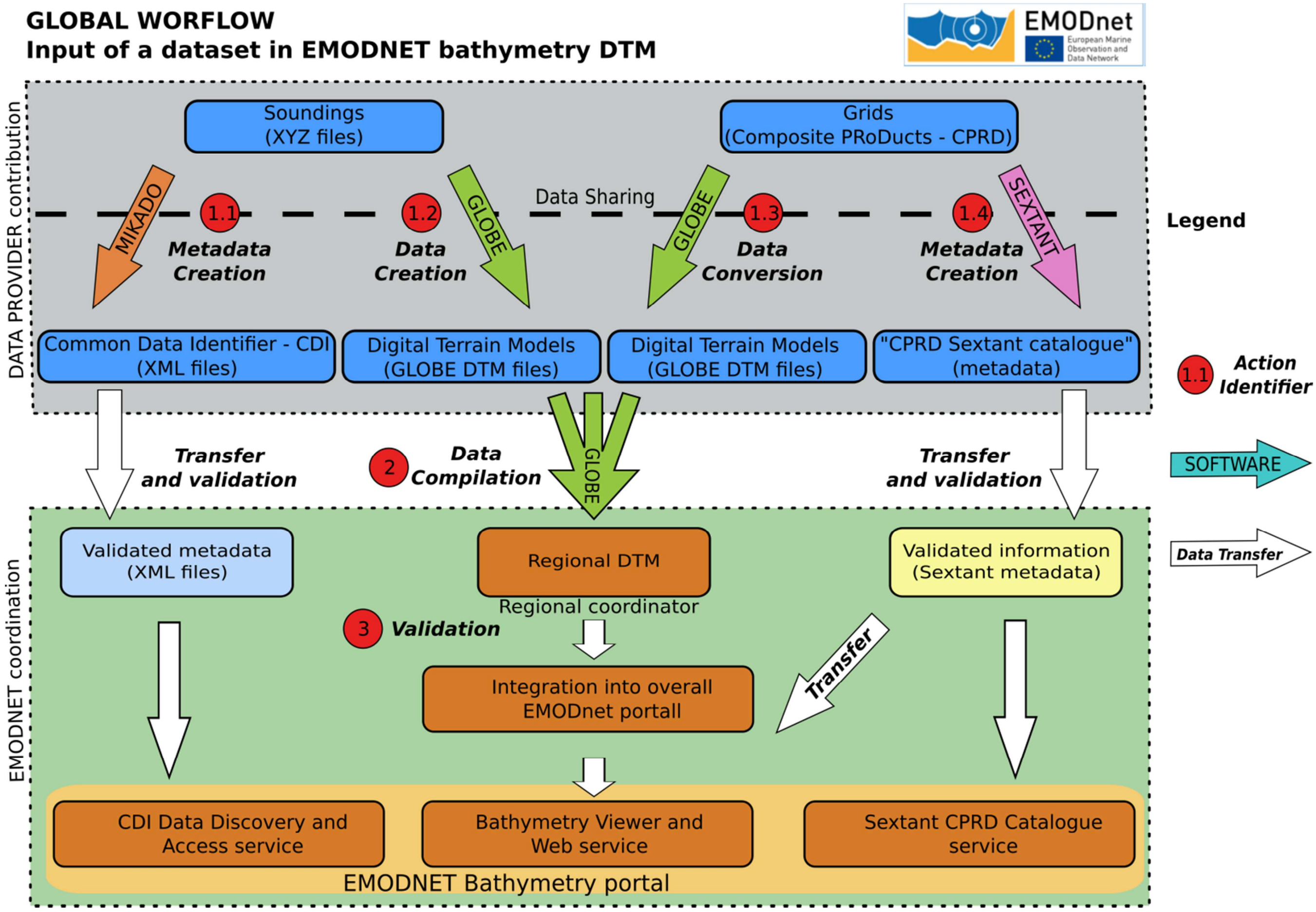

Figure 2: Overall metadata and data workflow illustrating the need for strong interoperability both at the internal level (ensuring understanding between data providers and regional coordinator) and at the external level (as of rendering and serving the product to users)

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 might exceeds the coverage of the ETRS89).
- Other worldwide or regional projects such as the general bathymetric Chart of the Ocean (GEBCO 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. 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, harbors etc.) usually references “Chart Datum” which tends to be consistent with the LAT (at worst with an acceptable difference of 50 cm).

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.

Note that in terms of data delivery, the bathymetric DTM is provided both at the Lowest Astronomical Tide (LAT) and Mean Sea Level (MSL) ensuring flexibility for all types of usage.

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 Organization for Standardization (ISO) and the World Wide Web Consortium (W3C). It has an active cooperation and tuning with the INSPIRE community (see next chapter), and in particular with 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 center 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 work related to the indexing of source data undertaken as part of the current EMODnet HRSM2 project in Work Package 1 is described 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.

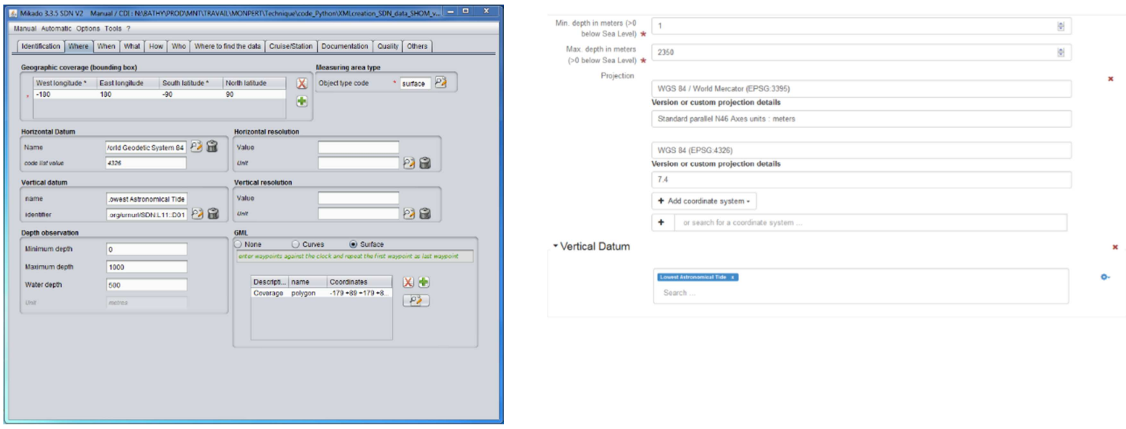

Figure 3: Human readable interface of MIKADO (left) and Sextant (right) used to fill metadata associated with bathymetric data

