Big Data

The challenges of large-area bathymetric surveys

An article by KLAUS MICHELS

According to the IHO's »Status Report on Hydrography and Mapping of the World's Seas, Oceans and Coastal Waters« (IHO 2013) a large percentage of the world's seas and oceans are still unsurveyed. Even areas covered by nautical charts need to be resurveyed since, in the absence of any other data, many of today's charts contain significant amounts of information derived from non-systematic observations and survey data dating back up to 200 years (IHO 2013). The demand for hydrographic and bathymetric data for a broad range of offshore activities was never higher than it is today. Advances in multibeam echo sounder (MBES) and airborne LiDAR bathymetry (ALB) technology allow safe hydrographic and bathymetric survey of large areas at a speed and accuracy previously unknown. However, increasing sizes of survey areas and improving resolutions of survey systems come with larger data volumes and greater requirements related to management and operations. Big Data* need to be managed.

Big Data | Blue Economy | large-area survey | data management | project management | tender | deliverables

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Introduction

»We know less of the oceans at our feet, where we came from, than we do of the sky above our heads« (US President John F. Kennedy, 1963).

President Kennedy made this statement 42 years after the foundation of the International Hydrographic Organization (IHO) whose principal aim – to ensure that all the world's seas, oceans and navigable waters are surveyed and charted – still persists. According to the Committee of Experts on Global Geospatial Information Management of the IHO and its »Status Report on Hydrography and Mapping of the World's Seas, Oceans and Coastal Waters« this aim remains far from being met. Contrasting the knowledge about the oceans and the planets it states that »there are higher resolution maps of the Moon and Mars than most of the world's sea and ocean areas« (IHO 2013).

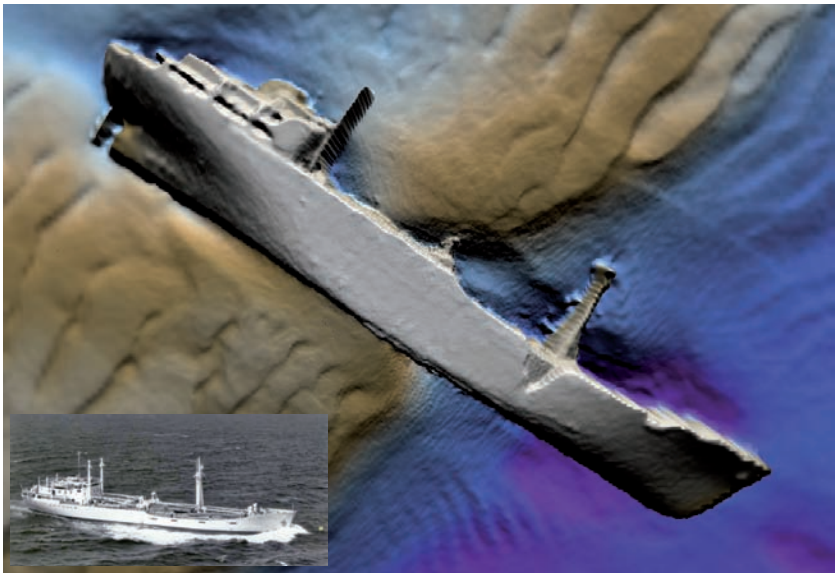
IHO Publication *C-55* – »Status of hydrographic surveying and charting worldwide« (IHO 2015) lists the areas that require a hydrographic (re)survey in somewhat more detail, on a worldwide scale. The largest unsurveyed parts are made up of deep-water areas greater than 200 metres water depth. However, in water depths shallower than 200 metres there are also significant areas that need to be surveyed or resurveyed.

Nevertheless, the recent history of hydrographic surveys shows that numerous projects were carried out to obtain high-quality validated data for large coastal, shelf and deep-water areas covering hundreds of thousands of square kilometres. A significant number of these surveys were carried out by Fugro. The largest single hydrographic survey contract comprised 110,000 square kilometres, and involved ten MBES survey vessels and launches and three ALB survey aircraft (Fig. 1).

