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MODELING AND IMPLEMENTATION OF BASIC DIGITAL OCEAN CONSTRUCTION FRAMEWORK

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MODELING AND IMPLEMENTATION OF BASIC DIGITAL OCEAN CONSTRUCTION FRAMEWORK

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Key words: digital ocean, framework model, running model, marine green tide disaster application system.

ABSTRACT

This paper presents a new framework for Digital Ocean construction that includes a supporting layer, basic layer, data layer, service layer, application layer, and assurance layer; the functional composition and architecture of each layer are described. The model framework realizes effective integration, exchange, and sharing of marine information, basic geographical information, and closely related economic and social information through open architecture and a standardized service mode. The research results revealed that the proposed framework overcomes the defects inherent in the existing Digital Ocean systems. Therefore, it serves as a basic framework for policymakers, provides unified technical architecture for constructing a Digital Ocean system for use by managers, provides a unified platform for industry users to integrate marine information, and provides an interface for use in developing application systems. The proposed basic framework model for Digital Ocean construction has already been adopted for implementation by the Qingdao Municipal Government in China and has now been extended to Shandong Province. The framework model will be further extended over a broader range.

I. INTRODUCTION

Since former American vice president Al Gore (1998) proposed the concept of Digital Earth, researchers globally have devoted themselves to constructing Digital Earth, Digital Area and Digital City systems. Developed countries (such as European countries and the United States) have begun constructing a digital geospatial framework to promote the extensive-sharing and full utilization of information resources, and remarkable results have been achieved.

The concept of Digital Ocean is an important part of Digital Earth. With a shortage of land resources, the world is turning its focus on the ocean, and an ocean blue economic plan has already been proposed. As a spatial data tool for management and analysis application, GIS technology has been extended from Digital City applications to the ocean field, and related Digital Ocean research is gradually being developed.

However, currently, the construction of Digital Ocean focuses on a single system and lacks a unified framework, which is of importance to such a construction process. The aim of this study was to provide a unified model and standards for the construction of Digital Ocean to overcome the current defects and lack of a united overall framework. This study models the framework for Digital Ocean from the perspective of GIS technology, proposes a Digital Ocean framework model with six layers, each of which is defined. In addition, an operating mode was designed, and an optimization strategy for Digital Ocean was developed.

II. MODELING BASIC FRAMEWORK FOR DIGITAL OCEAN CONSTRUCTION

Digital Ocean is a large and complex system that uses objective marine phenomena as research objects, employs the national information infrastructure (known as the information highway) as its basis, uses marine spatial data infrastructure as its foundation, and is supported by the latest information technology. To enable the constructed Digital Ocean to work scientifically and efficiently, this paper presents a framework for the construction of a Digital Ocean platform (Fig. 1) that contains six logic layers: a key technical support layer, basic layer, data platform layer, service platform layer, application system layer, and standard and norm assurance layer. Of these layers, the basic layer, data platform layer, service platform layer, and application system layer are primarily used to create Digital Ocean structures.

1. Key Technology Support Layer

The key technologies used in a Digital Ocean system provide the technical support for the construction of the system and guarantee the scientific nature of the Digital Ocean system. These key technologies include related data collection, data integration and processing, data exchange and release, multidimensional data visualization, and service system construction technology.