Mikado and Sextant interfaces both generate metadata files encoded in XML format, using XML tags and values defined to be compliant with ISO 19115 - ISO 19139 standards along with SeaDataNet vocabularies. The following snippet of metadata file, shown in *Figure* **4**, provides an example. These types of files enable machine-to-machine processing as demonstrated in section 3.6 concerning product delivery.

```xml
- <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. INSPIRE compliance

As mentioned above, the EU INSPIRE directive and 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 the beginning of EMODnet Bathymetry project, in 2009 compliance with INSPIRE has been sought.

The SeaDataNet CDI metadata schema is based upon the ISO 19115 content standard, while for XML encoding it is based upon the ISO 19139 Schemas, which are also the basis for the INSPIRE metadata standards. The CDI XML encoding Schema has been extended into a marine community profile to support the use of the SeaDataNet common vocabularies and directories, and to accommodate additional metadata elements which are of particular use for the marine data community to describe marine data in a FAIR (Findable, Accessible, Interoperable, and Reusable) way. This has been encoded by expanding the basic ISO 19139 schema with Schematron language.

By adopting and applying the CDI standard for many disciplines, such as physics, chemistry, geology, bathymetry, biology, and geophysics, as well as for many data types within these disciplines, and for point, track and area observations, the CDI standard and its supporting vocabularies have expanded and matured during the many years since its inception. This was largely done by the SeaDataNet Technical Task Group in dialogue and close cooperation with many marine communities and projects, such as several EMODnet lots.

This way, the uptake by EMODnet Bathymetry has also resulted in adding new elements, for instance quality indicators (see section 3.4), and additional vocabularies and terms. As of December 2019, Upgraded new versions of the CDI XML schema together with ISO documentation and examples are published at the SeaDataNet portal at: https://www.seadatanet.org/Standards/Metadata-formats/CDI

Moreover, all relevant CDI services and software (such as MIKADO as XML editor) for populating and querying the CDI services by data providers and users, have been updated at the same rhythm that upgrades were made in the CDI Schema versions.

By regular contacts and following activities of international standards communities such as OGC, ISO, and W3C, it has been ensured that the CDI XML schema and its CDI services continued to be in compliance with those international IT standards. A comparable cooperation was set up with the INSPIRE team of the EU-Joint Research Centre (JRC) to ensure that the CDI schema is INSPIRE compliant, so that activities by data providers for preparing and populating CDI XML entries also have a win-win effect for them in implementing and maintaining INSPIRE compliant discovery and access services for their own data sets. **This way, data providers of EMODnet Bathymetry, who are for a large part public services, fulfill their INSPIRE duties by contributing to EMODnet Bathymetry.**

The adaptation of the CDI XML schema to INSPIRE progressed well and in September 2013 a situation was achieved that the CDI XML Schema, based upon ISO 19139, was declared fully INSPIRE compliant, which could be demonstrated using the INSPIRE metadata validator that was provided by the INSPIRE team at the time.

However, around 2018, the INSPIRE team has upgraded its INSPIRE ISO 19139 metadata schema (V11), but also replaced the INSPIRE metadata validator with a new (beta) validator service. Tests were undertaken with the INSPIRE Executable Test Framework (ETF) metadata validation report, which could be found on:

http://inspire.ec.europa.eu/validator/v2
At that time the SeaDataNet definition file was:
https://www.seadatanet.org/content/download/2602/file/CDI_ISO19139_full_example_11.0.0.xml.
The following table provides a summary of the qualifications of the CDI XML schema since its version 1 in 2012.

SeaDataNet	2012: SeaDataNet • Mandatory metadata fields • SeaDataNet vocabularies	✓
ISO	2012: International Organization for Standardization • ISO 19115 – Geographic information – Metadata • ISO 19115-2 – Geographic information – Metadata – Part 2 • ISO 19106 – Geographic information – Profiles • ISO 19139 – XML schema implementation of ISO 19115	✓
	2013: Infrastructure for Spatial Information in the European Community • INSPIRE directive • INSPIRE metadata regulation • INSPIRE metadata Implementing Rules • Old INSPIRE metadata validator	✓
ETF	2018: Testing of CDI XML output following V11 schema: • New INSPIRE metadata validator (ETF) • Implementing Rules on the Interoperability of Spatial Datasets and Services	WORK IN PROGRESS

Table 2: Chronology of the Validation of CDI XML schema since V1 originated in 2012

As illustrated in *Figure 5*, the validator was not able to accept CDI XML documents any more, which were accepted in the Version 1 of the validator. These tests showed that all 3 metadata conformance classes **failed.**

- **XML encoding** (basic)
- **Metadata for discovery** (core)
- **Metadata for interoperability** (advanced)

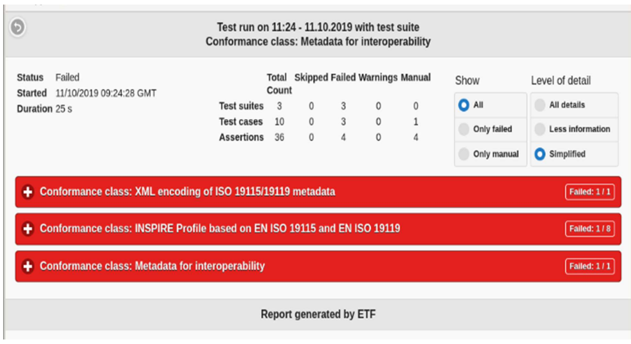

Figure 5: Snapshot of the output of the SeaDataNet schema with the ETF validator, prior to mutual updates

