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Analysis-enhanced virtual globe for digital earth

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Virtual globe has been recognized as an appealing technology to support the digital earth. It provides an intuitive and appealing way to visualize geospatial information, and is being used frequently to bring the globe-scale geospatial information to our fingertips. The easy access to virtual globes such as Google Earth, Microsoft Virtual Earth, and NASA World Wind allows both the general public users and professionals to use them for educational and research purposes. While virtual globes provide a number of functions for geospatial data visualization and annotation, the geospatial analysis functions available in the current virtual globes are limited. This paper addresses an approach to the establishment of an analysis-enhanced virtual globe. The approach is based on the integration of virtual globe and interoperable geoprocessing services. Such an analysis-enhanced virtual globe combines the visualization and communication power of virtual globes with the conventional powerful analysis functions of GIS, thus meeting the analysis demands in digital earth.

virtual globe, digital earth, geoprocessing service, GIS, GeoGlobe, GeoPW

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1 Introduction

Digital earth, a vision firstly proposed by former U.S. vice-president Al Gore in 1998, has been involved into a global initiative aimed at harnessing the world's data and information resources to develop a virtual three dimensional model of the earth in order to monitor, measure, and forecast natural and human activities on the planet [1]. The recent popular virtual globe software systems such as Google Earth, Microsoft Virtual Earth, and NASA World Wind provided elegant technologies and fresh life for Gore's dream after Gore lost the 2000 US presidential election [2]. In China, various virtual globes software systems exist, including GeoGlobe, EV-Globe, China Star, and GeoBeans3D. A virtual globe software system is capable of letting users freely fly anywhere on a virtual earth, with different views of the earth such as satellite imagery, geographical features, terrain, 3D buildings, and advanced stars, atmosphere or sunlight effects. It allows users to add annotations, fuse heterogeneous geospatial data from multiple sources, conduct network-based local-to-global multi-resolution visualization, and share data with others. Thus, it revolutionizes the traditional way of using geospatial information, making geospatial information easily accessible and usable by general public users instead of only domain experts. Millions of people across the world are using these software systems in their spatial exploration, and scientists are already experimenting with these tools to show their research to the public [3].

While virtual globes provide a number of functions for geospatial data visualization and annotation, the geospatial analysis functions available in the current virtual globes are limited. Once educational and scientific users become to enjoy the three dimensional visualization provided by virtual globes, they will need powerful analysis beyond the

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straightforward visualization. The rapid development and employment of sensors and platforms has demonstrated powerful data collecting capabilities. The four satellites of National Aeronautics and Space Administration (NASA)'s Earth Observing System (EOS) currently collect 1000 terabytes annually, far more than earth scientists can hope to analyze [4]. Geoscientists are experiencing a data-rich yet analysis-poor period. The vision of digital earth is not limited to the discovery of and access to the global geospatial data, and should include the analysis of these data. Through many years' development, traditional geographic information system (GIS) software has accumulated lots of powerful analysis functions. These analysis functions can be incorporated into existing virtual globe software to help test scientific hypotheses or enable new scientific findings in a more intuitive and natural way.

This paper proposes an approach to the establishment of an analysis-enhanced virtual globe. The approach is based on the integration of virtual globe and interoperable geoprocessing services. The geoprocessing services are provided by GeoPW, a set of services wrapping legacy GIS analysis components to provide the Open Geospatial Consortium (OGC) web processing service (WPS) interface. In the geospatial web services area, OGC is the only organization working on developing geospatial web services standards by adapting or extending the common web service standards. The analysis-enhanced virtual globe combines the visualization and communication power of virtual globes with the conventional powerful analysis functions of GIS, thus meeting the analysis demands in digital earth. The results were tested through the GeoGlobe system, a leading enterprise virtual globe software system in China. The remainder of this paper is organized as follows: Section 2 introduces the literature in this field; Section 3 presents the functional requirements and approaches for an analysis-enhanced virtual globe; Section 4 describes the architecture design and Section 5 describes the system implementation details; conclusions are given in Section 6.

