Surface Current Visualization in Waterway Based on Mike 21 Model and S-100 Standards

Zixuan Wang, Mingyang Pan*, Shaoxi Li, Chao Li and Zongying Liu
Navigation College, Dalia , Liaoning, 116026, China
panmingyang@dlmu.edu.cn

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Abstract: The S-100 standard, proposed by the International Hydrographic Organization (IHO), aims to address the limitations of the S-57 standard in terms of data application and interoperability. This study focuses on the Fujiangsha water area, using the Mike 21 hydrodynamic model to simulate the flow dynamics in the region. The standardized processing of this data generates S-111 surface current data that complies with the S-100 specifications. The visualization of surface current data is realized using Cesium, which displays the flow field characteristics of the Fujiangsha water area. By integrating the standardization of S-111 data with visualization technology, this paper seeks to provide new technical support and application demonstrations for maritime management and navigation safety, while exploring the potential for further development of the S-100 standard in practical applications.

1 INTRODUCTION

The S-100 Universal Hydrographic Data Model is a new generation of marine geographic information standard officially established by the International Hydrographic Organization (IHO) in 2010. It aims to address the limitations of the S-57 standard in terms of data application and interoperability, facilitating data fusion and sharing (Luo, J. N. et al., 2019). S-100 covers electronic charts and various marine environmental information data products, enhancing the visualization and application of dynamic hydrological data. Its product specifications (such as S-101 electronic charts, S-102 bathymetric surfaces, S-111 surface currents, etc.) provide technical support for navigation safety and efficiency, becoming a crucial foundation for modern marine surveying and mapping(Wu, L. L. et al., 2019).

However, current research on S-100 remains largely theoretical (Peng, W. et al.,2017; Dou, H. X., 2013; Liu, Q. C.,2012), with limited studies focused on its practical applications, particularly in the area of channel information visualization. To address this gap, this paper takes the Fujiangsha water area as the study subject, generating surface current data that complies with the S-111 standard through standardized processing. These data are derived from simulations of the channel flow field using the Mike 21 hydrodynamic model, which provides hydrodynamic characteristic data of the region, including high-resolution data on water flow speed, direction, and other parameters. To further demonstrate and apply these data, a front-end platform based on Cesium was developed, and the surface current data were visualized, providing an intuitive representation of the flow field characteristics in the Fujiangsha water area.

2 METHODOLOGY

2.1 S-111 Data Structure

Surface current data in the S-111 standard can be represented in two formats: point data contained within a regular grid and point sets described by an irregular grid. Based on the source of surface current data, it can be categorized into four basic types: observed or predicted values at multiple fixed locations, predicted values arranged in a regular grid, values at multiple locations but not within a regular grid, and values observed at mobile stations. In this

* Corresponding author

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study, the surface current data type is predicted values arranged in a regular grid.

The S-111 regular grid is an implementation of S100_GridCoverage. A regular grid is a two-dimensional orthogonal spatial grid defined by several attributes, including the grid origin, spacing, and grid indices. The velocity and direction of surface currents correspond to the nodes within the regular grid. The grid values are stored sequentially along the X-axis at the lowest position of the Y-axis, starting from the leftmost value and proceeding to the next X-axis values for each subsequent Y-axis position until the top of the Y-axis is reached. A typical regular grid and its parameters are illustrated in the figure 1.

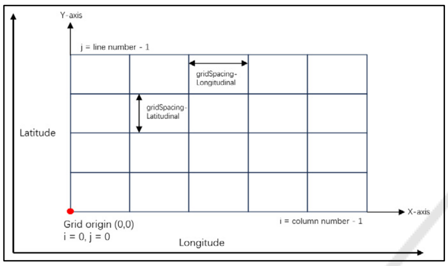


Figure 1: Typical structured grid and its parameters.

According to the S-111 Surface Current Product Specification of the IHO-released S-100 series product standards, surface current data products must be encoded using the Hierarchical Data Format version 5 (HDF5). The HDF5 data format is capable of efficiently organizing massive amounts of data through its inherent structural features. Typically, files adopt a hierarchical tree structure, where the nodes of the tree are Groups, representing collections of objects. Each group contains one or more Datasets, which are multidimensional data arrays that include attributes and other metadata. The structure of an HDF5 file is shown in the figure 2.

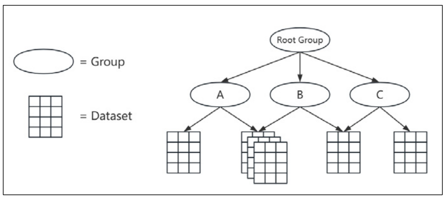


Figure 2: HDF5 file structure.

According to the mandatory naming conventions outlined in the S-100 standard, the following groups and data names are required in the S-111 data product: Group_F, featureCode, SurfaceCurrent, axisNames, Positioning, SurfaceCurrent.nn, and Group_nnn (n is an integer from 0 to 9). The figure 3 illustrates the structure of example S-111 data provided by the UK Hydrographic Office.

