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A survey of official online sources of high-quality free-of-charge geospatial data for maritime geographic information systems applications

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ABSTRACT

Maritime information systems are innovative geographic information systems for study, monitoring and action-taking in maritime areas. They respond to needs in the development of intelligent systems for applications such as scientific research and safety (monitoring the global ecosystem, the atmosphere, the oceans, the biosphere, ice fields, fish populations *etc.*) or the support of the maritime industry and its related organizations (tracking the position of vessels in motion, providing them with safe routing *etc.*). For these systems to efficiently handle the complex demands made on such specialized applications, up-to-date real-world data purchased or downloaded from official, trustworthy online data sources is needed. This article examines geospatial free-of-charge data sources and discusses the various classes of available data. Several hundred resources and their available datasets were empirically tested and their quality and usefulness verified, producing a selective thesaurus. An accompanying website summarizing useful available information about the data sources and datasets also includes information which could not be mentioned in the article. The survey, covering a wide spectrum of online information regarding up-to-date sources for genuine valuable real-world high-precision maritime data worldwide, is, to the best of the authors' knowledge, the only one of its kind at the time of writing.

1. Introduction

Salt water covers about 70% of the surface of the Earth. Research and analyses pertaining to the aqueous expanse of the planet used to be carried out by coastal engineers, biologists and oceanographers, maritime transportation experts, naval architects, socio-economists and so on. The advent of new technologies and equipment —such as deep-ocean research vessels, drifter buoy arrays, side-scan sonars, satellite imagery, precise global positioning systems (GPS) *etc.* — has widened the scope and potential of research in the maritime context, thus making it an interdisciplinary enterprise. The methodologies used by geographers and geologists, now applied to the hydrosphere, are bringing about entirely different perspectives, while the pace of charting and mapping the liquid environment has accelerated in step with technological changes.

A maritime information system is a geographic information system (GIS) designed to capture, store, integrate, manipulate, analyze, manage, and visualize all classes of maritime geospatial data, which are capabilities serving a cross-section of disciplines. An increasingly cost-effective active maritime information systems market has also been developed, which benefits from an ongoing process of improvements in the hardware and software components of GIS. A variety of fields have gained from the application of maritime information systems, made possible by this technological boost from science, research, education, government, business and industry, to domains such as public health, homeland security, natural resources management, astronomy, meteorology, climatology, naval archaeology, shipping transportation and logistics *etc.*

This work defines the classes of data which constitute valuable resources towards the development, performance-tuning and efficient operation of maritime information systems and it subsequently surveys both the open and restricted data sources which provide, free-of-charge, these classes of real-world geospatial data. Data sources on the international scale are outlined, and special cases of sources significant for their propensity to provide specialized high-quality data relating to specific areas of the planet, such as specific countries or continents, will be focused upon. To the best of the authors' knowledge this is the first comprehensive study that classifies and analyses such a wide spectrum of official online resources, compiling a thesaurus of high-precision real-word geospatial data to serve the needs of scientific research and development or educational work in the maritime information systems domain for operational, benchmarking and experimentation purposes or for pattern recognition and data mining.

Henceforward, Section 2 outlines the history of the development of

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maritime information systems and highlights interesting examples of systems which have been developed in the recent past in the global maritime context. Section 3 provides an overview of the steps to follow in order to access valuable real-world data to fulfill the operational demands of their maritime software applications. Section 4 records a wide range of maritime geospatial data, the availability of which in the digital form can boost the efficiency and effectiveness of maritime information systems tools from a number of perspectives. Section 5 describes the official online data sources from which these data can be retrieved, free-of-charge, at the time of writing. Section 6 discusses various restrictions that might apply when using these data. Section 7 concludes, with some comments, on this study.

2. Examples of historical & modern maritime information systems

An endeavor by oceanographers of the United States of America (U.S.) National Ocean Survey (NOS) to develop an electronic mapping scheme in the early sixties was one of the precursors of marine information systems. The computer resources that the U.S. NOS had at its disposal were prohibitively expensive and, hence, exclusive at the time, and enabled them to pioneer the production of "figure fields" and matrices of depth values for the creation of hundreds of nautical charts [1].

The seventies and eighties witnessed the development of sophisticated technologies for ocean data collection, resulting in the explosion of data and information which marked the nineties. Realizing the potential of GIS for managing, interpreting, and visualizing these data, one of the first research works on the potential of marine information systems was published in 1990 [2]. This work not only focused on the data management and display functions for which GIS had become well-known, but was far-sighted in its discussion of truly 3-dimensional property modeling, volumetric visualization, and quantitative analysis in GIS, particularly for physical and chemical oceanographic data. A little later, the Sea Technology magazine featured its first article on marine information systems [3], highlighting the use of technology for the search and recovery of lost objects on the sea floor. Around the same time, oceanographers and geographers in the U.S., Canada, and Europe presented the first works on a variety of marine information systems applications, including: the modeling of tidal currents and winds in Canada [4]; a digital marine atlas of the United Kingdom (U.K.) [5]; the monitoring of the quality of the water in the New York Bight [6]; the processing of Exclusive Economic Zone data along the U.S. West Coast [7]; the monitoring of pollution outflow and diffusion in Scandinavia [8]; the investigation of natural oil seeps in the Gulf of Mexico [9] *etc.*

The evolution and increasing importance of maritime technology has led to the current development of numerous powerful maritime information systems and projects at national and international levels. A number of examples include the Pattern Mining and Monitoring Ocean Eddies project [10]; the Long Range Identification and (Ships') Tracking system [11]; the SafeSeaNet [12], and the ClearSeaNet project [13]; all three of the European Maritime Safety Agency [14], the European Border Surveillance System [15], and the Maritime Surveillance project [16] of the European Defence Agency [17]; the CISE (Common Information Sharing of the Environment for the surveillance of the European Union Maritime Domain) initiative [18] and the Copernicus (European Space Agency's Global Monitoring for Environment and Security) program [19]; the European Commission's Directorate-General for Maritime Affairs and Fisheries [20], together with the three Copernicus' supporting projects DOLPHIN (Development of Pre-operational Services for Highly Innovative Maritime Surveillance Capabilities), NEREIDS (New Service Capabilities for Integrated and Advanced Maritime Surveillance) and SIMTISYS (Simulator for Moving Target Indicator System) [21]; the project related to Copernicus, MyOcean2 [22], [23]. A non-negligible number of such systems relate to specific seas, such as the Baltic Sea, which figures on the International Maritime Organization (IMO) [24] list of Particularly Sensitive Sea Areas [25], and for which a large number of related programs has been developed, such as the Monalisa 2.0 [26], the EfficienSea [27], the BaSSy [28], the SafetyAtSea [29] *etc.*

3. Setting out the problem and applying the solution

Before discussing the various marine geospatial data classes and sources provided online, we will briefly discuss the steps that need to be taken when such data is required for the operational needs of maritime software applications. The first step –prior to the collection of data– is the identification of the classes of data required in order to make the system work efficiently and reliably. Subsequently, a variety of data sources for each kind of data are surveyed towards the selection process. These sources are refined on the basis of a number of predefined criteria to which minimum standards apply in respect of quality and precision and on the basis of the area covered by the data needing to be found. Once usage restrictions (which will be adhered to for the extent of the life-cycle of the marine information system) for these data have been duly taken into account, the data are collected from their sources and appropriate software tools are adopted or developed to enable the efficient integration and storage of these data in the database of the maritime information system.

The backbone storage system can be anyone of the open access database management systems, from the PostgreSQL and the MySQL to any of the commercial ones, such as the Oracle Database and the Microsoft (MS) SQL Server, necessarily accompanied by their specialized extension subsystems for the efficient handling of the geometric nature of these data. For example, the corresponding spatial extension of PostgreSQL is the PostGIS [30], while Hermes [31] is its extension for managing trajectories of moving objects such as those created by moving vessels.

At this point a selection process of the data needs to be initiated in order to eliminate duplicate entries caused by the possible partial overlap between data are collected from heterogeneous sources. It might also be necessary to transform the format of the data –*e.g.* from raster to vector or vice-versa– because the manipulation and joining of related datasets that appear to be in different formats is both difficult and time-consuming. The collected data are then safely stored and their optimization for efficient manipulation in the database system is performed: database indices for fast retrieval might need to be built; the responses of users' popular queries for data that are not dynamically changed overtime (*i.e.*, such as coastline static data) might need to be pre-computed and their results stored separately in the database so as to minimize avoidable delays in the system's operations in the future, *etc.*

Once these steps are taken, the data become available to fulfil the requirements of the maritime information system.

