Application of GIS to Supporting Atmospheric and Oceanographic Data Management and Visualization

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Abstract  A GIS for ocean applications called “the Xiamen Atmospheric and Oceanographic Data Management and Display System (AODMDS)” has been designed and developed. The system is based on ArcObjects (AO), a component-based GIS development tool. The paper discusses in detail the storage and organization of the atmospheric and oceanographic data, the strategy and methods for the visualization and mapping of oceanographic and atmospheric data, and the implementation of the methods in AODMDS. It also discusses some advanced display control techniques that expand the functions of ArcObjects. One of the techniques is “gradient-fill-style color-map control,” which provides a feasible color-rich display control for all types of raster maps. As a stand-alone desktop GIS system built on AO, AODMDS provides effective data management and powerful mapping and visualization functions for atmospheric and oceanographic data.

Keywords  atmospheric and oceanographic data; visualization; mapping; component-based development; ArcObject

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Introduction

As we know, ocean monitoring plays an important role in sustainable exploitation and utilization of ocean resources. With the progress on ocean observing systems and the increase of ocean monitoring activities, a large amount of ocean data has been collected and many results have been obtained from the analysis of these data[1]. However, the current data management and mapping in the oceanographic community lag behind the development require-ment[2]. Here are some current status and issues in China oceanographic community.

(1) File-based data management. File-based management has a lot of shortcomings such as inefficiency and lack of centralized management[3]. AODMDS (the Xiamen Atmospheric and Oceanographic Data Management and Display System) can provide more unified, reliable and effective management, analysis and application of dynamic ocean data by means of the commercial database.

(2) Manual or semi-automatic. The disadvantage of manual or semi-automatic map-making is inefficiency and trivial[3]. AODMDS can provide a series of easy-to-access, automated, integrated GIS graph and map making capacity for the user.

(3) The separation of data and graph. It makes users hard to search from graph to data or from data to graph. AODMDS can provide strong connection between data and graph, and support double-direction searching between them.

(4) Obsolete visualization technology. With the development of computer technology, GIS can sup-
port 3D, animation, multimedia and simulation; these new technologies can enhance the visualization level of oceanographic data.

Traditional methods have difficulty in the comprehensive management, analysis and application of dynamic ocean data, because of their spatial and temporal complexity. Geographic Information Systems (GIS) can provide powerful functions to support the comprehensive management of spatial data. Introducing GIS technology and methods to oceanographic data is a step towards the comprehensive management of dynamic and complex atmospheric and oceanographic data and information. It is also the major goal of the AODMDS.

1 System architecture and system function

1.1 System architecture

AODMDS adopts a client-server architecture that can run on a single computer or be distributed on multiple computers. The whole system can be divided into two parts. One is the back-tier database server, which uses Oracle 9i server, providing database service for all clients. The other is front-tier GIS clients, which includes Oracle 9i client tools and AO component library coming with ArcGIS 8.3, manages, queries, displays, and maps the Xiamen Atmospheric and Oceanographic Data. Fig.1 shows the architecture of the system.

![Fig.1 Architecture of AODMDS](image)

1.2 Functions of the system

In line with the requirements of the users of the Forth Institute of Oceanography, China, AODMDS has been divided into 3 subsystems: one for processing raw data, one for processing and mapping intermediate results, and one for submitting final-results. Here is a description of the basic functions of the three subsystems.

(1) Subsystem for processing raw data

This subsystem provides the input, archival, retrieval, and maintenance functions for raw observational data and its documentation, as well as gathering statistics.

(2) Subsystem for processing and mapping intermediate results

This subsystem performs geographical analysis and calculates statistics to create thematic maps on raw monitoring data. In detail, three kinds of functions are provided: (1) Creating the second-time value based on the raw observance data and writing them into second-raw-database; (2) Creating maps using the raw or second-raw observance data and writing them into middle-results database; (3) Layer management, table management and map editing.

(3) Subsystem for submission of final-results

This subsystem submits and manages final-results. The data it uses can be observational data, processed results, statistical results, or it can be pictures or maps. The data can come from the raw database and the second raw database or the intermediate results database. The final results are stored in the final results database. The final results database will provide simple query and statistics functions, and complex data querying and statistics functions that require complex graph and attribute conditions.

![Fig.2 Structure of system hierarchical module](image)

1.3 Data organization and management in AODMDS

The most important property of the system to the user is to protect the safety of the raw data, neither making any change in them nor destroying them. To achieve this point, logically, the database is divided
into five parts: the raw database, the second-raw database, the intermediate results database, the final results database and the user access rights database. The last one is used to strictly specify user access rights for different databases.

