A comparative analysis of capabilities and limitations of acquisition systems of hydrographic marine data

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SUMMARY

During the last decades the protection and the proper management of the oceans and their resources, as a provider of essential goods and services for humans, has become the main focus of numerous policies and conventions, at both national and international level.

In a specific way, the European Union (EU) has started several legal and financial initiatives in order to move forward the sustainable use of the sea and oceans. In this regard one of the main goals of the EU's integrated maritime policy is to create a base of scientific marine knowledge and it emphasizes in the availability of coherent, quality-checked and georeferenced data as an especially important tool.

In accordance with the INSPIRE Directive, and with the aim of fostering the creation of coherent and integrated networks of data to ensure interoperability between them, diverse initiatives are being developed in Europe in order to establish an operational marine data infrastructure, facing the current problems of fragmented, dispersed and heterogeneous marine data and observations.

The present communication focuses in a comparative analysis, at European level, of different sources of marine information that provide data for hydrographic applications, as well as to give a global view of the current availability of them.

This paper analyzes aspects relating to capabilities and limitations of the European main sources, throughout the analysis of the different methods and technologies used to obtain the data and how they are assembled, just as the main features of the different kinds of information that are finally accessible to the end user.

SUMMARY

La protección y adecuada gestión del mar, como proveedor de bienes y servicios esenciales para el ser humano, se ha convertido en las últimas décadas, tanto en el contexto europeo como internacional, en el foco de numerosas políticas y convenios.
De forma específica la Unión Europea, ha puesto en marcha diversas iniciativas legislativas y financieras con el objetivo de avanzar en el aprovechamiento sostenible del mar y de los

océanos. En este sentido, la Política Marítima Integrada de la UE establece como uno de sus objetivos la creación de una base de conocimientos científicos sobre el medio marino, y destaca como elemento particularmente importante disponer de datos georreferenciados de calidad controlada, accesibles y coherentes.

De acuerdo con las directrices marcadas por la Directiva INSPIRE y al objeto de promover la creación de redes integradas y coherentes de datos que aseguren la interoperabilidad de los mismos, se están desarrollando en Europa diversas iniciativas destinadas al establecimiento de una arquitectura operativa de datos marinos de calidad controlada y rápidamente disponibles, como respuesta al actual problema de fragmentación, heterogeneidad y dispersión de la información sobre el medio marino.

La presente comunicación se centra en el análisis comparado de las diferentes fuentes de obtención de información marina que proporcionan datos de aplicación hidrográfica, y en ofrecer una visión global de la disponibilidad actual de los mismos.

El trabajo analiza los aspectos relativos a las capacidades y limitaciones de las principales fuentes actualmente utilizadas, mediante el análisis de las tecnologías y métodos utilizados para la obtención de los datos, la organización de los mismos, así como el tipo y las principales características de la información puesta a disposición de los usuarios.

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1. INTRODUCTION

1.1 Marine information within the European context

The use of the oceans as a goods and services supplier requires more specific and appropriate knowledge about how it works. Moreover, it is not only possible to identify the impact caused by the exploitation of marine resources, but it reveals new opportunities of use to promote economic growth along with sustainable development.

In the Blue Book for Maritime Policy the European Comission (Brussels, 10.10.2007, COM (2007) 575 final), it recognizes the importance of establishing an appropriate marine data and information infrastructure, for better maritime governance and sustainable development. For this reason, the creation of a comprehensive and accessible source of data and information is considered a cross-cutting tool of this policy.

To improve scientific knowledge the European Commission proposes, in the Communication "Marine Knowledge 2020" (Brussels, 8.9.2010, COM (2010) 461 final), a more coordinated approach to marine data collection and assembly, providing wider access to quality-checked, rapidly available and coherent marine data.

Despite the fact that there is large quantity of information that exists about marine environment, it is currently fragmented due to the inappropriate, non uniform, and inefficient processes for sharing data across different sectors.

To face the issue related to fragmented marine information the EU has adopted measures that address exchange, sharing, access and use of interoperable spatial data and data services. The Directive 2007/2/EC of the European Parliament and the Council (INSPIRE Directive) is a legal action of relevant importance within this context, establishing an Infrastructure for Spatial Information in the European Community, to ensure the interoperability of spatial data sets and services. The INSPIRE Directive mandates Member States to adopt measures in order to share data sets and services between public authorities for the purposes of public task.

Currently, the most relevant initiatives in Europe related to providing marine data and information are the GMES initiative (Global Monitoring for Environment and Security), SEIS (Shared Environmental Information System) within its marine environmental component and EMODnet (European Marine Observation and Data Network). They are focused on different, but complementary, aspects involved in the process of data sharing.