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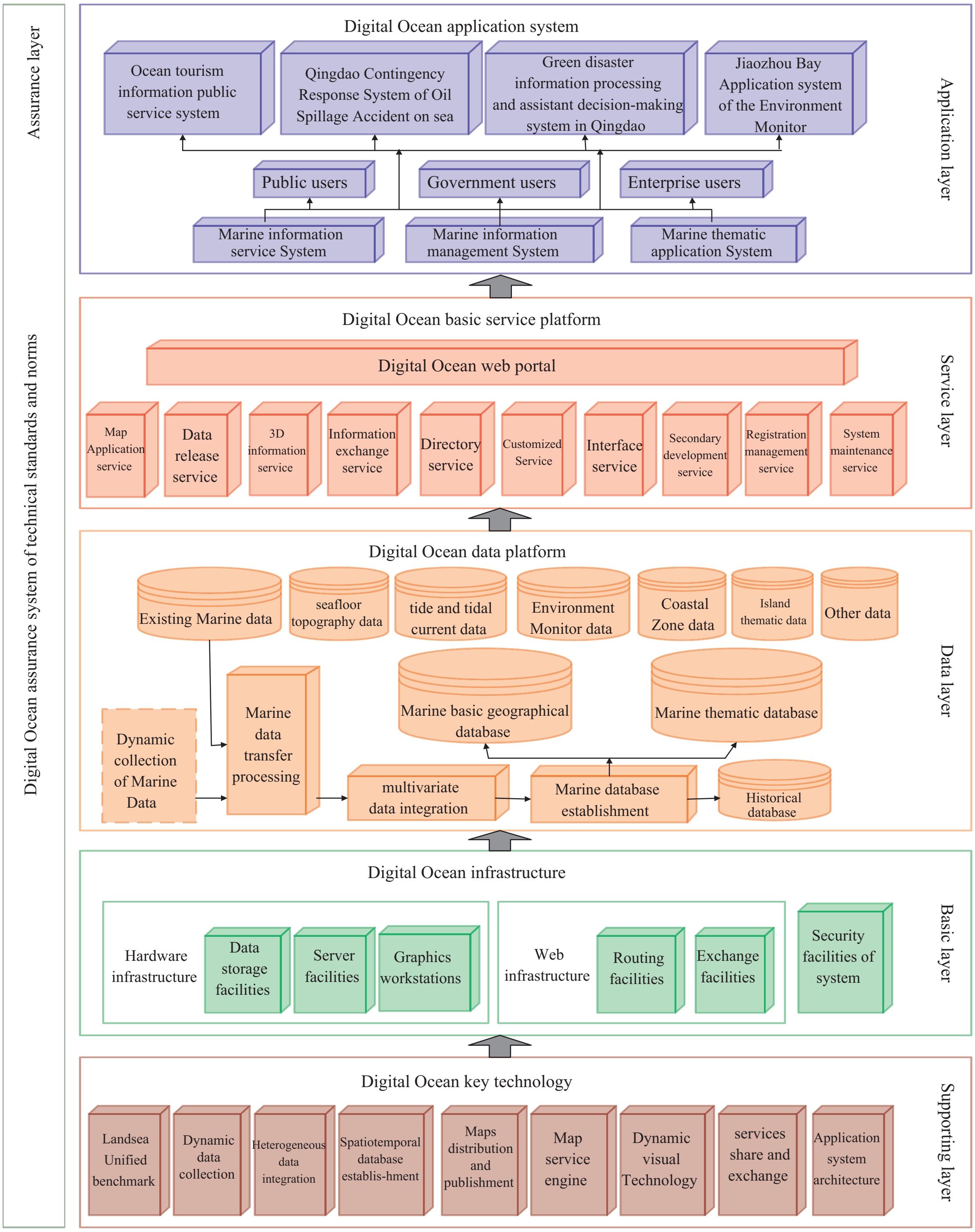

Fig. 1. Framework for Digital Ocean platform construction in Qingdao.

To ensure the smooth implementation of Digital Ocean construction, it is necessary to actively adopt current advanced technology at home and abroad related to the acquisition and processing of ocean data in order to take advantage of universities and scientific research institutions to actively conduct research on technologies involved in the construction of Digital Ocean.

2. Basic Layer

The basic layer mainly involves the infrastructure layer. Digital Ocean infrastructure includes storage devices, server cluster system, graphics workstations, network infrastructure, and security facilities. The storage devices enable the storage and back

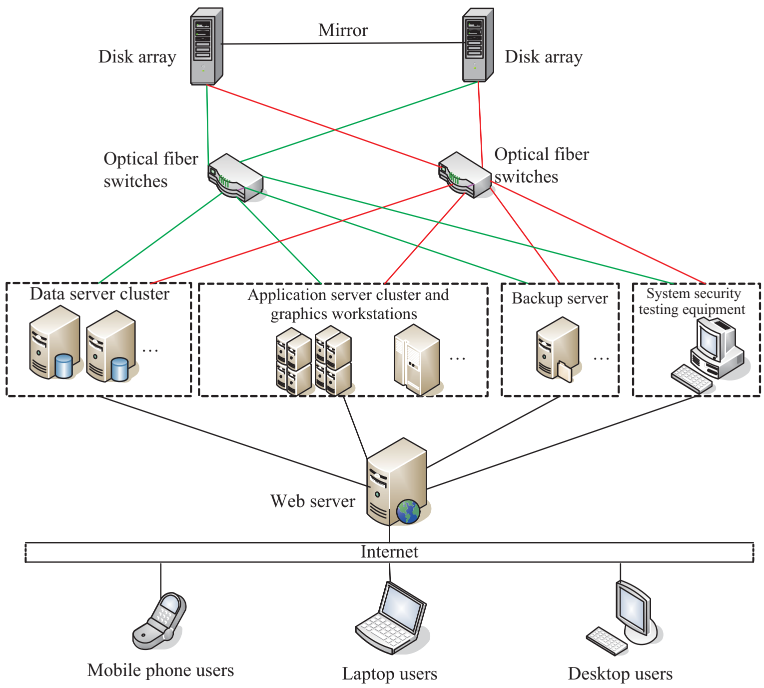

Fig. 2. Structure of Digital Ocean hardware system.

up of mass data. Concurrent processing, managing, and releasing of massive spatial data are conducted in the server cluster system. The graphics workstations achieve remote sensing image processing and three-dimensional marine visualization. The network infrastructure comprises routers and switches. The Digital Ocean platform uses two networking methods: for the marine information service system, which does not involve a confidential service, the Internet is used directly; for the marine information management system and thematic application systems, the E-Government Affairs Network is used. Finally, the security facilities realize the unified configuration and management of security and privacy strategies for the entire Digital Ocean system.