4. Maritime geospatial data classification

The wide range of nautical or marine data needed to develop and operate an efficient maritime information system (examined further below), falls under one or more of the following wide categories:

- up-to-date geospatial data related to human-life on or near the seas, such as ship traffic data and technical data regarding the various characteristics of ships, data related to maritime areas of particular interest to humans (*e.g.*, harbors, fishing areas) *etc.*,
- geospatial data related to marine biome and wild-life in/on or around the seas, such as data regarding particularly sensitive maritime areas for wild-life and data for fish and sea animals reproduction areas *etc.*,
- annotated data related to accident history at sea,
- marine meteorological forecasts and climatological data,

- nautical cartographic data related to geospatial objects of critical importance in/on or around the seas *etc.*

Maritime traffic data are usually transmitted in the form of real-time streams of Automatic Identification System (AIS) messages [32]. The benefit of AIS for all mariners lies mainly in its capabilities with regard to increasing navigational awareness, to assisting with avoiding collisions and with the port authorities' more efficient control of maritime traffic.

The technical characteristics of the ships are mostly static or rarely affected by changes. If they are affected, the changes take place under certain conditions (e.g. should the type of usage of the ship change):

- type (passenger, tanker *etc.*), size (length *etc.*),
- manufacturer, year of manufacture,
- owner/manager, firm, home port, flag,
- fuel consumption, maximum speed, draught,
- type of cargo, weight of cargo, tonnage,
- Froude number (related to wave resistance), several coefficients related to the hull of the ship (*e.g.*, block/midship/prismatic/waterplane coefficients) *etc.*,
- photographs and videos (if they exist) depicting the ship and some of its characteristics *etc.*

The geographic regions of marine areas with particular sensitivity and restrictions may include:

- environmentally protected areas (*e.g.* parks that are strictly protected by laws and legislations),
- significant areas for marine biodiversity (*e.g.* marine mammals, sea turtles, birds),
- island wetlands and coastal waters surfaces,
- major fishing areas,
- areas where fish farms are located and demarcated areas of organized aquaculture,
- military shooting ranges,
- hazardous shipwrecks (location and depth),
- submersible cables (location and depth) *etc.*

With regard to accident history at sea, the following data carry great weight:

- exact geographic coordinates and description of marine accidents which have occurred in the past, involving either ships/vessels (*e.g.*collision or contact or capsizing or grounding of vessels, including the IMO numbers of the ships involved, if any), or oil and gas drilling platforms (*e.g.* explosions, oil spills), or any other on-sea or on-land source around the sea (*e.g.* marine chemical pollution incidents caused by industrial activity near a coastline) *etc.*,
- up-to-date tracked information for any man-made source near or on the sea with a heavily documented accident history (*e.g.* ships, oil and gas platforms, underwater pipelines, on-land installations of several types), including a history of violations or of incidents of non-compliance with international and national maritime regulations,
- incidents involving dangerous vessel movements and trajectories on record,
- the list of 'flag of convenience' countries [33] under the protection of which some ships are registered to eschew regulations and tax obligations in the owners' country *etc.*

The supply of highly accurate location-based meteorological forecast data in real-time streams is a major factor for efficiency and may include the following parameters:

- weather forecast: surface wind, rain fall, cloud cover, temperature, atmospheric pressure *etc.*,
- wave forecast: wave height, swell height, swell period *etc.*,
- sailing forecast: wind speed and direction, wave height and direction, visibility *etc.*,
- sea level forecast: total elevation, tidal elevation *etc.*,
- sea traffic forecast: surface temperature, salinity, surface movement, free surface elevation *etc.*,
- ecosystem forecast: chlorophyll, nitrates, phosphates, bacterial biomass, phytoplankton biomass *etc.*,
- oil spill, satellite imagery, high-frequency telemetry *etc.*

For the safeguard of maritime navigation and transportation, by minimizing the risk of accidents *etc.*, additional statistical data can also be extracted on the basis of historical weather data in order to analyze the level of influence of every weather data parameter in monitoring the health of the maritime wildlife and climate change (*e.g.* phytoplankton, temperature, oxygen levels).

Nautical cartographic data related to geospatial objects of critical importance in/on or around the seas may include:

- nautical digital charts containing the land and sea boundaries of countries worldwide; the geographic names for regions near, over and under the sea *etc.*,
- bathymetry data in geometry and raster formats,
- ports and harbors (*i.e.* exact geographic location and surface, operational and activity status *etc.*),
- shores, beaches and land along the coastline,
- lighthouses (*i.e.* exact geographic location, type, color and lighting periods, size, range, operational and activity status) *etc.*

Additional advanced knowledge can be indirectly extracted (for example such as in [34] and [35]) from combinations of existing datasets of a heterogeneous nature using machine learning [36] and data mining [37] techniques, which will, for example, identify hazardous maritime regions and routes, suspicious and dangerous vessel movements, popular maritime highways and traffic patterns, accident high-risk areas, areas under the influence of strong sea currents, highly polluted areas *etc.*

Such data can highlight information of critical importance on such matters as the navigation behavior and performance of a vessel or of a type of vessel in relation to, and depending on, prevailing meteorological conditions (inclination, route deviation), the condition of the sea surface and the intensity of sea currents, again in relation to the meteorological conditions, the seasonal habits of fish and other maritime fauna, the impact of human activity on the sea near fish reproduction areas, the pattern of pollution of the water depending on the weather conditions, and other useful related information, depending on its application.

Table 1 summarizes a selection of classes of data surveyed in this section in the format in which they are most commonly found. The time categorization gives a rough estimation of their lifetime and validity. The 'Real-time' column refers to data that are continuously updated (stream data), the 'Current & recent historical' column refers to data that could go as far back as 10 years, and the 'Long term historical' column refers to data still considered to be highly important for most related applications years after they have been produced.

5. Data sources

5.1. Vessel tracking and monitoring services

MarineTraffic [38] is the most popular interactive maritime information system developed by the University of the Aegean. Its key objective is the online monitoring of ship movement worldwide, while providing the public with real-time information about port arrivals and

Table 1
Data classes in their most commonly found formats.

Data class description	Most common data format	Real-time	Current & recent historical	Long term historical
AIS data	AIS raw messages	√	√	no existing data
Vessels' data	Clear text	–	√	–
Accidents-related data	Clear text	–	√	√
Weather data	XML	√	√	√
Climate data	Clear text & geospatial	–	√	√
Marine biome-related data	Clear text & geospatial	–	√	–
Nautical cartographic data	Clear text & geospatial	–	√	–

departures. The success of the coverage provided relies on voluntary participation in the community and on local authorities installing receivers and sending the collected data in real-time to the central MarineTraffic server that in turn collects the data and visualizes them on an online map. The data are sent and collected in raw AIS messages format through UDP channels. Additional TCP requests can be performed in order to retrieve data in XML and JSON formats. Historical data can be retrieved on demand, using requests in XML format.

Vesseltracker [39] is a provider of AIS vessel movements on the global scale and of maritime information services such as maritime news and events, vessel information, reports and statistics. More specifically, Vesseltracker provides its registered members with customized real-time and historical AIS data; a comprehensive database of vessels specifications, characteristics, equipment, ownership and management information; alerts on vessels status and on customizable regions *via* email, SMS and telephone; information and alerts on expected, arrived and departed vessels for a single port or for a list of ports; information about the distance to be covered by vessels to reach ports; port events; map views and layers including nautical charts; global and local piracy information; and weather forecasts information.

MariWeb [40] is a monitoring service for the movement of ships and for other relevant maritime information, such as the characteristics of ships, their destination, estimated time of arrival, photographic data, traffic statistics for ports *etc.* The platform is developed by the IMIS Global [41] which is a technology-oriented company focusing on offering AIS network management software tools, *i.e.* tools that efficiently collect, store and display AIS data securely providing navigational and fleet monitoring services to its customers in the maritime context. The company uses its own private network of receivers that forward the collected data to the central server of MariWeb for visualization.

ShipFinder [42] and FleetMon [43] are services of characteristics similar to those of MarineTraffic, Vesseltracker and MariWeb services. The Lloyd's List Intelligence [44] is a specialized service of the Lloyd's List Group, dedicated to the global maritime community and access to their monitoring service of ships is limited to certified members on a subscription basis.