2 Related work

Digital earth has received a substantial research ever since Gore's proposal in 1998. On Nov. 29th to Dec. 2nd 1999, China initiated the first international symposium on digital earth in Beijing, sponsored by 19 ministries and organizations. Until now, the International Symposium on Digital Earth has been held six times in different countries. In 2006, an international society for digital earth was established to promote international cooperation on the digital earth vision, and enable the digital earth technologies to play key roles in various natural and human society issues. Virtual globe has been identified as an important technology towards the implementation of digital earth. Ever since the publishing of Google Earth software in 2005, numerous virtual globe related applications are emerging [5]. The easy to use, visually appealing, and high performance characteristics make virtual globe more acceptable and effortless to the general and scientific users than conventional and professional GIS software. As more users experience virtual globe, GIS is known to more people.

While virtual globe provides an excellent visualization experience, most current virtual globes have no or few analysis functions. As commented by Jack Dangermond, the founder and president of the Environmental Systems Research Institute (ESRI), the world's largest creator of GIS software, Google Earth opens up GIS world and "business is booming" [2]. GIS companies are eager to capitalize on Google Earth's success [2]. ESRI now releases a free visualization tool, ArcGIS Explorer, which can not only visualize GIS information, but also perform spatial analysis. The spatial analysis functions in professional GIS software have been developed for over decades and thus are integrated with virtual globe to make it more powerful. However, the business GIS software or improved virtual globes cannot support an open analysis environment. The analysis functions can only be used in their own proprietary environments.

With the evolvement of the web and wide applications of web service technologies, service-oriented architecture (SOA) has shown great opportunities for scientific research. The term "service-oriented science" was proposed to refer to the scientific research enabled by distributed networks of interoperating services [6]. Processing heterogeneous and distributed data into information requires interoperability among diverse data. This necessity led to the development of a set of standard interfaces for geospatial web services, and a number of interoperable services have been available in the geospatial community. Most of these services are compliant with the OGC standards such as Web Feature Service (WFS), Web Map Service (WMS), Web Coverage Service (WCS), WPS, and Catalogue Service for Web (CSW). These web service technologies, especially those standards-based interoperable geospatial services, make a large amount of geoprocessing functionalities easily accessible to educational users and researchers like their local resources. In the geospatial web service context, the analysis functions are called geoprocessing functions. In fact, the term "geoprocessing" has a broader meaning than traditional analysis functionalities in GIS and can refer to any sort of geospatial processing or analysis functionality. For example, it can include computational models such as an earth system prediction model that is not available in traditional GIS. However, in the context of this paper, these two terms are used interchangeably.

3 Functional requirements and approaches

The vision of digital earth is not limited to a representation of virtual planet. It will bring the analysis power into the planet system to help compute and predict natural and human activities on the planet. An analysis-enhanced virtual globe would address the demands of digital earth for both easy perceiving the geospatial world and ready use of computational models or processes to explain or predict geospatial phenomena. In a service-oriented environment, the key challenge is then how to integrate virtual globe and geospatial web services to implement a plug-and-play analysis-enhanced virtual globe. Such a plug-and-play system depends on the use of standards-based interoperable services.

From the viewpoint of SOA, the use of services follows the "publish-find-bind" paradigm. The individual geoprocessing services are published into the service registry. The geoprocessing requestor is able to find geoprocessing services through the registry. When appropriate services are located, the requestor can bind and assign geoprocessing tasks. In a distributed environment, a complex geoprocessing task may include services coming from multiple service providers. A geoprocessing model that contains multiple geoprocessing steps will be bound to an executable service chain or concrete workflow. A virtual globe is composed of servers and clients. Therefore, the main focus for development is how to enable virtual globe servers and clients to coordinate with the provider, registry, and requestor partners in SOA.