The structure of the Digital Ocean hardware system (components of Digital Ocean System) is shown in Fig. 2. The server connects optical fiber switches through the HBA (Host Bus Adapter) with a dual circuit, and it then connects with a disk array to invoke data and realize a functional response. The data servers and application servers use a server cluster scheme and load equilibrium strategy to achieve the concurrent processing, management, and service issuing of massive spatial data. The backup server then offers load balancing and acts as a rapid transfer service in a disaster situation. The Digital Ocean system must process enormous numbers of images and graphics; therefore, graphics workstations must be employed to optimize service function. The optical fiber switches meet the requirements of high-speed data transmission and backup and achieve integration between the server and storage resources. The storage equipment uses the disk array, is deployed in the SAN (storage area network) mode, establishes an independent data storage area, and realizes mass data storage management and online integrated optimization management. Concurrently, offsite backup systems for separately storing copies of fundamental marine geographic data and data relating to application systems are constructed to prevent accidents that could destroy the data and application systems. The two disk arrays are mirror images of each other, and the two optical fiber switches provide mutual backup to ensure data security from a hardware mechanism perspective. The safety equipment realizes the unified allocation and management of the system security strategy and uses one host to achieve system vulnerability scanning and intrusion detection, thereby ensuring that the entire hardware system is safely and stably operated.(End of writing checking)

3. Data Layer

The data layer comprises both a database system and a database management system for marine geographic information, and it was constructed in accordance with uniform technical standards and specifications. It can convert and integrate multisource data collected by marine-related sectors with existing marine data. The data layer provides marine spatial data for the service and application layers and is the core of the Digital Ocean platform. The data layer uses dynamic database technology to enable time and space management. Dynamic database technology is based on the "Version and Spatio-Temporal Increment" data model proposed by the authors, which includes both "the current database" and "the historical version database". This data management mechanism can restore the latest data by adding data increments from a given moment to the historical data. Marine data are inherently dynamic and represent spatiotemporal changes and processes; therefore, recording data moment-by-moment would inevitably lead to an increase in the total amount of data. The dynamic database management mode

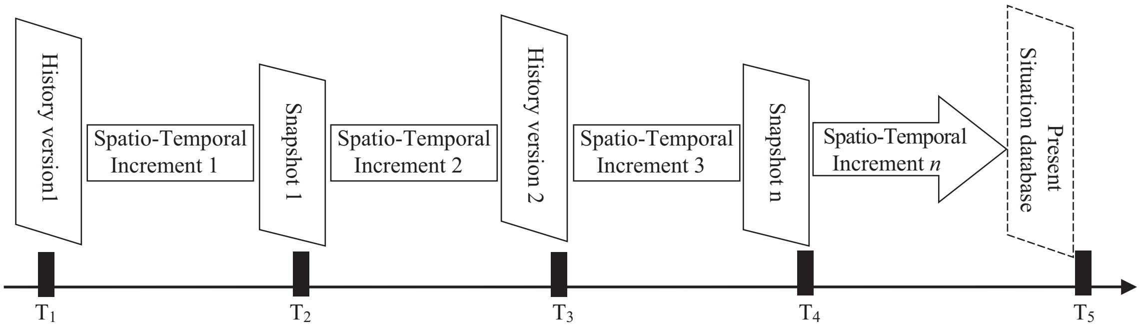

Fig. 3. "Version and Spatio-Temporal Increment" data model.

