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# Design and Implementation of a Web-based Integrated Marine and Atmospheric Geographical Information System

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**Abstract**
Traditional geographic information systems and modeling systems have specific limitations in marine and atmospheric research area, such as using ocean mode analysis method to deal with massive remote sensing data. To overcome such limitations, in this paper, a web-based distributed geographical information system for the automatical execution of marine and atmospheric research simulation and analysis is presented. It integrates a group of individual applications by combining marine and atmospheric data acquisition, storage, retrieval, analysis and visualization functions. The system exhibits a modular, extensible, and scalable architecture. The well-established three-tier architecture is exploited to build the user interface. An execution model and distributed system techniques are deployed to support the high efficiency execution of user's request. The user interface of the system is implemented in C#, the distributed execution system is implemented based on Web Services technique, released on cloud service. Major advances are inclusions of models from expert knowledge(execution model) and techniques to get high performance(distributed system).

**Keywords: Marine and atmospheric information; Distributed system; Execution model; EOF.**

## I. Introduction

For the past decade, many countries have developed different ocean and atmospheric observatory systems for continuously monitoring and collecting the environment data. The data acquired from these systems allow scientists to study the trends and variability of sea. An important step in dealing with the data is extracting information from huge amount of data automatically. Also in many applications, scientists often become overwhelmed by the process of running their simulations and have little time left to pursue the scientific questions they set out to investigate. They also need an automation data processing and information extraction tool to release them from these tasks. Stein Sandven built a prototype marine information system that will provide end-users with a single-entry access point to meteorological, sea ice and oceanographic data and products in electronic form for users of operational services[1]. Benjamin D. Best apply web services technique to predict marine mammal habitats in a dynamic environment automatically[2]. NOAA Earth System Research Laboratory built a workflow management system for automating weather and climate simulations[3] in 2008, it adopt a simple workflow management system to automate the orchestration of weather simulation experiments. Many scientists and engineers also tried to apply traditional GIS theories and tools to marine research area, used their functions or modules for marine information sharing and data analysis[9-11].

This paper presents a web-based marine and atmospheric geographical information system(MAGIS), which integrates data sharing, temporal spatial analysis and visualization seamlessly. Compared with other MAGIS systems, the proposed system has the following features: 1) It is a large-scale system which can handle the huge amount of remote sensing data and the computation of high time complexity required for analysis and visualization; 2) It aims to support both professional and general-purpose users in a very convenient way, an execution model is built to support the user's transaction request automatically.

The rest of this paper is organized as follows. First, the overview of the system is discussed briefly, the data model and data engine are described, and analysis and visualization methods that integrated into the system are introduced. Next, the system design is introduced from the architectural point, the function of user interface and the procedure that background system deals with data are listed. Then implementation of the major system components are described in a comprehensive way mainly focus on the execution model and distributed execution system. After that, an application example about EOF analysis of sea surface temperature is demonstrated. Finally, the last section gives the conclusion.

## II. Overview of the System

This paper presents our work in designing and building a web-based MAGIS system that can be used to share data, analysis results for the research of marine phenomena. This function is manipulated by the data management module of the system. One of the goals of the marine and atmospheric data model is to provide a structured framework that more accurately represents the dynamic nature of water processes[4]. All data items have been time stamped and have a mechanism to be geo-referenced. The data that represents the value of a very small area or what may be interpreted as a point in space such as rainfall data of a measurement station, and data that represents huge data that has a large span in time and space, such as the global sea surface temperature data of 100 years can all be managed by the data engine.

Figure 1 shows the data types and their structures that have been integrated into the system. Database is mainly deployed to store meta data and station survey data.