The following outlines the functional requirements of building a plug-and-play analysis-enhanced virtual globe and the approaches to implement these requirements.

Making virtual globe data easily accessible through standards-compliant interface: The data located at the virtual globe servers are accessed by virtual globe clients through proprietary protocols. The data are usually organized in hierarchical tiling structures and transmitted progressively in different resolutions. In geospatial domain, standards for geospatial data services already exist. Thus to allow interoperable geoprocessing services to access the data managed by virtual globe, it is necessary to provide standard interfaces to virtual globe data providers, wrapping virtual globe data servers as OGC standards-compliant services.

Discovery of distributed services: There will be many service providers in an open, distributed environment. The key actor in SOA, i.e. broker, is used to register and publish metadata information of services, and then provide the functionality of service discovery. Therefore, technologies relating registry services can be introduced to provide the registry and discovery of geospatial services. In the geospatial domain, the OGC CSW has provided standard interface and protocol for a metadata catalogue service, and thus can be used to provide this discovery function.

Geoprocessing service chaining: In a service-oriented environment, where large volumes of geospatial data and diverse geoprocessing functions are accessible as services, it is necessary to create service chains as geoprocessing workflows to solve complex geospatial problems. A service chain can be represented using control flow and data flow between a sequence of dependent services. The control flow specifies the locus of control moving through the services. It concerns about the order of (atomic) services, while data flow focuses on the data exchange among the services. Existing service composition language such as the Web Services Business Process Execution Language (WSBPEL) can be used for description of service chains.

Geospatial process modeling and knowledge sharing: In the knowledge discovery aspect, raw data can be transformed into the knowledge-added data product through the geoprocessing workflow, for example, a landslide susceptibility image, generated from the workflow processing the digital elevation model (DEM) data and Landsat enhanced thematic mapper (ETM) imagery, is a product from knowledge discovery. The process model of a geoprocessing workflow represents a high level geospatial knowledge. It is an abstract composite process model consisting of the control flow and data flow among process nodes. Each process node represents one type of many individual services that share the same functional behaviors such as functionality, input, and output. Such a process model can be mapped to an executable service chain dynamically. Both the existing process models (either atomic or composite) and developed process models can be shared as knowledge and support decision making.

Client integration: When functional requirements mentioned above are satisfied, the functions provided are integrated into the virtual globe client to support plug-and-play analysis. The approach to client integration is to follow the "publish-find-bind" paradigm in the SOA. Geoprocessing services providing analysis functions can be discovered from registration centers. If no services are available to meet the analysis demands, service chaining tools can be used to create geoprocessing workflows. The invocation results of geoprocessing services or service chains can be overlay with the data in the virtual globe for efficient and intuitive spatial explorations.

4 Architecture design

The architecture of an analysis-enhanced virtual globe follows the service-oriented architecture and is designed to meet the functional objectives mentioned in Section 3. Figure 1 shows the proposed architecture of the integrated system. The central part is the integration of web services and virtual globes. Such integration takes place at two key points.

The first one is to integrate geospatial web service servers and front-end of virtual globe servers, making data managed by virtual globes accessible through geospatial web services. This involves the implementation of OGC data service protocol access to virtual globes-managed data. OGC