Different hydrographic survey campaigns tendered out by national hydrographic agencies and other governmental institutions, energy providers and exploration and exploitation companies usually fall into one of the following categories:

- Safety of navigation: Surveys and resurveys are covering navigation routes and ports in order to create and update nautical charts and electronic navigation charts.
- Strategic environmental assessments: Hydrographic surveys in this context are related to the appraisal of marine areas with regard to their environmental protection and sustainable development. The results are considered in national and local decisions for the use of marine areas such as oil and gas licensing rounds, offshore renewable energy developments, the designation of environmental protection areas and gas and carbon dioxide storage. The overarching goal is the development of successful and environmentally sustainable human activities in the seas and oceans as part of The Blue Economy**. Hydrography is increasingly being recognised as a fundamental prerequisite for a sustainable, cost-effective and environmentally sensitive development of The Blue Economy.
- Exploration for marine metallic and non-metallic resources (e.g. hydrocarbons and polymetallic nodules): Hydrographic surveys of this type are regarded as an essential basis for the planning and safe execution of further exploration and exploitation activities.

Fig. 1: A typical modern dedicated survey vessel for hydrographic data acquisition (MV »Fugro Helmert«) and a typical airborne LiDAR bathymetry aircraft



With permission of the Maritime and Coastguard Agency; small photo: wreck image collection

Fig. 2: The wreck of the MV »Höegh Aigrette« depicted by multibeam bathymetry data. The example shows the capability of modern systems to image even details of objects on the seabed (for comparison the intact vessel is shown). The wreck clearly shows the notch caused by collision with another vessel, which led to the loss. The length of the vessel is 112 metres, water depths at the wreck site range from 28 metres to 39 metres

- The determination of the foot of the continental slope by hydrographic methods: This is one of the major features in the establishment of the outer limits of the juridical continental shelf under Article 76 of the United Nations Convention on the Law of the Sea. Potentially it entitles coastal states to an extended continental shelf beyond 200 nautical miles.

Common to all these hydrographic survey projects are survey specifications in compliance with (or even exceeding) the Standards for Hydrographic Surveys of the IHO (IHO 2008). This basically determines the amount of data to be acquired, the data processing procedures, the quality control process and the deliverables. Given the performance of state-of-the-art multibeam echo sounder bathymetry (an example is given in Fig. 2) and airborne LiDAR bathymetry systems (Fig. 3) the storage capacity requirements for larger projects can easily add up to several hundred terabytes.

Often the time frame for the execution of the survey and the range of water depths in the survey areas demand the deployment of multiple survey sensors. Either the combination of MBES and ALB systems, or several of either sensor may be deployed at the same time in one field campaign.

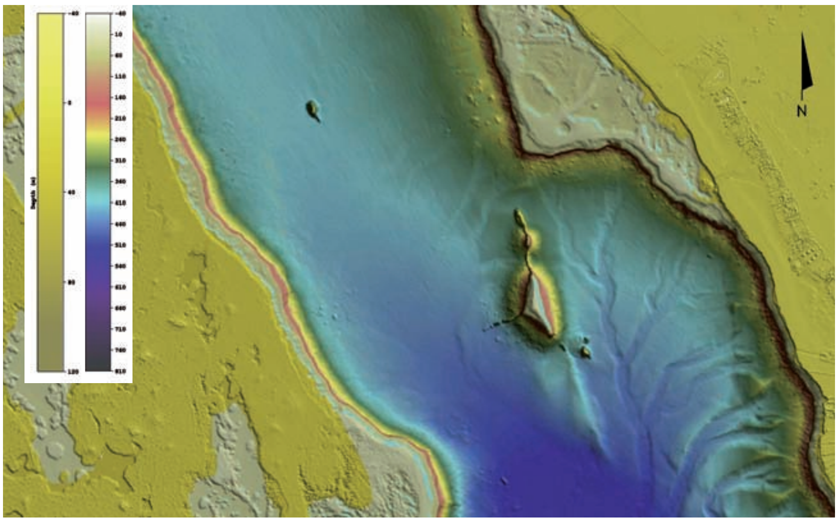
This framework of requirements is quite demanding for the planning, execution and control of this type of hydrographic survey project. This paper deals with the associated challenges of the projects and describes the approaches chosen by Fugro. It will discuss the requirements and possible approaches by going through the different stages of the projects: tender and planning, survey, processing and delivery.