GMES and the marine environmental component of SEIS, are principally oriented to collect new data and deliver services based on its application. On the other hand, EMODnet focuses on assembling existing marine data. This network classifies them in thematic groups based on the type of data, measuring their quality, ensuring the existence of metadata and making them available reinforcing their interoperability through common standards.

1.2 Hydrographic information

Within the framework of the creation of marine information systems in Europe, EMODnet is of particular relevance. Given the wide variety of existing marine information, the data are classified into five thematic groups to facilitate the collection and processing: geology and hydrography, physics, chemistry, biology and human activity.

Currently, the ur-EMODnet which is the preliminary version of EMODnet, is developing thematic web portals, depending on the type of data, under preparatory actions, to provide the necessary feedback to move forward an operational EMODnet. The "Pilot Portal for Hydrography" started in May 2009 and is the thematic web portal dedicated to hydrographic marine data. Its main objective is to provide access to data of a standard format and known quality, facilitating to identify possible "gaps" in coverage.

The Pilot Portal for Hydrography, built from previous experiences for data management, has adopted the Common Data Index (CDI) standard, developed within the SeaDataNet infrastructure (EU I3 Project 2006-2011). It gives users detailed information concerning the availability and geographical extent of bathymetric data and the metadata of individual data sets.

Regarding to the services provided by this web portal, there are currently two main products. On one hand, it provides a service for downloading high resolution data according to CDI information. However, in order to respect data copyrights, the online shopping mechanism facilitates users requests for data set in a standard data transport formats (NetCDF).

On the other hand, the portal provides free digital terrain models (GIS layers with moderate resolution), and the user can view, share and download data via the EMODnet of "Viewing and downloading of hydrographic data" service, supporting Open Geospatial Consortium (OGC) services and in accordance to the INSPIRE Directive, ensuring their interoperability.

Within these steps towards the databases availability and interoperability between systems and users, specifically in the hydrographic field of study, it is essential to analyze the current situation of data acquisition techniques and their main capabilities and limitations. It is necessary to ensure the efficient use in order to obtain the best results at a low cost.

The following is an analysis of the main technologies used for the acquisition of bathymetric data, providing a comprehensive, comparative and integrated view of their use.

2. ANALYSIS OF TECHNOLOGIES FOR ACQUISITION OF BATHYMETRIC DATA

In recent years, the fast advances in technology provide more accurate data and information, tending to error minimization, and they allow collecting a great quantity of data in less time. In particular, advances in positioning systems, increasingly capacity of computer systems and the development of new depth measurement systems allow elaborating bathymetric information with greater precision and spatial resolution, reducing costs of the final product.

For this reason, it is available a wide range of possibilities about the choice of methods or instruments for bathymetric data acquisition exists. In most cases, the acoustic systems, and in particular multi-beam systems are positioned as the main technology to obtain such information. Systems such as LIDAR technologies and satellite traditionally were not used for this kind of work because of its limitations. However, in recent years, the technological advancements into these systems have led them to appear as powerful complementary techniques for seabed mapping.

In following sections basics and capabilities of several methods are briefly presented according to the next classification:

- Acoustic methods
- Non acoustic
  - LIDAR systems
  - Satellite systems
    - Data acquisition by active sensors
    - Data acquisition by passive sensors

3. ACUSTIC METHODS

The acoustic systems for depth measurement are based on the presence of a transmitter (usually working as receptor) that generates an acoustic pulse that travels through the water column. It is reflected off the bottom of the sea and then captured by the receptor, measuring the time interval of the pulse.

The resolution of acoustic systems depends mainly on the length and frequency of the pulse, in the form that higher frequencies provide higher resolution. However, these high frequencies are not able to penetrate into deep water.

For this reason, high frequencies are usually used in shallow waters. In very shallow waters (< 100 m) the measure accuracy under the best conditions is 2-3 cm. For depths up to 300 m the frequencies between 100 and 250 KHz are used. In deep waters (> 300 m), lower frequencies are used, typically between 20-50 KHz, which allows greater penetration.

These systems are used the most in hydrography, especially the multibeam echo sounders. The monobeam systems are also used, but they only measure a single strip along ship track.

The coverage is lower than when multibeam systems are used. The pulses emitted by multibeam systems are narrower, and it permits a high resolution. In addition, the process is faster, because the ship moves at a higher speed.

The main capabilities of multibeam systems are more vertical accuracy obtained in the measure, as well as more sea bottom coverage.

4. NON ACUSTIC METHODS

4.1 Airborne Systems: LIDAR Systems

Bathymetric LIDAR systems (Light Detection and Ranging) are based on a transmitter which sends light pulses that are registered by the sensor, and then the time it takes to return is measured. This kind of technology applied within a marine context is not new; in fact the laser pulses were used in the mid 1960's, whose main objective was to detect submarines. In 1972 the National Oceanic and Atmospheric Administration (NOAA) and NASA started field testing of the Airborne Oceanographic LIDAR (AOL) for hydrography (Guenther, 1985).

