A spatio-temporal process data model for characterizing marine disasters

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Abstract. Marine disasters are a more prevalent problem in China than in many other countries. Based on the development of a status quo of China’s marine disaster the space-time process model is used. The model uses the ocean’s temperature field, salinity field, water density field, surface wind field, wave field and other four-dimensional spatio-temporal quantities. This paper studies that model in detail. This study aims at using the theory to provide support during marine disasters in an effort to prevent or decrease their frequency in the future.

1. Introduction

China has more serious marine disasters than do most countries. In 2011, a total of 114 storm surges, ocean waves and red tides occurred in China, causing 44 disasters. Various types of marine disasters in 2011 (including those caused by sea ice and the Enteromorpha prolifera algae) caused a direct economic loss of 6.2 billion yuan and the deaths or loss of 76 people. Marine disaster prevention and mitigation directly affect the country’s social stability and economic security as well as its people's lives and property. The temporal variations of the exploration of marine disasters, disaster prevention and information system technology for disaster reduction are important subjects to research in marine disaster prevention and mitigation. At present, there exist a few types of expressing and analyzing marine disasters, such as the spatio-temporal processing of storms, tides, typhoons and sea level rise [1,2], but these methods have varying degrees of limitations. The techniques need further development, especially at the data model level, if they are to better display and analyze the marine disasters’ four-dimensional space-time characteristics.

2. Analysis of current domestic and foreign research

The application of and research on three-dimensional geographic information systems (GISs) mainly focus on the basic expression of marine elements and phenomena and the basic structure of marine data. The present marine GIS field has three main methodologies. The first is based on the theory of the land system combined with marine characteristics, which is then applied to the marine field. For example, the method of Li [3] is based on the theory of land system, summarizes 8 models of marine object expression, and proposes the use of dynamic segmentation technology for shoreline...
modeling. The authors applied the organization and management of the hypergraph data structure to water depth data. Gold [4] discussed the potential applications of several basic algorithms to the Voronoi spatial data model in GIS. Lucas [5] used this method based on the processing of various data sources in the Kara Sea study area to analyze the data synthetically. The authors analyzed seasonal distribution patterns of diluted water, which has been involved in the problems of sensitive marine data. A variety of land-based construction theories and technology applications, such as physiognomy analysis, have been applied to seabed terrain construction [6,8]. Because of the particular performance factors in marine environments and the differences in data acquisition technology and form, the direct application of land-based theory to the marine field is difficult.

The second method is the use of GIS to express and communicate the results from basic physical oceanography research. Numerical models use the laws of physics and the characteristics of observations to simulate marine phenomena and then use existing software to visually express the model data. For example, Xu [9] used a marine dynamics model to simulate the diffusion of pollutants. Li [10] studied and analyzed a numeric model of waves and tidal currents and displayed the results using visualization technology. Bai [11] applied virtual reality technology to the visualization of underwater landforms using software such as Surfer. Owing to applying the laws of physics from marine elements as the foundation, this method can display the laws and characteristics of the ocean well, but in the analysis of space remains to be further studied.

The third method is research on marine expression from the perspective of virtual simulations, which is mainly expressed in the visualization of natural marine phenomena, such as simulations of ocean waves and tides. The complexity of marine phenomena causes irregularity and non-repeatability in both time and space. Because of the demand for a realistic-feeling product, visualization research has traditionally focused on maximizing the realism of the simulation effects. In recent years, many people have successfully produced realistic surfaces and have accurately simulated waves. Peachey [12] used a combination of linear functions, the sine function, and quadratic functions to represent the height of the sea surface. Fournie [13] expressed the water surface as a parametric surface, thus solving the problem of modeling the wave with a curling crest. Kass [14] applied the simplified shallow water equations to simulate wave animation. Yan [15] introduced a probabilistic way of thinking about ocean wave amplitude and adopted triangular mesh technology with correlated viewpoint to realize waves roaming the sea in real time. Yang [16] used a formula for the frequency and directional spectra of ocean waves to characterize the wave shape and displayed this shape based on the ocean wave spectrum. Many scholars [17-24] have used graphics and virtual reality technology to study various hydrodynamic processes of rivers, sea currents, and tides.

The aims of this study are to explore the spatial and temporal processes of marine disasters from the level of logical models and to propose a marine disaster spatio-temporal data model based on the four-dimensional space-time field in an effort to further develop methods for marine disaster prevention and mitigation work in China.