Tender phase

Compiling a competitive tender for a large-area hydrographic survey requires the input of many different types of information. The most important – and sometimes most challenging – task is to obtain reliable information about the distribution of water depths in the survey area in order to calculate a realistic length (survey kilometres) to cover the survey area with the quoted MBES or ALB system(s) according to the specifications. Due to the fan-shaped sound signal emitted by MBES systems the coverage increases with increasing water depth (at the cost of resolution and accuracy), which makes water depths the dominant factor when calculating the required survey lines and thus survey duration. Potential sources of bathymetric information of the seabed are nautical charts (although even the latest revision can be based on old data) and free or commercial data sets (e.g. GEBCO, ETOPO for global coverage) based on ship depth soundings and satellite-derived gravity data. Aerial photographs and satellite images can serve to assess the distribution of shallow water areas and map potential shoals, which pose a risk to navigation and are specifically important for an estimate of the coverage that can be achieved by ALB. The resulting number of survey line-kilometres and the survey duration, together with the survey specifications, are the basis for estimating the data storage requirements for the vessels and the processing centre. The provision of suitable data storage facilities can contribute significantly to the infrastructure costs of a project.

Other information relevant for compiling a tender for a hydrographic survey in a specific area are the weather and climate conditions; oceanographic restrictions – such as the tidal characteristics, the current and wave climate, the formation of distinct thermohaline layers and strong turbidity in the water column; the legal framework for vessel operations in territorial waters; and furthermore the operational costs for vessels such as permitting costs, port and harbour fees, bunker costs, travel and visa costs for the vessel and survey crew, etc. For surveys with a longer duration even the access to repair and shipyard facilities needs to be considered. When clients stipulate in-country processing of all data (or when in-country processing offers an operational advantage), local facilities and staff accommodation costs can contribute significantly

Fig. 3: Example for the seamless integration of multibeam and airborne LiDAR bathymetry data (different data types are distinguished by different colour scales: LiDAR on the left, multibeam on the right side). The area in the east comprises terrestrial LiDAR data; buildings and infrastructure can be recognised. The shallow water areas north of the island and in the west consist of coral reef. The size of the area is 10.6 × 6.4 kilometres



With permission of the General Commission for Survey of the Kingdom of Saudi Arabia to the overall operational expenditure. Altogether these factors and conditions, and the allowance for contingencies, determine the overall survey expense.

Project planning phase

Once the contract for a survey project is awarded based on the successful tender, the concrete planning for the project execution will start. The permitting application procedures may take considerable time (often of unknown extent) and therefore are among the first activities when vessels and aircraft are to be mobilised. This guarantees a mobilisation and start-of-survey date as early as possible (which usually is requested by the client).

Based on the project proposal a line plan is developed which makes sure that all survey data will be acquired throughout the survey area at the required quality and density in the most efficient way.

The identification of potential risks to navigation – especially uncharted shoals – is another step in the planning phase which needs to be accomplished before the shallow water vessel operations start. This is best completed using geo-referenced aerial and satellite photographs where shoals can be identified and mapped using remote sensing methods.

Personnel planning is another important part of the planning phase. The critical questions that need to be answered are:

- Do we have the right people to fill all key project positions, i.e. a project manager, the party chiefs, a chief surveyor, a processing and reporting manager, etc.?
- Do we have enough qualified personnel to man all vessels and aircraft planned for the project?
- Do we have enough ›Category A‹ certified surveyors to man all key positions dealing with hydrographic data?
- How do we best put together the survey teams and vessel crew on board so that maximum safety for operation is achieved (especially in very shallow waters where the risk of grounding exists)?
- Will all planned staff obtain the required visas in time?
- Is all staff able and permitted to work in the project country (e.g. there might be medical restrictions on working in tropical areas, there are cultural restrictions on working in the Middle East)?