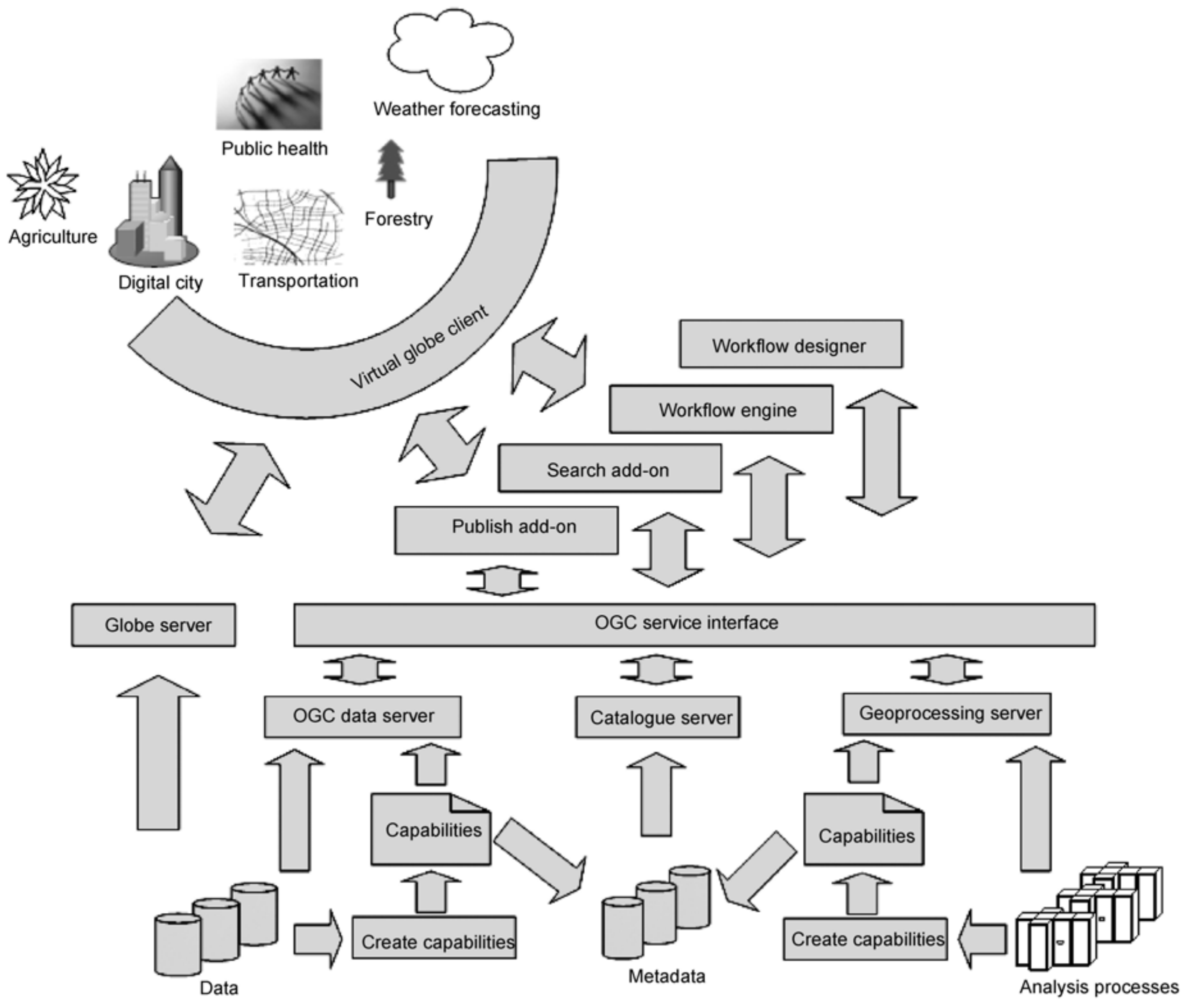

Figure 1 The architecture design of an analysis-enhanced virtual globe.

web data service protocols such as WFS, WMS and WCS allow geospatial services and value-added applications to access diverse data provided by different providers in a standard way without worrying about their internal handling of data. A standard operation provided by OGC data services is the GetCapabilities operation that provides capabilities of the services including both invocation details of services and meta-information of data provided by services. Therefore, such metadata are generated for data managed by virtual globe servers and stored in the capabilities document. The metadata can be harvested by the metadata catalogue (e.g., CSW) to facilitate discovery of data. The standards-compliant data services make geospatial data managed by virtual globes be easily accessed and processed by other geoprocessing services or clients, thus supporting geoprocessing service chaining and client integration.