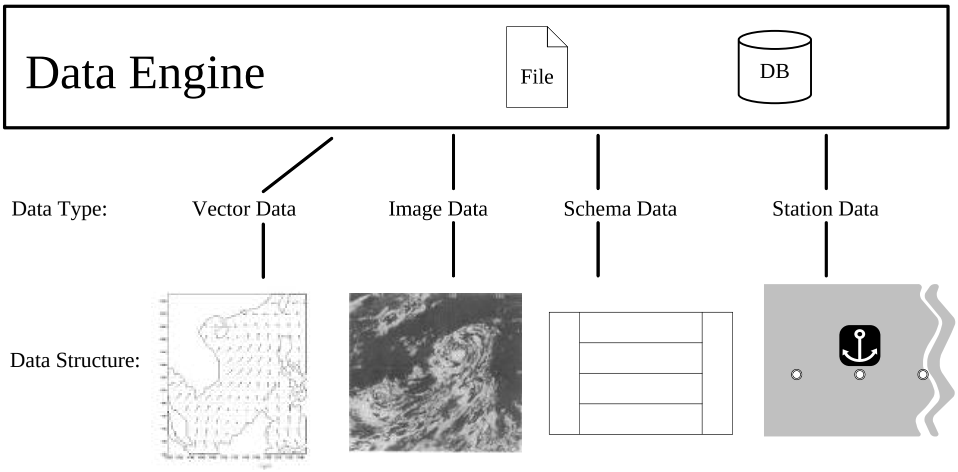


Figure 1 System Data Types and Structures

The system can also let the user build simulation or analysis models from the historical data stored in the file system and database. It provides various analysis and visualization modules so that the user can run information extraction procedures conveniently. The execution modules can be divided into five main types: basic statistical analysis, advanced analysis, GIS analysis, data preprocessing and visualization methods. The system applies an execution model to convert user's request to manage, analyze and display marine and atmospheric data. It will form a chain of modules according to user's request and perform these modules in a serial or parallel way. The data get from the foresaid data engine can be used in an execution chain composed of these modules. The adoption of this technique make the research in marine and atmospheric transformed from function-oriented to the comprehensive automation support, which enormously improved the working efficiency of scientific research and other applications. The following table lists the function categories integrated into the system along with a brief description and examples of each.

Table 1 Function Modules in the System

| Category | Description | Examples |
|---|---|---|
| Basic statistical analysis | Calculates statistical values of a series of data | Average, deviations, kurtosis, skewness… |
| Advanced analysis | Calculates temporal spatial modes of multidimensional data | PCA, SVD, CCA… |
| GIS analysis | Uses traditional GIS algorithms in marine and atmospheric research area | Point buffer, line buffer, shortest path… |
| Data preprocessing | Makes data suitable to be input of next module | Interpolation, normalization, filtering… |
| Visualization | Exports grid data to 2 dimensional image. | Contour map, image map, vector map… |

**III. System Design**

The system is composed of two parts: web user interface and background distributed request execution system. This figure shows the data flow in the system.

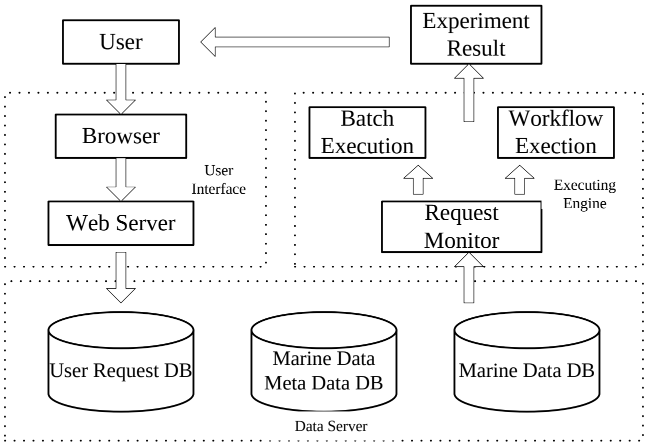


Figure 2 Overview of the data flow in the system

**1. User Interface**

The system is intended to be distributed into Internet, therefore, the design and implementation of the system user interface mainly becomes a job of designing and implementing web pages. The users can gain access to the system through any commonly used commercial browser. The website collects user's requests and stores them into execution data tables. It is composed of three layers: the web interface layer, the web logic layer and the database layer. The interface layer in the three-tier architecture offers the user a friendly and convenient entry to communicate with the system while the application logic layer performs the controlling functionalities and manipulating the underlying logic connection of information flows; finally, the data modelling job is conducted by the database layer, which can store, index, manage marine and atmospheric data or system data needed for this application. Figure 3 shows the dataflow and the function of the three tiers.