Data management, which involves data storage, backup and transfer, also needs to be thoroughly planned and prepared. All vessels and aircraft need

References

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to be equipped with storage capacity (including backup) capable of holding all data acquired and processed until transfer to the processing centre storage system (in-country or at the head office) is fully completed. Data transfer can either happen by physically hand-carrying or mailing storage media (e.g. USB flash or hard drives, NAS or RAID systems), or by using electronic transmission methods (e.g. e-mail, Internet or cloud-based transmission, FTP, Aspera, etc.). The total amount of project data is not only defined by the size of the survey area but also by the requirements for data delivery and formats, necessary intermediate formats and products, and the number of different processing facilities.

It might be also part of the contractual obligations to establish a method of correcting the acquired bathymetric data for tidal variations in the survey area, which needs to be planned prior to survey start. Some clients require the collection of comprehensive tidal data even covering seasonal changes by means of tide gauges installed on the coast and offshore. These tide gauges are ideally operational before vessel operations commence and should not finish until all ALB and MBES data are acquired. Tide watches carried out by vessels may complement the tidal observations and help to enhance the vertical control.

Last but not least the mobilisation of the vessels and aircraft according to the specifications of the contract needs to be completed and the transit to the survey area planned and scheduled.

Survey phase

Safety is the utmost priority during survey operations and it will verify the efficiency of planning. For efficient management of the operation the survey teams on board the vessels and aircraft should make sure that (1) the survey data they acquire are of the required quality and cover the specified area; (2) no gaps are left within the designated survey area, and within the capabilities of vessel and equipment; (3) other vessels and aircraft operating in the same or neighbouring areas receive the information necessary to operate safely, avoid excessive overlaps and close all gaps left by other survey platforms because of limitations in their capabilities. Gaps may be left by a survey platform when waters become too deep for LiDAR sensors or shallow-water MBES systems, or too shallow for larger vessels; alternatively safe navigation may prevent vessels entering a specific area, or survey crews may be inattentive. Generally survey gaps must be closed wherever possible whilst the highest level of safety is maintained.

A great deal of background management is required, both in the head office and on board, to ensure the data flow between the survey platforms and the processing centres and to ascertain the availability of qualified personnel on board. The documentation of the data acquisition procedures and on-board processing and QC is essential to allow for a problem-free transition from data processing and QC to the processing centre.

The most efficient way to cover areas in a multi-sensor survey operation is usually developed in close cooperation between the project manager, the party chief(s), the chief surveyor(s) and the processing and reporting manager.

Processing

The processing of hydrographic and bathymetric data needs to be carried out in compliance with the specifications for the relevant survey. Important steps in the processing procedure are

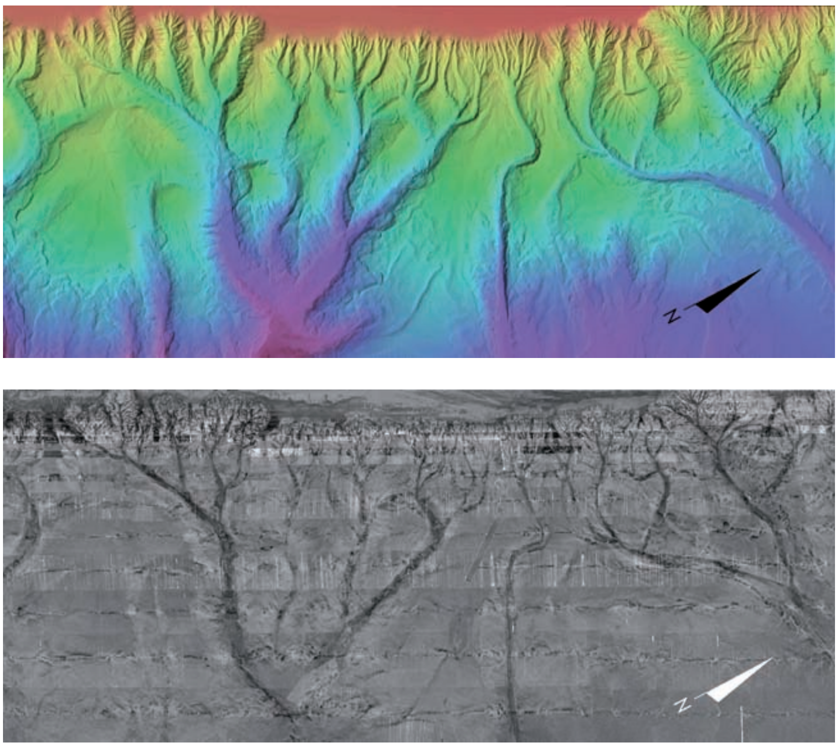
- the filtering and editing of data,
- the integration and merging of data from different platforms and sensors,
- the tidal correction of the final edited data set,
- the shift of bathymetric data to the required datum,
- the systematic check of the data set with regard to compliance with the specifications and finally
- the creation of the deliverables.