From this moment, a constructive discussion took place between the SeaDataNet/EMODnet community and the INSPIRE JRC team to help solving the different issues.

XML encoding test:

The validator did not support well XML schemata importing and extending the base ISO 19139 at this time (community profile schemata), which theoretically is accepted by the INSPIRE specification. This implicated that the validator was no longer fit for community profiles, but only for a core INSPIRE profile, which was hurting not only the marine community but also other communities that have had adopted and elaborated ISO standards following the official INSPIRE guidelines in order to make the metadata format useful for their specific communities and applications.

Actions by the SeaDataNet and EMODnet communities were undertaken to report the issue on the ETF GitHub issue tracker (https://github.com/inspire-eu-validation/ets-repository/issues/183). In the meantime a temporary workaround was applied by SeaDataNet by explicitly declaring the base ISO 19139 schemata in the schema Location, in addition of the extended CDI schemata.

Metadata for discovery test:

SeaDataNet added conformance on elements relative to interoperability regulation, which strongly helped the Dataset conformity test. Dataset linkage was also solved by SeaDataNet by thoroughly checking WMS URLs.

Metadata for interoperability:

Explicit and detailed considerations on the spatial representation type (e.g. vector, grid) were added by SeaDataNet on the metadata profile depending on the dataset nature.

Issues related to the capacities of the validator were reported on the ETF GitHub issue tracker (https://github.com/inspire-eu-validation/ets-repository/issues/184, https://github.com/inspire-eu-validation/ets-repository/issues/185). These issues were concerning key points related to Coordinate Reference System expressions including support of EPSG codes, and format specification. These requests were finally accepted and solved, after quite some discussion and support from EU DG MARE and EU DG Environment. Those discussions mainly took part as part of the agenda Technical Group on Marine Data.

An updated version of the SeaDataNet CDI XML schema (Version 12.1.0) was released in December 2019 which included the changes above mentioned. Likewise, the release of an upgraded version of the ETF INSPIRE metadata validator service ([http://inspire.ec.europa.eu/validator/)](http://inspire.ec.europa.eu/validator/) was made by the INSPIRE team. Tests were undertaken, which highlighted the conformance of the updated SeaDataNet CDI XML schema (Version 12.1.0) with the current INSPIRE metadata validator (as illustrated in *Figure 6*).

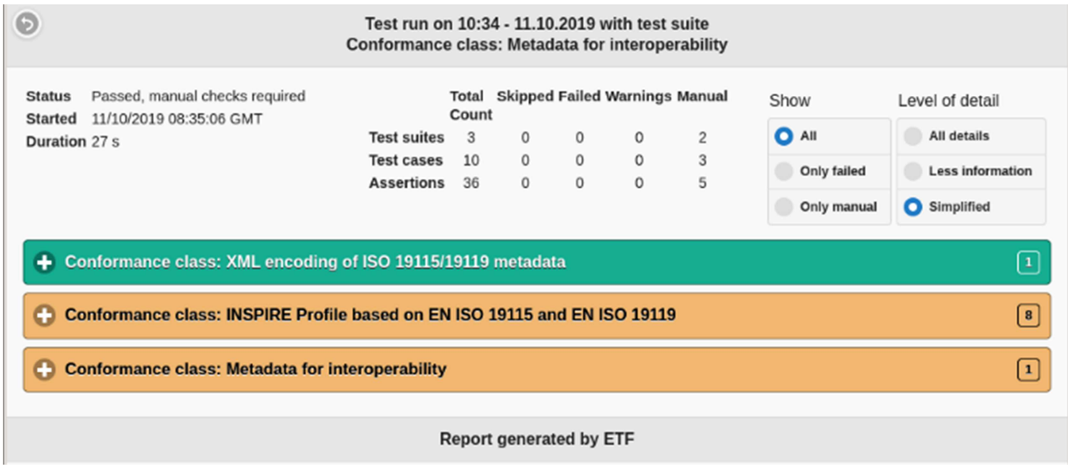

Figure 6: Snapshot of the output of the SeaDataNet schema with the ETF validator, after its upgrade and the upgrade of the SeaDataNet schema

As a result, all XML outputs of the CDI services at SeaDataNet, EMODnet Bathymetry, EMODnet Chemistry and EMODnet Physics portals are now fully INSPIRE compliant again, which makes all the contributors of these portals also fully compliant with INSPIRE. Furthermore, final steps are now underway for upgrading the SeaDataNet MIKADO XML editor software, in order to make an end-to-end compliance from the tools to the services with the latest CDI Schema (V12.1.0).

3.4. Qualitative assessment of the bathymetric data

The International Hydrographic Organization document S-44 [3] is a document that describes the specifications of bathymetric surveys, with respect, essentially, to the precision needed to ensure safety of navigation. The hydrographic offices members of the EMODnet HRSM consortium can state and provide elements that they are respecting this standard using free text attributes in 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 **7***.

Conscious that national classifications may differ, and also that several members of the EMODnet HRSM2 consortium are not hydrographic offices, and hence are not subject to the use of 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 indicator (QI_Horizontal) and the vertical indicator (QI_Vertical). Associated with these elements are the age of the survey indicator (QI_Age) and the purpose of the survey indicator (QI_purpose). *Table 3* 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 3: 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], who described their dataset to their best knowledge. Users seeking individual dataset can also use these indicators which are displayed as part of the metadata files by the EMODnet Bathymetry portal as demonstrated in *Figure **7***.

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

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 has also been used to provide a representation of the confidence that the user can expect locally from the gridded EMODnet DTM product. Example is given of the display of the age of the survey across the southern North Sea (*Figure **8***). A second display shows how such information is displayed, on a global scale, on the EMODnet web portal (*Figure 9*).

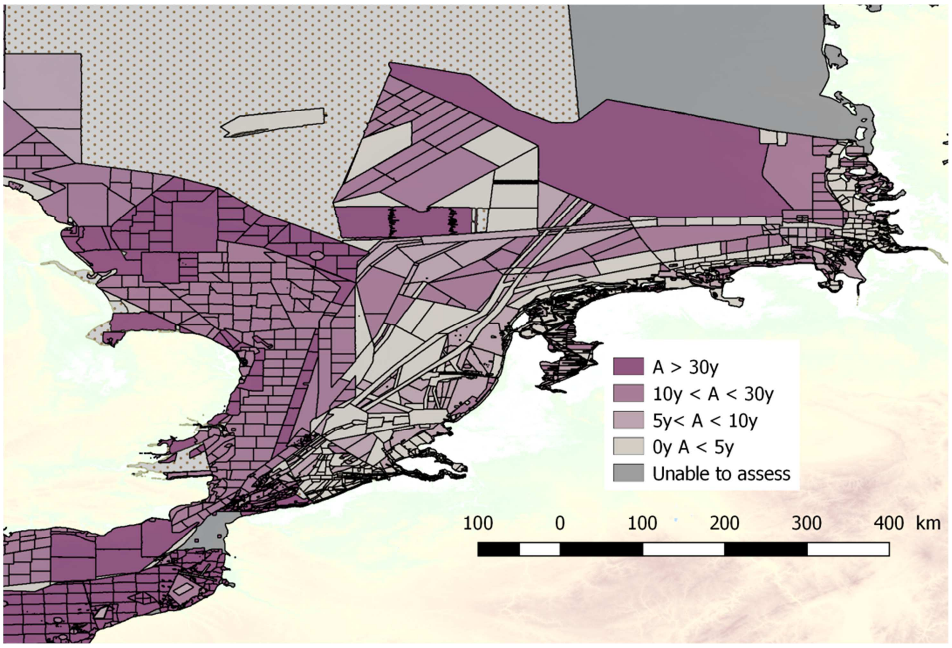

Figure 8: Geographic display of of the quality indicator associated to the age of each survey (Southern North Sea)

One can notice that the expression of uncertainty or confidence related to bathymetric grids is seldom provided by other DTM compilations. This is particularly the case for a large international global compilation such as GEBCO, for which only the type of sensor is given as an element of associated confidence. The work undertaken by EMODnet HRSM and earlier EMODnet bathymetry consortia for the management of the lineage of the data source, and its detailed description, shows here all its interest and the potential for new products and services.