VesselFinder [45] is another popular service that provides visualization of various real-time, time-evolving and static maritime data. The service, developed by the AIS Hub [46] data sharing center, is the only online service worldwide that distributes freely all its real-time collected vessel traffic data to any party volunteering to contribute reliable real-time AIS data to its network, constituting thus a valuable resource for maritime professionals and software applications developers. Its Web service can provide data in XML, JSON or CSV formats *via* TCP requests.

Free-of-charge real-time test data in the form of raw AIS messages can also be retrieved from Exploratorium [47] for non-commercial use. This source is also registered at the MarineTraffic service. It is considered to be an excellent source for educational and software applications development and testing purposes. The real-time raw data come from vessels in the region of the San-Francisco Bay.

Real-time satellite data in the form of raw AIS messages can be retrieved on a subscription basis from the MarineTraffic service [38] or from the IMIS Global [41]. Satellite AIS data guarantee coverage in every maritime location on the Earth *via* dedicated hardware, the elevated cost of which has meant that vessels are not yet mandatorily equipped with it under the current international legislation. This approach has been developed in order to address the poor quality, or the absence altogether, of AIS coverage in the larger oceans.

5.2. Vessels and shipping companies data

Over 160,000 ships, passenger and cargo vessels of 100 t and over are sailing the seas or are stationed at over 13,000 ports globally. For this reason, several specialized online databases have been developed, providing both historical and current accurate and detailed data related to vessels and shipping companies.

The IMO Numbers Database [48] is a freely accessible – through free registration – database provided by the IMO, which was promoted following 9/11 to enhance the security of vessels and ports facilities. Every passenger carrier and seagoing vessel of 100 t or above receives a mandatory and unique IMO number. For every ship identified by its IMO number, the database provides accurate information about its name, its flag, its type, its overall capacity and weight, and its year of manufacture.

ShipList [49] provides a free access database of characteristics that partially complement that of the IMO Numbers Database. The service stores important details for every ship but, in practice however, some fields of information often remain void and the data elusive, in particular in respect of the maximum ship speed, net tonnage, fuel capacity, *etc.*

ShipNumber [50] is another freely accessible online source that provides information, for a specific ship name or IMO number, about the ship's flag, call sign, ship type, gross tonnage, dead weight, total length, extreme breadth, draught and year of construction. VesselFinder [45] is another free access database containing information about the identity but also the dimensions and other technical and design features of the ships. This information partially overlaps with the data that can be retrieved through other similar databases on this list.

Equasis [51] is an outstanding service that has been developed to become a powerful and reliable tool dedicated to the safety of ships and shipping. The service provides to its registered members free-of-charge historical details about vessels, the companies owning them or their ownership history, inspection, manning, and other categories of data. Very importantly, it also provides information not available anywhere else regarding the status of blacklisted ships. Veristar [52] is a database that shares some features with the Equasis database. Overall the service provides free-of-charge information about vessels and shipping companies, inspection history data and so on.

Maritime-Connector [53] is an online database providing for every vessel historical information about its identity, its management/owner, its manufacturer and also the safety category/class to which it belongs. The IMO [24] also provides, among other information, a number of technical details for every ship travelling on the seas across the globe (it is to be noted that this data source is different from the IMO Numbers Database mentioned earlier). Finally, GrossTonage [54] provides its registered members with a free access repository containing technical information about the ships, along with a brief description of marine

incidents that can be visualized on a map.

5.3. Protected and other sensitive areas

The cartographic data of aquatic areas protected by international conventions (BIOGEN, BIOSPHERE, DIPLOMA, MPK, BARCELONA, *etc.*) can be obtained from the Protected Planet portal [55], the largest online geographic database of protected marine areas, which has been developed by the agencies that constitute the International Union for Conservation of Nature (IUCN) [56]. IUCN is the oldest and the largest global organization for the protection of the environment. The source provides cartographic data in electronic form for various protected areas, national parks, wildlife refuges, island wetlands *etc.*

A notable example of information about protected areas is the Natura 2000 network [57], which is a European Ecological Network of designated terrestrial and marine areas hosting natural habitat types and habitats of species important at the European level, and are thereby protected by European Union (E.U.) laws. The network includes hundreds of areas selected for special protection and sites of communal importance that have already been designated for strict legal protection, with numerous others waiting to be included. The Natura 2000 Network Viewer can be accessed from [58]. The complete and up-to-date Natura 2000 dataset is shared freely by the European Environment Information and Observation Network Central Data Repository [59].

The United Nations Educational, Scientific and Cultural Organization (UNESCO) Geoparks are geographic areas in which sites and landscapes of international geological significance are managed in accordance with a holistic concept of protection, education and sustainable development. The list of the geoparks around the globe can be found in [60]. At the time of writing, 116 national geoparks from 31 countries and 4 transnational geoparks have been included in the list with numerous others awaiting inclusion.

Many sources exist which contain data related to biodiversity and wildlife. The Global Biodiversity Information Facility [61] provides free and open access to biodiversity data around the world. The VertNet [62] is a National Science Foundation-funded collaborative project [63] thanks to which biodiversity data is free and available on the Web. The backbone of the VertNet project consists of four individual networks, the MaNIS database with mammals-related data [64], the HerpNet database with amphibians and reptilian-related data [65], the FishNet database with piscatorially-related data [66], and the ORNIS database with ornithologically-related data [67]. The OBIS [68] is a marine species database repository for the world's oceans, provided by the UNESCO. The users can identify biodiversity hotspots and large-scale ecological patterns, analyze dispersions of species over time and space, and plot species' locations together with temperature, salinity, and depth. The World Conservation Monitoring Centre (WCMC) [69] is the specialist biodiversity assessment arm of the United Nations Environment Programme (UNEP) [70]. It provides, among other data about biodiversity such as marine ecoregions and pelagic provinces of the world, global maps of various biodiversity indexes, chlorophyll-a concentration, global distribution of whales, dolphins, seals, turtle nesting and feeding seamounts and knolls, mangroves, *etc.*

The ReefBase [71] is an online collection of all available data and knowledge about coral reefs. The FishBase [72] is the premier biodiversity data website for all the fishes of the world. The Biodiversity Information System for Europe [73] and the European Nature Information System [74] provide data about the species, habitat types and protected sites across Europe, while other data exist that relate to land, water, soil, air, marine, agriculture, forestry, fisheries, tourism, energy, land-use, and transport. The European Marine Observation and Data Network's (EMODnet, [75]) portal for seabed habitats [76] is a free resource for marine habitat data in Europe.

The WWF Conservation Science Data and Tools [77] provides, among other things, a toolkit for the visualization of the global distribution of animal species. The portal also provides a variety of datasets for the Earth's freshwater and terrestrial biodiversity, marine ecoregions, hydrographic data for analysis and planning, biogeographical data of grassland ecosystems *etc.*

The IUCN Red List of Threatened Species [78] contains spatial data and assessments for just over 76,000 species. The portal includes information about taxonomical and conservation status and information about flora, fungi and fauna distribution that have undergone on a global scale a process of evaluation to determine the relative risk of extinction.

The the sensitive area of offshore archaeological sites is acknowledged in the creation of several online resources such as Pleiades [79], which is a gazetteer of ancient on-land and under-water places that provides archeological geospatial data. It covers extensively the Greek and Roman world, and is expanding into Ancient Near-Eastern, Byzantine, Celtic, Early Islamic and Early Medieval geography. The Ancient World Mapping Center [80] provides free maps with data-related elevation tints, labels, point symbols and shaded relief for the Roman Empire, Byzantium, the Aegaeum Mare, the Iberian Peninsula, as well as about aqueducts, inland waters and cultural geography metadata, such as Greek geographical names in Greek nominative forms (in UTF-8). The Greek archeological cadastre [81] and the American School of Classical Studies at Athens [82] provide archeological geospatial data about the ancient Greek world, among which are a large number of ancient cities and locations, rivers, elevation data, and so on. A digital Atlas of the Roman Empire can be found at [83]. The Pelagios Commons [84] is a community and online resource for linked open geodata in the Humanities. Its Peripleo service is a map-based search engine for exploring archaeological, textual and image-based data that has been annotated by the Pelagios community. Its Recogito service is a Web-based tool that makes it easy to identify and record the places to which historical texts refer, maps and tables.

World Heritage sites (cities, islands, lakes, mountains *etc.*) have been listed by the UNESCO and an extensive list will be found in [85]. The dataset can be downloaded as an MS Excel or XML or KML document. At the time of writing, 1031 sites from 163 countries that have signed and ratified the World Heritage Conventions are included in the list, the larger number of these countries figure in the list on the basis of cultural and nature-related criteria. The Managing Cultural Heritage Underwater project [86] provides a tool for the exchange and exploration of underwater cultural heritage information.