The decision whether on-board and in-country processing is established depends on strategic considerations in addition to contractual obligations. On-board processing – which is only possible on larger vessels – happens much closer to data acquisition and therefore identifies issues (such as technical problems, too much or insufficient overlap, or even gaps) much sooner than land-based processing can. On-board processing can also easily take advantage of 24-hour processing to achieve more efficiency and faster processing progress. On the other hand data storage facilities are more difficult to install, operate and maintain on board. Therefore, on-board data processing will most often be limit-

* The term ›Big Data‹ here refers to data sets characterised by their very large size, a diversity of data types, and sophisticated processing flows required to analyse them

** The Blue Economy is a design theory which is intended to bring natural ecosystems and economy into harmony and create jobs (cf. Pauli 2010)

Fig. 4: Comparison of multibeam bathymetry data and backscatter data from a continental slope with a dendritic channel system. The water depths in this example range from the shelf edge at 100 metres in the northwest to maximum water depths of approximately 2,900 metres in the deepest parts in the southeast (top). The seabed sediments in the channels and on the shelf clearly show a higher acoustic reflectivity, which indicates coarser grain sizes (bottom). The size of the area is approximately 83 × 34 kilometres



ed to the data acquired by the vessel itself and data from a smaller survey boat – either operated from the vessel or land-based near the survey area.

For large survey projects the data processing ideally is supervised by a dedicated data manager dealing with structuring and apportioning data for the editing, merging and QC process. ALB and MBES data generally have completely different processing requirements and therefore need different processing approaches (usually handled by different processing teams) before being merged.

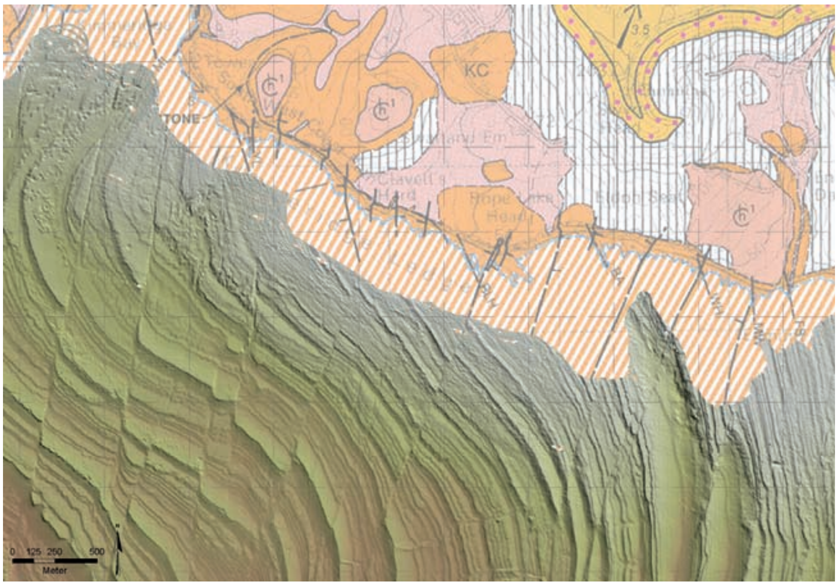
The integration of data from different survey platforms (Fig. 3) – either multibeam or aircraft – requires specific attention because of different physical measurement methods (i.e. acoustic MBES and laser-optic ALB), different footprints, different resolutions and/or different data densities.

Delivery

The creation of the specified deliverables is the last step in the project. Deliverables are created based on the final processed data.