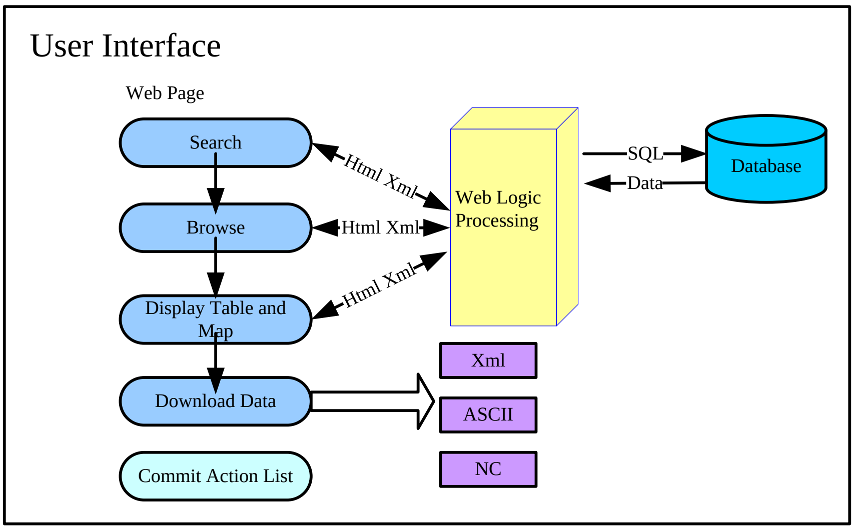


Figure 3 Data Flow and Function of System User Interface

**2. Background User Transaction Processing**

There is a service program called "Order Monitor" running on background servers, it detects the new coming user requests. The following steps show how the servers handle requests:

1) Order Monitor fetches the information of user's requests and analyze the category of these requests;

2) The information of the requests will be put into an execution queue;

3) Poll status of distributed execution servers and select the one has the lowest load;

4) Initialize server execution environment for the quest and create instances of the request modules;

5) Modules chain execute;

6) Result data and system status postprocess.

After these steps performed, the system will return to its original state and wait for new user's request, and the user's request will be transformed into analysis results and will be transferred to user automatically.

## IV. System Implementation

### 1. Execution Model

According to the user's requests, a chain of execution modules will be formed. There are 3 kinds of application nodes in the chain: data fetching module, data analysis module and data visualization module. Although many existing automatically execution software have provided powerful workflow definition techniques and have impressive capabilities for general purpose[5,6], they do not meet out needs. First, we have limited the scope of our system to the marine and atmospheric research domain so that our design can take advantage of any common properties of analysis and simulation in this area. Second, the system is designed to be of high scalabilities in the direction of module quantity and function category. New capabilities are developed incrementally to make the system evolve. The job of scientists to construct and run their experiments is minimized. A relational database schema is designed to facilitate the manageability. The overall view of the execution model schema is depicted in Figure 4.The execution model is simple and very suitable for the researchers that have absolutely no idea of the system, it allows them to define research workflows in their familiar way with the help of user interface.