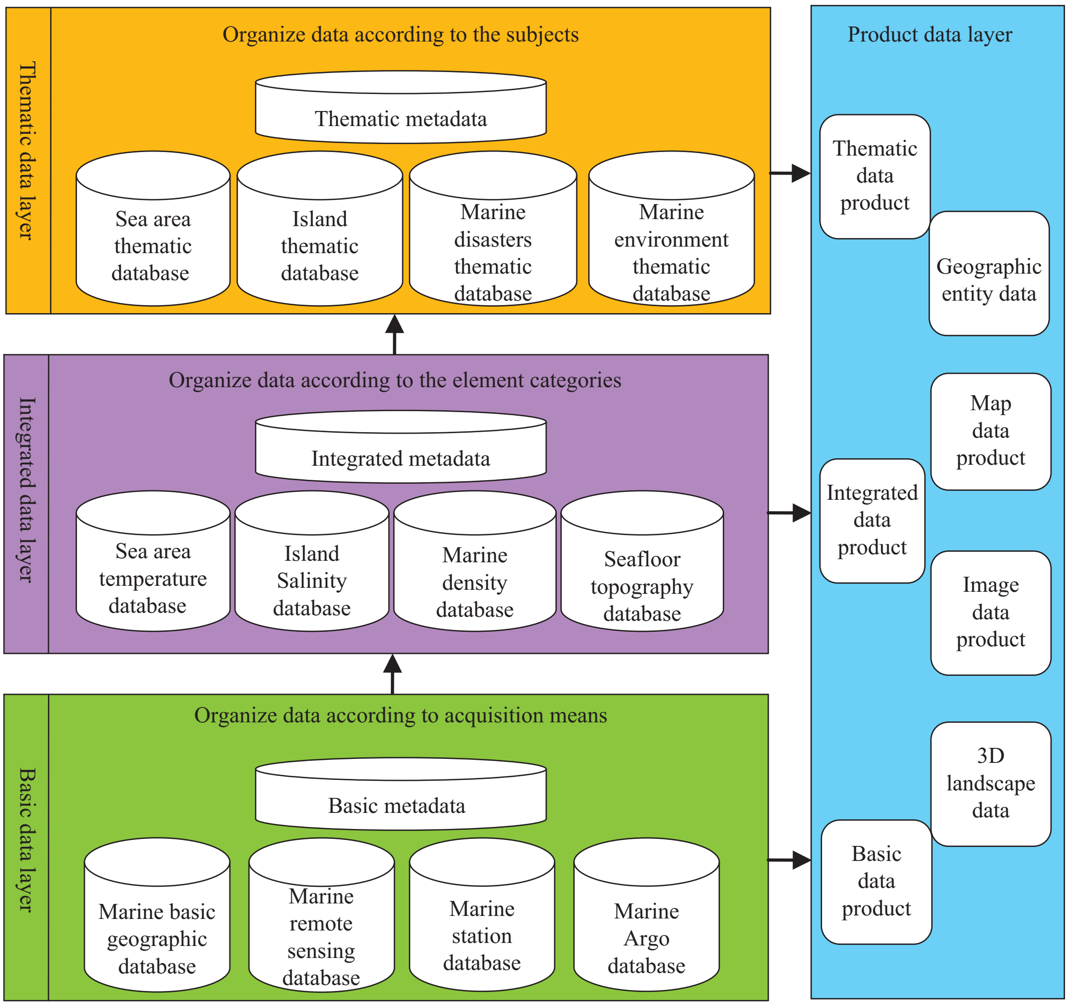

Fig. 4. Data system for Digital Ocean platform.

based on the "Version and Spatio-Temporal Increment" data model (Fig. 3) not only enables managing historical data but also facilitates reducing data storage redundancies. The data system for Digital Ocean consists of four levels, the hierarchy of which is shown in Fig. 4.

(1) Basic data layer. The basic data layer organizes data according to source, such as basic marine geographic data, marine remote sensing data, station data, BT (Bit Torrent) data, and Argo (Array for Real-time Geostrophic Oceanography) data. These data, which are collected through various methods, are stored in different formats, such as binary files, text files, image files, and XML (Extensible Markup Language) files, and can be converted to the format compatible

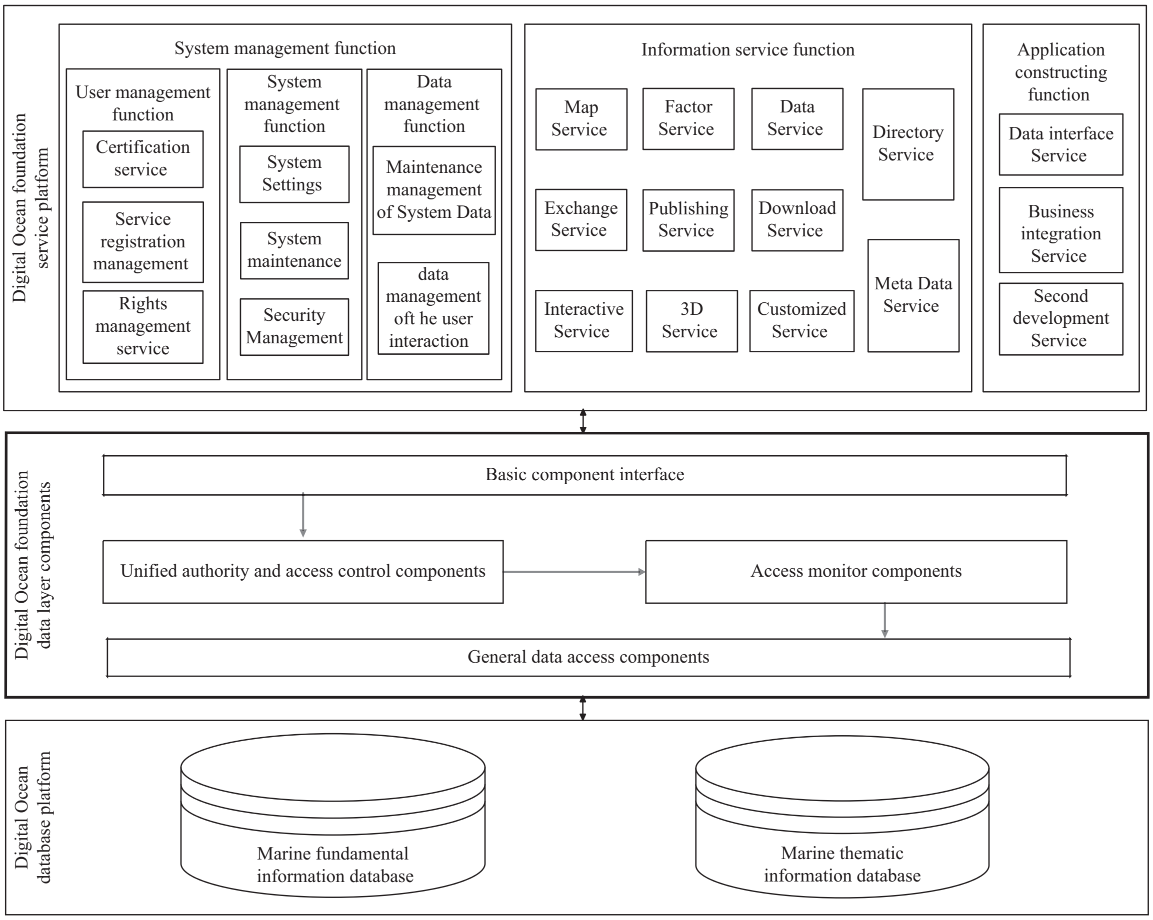

Fig. 5. Function structure of basic service platform.

with the basic data layer. The basic data layer also includes metadata, which describe the content, structure, and access methods of the basic marine data.