The Ocean Energy Systems initiative [87] makes available an interactive map of global offshore marine energy facilities and resources. The WindFarm Action Group [88] provides the location and other related information of onshore and offshore wind farms.

The Greg's Cable Map [89] is an interactive map with data related to currently active or planned undersea telecommunication cables. The dataset can be retrieved in raw, KML or ArcGIS format. Similarly, the TeleGeography Submarine Cable Map [90] provides information about submarine telecommunication cables and their landing points. On the Subsea Cables Consultants Ltd [91] site a number of maps can be found that represent the location of several submarine power cables on the global level. The International Cable Protection Committee portal [92] provides an up-to-date database of information relating to the majority of active and planned international submarine telecommunication, power and scientific cables, *i.e.* cables for scientific research purposes (*e.g.* oceanographic or seismic). The Kis-Orca interactive map [93] is an offshore renewables and cables awareness project that in addition provides data about offshore power cables, oils and gas pipes and renewable energy construction on the U.K. territory.

Because of the impact of any malfunction on the maritime environment, the EMODnet's human activities marine portal provides oil rig and gas rig data, boreholes and offshore drilling sites with their locations [94]. The Peace Research Institute Oslo (PRIO) network [95] hosts a petroleum dataset containing data concerning all known onshore and offshore oil and gas deposits along with additional

potentially relevant data about diamond resources, length of international boundaries, shared rivers and other non-geographic data such as economic and socio-demographic and warfare data. The U.S. Geological Survey (USGS) World Petroleum Assessment [96] provides information pertaining to the 2012 assessment of undiscovered, technically recoverable conventional world oil and gas resources. The Theodora World Pipelines maps website [97] provides information about the diameter, length and capacity of several crude oil (petroleum) and natural gas pipeline installations across the globe.

5.4. Marine accidents

On the national level, Maritime accidents history data can be retrieved from government agencies, such as the Search & Rescue Department or the Maritime Security Department, where they exist or, alternatively, from other agencies under the supervision of relevant national ministries and governmental departments dealing with the merchant navy and the maritime domain or the environmental protection domain *etc*. Whenever data history is provided on the condition that it is not to be published, its value lies in the possibility of extracting useful knowledge about hazardous areas and vessel routes and trajectories, and about ships and man-made above-the-sea-surface installations with a documented accident history. Some of these datasets might provide only approximate descriptions of the site of the incident, rather than the exact location. While some of these descriptions define specific bounded areas (*e.g*. '2NM West of Heraklion, Crete') others might refer to less defined areas (*e.g*. 'in the area in the sea to the east of Mauritius') and a user of the dataset would therefore need to geocode this information in order to extract the relative geographic coordinates or the estimated wider region in which the accident took place.

In a number of countries, organizations such as the National Bureau for Marine Casualties Investigation Organization (for example in [98] and in [99]) might be able to provide information about a number of marine accidents that have taken place on a country's territory and to also provide detailed investigation reports for everyone of these accidents. Statistics derived from the accidents can be found along with the national and international legislation related to marine accidents.

Lists recording vessel accidents are available for free on the Web. One example is the list of 114 marine accidents available from the U.S. National Transportation Safety Board [100]. The list includes the geographic position of every accident as well as an analysis of the various parameters that caused it. A more succinct list of seven accidents, which includes analyses of the ships' routes prior to these accidents, is available at [101]. Also, a detailed list of major maritime accidents that have been recorded across the world since the year 1120 AD can be found on [102]. The analysis (*via* links to Wikipedia pages with details for every accident) also includes the geographical location in which every one of these accidents occurred.

The WreckSite [103] database provides extensive online information about 163,020 shipwrecks worldwide, including data such as geographical location, vessel details, images, owners and builders, maritime charts *etc*. Another detailed list of accidents involving ships on the international scale is available from the IMO [24]. The accidents data provided by the IMO can be obtained free-of-charge on the condition that they will be strictly used for non-commercial purposes.

The Marine Accident Investigator's International Forum [104] provides a list to access the national accident investigation reports from 24 counties while the Maritime Bulletin [105] provides a list of marine accidents around the globe, along with piracy reports and weekly reports regarding shipping hazards. The European Maritime Safety Agency in [106] provides summaries and safety recommendations compiled from the marine investigation reports by the competent authorities of E.U. Member States.

Data specifically relating to oil spills can be retrieved online free of charge, for example from the International Tanker Owners Pollution Federation (ITOPF) portal [107]. The source also provides additional information for the 20 most catastrophic oil spills since 1970. The IncidentNews website [108] of the U.S. National Oceanic and Atmospheric Administration (NOAA) [109] provides abundant data about a selection of oil spills (and other incidents) for which incidents the NOAA's Office of Response and Restoration (OR & R) [110] provided scientific response-support. The software and datasets publications and other resources of the NOAA's OR & R, including training facilities, are dedicated to environmental restoration and provide response tools for oil and chemicals spills and marine debris.

5.5. Flags of convenience

A renewable list [111] of 26 flag of convenience countries [33] has been compiled by the Fair Practices Committee of the International Transport Workers Federation (*i.e*. a joint committee of the federation of seafarers and dockers unions) and a slightly different list including a few additional countries will be found in [112].

5.6. Port state control data

Port state control [113] refers to the inspection of foreign ships in national ports to verify their compliance with the requirements of international regulations and rules. There are nine regional agreements on state control of ports, or Memorandum of Understanding (MoU). All vessels currently detained by regional authorities around the globe will be found in a list of nine online databases that can be retrieved from the following sources: for Europe and the North Atlantic (Paris MoU) [114]; for Asia and the Pacific (Tokyo MoU) [115]; for Latin America (Acuerdo de Viña del Mar) [116]; for the Caribbean (Caribbean MoU) [117]; for West and Central Africa (Abuja MoU) [118]; for the Black Sea (Black Sea MoU) [119]; for the Mediterranean (Mediterranean MoU) [120]; for the Indian Ocean (Indian Ocean MoU) [121]; and for the Riyadh MoU [122]. U.S. port state control is carried out by the U.S. Coast Guard [123].

Data about the ships complying with the regional regulations of the Paris MoU, Tokyo MoU and the U.S. Coast Guard Port State Control can be retrieved from the Equasis portal [51].

5.7. Anti-shipping activities

The U.S. National Geospatial Intelligence Agency provides freely an up-to-date spatial dataset of more than 7,000 anti-shipping activity messages [124]. The dataset includes the exact geographical location and description of specific hostile acts against ships and mariners from 1985 until today. These data can prove useful to the future identification, prevention and avoidance of potential hostile activity. The dataset can be downloaded as a KMZ file, an ESRI shapefile or as a personal Geodatabase in MS Access database format.

5.8. Nautical weather forecast and climate data

Several services provide meteorological data *via* an application programming interface (API) which allows researchers and developers to access weather forecast information for both land and sea. The services provide data for temperature, precipitation or presence of fog, speed and wind direction, the height of sea waves, the direction of sea waves, and include weather description icons *etc*.

Some services make the data available free-of-charge for strictly personal use or for empirical purposes, while others allow the development of applications for commercial use. The data are usually available in XML or JSON. An extensive list of 76 relevant services *via* API can be found in [125].

Nautical or marine meteorological forecast data for research and development purposes tends to be scarce. In shipping applications it is

important to access detailed weather forecast data of up to six or seven days ahead, hence a brief reference to some of the few providers of free-of-charge meteorological forecast data for marine applications.

World Weather Online [126] provides land and marine meteorological forecast data through the use of a free account and a specific API key. The marine forecast data operate within a time window of 24 h, regularly updated and covering a time span of 6–8 h and include: temperature, humidity, visibility, cloud cover, wind speed, wave height, swell height, precipitation, atmospheric pressure *etc*. Someone using the free service can obtain meteorological forecasts for up to 500 requests per hour, and at a maximum frequency of 15 min for the same location. Land weather forecast data are updated every 3–4 h. The available information is sent to the user *via* XML, JSON and CSV format. The data request has to be accompanied by the longitude and latitude of the relevant location on the Earth. The meteorological forecast is retrieved from the nearest weather station to that location. World Weather Online also provides weather and tidal data history.

Weather Underground [127] provides detailed meteorological forecast data per hour for the following 24 h as well as a prediction of the weather for the next three to ten days ahead, along with running animated satellite images. The available data are accessed *via* API and can be obtained in the JSON or XML form. Rather more restricted than the Word Weather Online service, Weather Underground provides the service free of charge for up to 10 times per minute and up to 500 times per day.