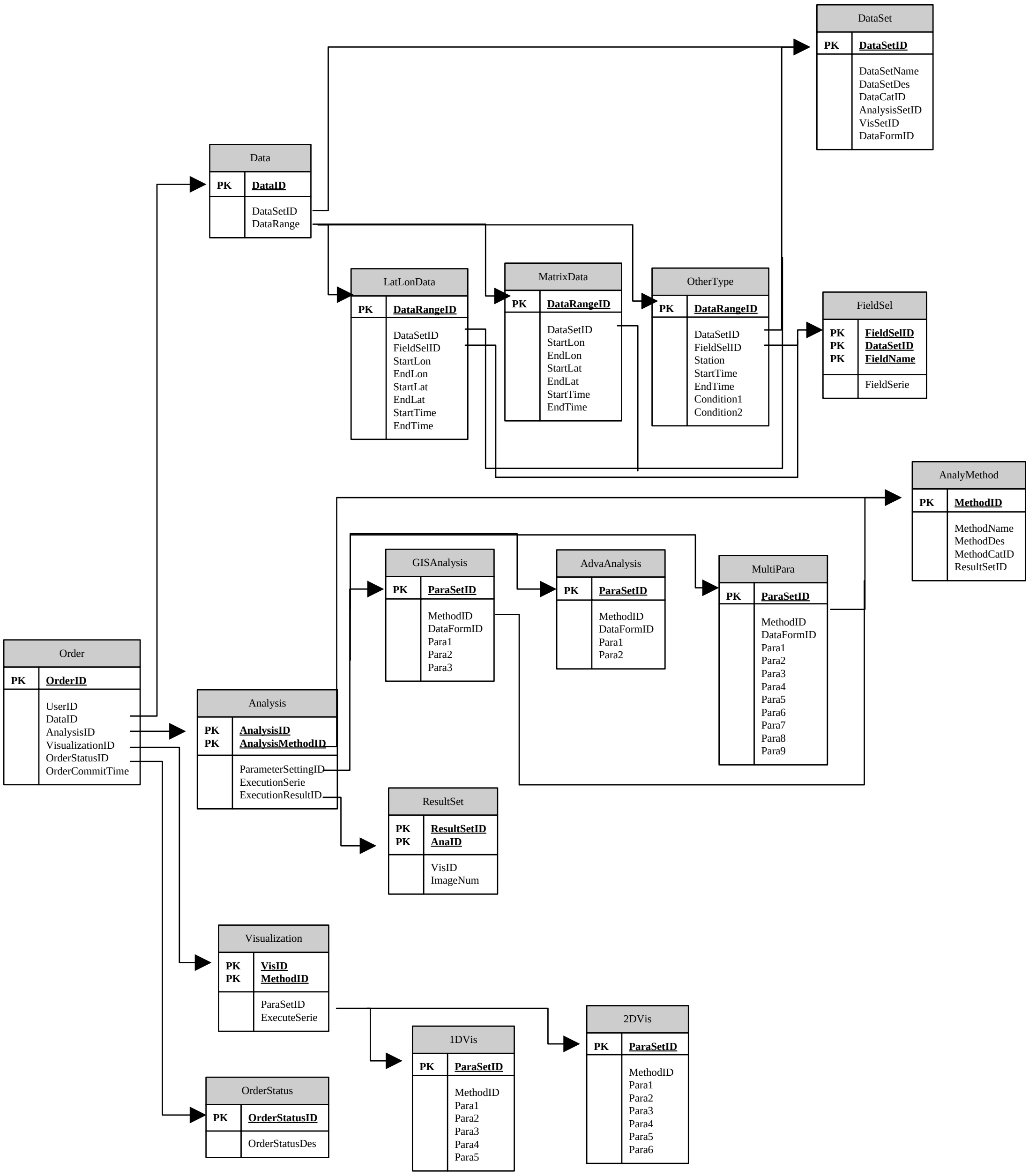


Figure 4 Execution Model Schema of the System

Based on the relational execution model, an execution engine is designed through an object-oriented approach, Figure 5 shows its class diagram:

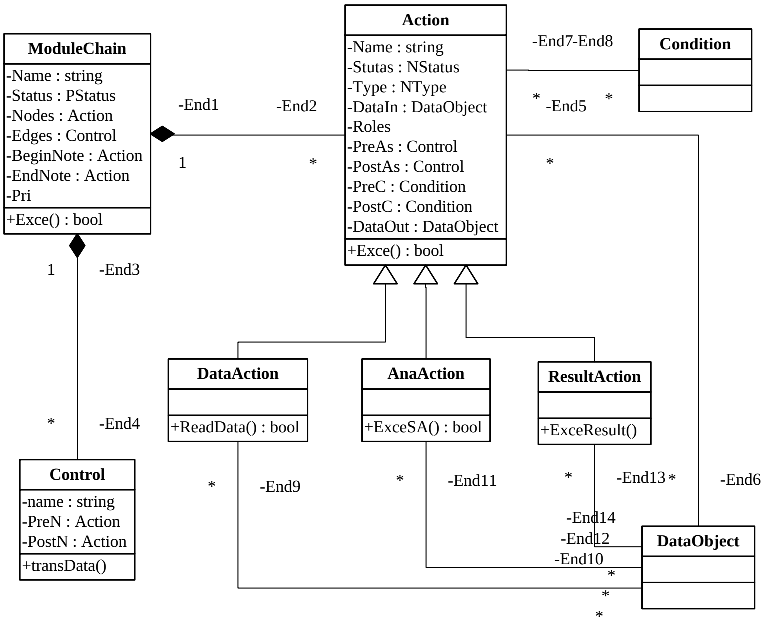


Figure 5 Execution Model Class Diagram

The Action object is the fundamental object of all action objects. It represents a generic atom action in a data processing application. It is meant to capture the features common to the three types of elements in data action, analysis action and visualization action. The three concrete action objects have their own properties to store parameters of execution. The Procedure is an object that contains a set of actions and execution controls, it describes one part of user's request. It also provides the interface *Exec()* to execute its all actions in a parallel way or a serial way.

## 2. Distributed Execution System

One of the key issues in the design of a scalable and efficient online MAGIS system is the huge computing. On one hand, because the system is intended to be distributed into the Internet, it allows multiple users, working on different client computers that are interconnected through networks to access the website and commit request, it has to deal with requests from many users. On the other hand, in marine and atmospheric research area, many analysis methods have high time complexities. In this paper, the server is implemented as distributed system to improve computing performance[7] using web services technology. Execution engine is reformed into a web service and the web service is released on many servers. There is a center server on which the Order Monitor service program runs too. The center server keeps a list of execution servers, it polls the status of every server includes memory utilization, CPU usage, I/O usage and calculate the load on every server in the following formula:

$$\mathrm{LOAD}(\mathrm{i}) = \mathrm{R}_1 * \mathrm{Lcpu}(\mathrm{i}) + \mathrm{R}_2 * \mathrm{Lmemory}(\mathrm{i}) + \mathrm{R}_3 * \mathrm{Lio}(\mathrm{i})\ with\ \mathrm{i} = 1, 2, ..., \mathrm{n}$$

$R_1$, $R_2$, $R_3$ denote the experience weight value of CPU usage, memory utilization and I/O usage. When user's new quest arrives, the Order Monitor will select the lowest load value in the server list and dispatch the new task to the server. This architecture has an extra advantage that the system gains high scalability, the system needn't restart when execution servers are added, moved or upgraded, only the server list on the center server should be modified.

## V. Application Example

In this section an empirical orthogonal function (EOF) on sea surface temperature will be carried out to demonstrate the system function. The EOF is a technique for simplifying a dataset, which is equivalent to Principal components analysis (PCA). It was frequently applied by the oceanographers and meteorologists to process the observation data, because it can decompose the observation data which is description dynamic phenomenon into time series and spatial patterns[8]. Figure 6 shows the steps to use the system EOF analysis and the execution results.