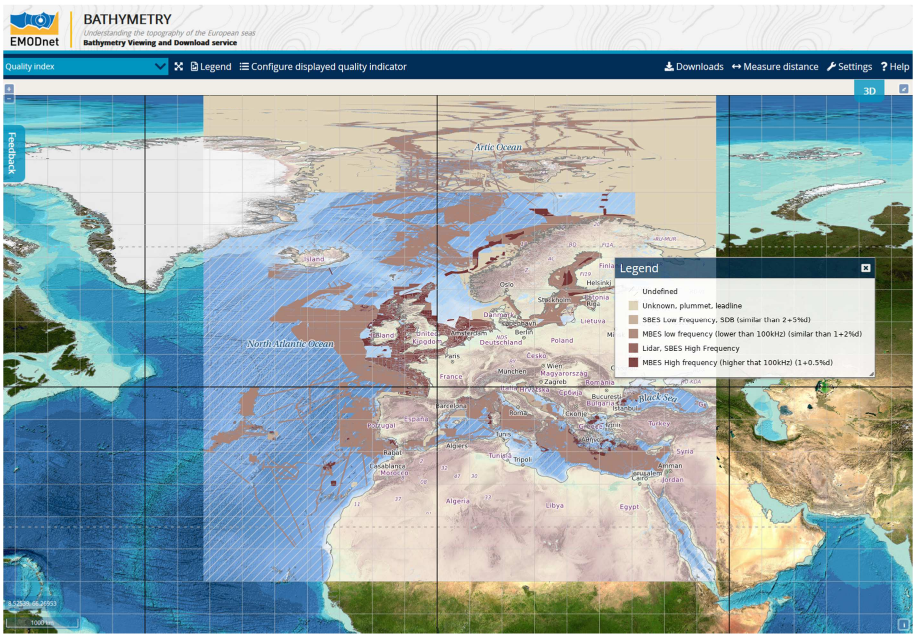

Figure 9: Quality indicator associated with the vertical component as displayed on EMODnet Bathymetry web portal.

3.5. Data sampling and gridding

While the previous sections of this chapter have been focusing on the source data and the description of its quality, 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. Here we will focus 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
- Benefit 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 fulfill 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 4: 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.

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 HRSM2 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 center 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 **10***)

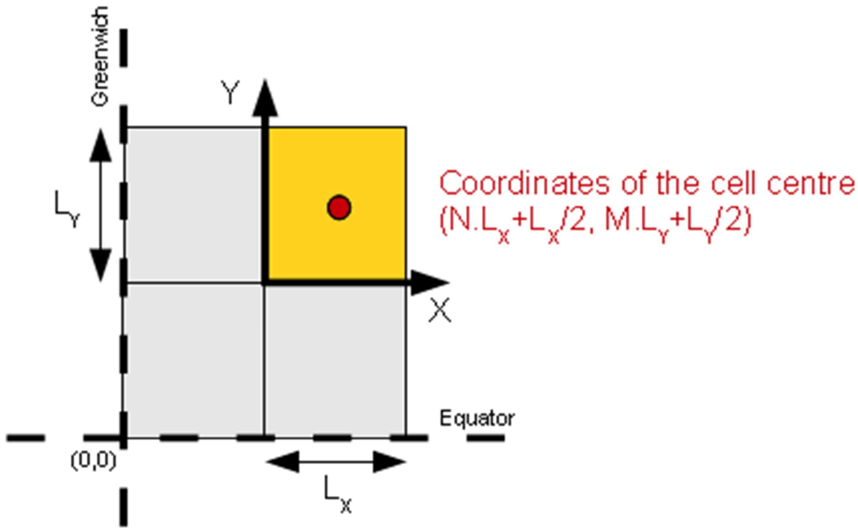

Figure 10: Cell/grid geometry

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 **11***) 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.

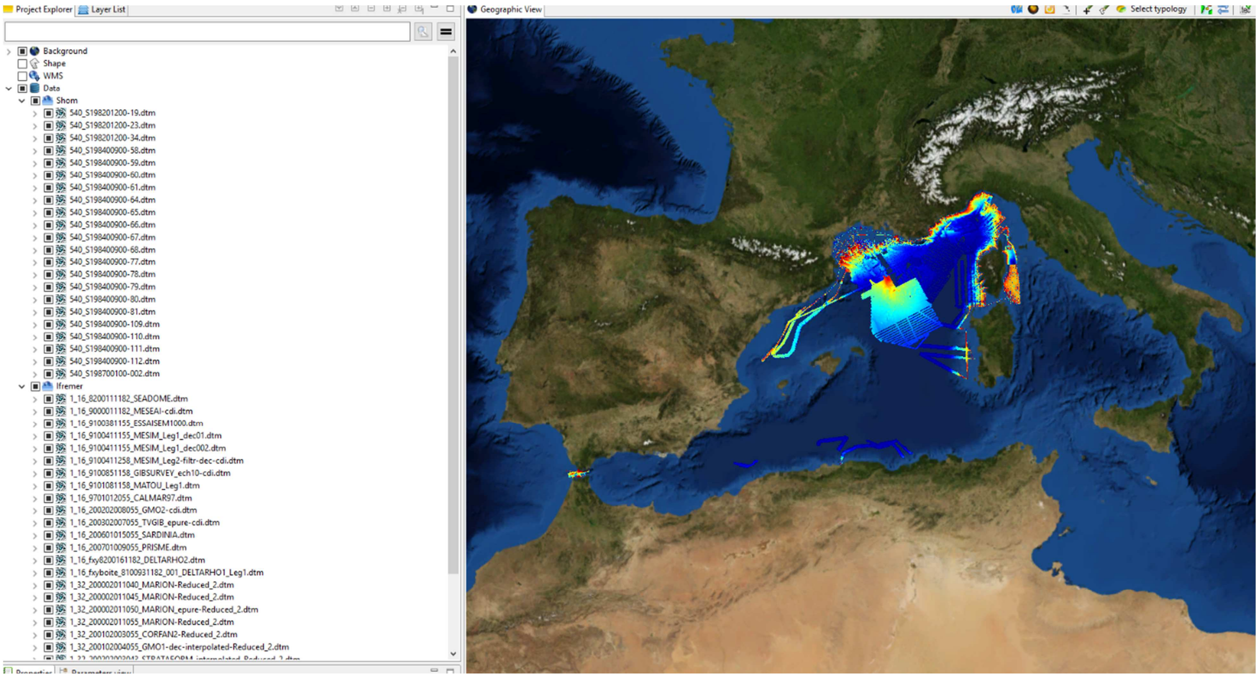

Figure 11: Implementation of the EMODnet bathymetry methodology for producing sampled source grid and associated merging within the GLOBE software used by all the partners of the EMODnet HRSM consortium

File format

Sampled grids and DTM products are internally generated in NetCDF-CF, which is widely adopted in the oceanography community. Internally, work has been undertaken during the present phase to stick to the most recent version of the NetCDF format, namely Version 4. Also other formats are delivered to the users 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.

The S-102 (v2.0) file format has been recently adopted by the IHO to become the defined format for gridded product. INSPIRE has already indicated that this file format is accepted as part of the Data specification on elevation [10]. Plans are to implement a converter that will enable an export of the EMODnet Bathymetry grid in the S-102 file format.

OGC DGGS initiative

Discrete Global Grid Systems (DGGS) are a new notation for addressing locations on Earth, distinguishing itself from older coordinate-based systems in two primary ways:

- It acknowledges that the earth is not flat but round, thereby avoiding misleading solutions to geographic queries.

- It deals with locations in terms of areas rather than points; thereby acknowledging that things in the real world have areas and that anything mapped has precision and accuracy.

A DGGS models the world by splitting the earth into regular polygons, splitting those polygons into small polygons, and so on in order to address smaller areas. Each of these polygons is indexed by a predictable identifier based on their parent cells. In doing so, a DGGS makes it particularly efficient to process large amounts of geospatial information. See examples of world-wide tessellation using DGGS (*Figure 12*).

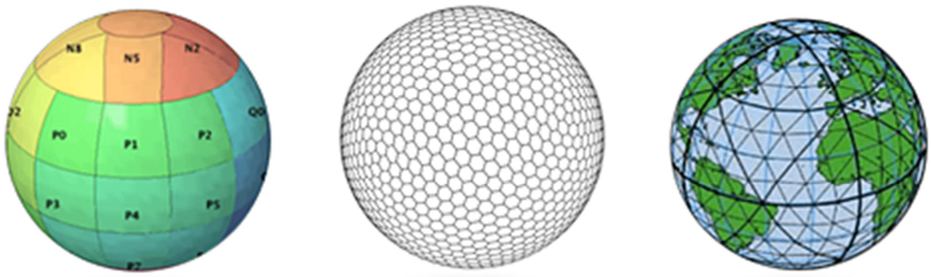

Figure 12: Example of world coverage tesselation envisionned by the OGC working group on Discrete Global Grid System

Work is currently undertaken by the Open Geospatial Consortium to develop a standard from this concept (https://www.opengeospatial.org/projects/groups/dggsswg). At the present stage tools to read or write such schemas are stills in their infancy. However, acknowledging that EMODnet Bathymetry grid geometry and gridding processes share some similarities (common geometry, recursive grid resolution, see beginning of this section) with the DGGS concept, mutual interest is strongly rising from both communities. Both communities have shared their views in several conferences (recently OGC's Marine Summit in Singapore, March 2019).

3.6. Product delivery

The EMODnet Bathymetry portal provides the ability to discover and access the data (both the DTM and its constituents) within a harmonized and human readable interface filled with the information provided as part of the metadata content described in sections 3.2 and 3.4. 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 **13*** 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.

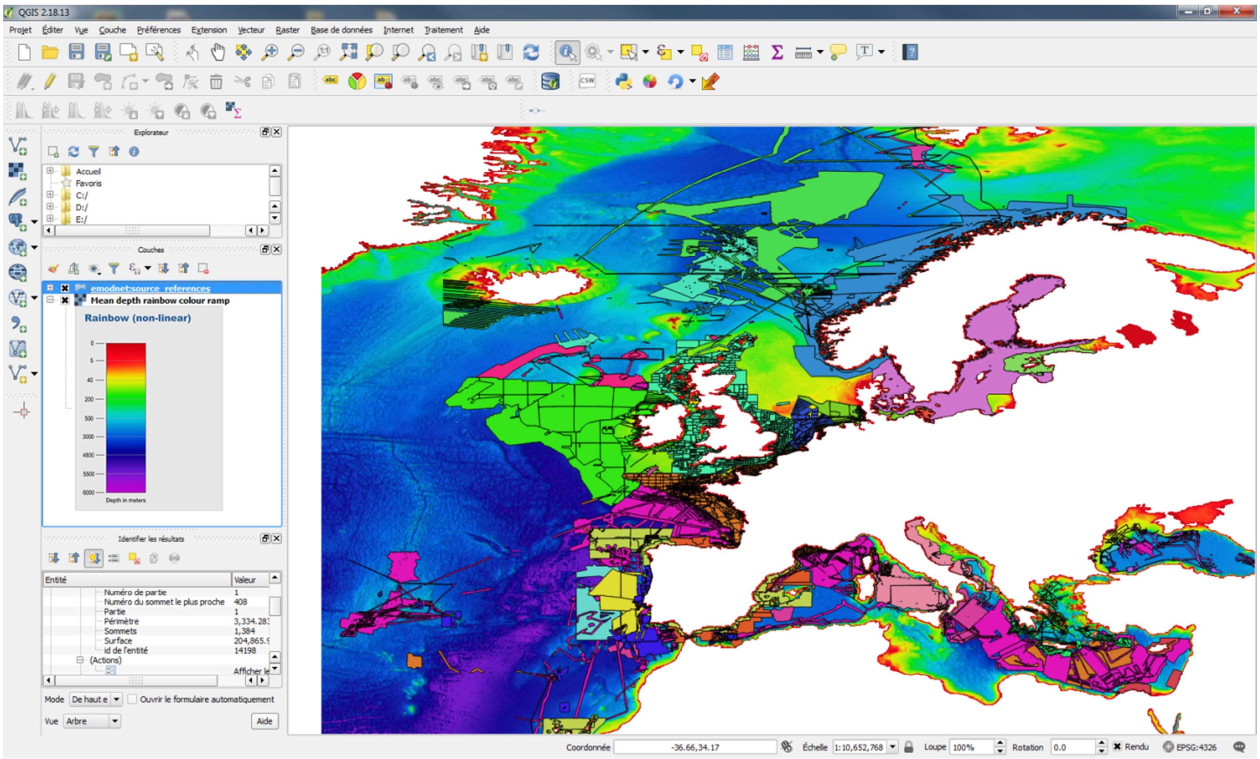

Figure 13: Example of EMODnet data access using OGC web services within on-the-shelf open source GIS software (QGIS). The bathymetric grid (back) is served using WMS. Polygons (front) representing each of the components of the bathymetric grid (except GEBCO left transparent) are served using WFS.

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

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

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

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

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

CDI WMS: https://geo-service.maris.nl/emodnet_bathymetry/wms?request=getCapabilities

CDI WFS: https://geo-service.maris.nl/emodnet_bathymetry/wfs?request=getcapabilities

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, analyze the EMODnet products, which could open the door to automation and detailed multi-thematic analysis using other available datasets such as demonstrated during the EMODnet Open Sea Lab (held in

September 2019). The piece of code below (provided during the OSL'19) simply extracts a region of the DTM, with boundaries specified by the user and display it in a dedicated graph (*Figure 14*).