The Severe Weather Information Center [128] provides global warnings about tropical cyclones, heavy rain, snow, thunderstorms, gales and fog. Its equivalent system for Europe is named Meteoalarm [129]. The Arizona State University [130] holds an interactive map and an archive for extreme global weather and climate conditions. The NASA Earth Observatory [131] provides 16 global animated maps and datasets which are related to weather and climate conditions such as sea and land surface temperature and anomalies, rainfall, snow cover *etc*. over a time span of 12 months.

Daily reports acquired through sensors about air pollution and ozone can be retrieved at the national level from environmental agencies or from the ministry of the environment of a country concerned, such as in [132] which provides live and historical data. Additional information about air quality, air pollutants and emissions can be retrieved from sources such as the Air Quality database [133] which is provided by the European Environment Agency (EEA) [134].

And, finally, there are online databases that offer historical weather and climate data and some useful statistics:

- the collection of global daily measurements of weather features (temperature, wind speed, humidity, pressure, *etc*.) for the period 1929–2009, from over 9000 meteorological stations around the world, which data have been uploaded from Infochimps.org onto the Amazon Web Services [135],
- the Climatological Database for the World's Oceans [136] which is based on the climatic data contained in ship logbooks for the period 1750 to 1850,
- the European Climate Assessment and Dataset project collection [137] which provides historical data for the period January 1, 1950 - December 31, 2012 *etc*.

5.9. Natural hazards

In the light of their bearing on tsunami phenomena, seismic and volcanic activity monitoring is crucial. Such data are usually provided in almost-real-time by the institutes for geodynamics at the national and international levels, such as [138] and, correspondingly, [139], the latter being a globally-recognized creditable online center for almost-real-time information for European–Mediterranean earthquakes and for worldwide earthquakes with M4.0+. Earthquakes and waveform data for Europe are also provided by the GEOFON Program [140] and, for the U.S., by the USGS Earthquake Hazards Program [141]. Both sites provide almost-real-time data feeds.

The International Tsunami Information Center [142] provides international tsunami warnings and contains further data related to seismic activity and sea level stations along with historical data. The Global Risk Data Platform on Natural Events [143] covers data relating to tropical cyclones, storms, surges, droughts, earthquakes, biomass fires, floods, landslides, tsunamis and volcanic eruptions. Finally, Volcanoes of the World [144] is an online database describing the physical characteristics of volcanoes and their eruptions.

5.10. Navigational aid systems

A database of international navigational aid systems around the globe can be retrieved *via* the MarineTraffic service [38], with every entry containing information relating to the name of the navigational aid system, its location, a representative photo, its type, its range, the color of its light, the flash duration, at which time intervals it operates, and whether or not it is active. The geospatial sea surface covered by a navigational aid system can be computed by its range, taking into account the local coastline.

5.11. Sea ports locations and facilities

The U.S. National Geospatial Intelligence Agency provides the geographic locations and characteristics of ports around the Earth through the dataset “The World Port Index (Pub150)” [145], which keeps a record of the location of 3717 ports worldwide. The dataset is provided free-of-charge for non-commercial use in an MS Access database or in an ESRI shapefile, and provides useful detailed technical information such as the size, type, anchor depth and tidal range of harbors, their fuel/oil supply facilities, available repairs support, and much more. Wikimapia [146] provides similar data in KML geoformat that includes 10,478 port facilities worldwide. No other important technical information about the recorded ports is provided by this particular dataset.

Additional information about ports worldwide can be extracted from VesselFinder [45]. This database contains the name of the port, the country in which it is located, its size (in such categories as: small, medium-sized port *etc*.) and its geographic position on the map. Information about ports can also be found in MarineTraffic [38], including the name and location of every port, together with real-time data about the presence of vessels and their expected arrival and departure times.

Finally, data about airports, runways, airlines, radio navigation aids and waypoints that can become relevant in the domain of a maritime GIS application can be found at OurAirports [147], OpenFlights [148], and WELT2000 [149].

5.12. Essential naval cartographic data

Borders between countries, while they represent mainly static data, are occasionally updated when affected by changes. Such a dataset can be retrieved from several online sources in various formats and sizes (*i.e*. resolution). An excellent source for this dataset is the Blue Marble Geographics [150] which provides country boundaries in ESRI shapefile or TBA files format.

An unclassified vector-based digital dataset compiled from a portfolio of approximately 5000 nautical charts and containing the boundaries of countries worldwide enriched by several additional maritime features is provided free-of-charge by the Digital Nautical Chart portal of the U.S. National Geospatial-Intelligence Agency [151]. It is available in 29 subsets of data broken down according to the region of the planet to which they correspond.

5.13. Maritime borders, coastline and land areas

The coastline (or shoreline) is an important dataset that defines which areas of the Earth are land and which are ocean or sea. Several online sources provide global coastline datasets in different resolution and formats. An excellent example is the high resolution and complete (without gaps caused by missing data) related dataset which is provided by the U.S. NOAA Shoreline website [152]. A dataset of coastlines of the world in ESRI shapefile format which the U.S. Defense Mapping Agency developed from various sources is also provided by the Pacific Disaster Center in Hawaii [153]. Finally, the global coastline with the exception of Antarctica, can be retrieved in a range of resolutions (full, high, intermediate, low and crude) and formats (ESRI shapefile and native binary files) from the GSHHG database [154], which is a global geographic database that is kept constantly updated.

Many organizations and projects produce and distribute high resolution national or continental coastline data. Focusing on the European continent, the geographic data of the European coastline [155] and the European maritime borders [156], which were produced in the context of the EUROSION project [157] derived from the United Nations Convention for the Law on Sea, can be retrieved from the list of datasets in [158] which are provided by the EEA [134], which is responsible for the independent provision of information relating to the environment. High-resolution data for the European Coastline (and land surfaces) [155] may also be obtained from the EU-Hydro, which is a set of hydrological data developed under the umbrella of the Copernicus program [19], the largest scale Earth observation program. Interested parties might find it worthwhile to give precedence to the first of the above-mentioned geospatial datasets (*i.e.* that of the EEA), and to view the second (*i.e.* that of the EU-Hydro) as a support dataset because the coastline from the EU-Hydro represents the separation between land and sea, as indicated by satellite images of the dataset in [159], provided by the European Space Agency. The tidal data depend on the date and time when the images were taken, hence the dataset's insufficiency in respect of the requirements to define the coastline.

5.14. Naval bathymetry data maps

Bathymetric data can be retrieved from various heterogeneous sources. The datasets may share overlapping information in different data formats or precision, therefore appropriate data transformation and refining processes might be needed prior to the process of integrating the data into the same database. Important data sources that can be accessed online are:

The Marine Geology & Geophysics and the Bathymetry & Global Relief discipline of the National Center for Environmental Information [160] of the NOAA [109] provides access to sonar data (single-beam trackline bathymetry surveys), magnetic, seismic and other data [161] that have been collected on the basis of marine survey trips since 1939 until today. The source also provides rich multi-beam sonar bathymetry data [162] that contain over 1,187 international marine trips that collected bathymetry data from several areas around the world.

The International Hydrographic Organization (IHO) [163] globally collects and quality-checks oceanic sounding data acquired by hydrographic, oceanographic and other equipment during surveys or by vessels simply passing by. The IHO members have also made additional contributions with shallow water sonar data derived from electronic nautical charts.

The International General Bathymetric Chart of the Oceans Cooperation [164], [165] which is maintained by the British Oceanographic Data Center (BODC) [166] provides free-of-charge bathymetry data relating to all the seas across the globe. The data are collected by echo-sounding and the dataset is enhanced with satellite data.

Another notable example of high-precision bathymetry data is offered freely by the EMODnet bathymetry portal [167] of the European Marine Observation and Data Network which contributes to the provision of reliable and interoperable marine data in public and private organizations. The bathymetry dataset of the EMODnet service covers a wide range of marine areas across and around Europe, providing highly accurate Digital Imaging Modeling Soil data and substantial coverage of the corresponding seas.

5.15. Tides, eddies and sea levels

The NOAA Center for Operational Oceanographic Products and Services [168] has been gathering oceanographic data for over 200 years, serving both the public and government agencies. Its data include sea-level measurements over time; tide prediction locations; a history of currents activity at different levels of depth; *etc.* The dataset can be downloaded in KML format from [169].