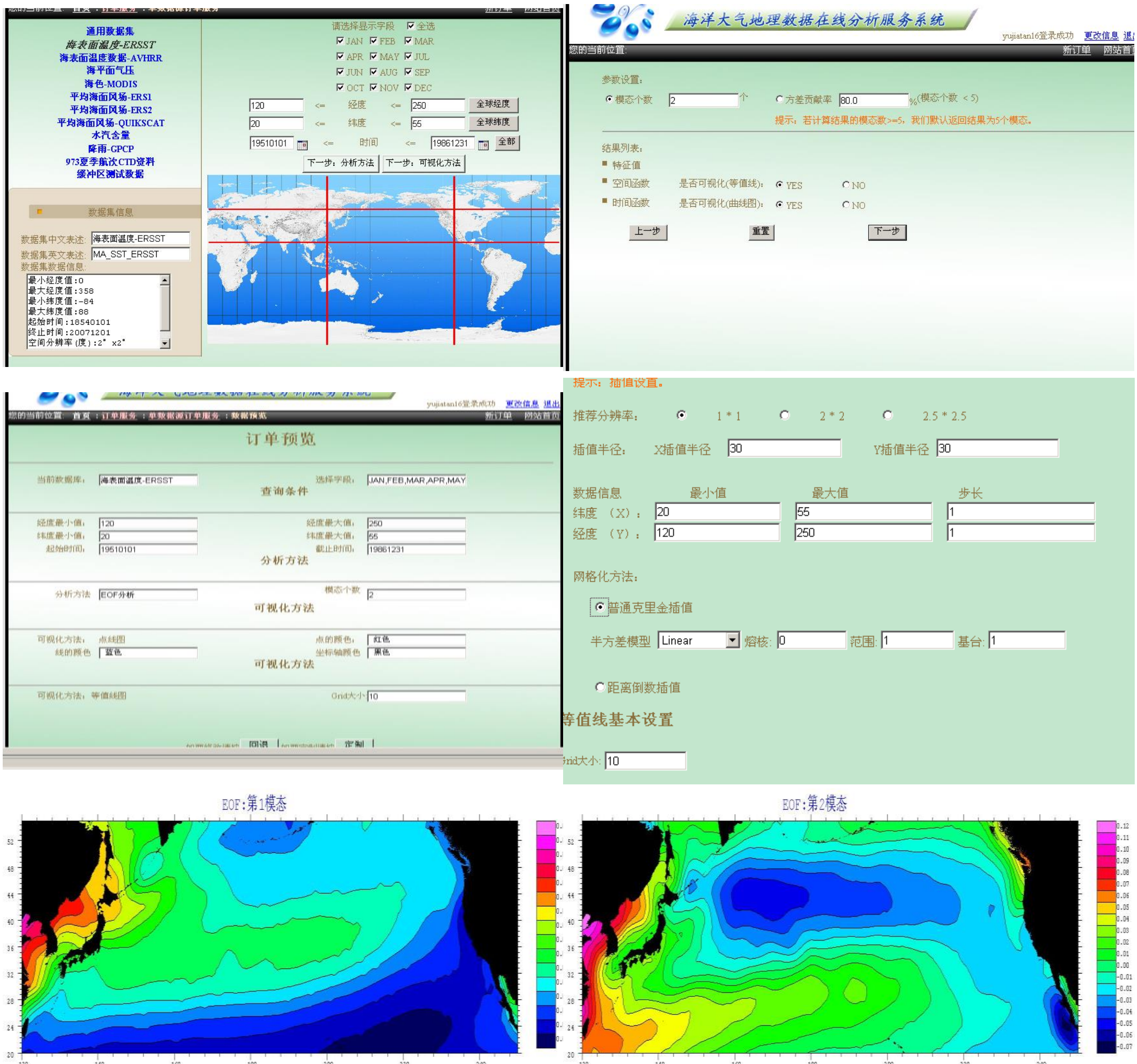


Figure 6 These pictures demonstrate the user interface: select data type and input space-time range, select EOF analysis method and input parameter, select visualization method and select data preprocessing algorithms and preview user's request in the page. The last 2 pictures show the result image that will be transferred to user after execution, they are the first two modes of EOF analysis.

The platform also integrated some pattern recognition algorithms. This is an example of how to insert a T-pattern module into the system. Chart of flow to extend the system. Mesoscale eddies near south Africa are selected to test the module, and the hot routine and hot area of eddy moving are generated automatically.