```
# define the connection
url = "https://ows.emodnet-bathymetry.eu/wcs?"
wcs = WebCoverageService(url, version='1.0.0', timeout = 320)
print(wcs.identification.type)
## OGC:WCS
print(wcs.identification.title)
## EMODnet Bathymetry WCS

# define variables
clipfile =  r'temp.tif'
requestbbox = (2,51.5,5,54)
layer = 'emodnet:mean'
# get the data
bathyml = 'emodnet:mean'
sed = wcs[layer] # this is necesaary to get essential metadata
from the advertised layer
print(sed.keywords)
## ['emodnet_v9_mean', 'WCS', 'GeoTIFF']
print(sed.grid.highlimits)
## ['75840', '72000']
print(sed.boundingboxes)
## [{'nativeSrs': 'EPSG:4326', 'bbox': (-36.0000001152,
14.998958381330127, 43.00104180426987, 90.00000028800001)}]
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

# get the data
gc = wcs.getCoverage(identifier=bathyml, bbox = requestbbox,
coverage=sed, format='GeoTIFF',
crs=sed.boundingboxes[0]['nativeSrs'],resx=resx,resy=resy)

# write to a file
fn = clipfile
f = open(fn,'wb')
f.write(gc.read())
## 27648645
f.close()

# load the geotiff file
ds = gdal.Open(clipfile)

# get the dimentions of column and row
nc   = ds.RasterXSize
nr   = ds.RasterYSize

# read elevation data
bathy = ds.ReadAsArray()
```

```
# only get positive depth values
bathy[bathy < 0] = 0

# get Longitude and Latitude info
geotransform = ds.GetGeoTransform()
xOrigin      = geotransform[0]
yOrigin      = geotransform[3]
pixelWidth   = geotransform[1]
pixelHeight  = geotransform[5]

# generate Longitude and Latitude array
lons = xOrigin + np.arange(0, nc)*pixelWidth
lats = yOrigin + np.arange(0, nr)*pixelHeight

# Plot setup
fig= plt.figure(figsize=(10,10))
ax = plt.subplot(111,aspect = 'equal')
plt.subplots_adjust(left=0.1, bottom=0.1, right=0.9, top=0.9,
wspace=0, hspace=0)

#Map setup
map = Basemap(resolution='f', projection='cyl',
llcrnrlon=requestbbox[0],llcrnrlat=requestbbox[1],
urcrnrlon=requestbbox[2], urcrnrlat=requestbbox[3]) #EDIT
parallels = np.arange(-90,90,0.5)
meridians = np.arange(0,360,0.5)
map.drawparallels(parallels,labels=[1,0,0,0],color='w',
fontsize=10, fontweight='bold')
meri = map.drawmeridians(meridians,labels=[0,0,0,1],color='w',
fontsize=10, fontweight='bold')

#Load colormap and setup elevation contour levels
cmap=plt.get_cmap("GnBu")
keys = np.linspace(round(bathy.min(),-1), round(bathy.max(),-
1), 36)

#Contour plot
x, y = map(*np.meshgrid(lons, lats))
cs=map.contourf(x, y, bathy, keys, cmap=cmap)

#add land area
map.fillcontinents(color="#FFDDCC", lake_color='#DDEEFF')
map.drawmapboundary(fill_color="#DDEEFF")
map.drawcoastlines()

map.drawparallels(parallels,labels=[1,0,0,0],color='k',
fontsize=10, fontweight='bold')
meri = map.drawmeridians(meridians,labels=[0,0,0,1],color='k',
fontsize=10, fontweight='bold')

cb = map.colorbar(cs, 'bottom', size='5%', pad='10%')

cb.set_label('Elevation (m)', fontsize=12, fontweight='bold')
cb.ax.tick_params(labelsize=10)
```