3. Spatio-temporal data model of marine disasters

The preparation, formation and development of marine disasters are typically affected by changes in the three-dimensional tide field and the velocity field during storm tides, typhoons, and rising sea level disasters; spatial diffusion and three-dimensional changes in concentration; the sea-surface winds, ocean waves, tides, coastal landforms; and the distribution of coastal residents and coastal land use. In this paper, we propose that the spatio-temporal process of marine disasters is a function of the marine four-dimensional space-time field and develop a marine disaster data model based on the four-dimensional space-time field that can be described as follows. The four-dimensional space-time field includes a tide field, a temperature field, a salinity field, a density field, a velocity field, a sea-surface wind field, a wave field, and other fields:

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(st1, st2, pg, dp, \{a1, a2, \ldots\}, \{r1, r2, \ldots\}, \{ir1, ir2, \ldots\})
\]

where st1 represents spatio-temporal state 1, st2 represents spatio-temporal state 2, pg represents temporal granularity, dp represents the marine dynamics forecast principle, the set \{a1, a2, \ldots\} represents the attributes of the marine disaster, the set \{r1, r2, \ldots\} represents the influence rules of the
marine disaster, and the set \{ir1, ir2, \ldots \} represents the influence result of the marine disaster.

The base of the marine disaster space-time state description is the structure of the marine four-dimensional space-time field. Figure 1 shows the structure and relationship of the marine four-dimensional space-time field. This structure is conducive to the integration and expression of marine disaster factor vector and scalar data. As shown in Figure 2, a node can be used to represent (a) a vector or scalar (e.g. flow velocity, flow direction, temperature), (b) a line (such as ocean wave object trajectory), (c) a face (such as the temperature profile), or (d) a volume element (such as the concentration of pollutants).

Figure 1. Marine four-dimensional space-time field structure expression.

Figure 2. Expression of marine four-dimensional space-time field structure elements.
To reduce data redundancy and improve the efficiency of each data query, we consider the structure and storage of data because that angle of a physical data storage model must be used to correct the ground state according to the spatio-temporal data model. The ground state of the spatio-temporal data model generally refers to the data state at the last update, which in this case, is all data fields at a single moment during a marine disaster. The change in data values between two adjacent states is known as the ground state distance. Marine data fields such as the flow field differ from land spatio-temporal data fields because the land (e.g., the continental shelf and terrestrial templates) is fixed, so there are no objects to add or delete. If the attribute value at a single grid point changes between two adjacent times, it is called the domain of variation. Vector data has two attributes size and direction; changing one or both is regarded as an object state change. The ground state distance is primarily affected by the properties of marine disaster forecasting products: time interval, region size, grid density and disaster stage. The ground state distance also affected by data size at both a single moment and over the time series. The density difference on data grids directly increases the amount of data in the geometric series. The ocean is in constant flux; the change in domain value is primarily determined by the numerical simulation data of the reflected seas. When the selected physical quantity changes significantly, the domain value can be relatively large. When the change is inconspicuous, the domain value is relatively small. The data are stored according to the marine disaster forecasting period and the sea physical field; the ground state and the correction field are determined dynamically. Skipping data values at certain grid points, storing only the last data values at the grid point of the correction domain, and only storing grid points that are more than the correction domain can save data storage space and improve the efficiency of data queries.

4. Case study
From our comparison of the model output and the data of multilayer currents and the sea temperature field, it is evident that a single point element varying with time, a single point element varying with depth, or a single layer element field varying with time can help visualize and analyze a spatio-temporal process in a multilayer marine element field.

A single point element varying with time is primarily used to display the element field data at one coordinate position over time. A sphere model is used for this rendering, generally using the single element field data, which is two-dimensional and time-varying, in the curve form of expression. The method of visual point process is applied to spatial point objects. To obtain a time series, data from every station can be inverted into a point process associated with its station. These data space leaves position relatively unchanged and allows attribute information to vary with time. For example, the seasonal variation of sea temperature can be represented by the point-process method. The purpose of a single point element varying with depth is primarily to display, for visual expression, the data contained in the elements field, which varies with depth based on the sphere model at a coordinate position.

A single layer element field that varies with time is primarily used to realize the element field process for visual expression so that users can easily reproduce the physical processes at the surface through changes in the marine elements and can thus identify patterns. The elements field can be a horizontal plane or in an inclined plane at any angle. In this study, the visual expression of the single element field process that varies with time can be animated and viewed immediately. The animation is a sequence of images from different discrete time points; the interface is a continuous frame animation playback file that is generated through the program controls or an animation generation tool. Figure 3 shows the visualization diagram of the surface flow based on texture. Figure 4 is the expression diagram of the surface flow data at a point.

Using the expression described above, we can perform further four-dimensional visualization and display a multilayer element field that varies with time and can then analyze its temporal and spatial variation.
5. Conclusion
Due to the diversity of marine disasters and the complexity of spatio-temporal processes analysis, the marine disaster space-time model based on the four-dimensional space-time fields provides the basic conceptual framework for the representation and modeling of marine disaster processes. To form specific applications to future research, the model also needs to be analyzed in depth and instantiated in conditions that are characteristic of marine disasters.

Acknowledgements
This work was supported by the State Oceanic Administration People’s Republic Of China Young Marine Science Foundation (Grant No. 2012611), the Special Research Project for the Commonweal of the Ministry of Water Resources of the People’s Republic of China (Grant No. 201201092), the National Natural Science Foundation of China (Grant No. 61074132), and the International Science & Technology Cooperation Program of China (Grant No. 2010DFA92720).

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