The second one is to make geospatial web services accessible through clients of virtual globes. This involves the implementation of access from virtual globe clients to geospatial web services and services integration. OGC has developed a series of interface specifications following this paradigm. In addition to OGC web data service protocols, OGC WPS can provide conventional GIS analysis functionalities over the web. The capabilities of geoprocesing services, accessed also by standard GetCapabilities operation, provide the geoprocessing functions. The meta-information of geoprocessing services is registered into the metadata catalogue. The registry service, i.e. OGC CSW, provides the discovery not only on the services, but also on the geospatial data. Virtual globes, therefore, should be able to discover, bind and invoke these standards-based interoperable services. Such functional requirements are implemented through various add-ons such as publish and search add-ons into the virtual globe clients. The applications in different domain such as agriculture, digital cities, or transportation are complex and may require integration of multiple geoprocessing functions. Therefore, service chaining capability is needed to integrate into virtual globes. The geoprocessing service chaining and geospatial processing modeling capabilities can be supported by additional virtual globes add-ons such as workflow engine and workflow designer.

5 Implementation

To implement the analysis-enhanced virtual globe, GeoGlobe system is used and integrated with geospatial web services. OGC standards and technology specifications for geospatial data, service and system interoperability are adopted in implementation for promoting data, functional services, and system level interoperability. OGC specifications are widely used by geospatial communities for sharing data and resources and are becoming standards in the International Organization for Standardization (ISO). For standards that are not available at OGC, the work adopts standards from the World Wide Web Consortium (W3C) and Organization for the Advancement of Structured Information Standards (OASIS), since the standards developed by these international bodies are widely used. These standards allow seamless discovery of and access to geospatial data in a distributed environment and provide the technology foundation for developing interoperable web services and workflow management.

5.1 Development of geoprocessing web services

The geoprocessing services are implemented through developing middleware wrapping the conventional powerful analysis functions of GIS. An open web service toolkit, named GeoPW, has been implemented [7]. It leverages web services, legacy GIS software, and OGC specifications to make traditional desktop analysis functions configurable, accessible, and interoperable over the web.

The legacy GIS components include analysis utilities of GIS software systems GRASS and GeoStar. The geographic resources analysis support system, commonly referred to as GRASS GIS, is one of the most widely used open source GIS software systems. GeoStar is a leading enterprise GIS software system in China. It has been developed by the State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing (LIESMARS), Wuhan University (formerly Wuhan Technical University of Surveying and Mapping) since 1992 [8].

Based on the geoprocessing functions provided by GRASS and GeoStar, GeoPW has already developed over one hundred geoprocessing services, which follow the OGC WPS standard. The standard operations are GetCapabilities, DescribeProcess, and Execute. These services provide geoprocessing functions including vector spatial analysis, vector geometry operation, vector network analysis, vector data processing, raster spatial analysis, raster data processing, raster aggregation, hydrologic analysis, and geostatistical analysis (Figure 2).

5.2 Implementation of OGC data service protocol access to virtual globe-managed data

Similar to other popular virtual globe software, GeoGlobe uses a hierarchical tiling technique (or named pyramid structure) for progressive data transmission. For any given area, regional low-resolution tiles are first downloaded, followed by medium-resolution tiles and finally local high-resolution tiles. Data tiles following a pyramid structure are pre-built and provided through GeoGlobe servers. Such a pyramid structure allows the visualisation of multi-terabyte

Figure 2 The web access entry of GeoPW.

datasets. Implementation of OGC data service protocol access such as WCS to virtual globe-managed data allows geospatial services and value-added applications to access data in an interoperable way.

The internal management of the GeoGlobe server is based on a multi-server technology. Multiple data servers are deployed in a wide area network (WAN), registered into a catalogue center to support a publish-find-bind paradigm (Figure 3).