```
plt.show()
```

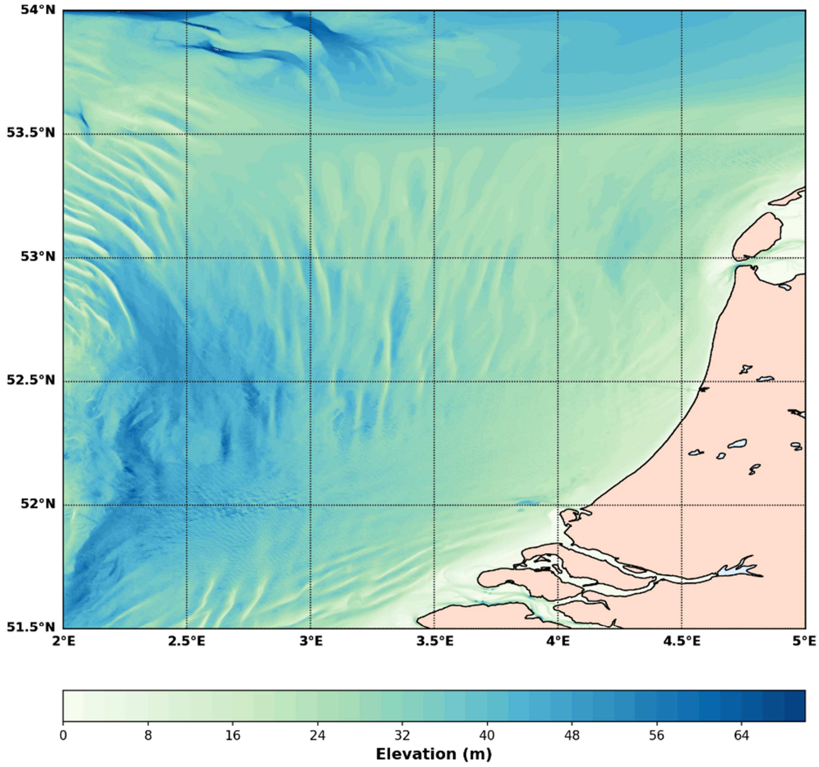

Figure 14: Graph automatically plotted using the above snippet of Pyhton code through a request of the EMODnet Bathymetry Web Coverage Serive

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 these 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 generates, along with explicit information on its individual data sources, 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 these efforts in the context of strong international collaborations.

As of December 2019, *Figure 15* describes the major interactions that the EMODnet Bathymetry consortium has in the global environment of bathymetric information delivery.

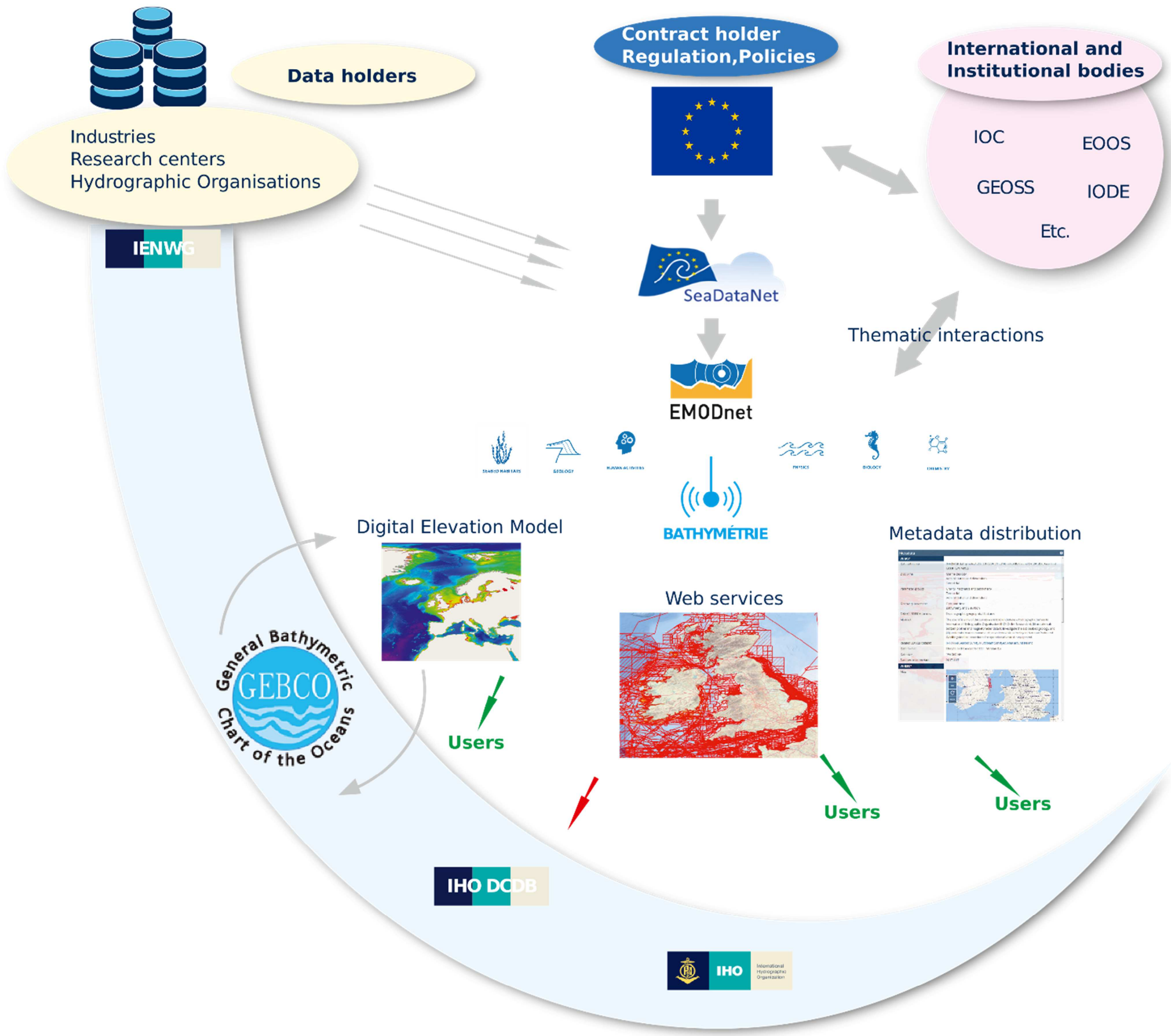

Figure 15: EMODnet Bathymetry's ecosystem

As mentioned earlier, EMODnet Bathymetry is part of a multi-thematic initiative (detailed in section 4.3). This initiative is contractually bound to the European Commission (EASME and DG-MARE) which is the owner of the results. The European Commission has also a key role in defining strategies on the use and the monitoring of the marine environment and also sets policies to open the access of bathymetric information originating from member states. EMODnet Bathymetry strongly relies on the infrastructure of distributed data providers built as part of SeaDataNet for which experts have designed and implemented metadata structure and associated vocabulary (see previous chapter). As mentioned earlier in sections 3.2 and 3.4, bathymetric data providers generate metadata files associated with pre-gridded surveys (Section 3.5) or their composite product and centralize them in the SeaDataNet catalogue. Their dataset, at their native resolution are left under the control of the data provider who can distribute them according to its national rules.

Identifying the data sources (metadata) and generating a composite product (DTM) is intended for communities of users (fisheries, earth science, cable routing…). As indicated in section 3.6 concerning product delivery, beyond the simple access to the EMODnet Bathymetry portal, users can take benefits from the use of web services in order to integrate bathymetric information in their GIS. Moreover, these services can be consumed and displayed by other inventory of bathymetric information. This is particularly true for the worldwide GEBCO / Seabed 2030 initiative for the DTM (section 4.1) and the Digital Center for Bathymetric Data (DCDB, see section 4.2) for the metadata.

Finally, international institutional stakeholders take part to the EMODnet Bathymetry's ecosystem. Naturally, one of the major actors in the field of bathymetry is the International Hydrographic Organization (IHO) for which EMODnet bathymetry has strong inter-relation by contributing to the IENWG (IHO – Europe Networking Group)

4.1. GEBCO and Seabed 2030 initiative

The General Bathymetric Chart of the Ocean (GEBCO) is the most comprehensive compilation of publically available bathymetric data. This worldwide model is now generated at 15 arc-second (~500 m grid size) from shipborne systems (singlebeam or multibeam sounders, leadline) or through indirect method based on spatial altimetry (with spatial resolution around 20 kms) (see [15]). Satellite altimetry, which has a limited accuracy (compared to acoustically measured dataset), 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 GEBCO technical coordinator (BODC) are 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 HRSM2 is the Chairman, Scrum (Sub-Committee on Regional Undersea Mapping) for which four EMODnet HRSM2 collaborators are members, and the GEBCO Guiding Committee in which two EMODnet HRSM2 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).

The most obvious proof of efficient collaboration between the GEBCO and the EMODnet communities is the mutual integration of bathymetric information within both DTM grids. *Figure **16*** shows the geographical distribution of measured data sources composing the recent 2019 GEBCO release. Note that darker areas indicate regions without direct measurement (i.e. not surveyed using a sounder). In these areas, the bathymetry is predicted from spatial altimetry. One can see that the European seas have largely been covered, despite some small areas (especially in the deep ocean) thanks to the contribution of the EMODnet Bathymetry DTM to the GEBCO compilation (see acknowledgement on GEBCO's portal: https://www.gebco.net/about_us/acknowledgements/our_data_contributors/).