(1) Raw database (DB). It is used to store all the data directly coming from the raw observations. These data cannot be edited; they are used only as the primary data source of second raw DB, intermediate result DB and final-results DB.

(2) Second raw DB. It has the same basic structure as the raw DB. The sole difference between the two DBs is that all the data in the second raw DB can be edited, while that in the first DB cannot. The data in the second-raw DB are derived from the raw database.

(3) Intermediate results DB. It is a temporary DB, used to store intermediate results or temporary results. We can perform a variety of operation and processing on the raw DB and second-raw DB, all intermediate and temporary results can be put into this DB.

(4) Final results DB. It is designed to store verified final result data that include graphs, maps, data files and tables, and related log files.

(5) User-rights DB. It is used to store the users’ access and operation rights and the information about how the user can use the functions of the system safely.

ArcGIS8.3 adopts object-relation database model, where the spatial data such as vector map will be stored into the geodatabase. All other data will be stored into ordinary database table, and huge data such as images and graphs will be stored into BLOB field of database.

2 Visualization of oceanographic data and its implementation

Graphs and maps are often used to visualize oceanographic observational data to uncover data’s hidden relations. The map-making function is implemented in AODMDS including 1D graph, 2D distribution map, vector map, and 3D view. They use a uniform and easy-to-use user interface. They are developed by using AO of ArcGIS.

2.1 One-dimensional graph

A one-dimensional graph is used to represent how an observational element or variable changes as a function of another one-dimensional element or variable. Very often, it is represented as a broken line that connects a series of points, with each point corresponding to one pair of observational values. To make a 1D graph in AODMDS, the user chooses the observational data, by specifying station name, observational filename, date, time, and project name and observational and dependent element. Time and depth are often used as dependent elements. This 1D graph function can be implemented using Igraph, a graph interface provided by EsriCore.OCX.

In AODMOS, the user can easily change the tick gap, line type and line color in any 1D graph. Fig.3 shows a 1D temperature-depth graph for a single station at time \( T \). In this graph, the horizontal axis represents the temperature of sea water, and the vertical axis represents the depth of sea water.

Fig.3  One-dimensional temperature/depth graph

The system supports two types of 1D graphs. One is called a single station vertical (or horizontal) distribution graph and describes the relationship of two physical variables at a single station and a single time; the other represents how an observational element changes with time at a particular spatial point.

2.2 Two-dimensional distribution map

A 2D distribution map reflects how an observed element or variable changes its value along a 2D surface. Isoine map or contour maps are commonly used to represent the distribution of observational
values along a 2D surface.

Usually, the raw observational data is collected only at discrete observational points. In order to create a contour map, regular grid data must be created by interpolation, and then contour maps are easily generated from the grid. In AODMDS, the 2D distribution mapping function implementation is based on the IRaster and IInterpolation Interface AO provided, which supports the creation, interpolation, and display of grids and contours.

In AODMDS, producing a 2D distribution map is very simple: the users are required simply to specify station sites, time, date, observation file name, project name, etc., to provide observational data. In addition, a horizontal or vertical surface of observation must also be given by the users or designated by default. Fig.4 displays a 2D surface distribution map of the seawater temperature.

AODMDS supports two types of 2D surface map: surface 2D contour map and profile 2D contour map. The elements that Surface (a designated depth) 2D distribution maps can express include water temperature, salinity, density, density deviance, force attitude, flow speed, and flow direction. The elements that profile 2D distribution maps can express include water temperature, salinity, density, density deviance, sound speed, water transparency, and water color.

![2D contour maps of temperature](image)

### 2.4 Three-dimensional view

In GIS, besides 1D graphs and 2D maps, 3D view is often used. 3D views are widely used to represent vividly the landforms based on DEM. Instead of landform, oceanography studies sea water temperature, salt density, and flow speed, etc. However, with the GIS 3D Scene tool, a 3D view can be easily created for oceanographic data to help to provide a vivid visual representation.

In GIS, 3D landscape views are created using DEM, which stores $x$, $y$, and $z$ values along a regularly distributed grid. In DEM, the $z$-value represents the elevation of the grid point. While $z$ represents an observed element of oceanographic or atmospheric phenomena, we can produce 3D views to observe oceanographic phenomena. 3D views can be suitable for nearly all oceanographic and atmospheric features, such as seawater depth, seawater temperature, wave height, seawater salt density, precipitation, and humidity. The 3D landscape view tool is implemented in AODMDS in the following ways.