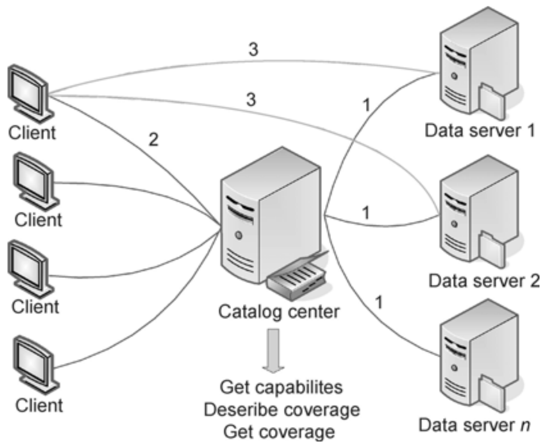

Figure 3 The architecture of the GeoGlobe WCS.

(1) Publish: Data server nodes are registered into the catalog center. The meta-information of pyramid, such as pyramid identification, lever number, pixel resolution and geospatial bounding box, are registered.

(2) Find: Client nodes login into the catalog center and discover the pyramids published in the WAN.

(3) Bind: Client nodes bind the discovered data node and download pyramid tiles.

The WCS interface and protocol for GeoGlobe server is implemented at the catalogue center (Figure 3). It can not only provide all meta-information for pyramid tiles registered in the catalogue center, but also support the load-balancing among multiple data server nodes providing the same pyramid tiles. The GetCapabilities and DescribeCoverage operations in the WCS interface are implemented based on the registered meta-information stored locally at the catalogue center. The implementation of the GetCoverage operation includes the following steps: First, the service selects the data server node with a lower load; then it downloads the tiles covered by the requested bounding box from the data node; finally, it outputs the coverage data through image data processing functions based on these data tiles.

5.3 Implementation of access from virtual globe clients to geospatial web services and services integration

Figure 4 shows the user interface of the GeoGlobe client. The tree on the left panel lists the available services registered in the registration center, e.g. geospatial data services, geoprocessing services, and service chains. The geospatial data and processing services follow the OGC service specifications. Geospatial service chains are represented using an OASIS standard, Web Services Business Process Execution Language (WSBPEL), shortly known as BPEL. The registration center is a web-based registry service following the OGC CSW specification. Currently, there are two prominent general information models for registry services: the ebXML registry information model (ebRIM) and the universal discovery description and integration (UDDI) model. For the geospatial community, ebRIM is more general and extensible because it provides comprehensive facilities, based on the ISO 11179 set of standards, to manage metadata. OGC has developed and recommended an ebRIM profile for CSW. The metadata for both geospatial web services and geospatial data are registered in a CSW-ebRIM server. Users can view the information of a service by clicking it on the tree in Figure 4.

An online geoprocessing model designer, called GeoPWDesigner, is developed using Asynchronous JavaScript and XML (AJAX) technology. It is able to create geoprocessing models by draging and droping atomic geoprocessing process, and transform the geoprocessing model into an executable service chain represented using BPEL. Figure 5 illustrates an example of a geoprocessing model for a flood submergence analysis. The atomic process models on the left column of the palette are chosen and dragged to the right area in the right panel, and then composed together through data flow and control flow links to generate a logical workflow that meets specific requirements of the flood submergence analysis. This logical workflow is stored as a process model contributed by experts. It can be transformed into a BPEL service chain and executed by the BPEL workflow engine. The model itself is reusable and evolvable.

6 Conclusions and future work

This paper presents an approach to the establishment of an analysis-enhanced virtual globe for globe geospatial information sharing, visualization, and analysis. It combines the visualization and communication power of virtual globes with the conventional powerful analysis functions of GIS. The use of standards-compliant, interoperable geospatial web services makes the system fully extensible. Both data and geoprocessing services can be easily chained together for complex geospatial data analysis and earth science modeling. The analysis processes, archived as service chains in catalogue services, can be shared and discovered. Such an environment allows researchers to investigate a wide range of geospatial problems through the large-scale geospatial data and analysis functions provided by either virtual globe servers or geospatial web services distributed at worldwide locations. It significantly enhances the use of geospatial data by making it much easier to publish, discover, access,