(2) Integrated data layer. The integrated data layer organizes data according to element categories as follows: ocean temperature data, ocean salinity data, marine density data, seafloor topography data, and integrated metadata. The integrated layer preserves data that have been processed by cleaning and conversion, and it provides data support for high-level data analysis and decision-making.

(3) Thematic data layer. The thematic data layer organizes data according to subjects of application as follows: marine area thematic data, island thematic data, marine disaster thematic data, marine environment thematic data, and thematic data metadata. The thematic data layer contains a thematic database. Data in the thematic database have been processed by means of extraction, expansion, integration, restructuring, fusion, and comprehensive analyses.

(4) Product data layer. The product data layer is a data product generated from the aforementioned three-level data. The product data layer includes geographical entity data, image data, map data, and 3D (three-dimensional) landscape data.

4. Service Layer

The service layer comprises a series of standard service interfaces, modes, online service systems, and maintenance management systems. As an online Digital Ocean service system, the marine geographic information web portal offers numerous types of basic services to users, such as map application services, data release services, services, information exchange services, customized services, certification services, directory services, metadata services, interface services, registration services, and second development services. The service layer is a basic service platform suitable for discovering, using, deploying, registering, and developing the service and application of Digital Ocean systems. It can flexibly and effectively meet user needs with respect to obtaining Digital Ocean information, sharing online, and quickly constructing a distributed thematic system. All marine-related departments can make full use of this platform, which enables them to assemble and develop their own applications and release their own services. The functions and structure of the service layer are presented in Fig. 5.

5. Application Layer

The application layer comprises all types of thematic ap-

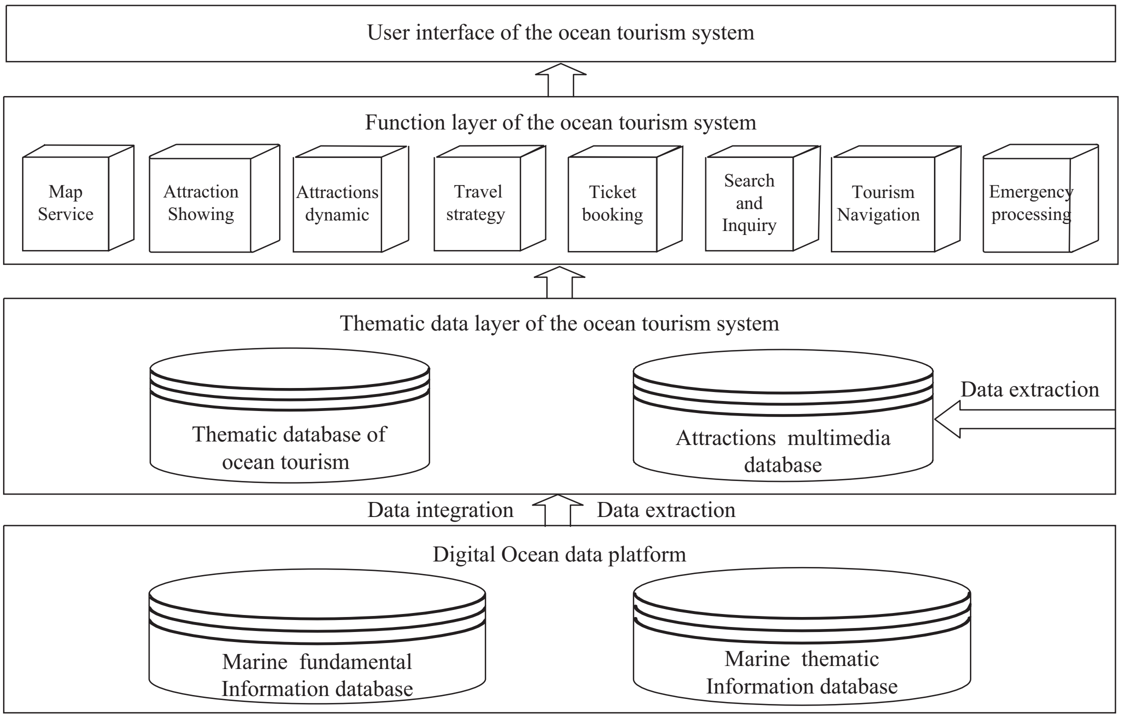

Fig. 6. Functions and structure of ocean tourism demonstration system.

plication system sets of Digital Ocean realized by the second development based on the service layer. The marine thematic application system includes the following: marine resource management information system, marine environment protection information system, sea-area management information system, coastal zone management information system, auxiliary decision system for marine disaster prevention and reduction, marine disaster warning and emergency system, marine law enforcement information system, marine engineering evaluation and decision support system, ocean information public service system, island thematic information system, and marine 3D simulation and display information system. Constructing and improving the application layer is a long-term process. In the earlier development stage of Digital Ocean, demonstration application systems that were urgently required should firstly be constructed, such as a public information service system for ocean tourism, marine disaster emergency management and decision support system, marine environment monitoring application system, emergency management system for marine oil spill accidents, and marine fishery information management system. The functions and structure of the public information service system we have developed for ocean tourism are shown in Fig. 6.