Sea-level data on a worldwide scale can also be retrieved from the Sea-Level Station Monitoring Facility [170] which utilizes an interactive map illustrating the locations of stations that measure the sea-level in real-time. A disclaimer on the portal indicates that quality control has not been applied to the data on display and that the data are provided in the state in which they were received.

The mesoscale ocean eddies are currents that transport heat, salt, energy, and nutrients across the world seas. Their accurate identification and tracking is crucial to the understanding of future marine and terrestrial ecosystems and their sustainability. A rich historical dataset of ocean eddies from 1992 to 2011 can be found in [23].

5.16. Various other geospatial data

The Global Earth Observation System of Systems (GEOSS) portal [171] provides on the global scale data about water, ecosystems, agriculture, climate, natural disasters *etc.* A number of datasets in raster and vector format related to land-cover; administrative boundaries; parks; hydrology and ocean water; drainages with lakes *etc.* on several scales of resolution (large, medium and small) is provided by Natural Earth [172]. The NASA's Earth Observation System provides Earth science data that can be retrieved from [173]. A large number of GIS datasets regarding elevation, transportation, demographics, environment, imagery, water *etc.* for almost all the countries around the globe is provided by the Massachusetts Institute of Technology (MIT) Geodata Repository [174].

The NOAA's Office of Coast Survey [175] offers a large number of links for U.S. national charts, wrecks, historical data and other useful nautical GIS information. In [176] several datasets relating to administrative boundaries, biological data, climate, land-cover *etc.* are provided for the U.S. region. The EEA hosts more than a hundred sets of environmental data related to the E.U. territory in [177]. The same portal also hosts a large number of related maps and informational graphs. Another large number of related datasets is stored by the European Space Agency in [178]. In [179], a number of datasets relating to land-cover, elevation, hydrography, protected sites and other data for the E.U. territory is provided by the EuroStat European Statistics Organization. The BODC [166] distributes biological, chemical, physical and geophysical marine data and also hosts various related portals and project websites. Most of the data maintained and re-distributed by the BODC are not restricted to the U.K. territory.

The Marine Plan website [180] provides a number of datasets that include the major regional fisheries areas controlled by governing bodies across the globe; the state of fish stocks; waters coming under the sovereignty of countries in geographically separate territories (this includes the waters of outermost regions and of overseas territories); disputed territories and conflict zones, piracy hazards; international straits and channels; oceans and continents; marine nuclear areas, oil and gas in the world *etc.*

A large number of links to worldwide marine and coastal GIS data and image portals is provided in [181]. An extensive framework for sharing world maps and digital geospatial data about the Earth's frozen regions (including snow cover, sea ice extent and concentration, glaciers, ice sheets, permafrost, and other critical components of the Earth's cryosphere) can be retrieved from the Atlas of the Cryosphere [182] in image, GML and GeoTiff formats. Also, the Quantarctica raster datasets [183] include geographical, glaciological and geophysical data for the region of Antarctica.

DIVA-GIS [184] is primarily a free and open-access software tool for data mapping and geographic analysis. Its corresponding portal also provides freely available spatial data, either at the country level (administrative boundaries, inland water, roads, railroads, altitude, land-cover, population density *etc.*) for any country in the world, or at the worldwide level (high resolution satellite images, global boundaries between countries, global climate data, species occurrence data *etc.*). The data can be used in DIVA-GIS and in other software tools.

A list of over twenty useful links to services databases for the marine science community, with resources such as abstracts, bibliographies, glossaries and directories, as well as articles published in conference proceedings which are otherwise not available online, are hosted by the Hellenic Centre for Marine Research [185]. Among them and of particular interest is the link for the Institute of Oceanography of the Hellenic Centre for Marine Research [186] which provides access to its Online Search and Download Service database [187] in relation to physical, chemical and biological parameters in the European and international waters; the European Directory of Marine Environmental Datasets [188], which contains datasets collected by Greek science laboratories, research institutes, universities *etc.*; and the EDIOS database [189] which provides sea observation measuring and monitoring data in the Eastern Mediterranean and the Black Sea.

Another list of links to over three hundred portals classified by category and providing free access to geographic datasets can be found on FreeGISData [190]. The datasets are related to physical geography (weather and climate, rivers, lakes, elevation, hydrology *etc.*) and to human geography (land-use, wars, population *etc.*) worldwide, and at the same time individual datasets for specific areas or countries are also available.

FreeGIS [191] is a blogspot which also offers links and detailed descriptions of numerous portals which provide free and open-access GIS software; remote sensing; and spatial and hydrology data. The following sources [192], [193], [194], and [195] direct the reader to some compilations of data worth noting, which provide equally relevant maps, articles of international interest *etc.*

Finally, the GEOnet Names Server (GNS) [196] is a repository of standard spellings of global geographic names for regions near, over and under the seas.

5.17. Satellite imagery

Copernicus [19] is a European GIS for monitoring the Earth. It consists of a complex set of systems which collect data from multiple sources, such as Earth observation satellites, ground stations and airborne and sea-borne sensors. Copernicus services address six main thematic areas: land, marine, atmosphere, climate change, emergency management and security [197]. To access the data, it is necessary to go through a free registration process to the Copernicus Sentinels Scientific Data Hub [198], which at the time of writing contains the Sentinel-1 and Sentinel-2 satellites data. Direct access to the data, along with additional information about the various Sentinel satellites missions can be retrieved *via* the European Space Agency's (ESA) Sentinel Online portal [199] or *via* its mirror data site at [200]. Satellite data for a number of ESA's missions dedicated to Earth observation can be found in [201].

And last, the eoPortal Directory [202] offers a database with an extensive list of past, operational and future spacebornemissions and a complementary database of several flight missions and projects involving airborne sensors.

5.18. Sources that reach beyond the maritime domain

The previous sections report on sources and repositories that provide maritime and maritime-related data. However, a large number of sources also exists that include a wider variety of data reaching well beyond the maritime domain but which can, in some circumstances, become relevant in the context of a maritime GIS application. Among these, one of the most popular sources is the collaborative mapping project OpenStreetMap [203], which also offers free-of-charge data about roads; trails; cafés; railway stations; *etc.* In a similar way, Wikimapia [146] provides data about roads; railroads; rivers and ferry lines; various types of points and areas of interest such as parks, villages, towns and cities *etc.* The GeoCommons Archive [204] is a collection of hundreds of thousands of open datasets created thanks to the contribution of communities from around the world. OpenEI [205] provides energy datasets on hundreds of topics, crowdsourced from industry and government agencies in relation to energy efficiency, consumption, demand, and much more.

International and national public open data portals are also significant sources of continental and governmental or country-specific data. For example, the INSPIRE Geo-portal [206] provides the means to search and access open geographic data provided by European governmental, commercial, and non-commercial organizations within the framework of the E.U. INSPIRE Directive [207], which aims at the creation of an E.U. spatial data infrastructure. The EEA's data and maps repository [208] of the E.U. provides sound and independent data on the environment. Some major datasets on this repository are related to air, water, land, biodiversity, climate change, noise *etc.* [209]. A Web map service for the repository is available in [210], while code and APIs (classified under specific topics) for developing GIS applications are available in [211].

The European Data Portal [212] harvests the metadata of public sector information which is available on public data portals across E.U. countries and gives access to governmental open data that were collected, produced or paid for by public bodies and the state sector. The E.U. Open Data Portal [213] is the single point of access to a growing range of data from the institutional and other bodies of the E.U. The portal is not restricted to GIS data and thus some of its main points of focus are employment and working conditions, economics, finance, trade, industry, education, science, *etc.*

At the national level, a governmental source paradigm for providing geographic-related data that also serves as a compliant data infrastructure center at a continental level (for example, for the E.U. INSPIRE and for the European Data portals), is the geospatial open repository of the territory of Greece [214], which offers freely accessible data on topics related to biodiversity, water, the environment, the economy, elevation, transportation, health, planning cadastre, social dimensions and many more topics. The data provided by this source can be complemented by the central library of public data [215] which offers access to the databases of the country's governmental bodies. Several other countries (such as Ireland in [216] *etc.*) offer similar data repositories, and it is expected that, in the years to come, every country (and possibly every municipal sector and region) will offer similar services to the public.