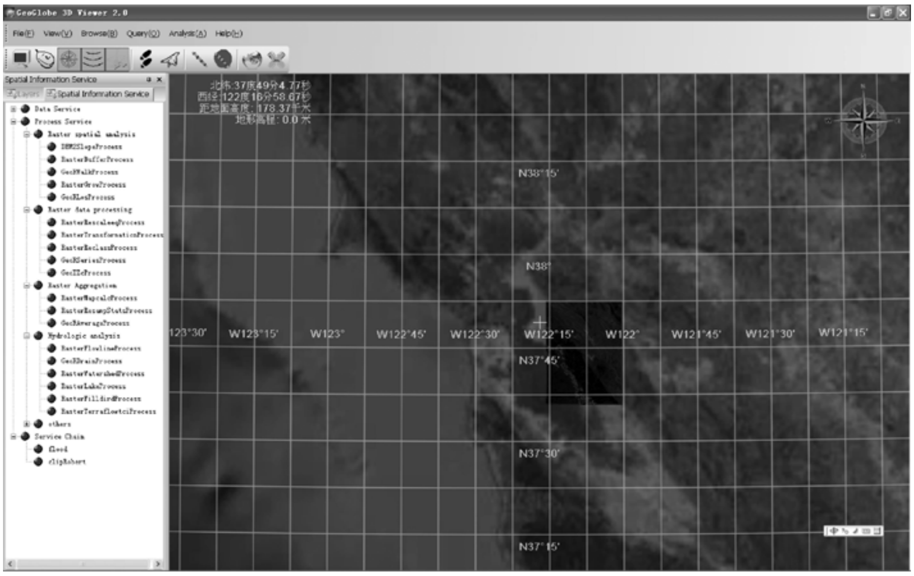

Figure 4 The user interface of the GeoGlobe client.

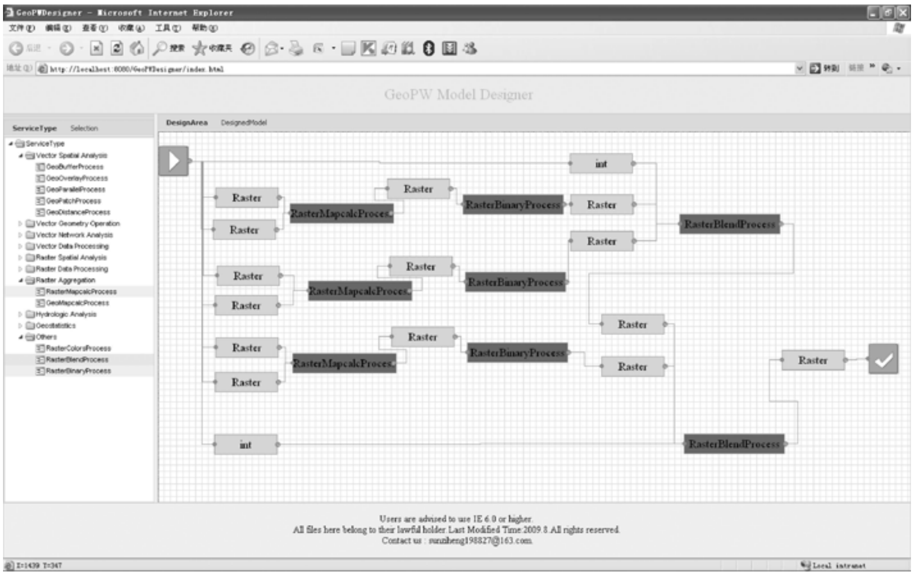

Figure 5 GeoPW model designer.

process, integrate, and analyze earth science data and information from distributed web sources, thus contributing to the development of digital earth. Future work includes the improvement of the system performance and further development of standardized, simple, and user-friendly tools for the functional requirements of analysis-enhanced virtual globes.

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