Contractually required deliverables can vary considerably from contract to contract and from client to client. The delivery of the final bathymetric product ranges from ASCII grids of specific resolutions to full delivery of the processing software file structure including raw data. However, not all clients are prepared to store and handle tens or hundreds of terabytes of data so this needs to be discussed with the client early in the project. Often the list of deliverables comprises data which are not directly of hydrographic nature but can be derived from the MBES or ALB data set, e.g. maps or geotiff files of the MBES backscatter (Fig. 4) and ALB reflectivity signals. Using a geologist's knowledge of the seabed and sediment properties or (semi-) automatic seabed classification tools, the bathymetry and backscatter/reflectance information can be used to create so-called bottom texture sheets, which delineate and map areas of the seabed with similar patterns and properties (an example for geological mapping based on hydrographic data is shown in Fig. 5). Often this information is used in addition to the bathymetry to conduct initial habitat mapping and undertake the planning for a dedicated habitat survey and sampling campaign.

A rapidly increasing demand exists for GIS-compatible deliverables from hydrographic and bathymetric surveys. This is regarded as a result of the same hydrographic and bathymetric data being used for several different purposes at the same time.



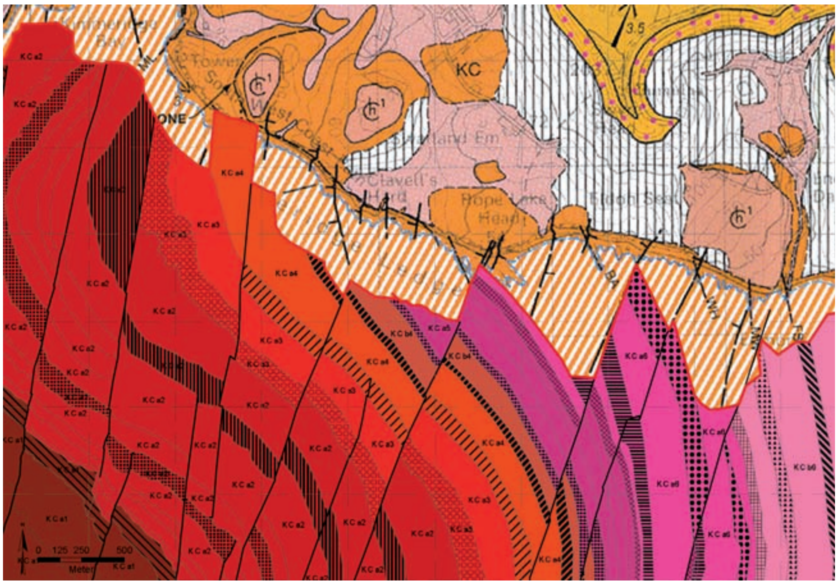


Fig. 5: Bathymetric coastal data shown on top of a geological map (top). The strata mapped onshore (in the north) could be identified in the bathymetric data so that a geological map of the seabed could be produced (bottom). The size of the area is approximately 5.0 × 3.5 kilometres

Summary

Hydrographic and bathymetric data are increasingly being recognised as a fundamental set of information needed to perform an assessment of coastal, nearshore and offshore areas with regard to the safety of navigation, the spatial management of marine areas, the variety of habitats, the environmental status, the effects of natural hazards and climate change, the exploration and exploitation of resources, and the development of renewable energies. Generally speaking the request for hydrographic and bathymetric data increases with an increasing use of the oceans, further powered by the demands of The Blue Economy.

Hydrographic and bathymetric surveys can provide the coverage of large areas within fairly short timeframes. The challenges of such surveys need to be managed in a suitable way especially when multiple survey platforms (vessels, aircraft, launches) and multiple sensor types (MBES, ALB) contribute to data acquisition.

Identifying the main challenges at the different stages of the projects – the tender, planning, survey, processing and delivery phases – and managing their completion in accordance with the available resources and contractual requirements is key to success.

The current survey status of the world's oceans leaves ample room for many more large area hydrographic and bathymetric survey campaigns. Big Data will continue to play an essential role in these campaigns. ⚓