6. Assurance Layer

The assurance layer refers to technical standards, technical specifications, policy mechanisms, and management measures related to Digital Ocean construction. The technical standards and norms of the assurance layer run through the other layers of the Digital Ocean system and mainly include data standards, service standards, application standards, and other standards.

Data standards relate to standards required for collecting, converting, processing, storing, maintaining, and updating ocean data and public geographic framework data. The standards and specifications involved are outlined as follows: GB21139-2007 specifies basic requirements for standard data of fundamental geographic information, CH/T9005-2009 gives basic specifications for fundamental geographic information database, HY/T136-2010 gives marine information metadata, and IHOS100 is about the universal hydrographic data model.

The service specifications are a series of standards related to the sharing of data and the basic services of the Digital Ocean platform, and some of these standards are outlined as follows: “OpenGIS Web Feature Service”, “OpenGIS Catalogue Service”, “OpenGIS Web Map Service” (WMS), CH/Z9011-2011 “Platform for geoinformation common services-Data specification for electronic map”, CH/T9003-2009 “Basic specifications of geospatial framework”, CH/T9004-2009 “Basic specifications for common platform of geographic information”, IHOS57 “Transfer Standard for Digital Hydrographic Data”, and GB12319-1998 “Symbols, abbreviations, and terms used on Chinese charts”.

The application standards are related to standards, norms, and guidance documents for the Digital Ocean platform and its thematic application, and some of these standards are outlined as follows: “OpenGIS Web Coverage Service”, “OpenGIS Web Processing Service”, “Guiding opinions on strengthening the construction and application of geospatial framework for Digital China”, ISO 1910 “Geographic Information Rules for Application Schema”, and “Platform for geoinformation common services-application specifications for common service of geographic information”.

The other standards are criteria and specifications for other software and hardware used by the Digital Ocean platform, including network standards and safety standards, as well as standards related to the platform operation mechanism.

III. RUNNING MODES OF DIGITAL OCEAN PLATFORM

1. Platform Docking Mode

The Digital Ocean platform was designed as a multistage distributed and sharing service model. The Digital Ocean web portal is the master node: in the horizontal direction, it enables data exchange and resource sharing among marine-related departments and simultaneously opens spatial information data closely related to daily life for public; in the vertical direction, it connects the basic geographic information platform or Digital City data center at all levels of government through sub-nodes. The network operates two node types. The first node releases unclassified information to the community through the ordinary wide area network (WAN) (through the web portal of the Internet); the second node releases thematic data to professional users through the government affairs network.

2. Data Storage Mode

Digital Ocean system data are stored in the distributed mode. Fundamental geographic data sets are stored in the Digital Ocean management center. As the only authoritative department, the Digital Ocean management center is responsible for updating basic data, auditing the accuracy and completeness of data uploaded by departments, and setting and approving service permission to each department. Digital Ocean thematic data are distributed and stored in marine-related sectors, and each sector can release thematic data using the data creation tools provided by the Digital Ocean system. The Digital Ocean management center registers data and services released by sectors through the Digital Ocean registration center with the aim of aggregating all open geospatial consortium (OGC) standard services. These standard services are then published in a unified directory. Thus, repeated construction of the marine GIS application system within sectors can be effectively reduced.

3. Information and Service Exchange Mode

The Digital Ocean system should be constructed and operated according to international standards. Therefore, the information and service exchange modes should be constructed according to marine and internet standards, such as the geographic information classification and coding standards, application framework sharing standards, and OGC service standards. If this is achieved, data and services can be proficiently exchanged and shared. Through data exchange orders, marine-related departments can realize the management of data applications, checks, and approvals with respect to the Digital Ocean system.

IV. PERFORMANCE OPTIMIZATION STRATEGY FOR DIGITAL OCEAN SYSTEM

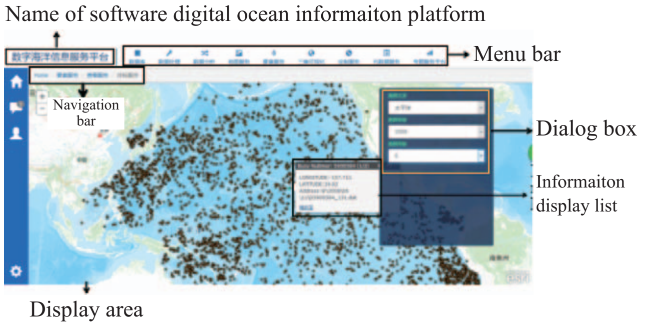

Fig. 7. Digital Ocean basic information platform.