The acquisition of bathymetric data is based on the measurement of the laser pulse's travel time. The transmitter sends a green beam (532 nm) and knowing its speed through both the atmosphere and the water column, the distance from the sensor to the seafloor is calculated. Therefore a laser pulse within the IR region is used to determine the sea surface, and to calculate the depth at the point using the height differences.

Since it is used a light beam, it is affected by several factors that they can produce a distortion on the received signal. The main reason is the presence of suspended material in the water column. The water turbidity is the principal determining factor that limits the use of these systems for hydrographic purposes. Consequently, the best conditions to obtain reliable data corresponding to that in clear waters (Costa, B.M. et al., 2009).

Its use is limited to 50 m depths in clear waters offshore, because of the effect of light extinction in the water column with depth. If the turbidity conditions are high the depth decreases to 10 m or less in coastal areas (Guenther et al, 2000).

In addition to the limitations because of environmental factors, limitations regarding the technology itself make the detection of small objects difficult. They do not ensure to detect a hundred per cent of the seafloor features which are smaller than a cube of one meter side (Guenther et al, 2000). In this regard, areas with high relief may limit the accuracy of this kind of system compared with the data obtained from multibeam systems (Costa, B.M. et al., 2009).

While the basic concept of these systems is not new, the development of its technology as well as new hardware and software for the processing of the signal have improved the resolution and accuracy in depth measurement. This makes them appear as a competitive method for hydrographic applications. In fact, the capabilities of this kind of method offer advantages in certain situations. The main reason, according to the "Manual on hydrography" (1st edition May 2005, corrections to December 2010) prepared by the International Hydrographic Organization (IHO), is a secure method in order to use in shallow coastal waters, where ships may have difficulty accessing, and it is suitable for areas with extreme temperature or salinity conditions.

Moreover, capabilities of LIDAR systems lie in the high speed for data acquisition, and the lower number of tracks required for obtaining full coverage of the area, because of the swath width is independent of depth. These reasons reduce costs, and according to Guenther (2000), they can be from one-fifth to one-half that of waterborne techniques for adequately planned projects, these have similar results to those obtained in studies carried out in Sweden and Australia

In short, LIDAR systems are applicable throughout the land/sea interface, and although far from maturity, they appear as an excellent choice complementary to multibeam systems (Guenther, 1985), by addressing the problem of the lack of data continuity in this area where a large numbers of physical, chemical and biological processes interact.

4.2 Satellite borne systems

The satellite technologies began several decades ago. Last advances had led to improve their capabilities and application fields. This is the case of bathymetric charts, elaborated using data from active and passive satellite borne sensors.

4.2.1 Data acquisition by actives sensors

Active sensors produce a pulse and that is received by a sensor. Two sensors are used in the field of hydrography, the radar altimeter and the synthetic aperture radar (SAR).

– Radar Altimeter

The use of the altimetry radar for hydrography is based on the measurement of the return time pulse emitted by microwave radar operating in frequency of 13 GHz. This pulse is reflected by the sea surface, and the topography of the sea surface can be established with an accuracy of 0.03 m. If the height from the satellite above the ellipsoid is known, as well as above the sea surface, then the geoid height can be calculated, and transformed into gravitational anomalies. In deep waters, where the layer of sediment is thin, these anomalies tend to be correlated with variations of the bottom topography, inferring the shape of the seafloor (Sandwell & Smith).

Sandwell & Smith (1997) constructed a map of the seafloor topography using altimeter data from the U.S. Navy's GeoSat Geodetic Mission and the European Space Agency's ERS-1 mission. Combining the data with conventional bathymetric data shows a good correlation, getting differences between both methods less than 100 m about 50% of the time, although in some cases they can exceed 250 m in areas of very rugged topography (Smith, Sandwell & Raney, 2005).

This method is applicable to meso-scale phenomena, such as ocean currents, of plate tectonics processes, submarine volcanism or petroleum exploration.

– Synthetic Aperture Radar (SAR)

The Synthetic Aperture Radar (SAR) is an active sensor that generates a pulse in the microwave region, corresponding to the C-band (5.3 GHz), collecting information relating to the roughness of the sea surface, as the result of the backscattered signal.

These sensors are not used across the broad for the development of marine bathymetric models. However they are used by the Bathymetric Assessment System (BAS) developed by the Dutch company ARGOSS supported by ESA's Earth Observation Programme, developed within the framework of the BABEL project.