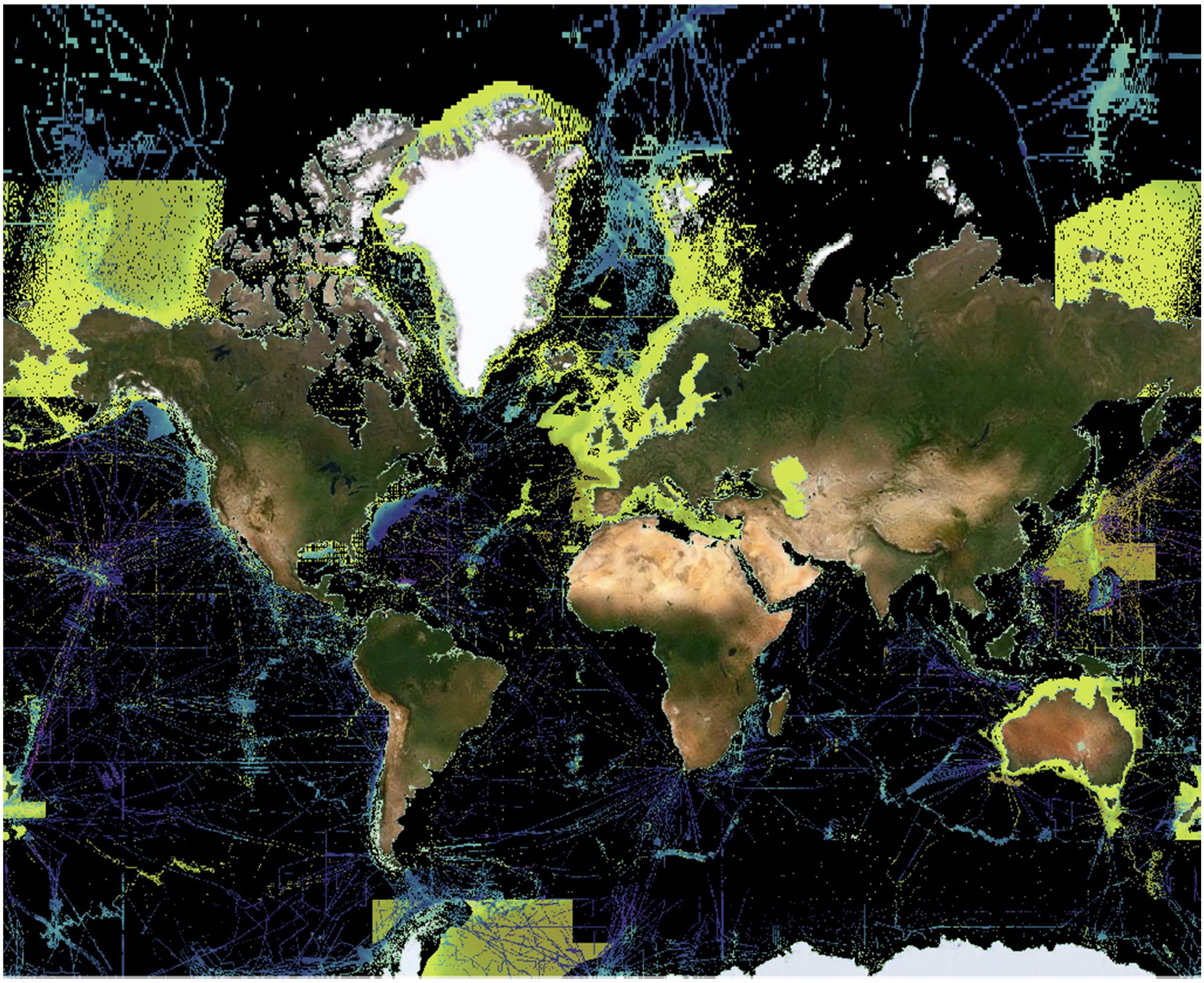

Figure 16: World-wide coverage of bathymetric information composing the GEBCO 2019 grid (last release) including the EMODnet bathymetry grid

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 technical choices made by the EMODnet community described in section 3.5 taken in order to facilitate interoperability of both gridded products.

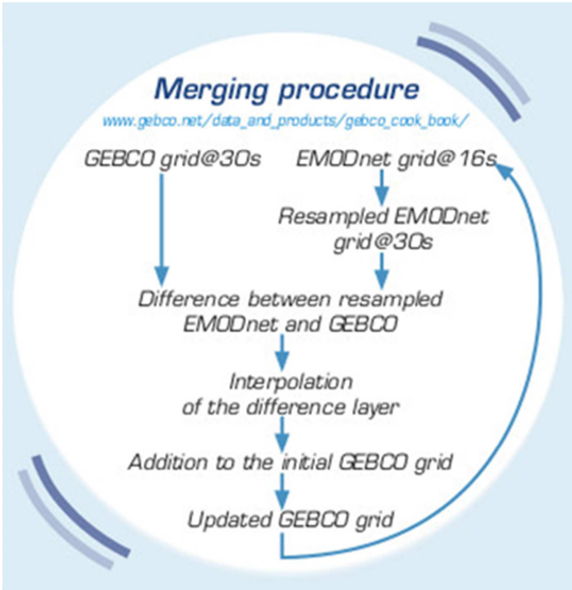

Figure 17: Schematic representation of the GEBCO EMODnet Bathymetry merging procedure

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

- The convergence of both bathymetric products for the European waters, hence minimizing the confusion for the users of both products;
- Smoothing the interface between the areas of measured bathymetric 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 not be synchronized, each product uses the most recent (and curated) product from the other part.

Seabed 203 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) [13]. The GEBCO project is the driver of this initiative which, in turn is run under the auspices of the IHO and the IOC. 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/or 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, 14], “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, 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. Members of the EMODnet HRSM2 consortium are active members of the emerging GEBCO – Seabed 2030 working group on metadata.

In order to strengthen this collaboration, on the 30/09/2019, was signed a Memorandum of Understanding between the GEBCO Seabed 2030 Project and EMODnet Bathymetry. The main objective of this MOU is to pursue the improvement of the coverage and resolution of the worldwide bathymetric knowledge. Mutual benefits are expected, especially on: the shared vision, contributions between both bodies in order to find and fill gaps in the bathymetric coverage and on the improvements of the methods and best practices related to ocean mapping and data management.

4.2. IHO – NOAA/NCEI

The International Hydrographic Organization has been mentioned earlier in this document several times. 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 HRSM2 community, IHO member states belonging to the EMODnet HRSM2 consortium are indirectly fulfilling this request.

The other important global contribution of the 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. Data are provided to the DCDB on voluntary basis. However, the DCDB represents one of the most up-to-date world-wide references of bathymetric data, in their vast majority raw (immediately following their acquisition at sea). Physically the DCDB is hosted solely by NCEI (National Centers for Environmental Information) of the U.S. National Oceanographic and Atmospheric Administration, which centralizes all datasets in a unique database. This data are particularly important to support the GEBCO Program but is not the only source.

A certain numbers of philosophical divergences do exist in terms of data management between the two approaches (see *Table **5***). However, as described in the next paragraph EMODnet Bathymetry is strongly collaborating with the IHO NOAA/NCEI DCDB data portals.

	EMODnet Bathymetry	NOAA IHO DCDB
Architecture of the system	Semi-distributed. Metadata Database is centralized, while dataset are located at the premises of the data holders.	Centralized. Metadata and data are located on the IHO DCDB server
Metadata content	19115,19335 based, ISO, INSPIRE compliant Complemented with a marine data vocabulary (including elements relative to the quality indicator)	19115,19335 based ISO compliant
Data download	Asynchronous. For most of the dataset an agreement between the provider and the data owner is sought prior to delivery.	Asynchronous, fully automatic.