The performance optimization strategy for the Digital Ocean system includes the enhancement of rapid response operations, optimization of concurrent operation performance, and achievement of platform stability and reliability. Many methods were proposed to achieve this, and these methods were developed step by step in line with construction of the platform.

(1) Rapid response strategies for marine information services include efficient spatial data indexing technology based on space-time integration coding and spatial multilevel indexes, adaptive scheduling technology, and multi-scale progressive transmission technology.
(2) Use a map service strategy based on server cache, flexible cache access technology, and a high-performance application server dynamically to improve the amount of time spent displaying complex maps.
(3) Asynchronous treatment technology shortens the server response time. Parallel computing and multithreading increase task processing speed.
(4) Advanced algorithms and virtual machine technology address load balancing problems for the server cluster and improve the concurrent operational capability for users.
(5) Use an optimized software structure, redundant hardware design, and detailed running log records to ensure the stability and reliability of the Digital Ocean system.

V. EXPERIMENTAL RESULTS

Constructing a Digital Ocean system is a long-term systematic process with strategic and prospective features. Although Digital Ocean construction in China is currently in its infancy, the basic framework for Digital Ocean construction presented in this paper has been adopted for implementation by the Qingdao Municipal Government in China. The hardware system is now nearly complete, and the software platform for the Digital Ocean system was developed (as shown in Fig. 7 with English annotations). Its main interface includes nine main menus, which are (from left to right) the database, data processing, data analysis, map service, elements service, 3D visualization, customized service, metadata service, and thematic service platform. The current screenshot shows the interface of the buoy service displayed by clicking on the "feature service" menu and then

Fig. 8. Data format conversion in "data processing" menu.

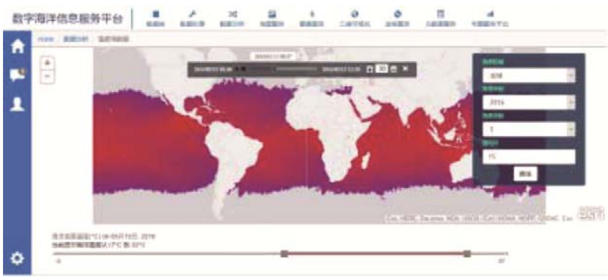

Fig. 9. Data analysis function in temperature field.

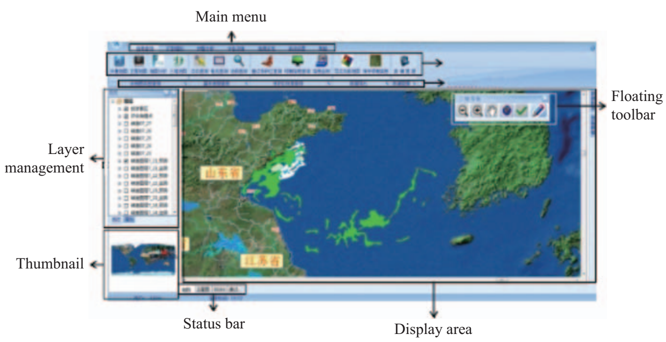

Fig. 10. Main interface of green tide information monitoring system.

selecting the "view service" submenu. When selecting values for "Sea area," "Year," and "Month" on the right side of the dialog box, the distribution of buoys in the Pacific Ocean in June 2008 is displayed. The screenshot of the data format conversion function in the "data processing" menu is shown in Fig. 8, and the screenshot of the data analysis function for the temperature field in the "data analysis" menu is shown in Fig. 9.

Based on this platform, the function of the application layer was expanded, and a Green Tide Information Monitoring and Evaluation System was developed for green tide natural disasters in Qingdao. This system deals with information queries, diffusion simulations, early warning analyzes, risk assessments, information release, and other functions about green tide disasters. It played a positive role in the prevention and control of green tide disasters along the east coast of Qingdao in 2015 and 2016. Fig. 10 shows the main interface of the software system (with each area of the interface annotated on the screenshot). The menu bar at the top of the interface includes seven menus,

Fig. 11. Diffusion analysis of green tide.

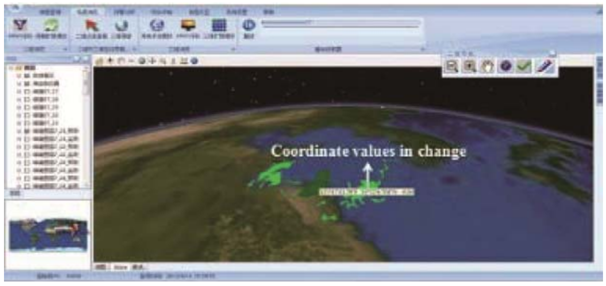

Fig. 12. Dynamic simulation of green tide.

which are (from left to right) "information query," "diffusion simulation," "early warning analysis," "evaluation and decision-making," "information release," "system settings," and "help." Clicking on the "information query" menu reveals five submenus: "multimap type query," "basic information query," "information query of reserve area," "data export," and "data management." Clicking on "multimap query" and selecting the different layers in the layer management area on the left side of the interface displays the green tide disaster zone in the form of charts, satellite maps, and a 3D view, as enables the observation of the distribution of green tides in the study area from different angles.