The EMODnet [75] network is a Joint European Coastal Mapping Programme which consists of more than 100 organizations assembling quality-controlled and expert-validated marine data that are made available through the EMODnet portal. This data relates to: bathymetry (water depth); coastlines and geographical locations of underwater features and wrecks; the seabed substrate; sea-floor geology; coastal behavior; geological events and minerals; modeled seabed habitats based on seadbed substrate; energy; biological zone and salinity; the concentration of nutrients; organic matter; pesticides; heavy metals;

radionuclides and antifouling in water; sediment and biota; the temporal and spatial distribution of species abundance and biomass from several taxa; salinity and temperature levels; waves height, shape and patterns; currents; sea-level; light attenuation; FerryBoxes (*i.e.* kits with instruments that are placed on board of commercial ships such as ferries in order to monitor temperature, salinity and other water conditions); the intensity and spatial extent of human activities at sea *etc.*

The EUMETSAT Product Navigator [217] is the catalogue of satellite data and products with regard to the weather, the climate and the environment that are offered in near real-time by the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) [218].

GEOSS links Earth observation resources worldwide across multiple socially beneficial areas. The GEOSS portal [171] provides data about biodiversity and ecosystem sustainability; disaster resilience; energy and mineral resources management; food security and sustainable agriculture; infrastructure and transportation management; public health surveillance; sustainable urban development; water resources management *etc.*

The Red List of Ecosystems (RLE) [219] of the International Union for Conservation of Nature [220] evaluates the conservation status of ecosystems around the globe. The RLE provides the ecosystem locations information and valuable assessments on the basis of a protocol which includes criteria for assessing the risk of collapse of an ecosystem and several categories of risks for every ecosystem.

NASA is a significantly important source of geospatial data, not only in respect of space exploration but also in respect of the Earth. The numerous domains it encompasses provide the material for the creation of an extremely large data center. The EarthData portal [221] provides a variety of Earth-related data. A worldview map of those data can be accessed *via* [222]. The NASA's Earth Observing System [223] is a coordinated series of polar-orbiting and low inclination satellites for long-term global observations of the land surface, biosphere, solid earth, atmosphere, and oceans which consists of the NASA's Earth Observations database [224], the NASA's Earth Observatory database [225], the NASA Visible Earth database [226] and other repositories, every one of which provide a variety of data. The Earth Science Projects Division [227] manages the missions which advance the understanding of the Earth. The NASA Science portal [228] provides data about NASA missions related to the Earth as well as several links to some related portals.

The NOAA [109], along with the USGS Earth Explorer [229] portals, are significant resources for various datasets in numerous disciplines, especially, but not exclusively, in relation to the U.S. territory. Natural Earth [172] also provides geospatial data related to populated places; disputed areas and breakaway regions; glaciated areas and Antarctic ice shelves; cross-blended hypsometric tints; grayscale shaded relief of land areas; worldwide terrain depicted monochromatically in shades of grey *etc.* The ESRI Data & Maps portal [230] displays data from across the globe such as country boundaries, roads cutting through aquatic areas, railroads, major cities, topography, bathymetry, population, gross domestic product, night time views of the Earth *etc.* The PRIO network [95] also contains some unique spatial and non-spatial datasets of specific interest, such as diamond resources, rivers shared between neighboring countries and data related to armed conflicts [231].

Table 2 outlines the most notable sources and repositories containing rich data that reach beyond the maritime domain, along with the most characteristic examples of types of data that they provide.

5.19. Marine conservation organizations

Hundreds of non-profit and non-governmental marine institutes and organizations (such as those listed in [232] and [233]) work either independently or by means of societies and coalitions (*e.g.* the Deep Sea Conservation Coalition [234]) on marine conservation and other environmental concerns such as biodiversity and global warming. These organizations are committed to researching and ensuring the protection of the marine environment, and to the conservation of terrestrial wildlife and are actively involved in lowering the risk of accidents on and near the sea, in providing statistics, scientific research reports, and case studies data analysis.

Much of this extensive and high-quality work is made available to the public and can therefore be put to use to enrich maritime information systems. For example, in [235] several datasets are provided for areas that are environmentally and economically sensitive to oil and other hazardous materials spills, for areas to which sailing restrictions apply, areas to be avoided, shallow banks, rivers, lakes, manatee population locations, sea turtles nests locations, submerged shipwrecks and other obstructions in coastal waters, public access boat ramps, color aerial photographs, coast guard facilities *etc.*, throughout the State of Florida and, more widely, throughout the the U.S. The data are published by the marine conservation Florida Fish and Wildlife Research Institute which works for the protection of the sea across the entire South East of the U.S.

6. Restrictions applying to the use of data

This section discusses the various types of restrictions applying to the use of data. The restrictions have been placed by the sources providing these data in order to protect the rights of the owners over the data that are made available to other parties for inspectionand downloading for the purpose of maritime applications.

Datasets acquired by ministries and governmental agencies, and other organizations, can be accessed free-of-charge for any form of use at any time, irrespective of whether the use of the data is for commercial purposes; alternatively, the datasets might be strictly confidential, which means that while they may remain available for data mining, under no condition can they be published. A number of

Table 2
Most notable data sources that reach beyond the martime domain.

Data source	Land and marine data	Atmosphere and climate data	Governmental and human activities data	Cultural data
Copernicus [19]	√	√	–	–
EMODnet [75]	√	√	√	–
NOAA [109]	√	√	–	–
FreeGISData [190]	√	√	√	√
Natural Earth [159]	√	–	–	√
EEA [134]	√	√	√	√
European Data Portal [212]	√	√	√	√
E.U. Open Data Portal [213]	√	√	√	√

sources might allow a degree of use of their datasets in combination with a license of Creative Commons [236] attribution, which means that the grantee of the data will need to acknowledge their source in the applications in which they are used and will in addition need to comply with some other restrictions that delimits the extent to which the data can be copied, distributed, edited, remixed, and built upon, all within the boundaries of copyright law.

The detailed data for vessels and shipping companies from the IMO Numbers Database [48], the ShipList [49], the Maritime-Connector [53], and the VesselFinder [45] services can be collected *via* their freely accessible online databases. The data, however, cannot be re-published although they remain useful resources to ensure the efficiency of maritime information systems. The data from the Equasis service [51] cannot circulate freely on the Web and free accessed is strictly limited to registered members.

The vessels accident data that can be obtained *via* the IMO service [24] requires the creation of an account, in return for access free-of-charge, and can only be used within the limits of the restrictions imposed on the service.

Access to the datasets of protected maritime areas that can be found online on the Protected Planet portal [55] is limited to use that is of a non-commercial nature [237] and cannot be obtained without the prior written authorisation of the *UNEP-WCMC*[69] who are the data suppliers. The same restrictions to use that is strictly of a non-commercial nature of [238] hold also for several other online data banks provided by the *UNEP-WCMC, such as the Ocean Data Viewer*[239] *etc.*

In the terms of use of the data [240], the World Weather Online service [126] makes it clear that researchers and developers may not share their API key with other users. The terms of use also indicate that the data are protected by strict copyright terms and must not be distributed, modified or reproduced in part or in whole, without the prior written authorization of the service.

Most of the types of bathymetry data that can be collected from the above-mentioned data sources cannot, in accordance with the restrictions that apply, be used for navigational purposes and, use is permitted, it is for personal use only (a free account is required for this). However, the largest and most precise bathymetry dataset that can be found online which, as has already been mentioned, can be retrieved from the EMODnet bathymetry portal [167], is not subject to restrictions. While it is indicated that the dataset is available to the public; for legal reasons, its source, however, also indicates that the data may not be used for navigation purposes.

The port state control data relating to most of the MoUs, and in particular to the Paris MoU [114], Tokyo MoU [115], Black Sea MoU [119], Caribbean MoU [117], Abuja MoU [118], and Acuerdo de Viña del Mar [116] are accompanied by a statement to the effect that the data may not be used for any commercial purpose, reproduced in any other sites, stored in a retrieval system, or transmitted in any form, or by any means, without the prior authorization in writing of the owners of the data.

The use of the datasets of global, continental and national coastlines in most of the sources is provided free-of-charge on condition that the source of the data is acknowledged. One example is the dataset of the European coastline [241] that is provided by the EEA [134] who are its copyright owners. Also, the maritime borders are provided online without restrictions within the framework of the EUROSION project [157].

Table 3 outlines the most commonly used published licenses for free and open-source data, and the restrictions applying to them in respect of linking, distributing and modifying the data [242]. The data on the Greg's Cable Map [89] are provided under the GNU General Public License v3 (GPLv3). The USGS World Petroleum Assessment [96] requires copyright permissions [243]. The owner of the archeological data provided in [82] states that the data are offered under the terms of the Creative Commons CC-0 licensing. Pleiades [79] states

Table 3
The most-commonly used licenses for free and open-source data[1].