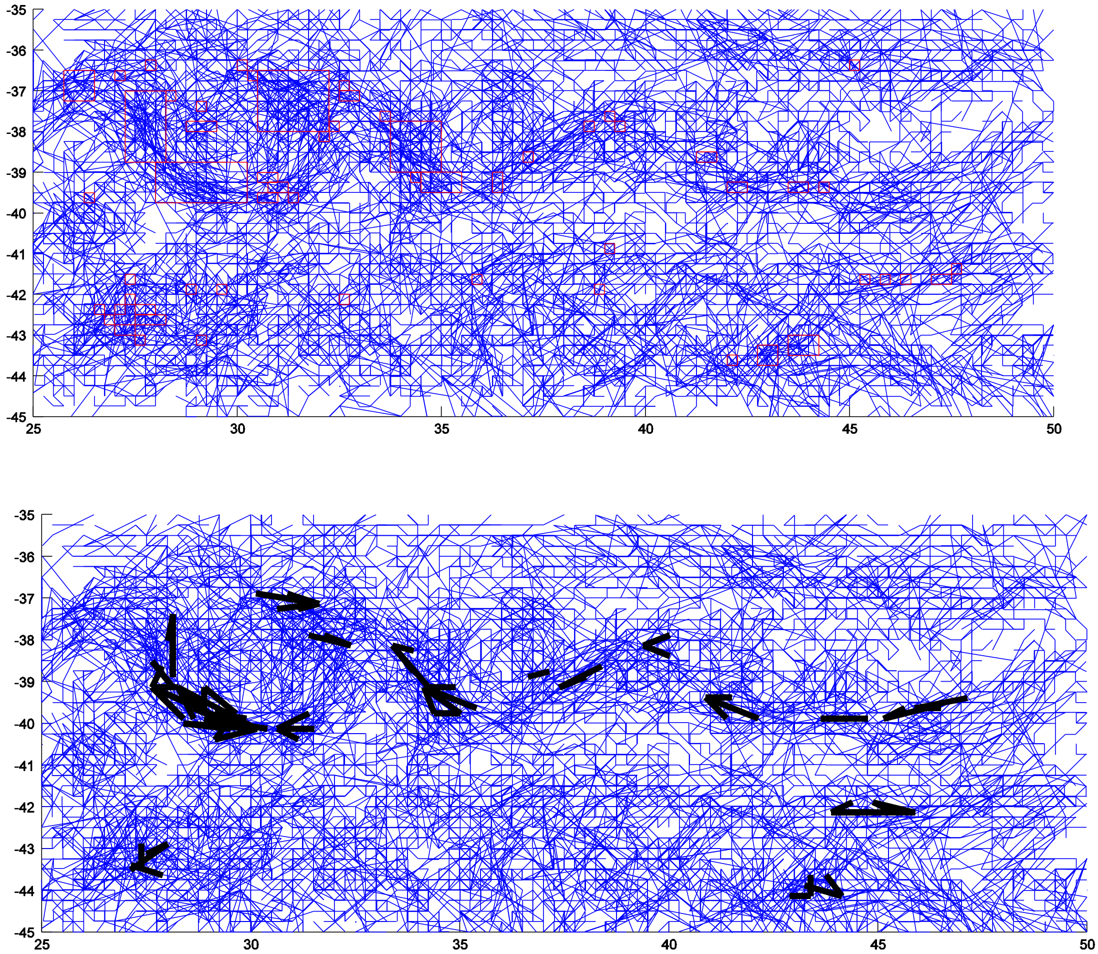


Figure 7 Hotspot and hot trajactory analysis of mesoscale eddies

## VI. Conclusion

In this paper, a web-based distributed system for the automatical execution of marine and atmospheric research simulation and analysis is presented. It integrates a group of individual applications by combining marine and atmospheric data acquisition, storage, retrieval, analysis and visualization functions. The system exhibits a modular, extensible, and scalable architecture that makes it possible to adapt to more complex tasks, such as marine and atmospheric data mining research. The well-established three-tier architecture is exploited to build the user interface. An execution model and distributed system techniques are deployed to support the high efficiency execution of user's request. The completed implementation is easy and convenient for marine area scientists to use. In addition, it is accessible to any user who is able to connect to the Internet and has interest in marine and atmospheric information. Although the system is successfully implemented, there are a number of areas where improvement is needed. For example, the architecture of distributed system is coarse-grained, sometimes this can cause the waste of temporary resources. To address these issues is the future work upon the research of MAGIS system.

## VII. Acknowledgement

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