On July 17, 2016, a large expanse of green tide originating from the shallows of Northern Jiangsu arrived in non-tourist areas on the southeast coast of Qingdao. Its initial scope stretched 2 km and then gradually expanded and impacted the coastal environment. Green tide information management, a display of its distribution, dynamic simulations, evaluations, and rescue planning, has been achieved by adopting the green tide information monitoring and evaluation system presented in this paper. Remote sensing monitoring data and on-site monitoring data of green tides were added to the database after preprocessing, and data are updated every 12 h. Combined with base maps, such as satellite maps and charts, the distribution of green tides could be monitored in a timely manner through the function of "green tide query and display." Selecting parameters such as sea area, time, wind direction, and wind class could enable the software system to provide a dynamic diffusion simulation of green tides in order to determine the diffusion direction and paths of green tides, thus enabling the prediction of their distribution. The function interface for the diffusion simulation of green tides is shown in Fig. 11 (which is enlarged for clarity). The function interface for a 3D dynamic diffusion simulation

Fig. 13. Sensitivity analysis of ecological health status.

Fig. 14. Scheme for green tide salvage.

of green tides is shown in Fig. 12 (where the pop-up box shows changes in coordinate values).

The loss assessment function of the developed software involves three types of assessments: ecological health, travel loss, and biological loss assessments. For example, when considering an ecological evaluation, the pollution level, number of salvage ships, and interception range can be seen and planned according to the *Enteromorpha* distribution area, wind field, temperature, and other conditions. The running interface of the ecological evaluation function is shown in Fig. 13, and it can be used to assess the regional sensitivity of a green tide disaster and display this using a hypsometric layer. Using the GPS function of a mobile phone on the salvage ship can yield location information in real time and thus enable monitoring the position of the salvage ship. Through this information, the salvage ship can be efficiently dispatched to maximize resource utilization and to improve the salvage efficiency for the green tide. According to the moving trend of *Enteromorpha*, the regional effect can be determined and analyzed, priority re-floatation or interception in some key areas can be initiated, and plans for the optimum routes of salvage ships and their numbers can be formulated. Fig. 14 shows the function interface of re-floatation, indicating inputs of the radius of the re-floatation area, the number of salvage boats, and other parameters; according to these input parameters, the re-flotation routes can be calculated and displayed.

The information release function of the software adopts "socket" technology; the mobile terminal uses the "server socket" to monitor designated ports; and the client uses "socket" technology

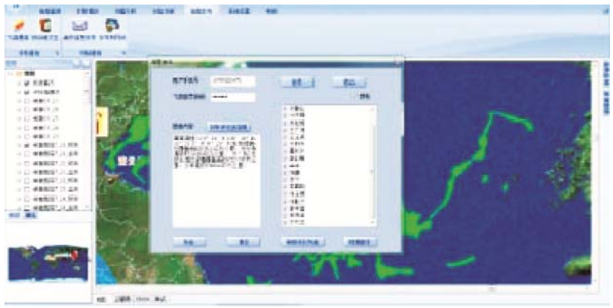

Fig. 15. Information transmission to phone.

to send a connection request to one of the ports on the network, which, if successful, automatically opens the dialog and implements cross-platform information interaction. The function interface for information release is shown in Fig. 15, which includes four methods of release. If selecting the Fetion method, input the contents for publication (including time, place, and description of green tide disaster) and select "publish object"; disaster information is then released. However, due to the space limitations of this paper, individual explanations of all the other functions cannot be provided.

The software system described in this paper was developed by the authors, and it has now been developed and tested for use with the Digital Ocean system of Qingdao. Interested readers can send emails to liulin2009@126.com if they require further information.

In summary, this paper proposes a basic framework for Digital Ocean construction, which includes six logical layers, and presents its operational mode and performance optimization strategies. Experimental results of the Digital Ocean application system, which was developed based on this framework, are also demonstrated. The results are significant and beneficial for the smooth development and scientific implementation of Digital Ocean construction.

VI. CONCLUSIONS

Although Digital Ocean systems are currently being constructed globally, such constructions are isolated with no unified framework. Existing business data are not normalized, and standards are not unified; therefore, ocean "information island" phenomena exist, which can lead to difficulty in using data effectively. In addition, the software function of current Digital Ocean systems is limited and may struggle to meet the demands of marine management. These issues are not conducive to the expansion and integration of systems, nor to promote achievements. However, this research presents a complete model framework for Digital Ocean construction with respect to supporting technology, hardware facilities, data management, a basic platform, an application system, and safeguard measures. The hardware layout and software interface of the complete framework were developed in accordance with existing marine-related standards. Thus, the system can be not only expanded and integrated into the national system upward but also extended downward to grassroots administrative regions, such as those related to cities and counties.

The research results provide a basic framework of Digital Ocean construction for policymakers, a unified technical architecture for managers, a unified information integration platform, and a developing interface for professional users. The research findings and test results reveal that the framework is innovative and overcomes the defects inherent in existing Digital Ocean systems. The framework has been successfully applied in Qingdao and extended to Shandong Province, and it will be expanded over a broader range in the future.

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