Level of processing of the bathymetric data	Processed datasets to the best knowledge of the data provider. Data provided in human readable format. Equivalent to level 2 processing stage[1]. Note that the DTM is considered level 3 processing	Raw datasets. Need to be processed. Need specific sonar to read data formats. Equivalent to level 1A processing stage[1]
Product and services delivered from the portal	Metadata, bathymetric datasets (surveys or grids), bathymetric DTM, web Services, 3D view	Metadata, bathymetric dataset, web service.
Role of the data holders	Each of the data holders is a key partner. The data provider decides with the user how and by whom the data will be used. Special care is taken so that the providers are fully acknowledged for the surveying and curation effort which is mainly their raison d'être	DCDB acts as the data holders. As data are provided to the DCDB they are free to be used by anybody. The data providers do not have any feedback on the use of the dataset.

Table 5: Comparative description of the EMODnet bathymetry versus the NOAA/NCEI DCDB conceptual models

[1] Level 0 : Unprocessed data, Level 1A : Unprocessed instrument along ancillary information, Level 1B: Data processed to sensor units, Level 2: Derived geophysical variables, Level 3: Variables that are mapped on a grid, Level 4: Modelled output or variables derived from multiple measurements

The implementation of the WFS EMODnet Service is allowing 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 the display of both sources on the DCDB portal (https://maps.ngdc.noaa.gov/viewers/iho_dcdb/ accessed on the 28/01/2020). More importantly, each of the EMODnet survey identified on this viewer can be interrogated through a direct forwarding from the NOAA/NCEI viewer to the EMODnet Bathymetry CDI/CPRD catalogues, where the interested users can read the entire metadata file, and get access to the data through the classical SeaDataNet shopping basket mechanisms.

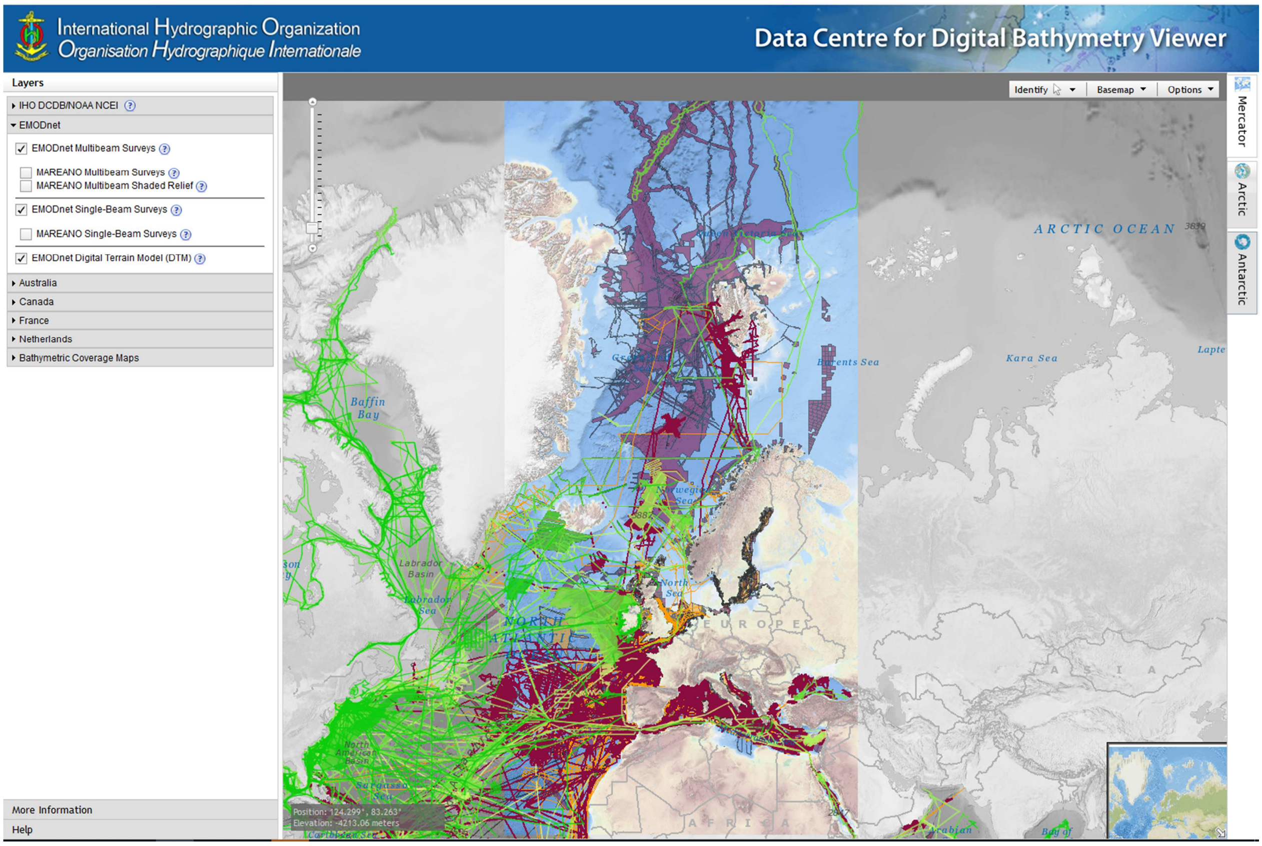

Figure 18: Data Centre for Digital Bathymetry portal presenting NOAA/NCEI held dataset (green) and EMODnet multibeam (purple) and singlebeam (orange survey).The light blue color coded DTM is the one from EMODnet, while the grey one is GEBCO.

Benefiting from the collaboration between EMODnet and the NOAA/NCEI, a 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 **19***, extracted from a published paper [10], describes the methodology and suggests survey priorities over deep sea areas lacking of bathymetric measurements. These priorities are driven by selected social and economic benefit (mining exploration, search and rescue, environmental and habitat conservation).

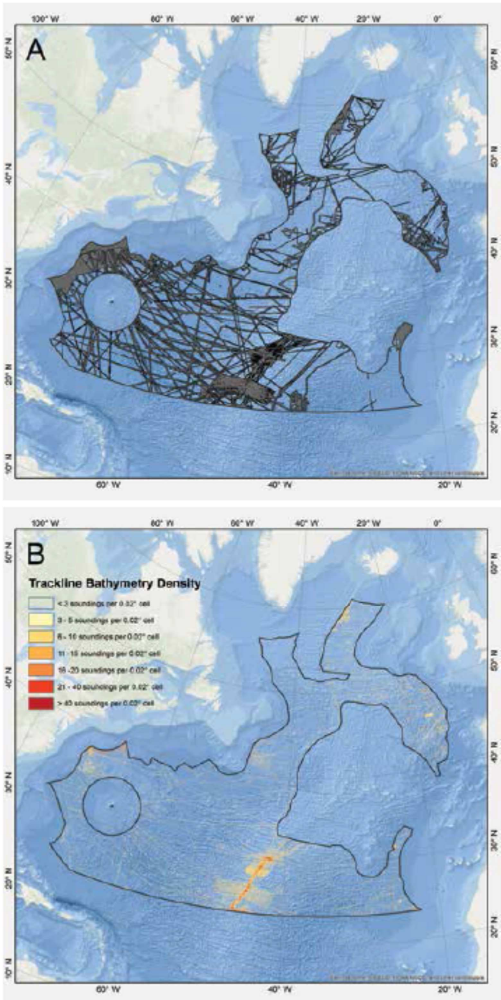

Figure 19: Bathymetric Coverage in international waters (as generated from DCDB and EMODnet Bathymetry repositories through the AORA viewer)

4.3. 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, the EMODnet Seabasin CheckPoints can benefit from direct access through the EMODnet Bathymetry portal or through the web services. EMODnet Bathymetry has been used to test adequacy to the EMODnet Seabasin ChekPoints 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 3.4 of this document.

4.4. GeoMapApp and other data viewing initiatives

The Lamont Doherty Earth Observatory 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 **20***.

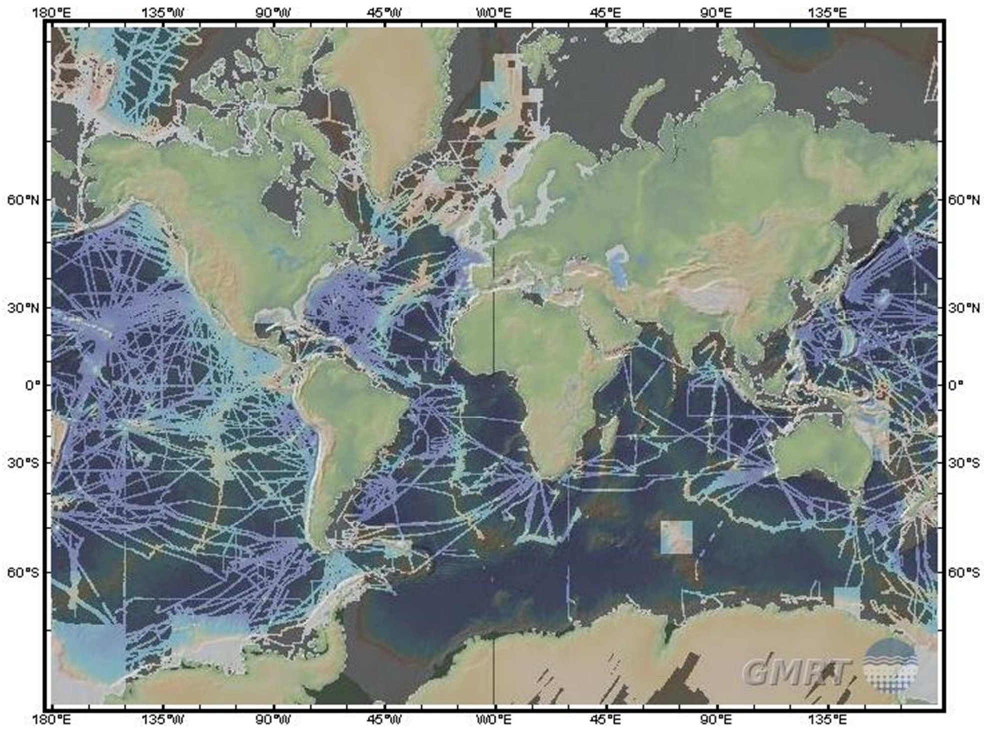

Figure 20: Output of the GeoMapApp bathymetric coverage (01/2020). Bright areas indicates measured (as of soundings) bathymetric data

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.

Since the previous version of this report, progresses have been realized , especially relative to the detailed description of the precision of the dataset in the metadata (Quality Indicator), the renewed conformance with the INSPIRE specification, the mutual integration of the European bathymetric grid within the GEBCO with the signature of the associated MOU, which are all specific actions seeking for further interoperability with existing infrastructure, all benefiting both to the users of the information and also their providers.

6. References

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Note that references marked with a star involve EMODnet contributors.