License	Linking	Distribution	Modification
CC-0	Public domain	Public domain	Public domain
CC-BY	Permissive	Permissive	Permissive
CC-BY-SA	Copyleft	Copyleft	Copyleft
CC-BY-NC	Non-commercial	Non-commercial	Non-commercial
GPLv3	With restrictions	Copyleft	Copyleft
OdbL	Copyleft	Copyleft	Copyleft

that sharing and remixing data is permitted under the terms of the Creative Commons Attribution 3.0 (CC-BY) License. The ReefBase [71] states that the data may be used for non-commercial purposes, including research, education, presentations, and non-commercial publication [244]. The FishBase [72] states that its work is licensed under a Creative Commons Attribution-NonCommercial 3.0 Unported (CC-BY-NC) License. The OBIS [68] makes the data available under the Creative Commons licenses CC-0 or CC-BY or CC-BY-NC [245].

The IUCN Red List of Threatened Species [78] states that the public may freely access the data for non-commercial use. The Global Risk Data Platform on Natural Events [143] states that all rights are reserved and none of the materials provided on the website may be used, reproduced or transmitted without permission, in writing, from the publisher [246]. The Quantarctica datasets [183] are freely accessible for non-commercial use. The data from the Copernicus Sentinels Scientific Data Hub [198] are made available to the public for free, with the exception of cases when the E.U. law allows that specific limitations of access and use be placed on them in the rare cases of security concerns, of the protection of the rights of third parties or of a risk that could threaten the disruption of the service. The ESA's Sentinel full online terms and conditions can be retrieved from [247]. The OpenStreetMap open data [203] provided by the OpenStreetMap Foundation [248] are licensed under the Open Data Commons Open Database License (ODbL 1.0). The WELT2000 [149] database is also made available under the ODbL 1.0 license. The data from Wikimapia [146] are provided under the Creative Commons License Attribution-ShareAlike (CC BY-SA).

The E.U. Open Data [213] portal provides the data for free for use and reproduction for both commercial and non-commercial purposes. The Theodora World Pipelines maps [97] include a statement to the effect that all the rights on the data are reserved by its sponsored Information Technology Associates Company. The ESRI Data & Maps [230] data usage policy can be viewed in [249]. For the data hosted by the NOAA's OR & R [110] along with many sources from U.S. data portals [109], [229] specific restrictions may apply for use and reproduction outside the U.S.

7. Conclusions and observations

The relatively new maritime information systems contribute to the understanding, modelling and digital exploration of about 70% of the surface of the Earth which is covered by sea water. The last decade has led to the full recognition of the crucial role played by this new age of decision-support information systems in transportation, the environment, hydrology, meteorology, oceanography, emergency, hazard and disaster management, defense and intelligence, public safety and law enforcement *etc.* When developing such a demanding maritime information system application or research model, obtaining the

[1] A 'Public domain' label states that there is absolutely no ownership such as copyright, trademark, or patent. A 'Permissive' license is subject to some limited requirements, such as crediting the original authors. A 'Copyleft' license allows people to freely copy, modify and redistribute the data as long as they do not keep others from enjoying the same rights.

Table 4
The number of data sources reviewed in the article per maritime geospatial data class.

Maritime geospatial data class		Number of surveyed data sources in the article	Sources in the article with free-of-charge data	
			In number	In percentage (%)
1.	Vessel tracking and monitoring services	9	2	22.2%
2.	Vessels and shipping companies data	9	9	100%
3.	Protected and other sensitive areas	39	39	100%
4.	Marine accidents	10	10	100%
5.	Flags of convenience	2	2	100%
6.	Port state control data	11	11	100%
7.	Anti-shipping activities	1	1	100%
8.	Nautical weather forecast and climate data	12	12	100%
9.	Natural hazards	6	6	100%
10.	Navigational aid systems	1	1	100%
11.	Sea ports locations & facilities	7	7	100%
12.	Essential naval cartographic data	2	2	100%
13.	Maritime borders, coastline and land areas	8	8	100%
14.	Naval bathymetry data maps	7	7	100%
15.	Tides, eddies and sea levels	3	3	100%
16.	Various other geospatial data	26	26	100%
17.	Satellite imagery	5	5	100%
18.	Sources that reach beyond the maritime somain	26	26	100%
19.	Marine conservation organizations	4	4	100%
TOTAL		**188**	**181**	**96.3%**

sufficient amount of the relevant real-world data to make the application or the model work effectively is a crucially important requirement. This article aims to provide comprehensive insights into the exploitation of maritime geospatial datasets available to the public and highlights the fact that the integration of these datasets from the available online open sources will improve the building of efficient maritime GIS advantageously, while the combination of these datasets with other restricted and non-free-of-charge data is also made possible.

To the best of the authors' knowledge this article represents, at the time of writing, the first endeavor to compile a comprehensive survey of almost two hundred carefully selected official online sources, which have been classified under several distinct categories and which can provide an up-to-date thesaurus of reliable high-precision real-world maritime geospatial data on the international global level. These data are resources that form the instrumental backbone of the development, experimental evaluation, tuning and smooth operation of efficient maritime information systems or of the scientific research and education in the field. Table 4 set out a summary per maritime geospatial data class of the number of data sources reviewed in the article.

All the sources[2] have been carefully checked for the availability of the datasets they claim to provide, and all the available geospatial data have been empirically tested and their quality and usefulness verified by the authors, in the expectation that this would save interested parties, whether organizations or individuals (*i.e.* practitioners, researchers, university students or application developers), the trouble and time of doing so.

The article also stresses the need to pay due attention to the legal binds that must be heeded and complied with prior to downloading and using data which are available free-of-charge.

The article is accompanied by a website,[3] which summarizes useful information, when available, pertaining to every data source and dataset to which this work refers. Some of this information, which could not be mentioned in the article, includes *e.g.* the type of the organization providing the data (*i.e.* governmental, corporation, open community, federation, committee *etc.*); the format in which the data are provided by the source (*i.e.* AIS, KML, KMZ, XML, JSON, GeoJSON, GeoTIFF, XLS, CSV, PDF, RSS or GeoRSS feed, ESRI shapefile, text, database *etc.*); the size of the dataset (*i.e.* in number of records or in number of entities – *e.g.* species or ships – under monitoring conditions or in number of stations/sensors that collect and stream the data *etc.*); the region covered (*i.e.* a specific continent, country, sea *etc.*); the time interval in which every spatio-temporal dataset was recorded (from ancient times until today and projection into the future in the cases of forecast data); the web link to the data source or to the download page of the dataset; references to any specific data quality control process applied to the data prior to its online publication, which process in a small number of cases is also described on the corresponding data source; a reference to the existence of any possible API that the source might provide to access the data (together with its corresponding web link for faster direct access); a reference to any relative mobile app that the source might provide; the direct web link to the dataset copyrights terms as well as to the terms and conditions applying to downloading, using and re-publishing the data *etc.* The website also provides searching facilities which make it possible to easily focus on chosen data sources or datasets on the basis of a set of keywords or characteristics *e.g.* bathymetry data for the maritime territory of Japan with no usage restrictions or locations of submerged archeological sites in ancient Europe *etc.* The website will be kept updated with data sources that provide reliable real-world maritime geospatial datasets that might not have been available at the time of writing. Should interested parties using the website know of other official data sources providing genuine maritime data, their contribution to the website is welcome in the spirit of a shared effort for the benefit of the global community, and in view of creating a virtual library of free-of-charge high-precision real-world maritime datasets that organizations and individuals working in the field might visit.

Finally, it is both hoped and expected that the sources recorded in this article, in the light of their importance and nature (*i.e.*, large and credible; governmental or non-governmental; profit or non-profit organizations and agencies, such as the UNESCO or the U.S. NOAA or the -inter-governmental- International Maritime Organization), will persist in making their highly-accurate official datasets available. It is also hoped that they will keep on operating as organizations, and that their activities will not be subject to transformations or changes of priorities that could lead to the removal of these data from their portals. It should be noted that many of these sources do not restrict themselves to the provision of marine data but offer other kinds of credible data, reaching beyond the range of the requirements of

[2] Permanent offline sources and sources with expired web-domains were discovered using the WHOIS search protocol [250] and were not included in the study. A cached view of any temporary offline source can be retrieved through web-cache services, such as [251].

[3] at the address: http://aminess.aegean.gr/papers/maritimegisdata/

maritime information systems (such as digital terrain elevation data of the Earth's dry land), making it thus possible to create and support a wider variety of GIS applications.

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