This method aims to produce bathymetric maps of coastal areas using SAR imagery from the ERS European satellite. It is based on the modulation of the flow speed in the sea surface produced by interaction between tidal currents and the sea bottom, producing changes in the wave spectrum. These cause variations on the backscattered signal recorded by the sensor, therefore leaving registered bathymetric features in the image (European Space Agency, 2000).

Starting from initial bathymetry information, a numerical model for tidal currents, wave prediction and the boundary conditions, this method generates the theoretical backscattered signal that would produce such waves. Then it is compared with the real backscatter signal collected by SAR. The difference between the synthetic image and the actual image is minimized, generating a bathymetry updated, and this process is repeated until the depth values converge.

Its spatial resolution corresponds to that of the SAR imagery (30 m). This model is applicable for shallow water areas up to 30 meters depth and do not comply with International Hydrographic Organization (IHO) standards for safe navigation (European Space Agency, 2000).

The main limitations of this method are those relating to the hydrodynamic conditions of the sea. This method is functional when the tidal currents are greater than 0.5 m/sec and wind speed is between 3 and 10 m/sec.

For the use of BAS it is necessary to have previous information about the bathymetry, as well as, the input variables for numerical models. Since initial boundary conditions are necessary, this method is suitable for monitoring changes in bathymetry of shallow waters.

4.2.2 Data acquisition by passive sensors

In this case, the sensor obtains information from the electromagnetic radiation previously issued by an issuer focus different from himself. The methods to obtain bathymetric data using satellite imagery are based mainly on the attenuation of optical radiation as it passes through the water column. Subsequently it can be set the relationship between the attenuation and depth.

To analyze the satellite imagery in order to produce information about sea bottom depth two types of algorithms are primarily used, the Lizenga's linear algorithm and the ratio algorithm (Stumpf, 2003). Both include parameters that have to be calibrated using field measures, and they are often site and environmental conditions specific (Lyons et al., 2011). For this reason, previous information about the environmental conditions in the study region is necessary to properly calibrate these algorithms.

Advances in these technologies allow improving spectral resolution, being able to evaluate the behavior of the sea water to more specific wavelengths, increasing the accuracy of derived depth.

Moreover recent satellites are improving more its spatial resolution. Satellites as IKONOS or QUICKBIRD give a value of 3.28 and 2.84 m respectively for spatial resolution, being used currently for mapping coastal areas. In 2009 the WorldView-2 satellite was launched providing a spatial resolution of 1.84 m and a greater spectral resolution that offers new possibilities in bathymetric studies as its operator, Digital Globe, assures. It is another example of the technological development rate of satellite imagery in the field of hydrography.

This is a solar radiation-dependent method so faces several constraints common to all satellite imagery applications within the visible region of the electromagnetic spectrum, i.e. presence of clouds, conditions of luminosity, etc. In concrete, maximum penetrations depths of solar radiation in the water column reach 20 m (in the blue region), consequently this method is only applicable to shallow waters.

Like in the case of LIDAR systems, the signal received by passive sensors can be affected by the presence of suspended material, for this reason the turbidity of the water column limits their capabilities. We must also consider the albedo due to the bottom and the water surface glint that can produce variations into the signal.

Its main advantages are in line with that of bathymetric LIDAR, i.e. to be a secure method for hydrographic works in shallow waters where boats cannot access. Therefore, it can be a solution to the problems regarding to the lack of bathymetric data in the coastal area and it can allow developing coastal terrain models (Hogrefe et al., 2008).

In this case, the reduction of the operation costs is significant, compared to LIDAR and multibeam systems. Its high temporal resolution is an important advantage too, because it offers more possibilities to choose an optimal scene to derive bathymetry. In addition, is accessible to remote areas, where bathymetry data could not be obtained otherwise, or would result in higher costs.

5. CONCLUSIONS

In a global context, the lack of information in coastal zones is a crucial issue. These areas are extremely important because of its high productivity in both economic and environmental aspects. However the stability of the coastal strip is in danger due to the pressures generated by human activities.

The necessity of better access to information and to assure the interoperability between systems and data are key objectives for Europe, as the EU's initiatives shows. The Hydrography Pilot Portal is the first web portal to provide bathymetric data in the European context.

Advances in technology, offer more accurate measures, along with an increasingly software and hardware capabilities for data management, analysis and visualization. It helps to manage the marine and coastal environment in a better and efficient way.

The field of application of depth measures has to be taking into account, because the vertical and horizontal resolutions vary depending of the scale of the study phenomenon. To assure the efficient use of available systems it is necessary to know the limitations of the method, as well as the factors that affect measurement process.

Bathymetric LIDAR systems are not a mature method and their technology is still in development. However, the use of satellite imagery to measure depths is evolving rapidly, and it shows a great potential to retrieve reliable depth measures. As a resume, satellite derived depths are complementary to that measure with LIDAR.

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BIOGRAPHICAL NOTES

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