**Step 1** Select one attribute field from all the attribute fields of a point feature map. This attribute field must be numeric. It must be of esriFieldType-Double, esriFieldTypeSingle, esriFieldTypeInteger, or esriFieldTypeSmallInteger.

**Step 2** Interpolate the raw point feature map of
the field for a single attribute into a raster. The available format includes ESRI GRID, TIFF and ERDAS IMAGINE.

**Step 3** Use the pixel value to select the infill for the box representing the raster point, and create a 3D visual presentation.

In Fig.6, an area in the Fujian Sea is used as an example. The salty density value is the Z value used to build a 3D view. Fig.6(a) uses the default setting; Fig.6(b) uses the color map setting. In both figures, the peaks represent the area with high salt density, while hollows represent those with lower salt density. In the color 3D view, sea areas with the same or similar colors have the same or similar salt density. In addition, the user can use a 3D browser tool to zoom in/out of the 3D view and change the view angle and point of observation.

![Image](image_url)

(a) Using the default setting

![Image](image_url)

(b) Using the color map setting

Fig.6  3D view of salt density

### 3 Creation of gradient fill style color combobox control

A raster image is a basic graph and image processing data type which uses an evenly distributed array of cells of the same size to represent the image. The users of AMODMDS expect to be able to use as many colors as possible to represent the raster image so as to better visualize and convey the meaning of oceanic and atmospheric information. However, ArcGIS8.3 EsriCore.olb only provides an ordinary color palette, from which it is difficult to meet these user’s requirements. We develop a gradient-fill style color palette to satisfy this requirement. The application of the AMODMDS’s Activex control based on MFC sub classified color palette can aid multiple-color presentation of oceanographic and atmospheric images.

The usual principles and characteristics of combobox control inherited from ordinary color combobox are that: every drop down item belongs to a particular rectangular object, and its interior can be filled using the regular rectangle filling methods for single color in CComboBox::DrawItem or CListBox::DrawItem. The methodology means that the user can choose only a single color at a time. When one color item is selected, only the color that the color item represents is selected; correspondingly, the control just transfers the RGB value of that color to the main program.

This gradient-fill style combobox control is implemented in the following ways. The sub classification technology is used to build a subclass of combobox, using the same interface style as the common control. Then, using the AO functions of gradient-color and display transformation, a function to implement the drawing function of gradient-fill style combobox is defined. The core methods reload the ComboBox::DrawItem. The drawing function of a gradient fill style combo box is required to specify the start color and end color. A method is specified to implement the gradual change between them. In this way, not only the selection of displayed colors is very rich, but also is self-relevant and present a good hierarchical property. When the user chooses a color item, the gradient-fill style combo box control will transfer the start RGB value and the end RGB value to the main program. The main program will then use a drawing method provided by the AO component and draw the raster image existing in the system’s main interface, implementing multiple-color display.

Instead of directly defining the item’s color in the
program, that color is based on the ColorRamp file of ESRI.mdb in the directory ArcObjects Developer Kit\Samples\ArcMap\Styles\Make Style of ArcGIS 8.3 Desktop Version. In this way, this design can reach a professional level.

The developer can introduce this form of color control into VB, VC and other programming environments supporting COM. Under the OnColorChange( ) function of the control, the selected color will be transferred to the main program, and finally the main program will implement the display of a raster image.

Fig.7 shows 3D views of the seawater temperature of the Taiwan Strait area. In Fig.7(a), the darker color represents lower temperature, and lighter color represents higher temperature. Fig.7(b) has the opposite relation between color and temperature. Both figures use the Gradient fill style combobox control described in this section to choose the gradient color.

![Fig.7 Sea water temperature 3D view](image)

## 4 Conclusion

AODMDS has been successfully deployed and running at the Forth Institute of Oceanography, China, since Dec. 2005, replacing the old data management and mapping system. As a stand-alone desktop GIS system built on AO, AODMDS has achieved effective data management and provides powerful mapping and visualization tools for atmospheric and oceanographic data. The system has met its performance requirements and the goals of the ocean user community very well.

As expected, AODMDS is a good example for showing the large application potential of GIS to the comprehensive management and visualization of dynamic and complex atmospheric and oceanographic data and information.

However, this system is not perfect. Some special sea statistics maps remain to be implemented, and some mapping methods and functions need improvement. These modifications need to be made to improve the efficiency and quality of this system.

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