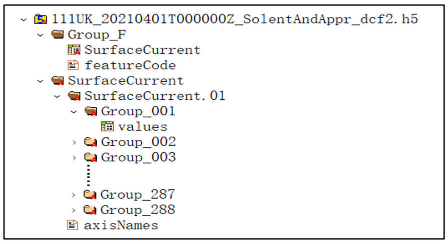


Figure 3: Structure of the UK Hydrographic Office's S-111 example data

2.2 S-111 Visualization Representation

The S-111 Surface Current Product Specification provides detailed guidelines for the display of surface current data. The grid data of the surface current field is depicted using multiple arrows. These arrow symbols are created using Scalable Vector Graphics (SVG) instructions, following the input specifications shown in the figure 4, and are scaled according to the surface current speed and the display area.

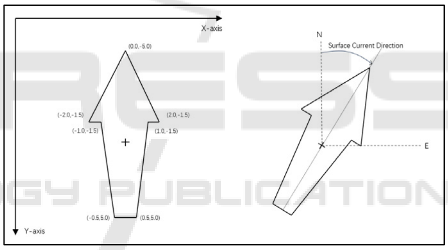


Figure 4: Input specifications for S-111 arrow symbols.

The direction of the arrow symbols must represent the direction of the surface current flow (referencing true north). The color of the arrows must be based on the speed values of the data, with the opacity adjusted according to the background chart. The size of the arrows must be a function of the surface current speed, where H_{ref} and S_{ref} are used as reference values for scaling the arrows. The minimum and maximum speed values, S_{low} and S_{high}, are used to calculate the length of the arrows. The surface current with a speed of S is represented by an arrow with a height of H. The calculation method is as follows:

$$H = H_{ref} \cdot min\{max(S_{low}, S), S_{high}\} / S_{ref} \quad (1)$$

The arrow symbols are placed over a geographically referenced background, and when the cursor hovers over the vector arrows, the corresponding speed and direction values for each arrow are displayed. The figure 5 shows an example of S-111 data from the UK Hydrographic Office, visualized using the KHOA S-100 Viewer.

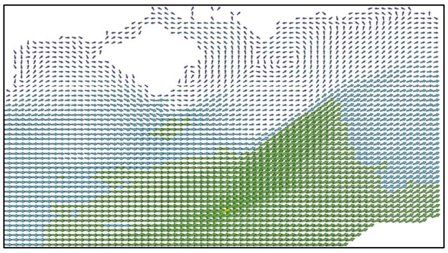


Figure 5: Visualization of the UK Hydrographic Office's S-111 example data.

2.3 Mike 21 Hydrodynamic Model

Mike 21 is a two-dimensional numerical model developed by the Denmark Hydraulic Institute, providing a comprehensive and efficient design environment for engineering applications, coastal management, and planning. Mike 21 is not only beneficial for simulating complex river channels but also supports a variety of control structures. Its relatively short computation time significantly improves computational efficiency(Li, X. B., 2024). Thus, this study uses the Mike 21 to simulate the channel flow field and further construct the hydrological characteristic dataset for the channel flow field.

Mike 21 neglects vertical flow acceleration and focuses on vertically averaged flow factors. It can use either Cartesian or spherical coordinates, and in the plane, it employs unstructured grids to simulate water level and flow variations caused by various forces, or to model two-dimensional free-surface flows that disregard stratification. The numerical method used in Mike 21 is the finite volume method, which computes the normal fluxes by establishing a unit hydraulic model along the outer normal and solving the one-dimensional Riemann problem(Lü, Z. Y., 2024). The specific equations of the two-dimensional shallow water equations in the Mike 21 are as follows:

$$\frac{\partial h}{\partial t}+\frac{\partial h\bar{u}}{\partial x}+\frac{\partial h\bar{v}}{\partial x}=hS \tag{2}$$

Momentum Equation in the X Direction:

$$\begin{aligned}\frac{\partial h\bar{u}}{\partial t}+\frac{\partial h\bar{u}^2}{\partial x}+\frac{\partial h\bar{u}\bar{v}}{\partial y}=f\bar{v}h-gh\frac{\partial\eta}{\partial x}-\\ \frac{h}{\rho_0}\frac{\partial p_a}{\partial x}-\frac{gh^2}{2\rho_0}\frac{\partial\rho}{\partial x}+\frac{\tau_{sx}}{\rho_0}-\frac{\tau_{bx}}{\rho_0}-\frac{1}{\rho_0}\\ \left(\frac{\partial S_{xx}}{\partial x}+\frac{\partial S_{xy}}{\partial y}\right)+\frac{\partial}{\partial x}\left(hT_{xx}\right)+\frac{\partial}{\partial y}\left(hT_{xy}\right)+hu_sS\end{aligned} \tag{3}$$

Momentum Equation in the Y Direction:

$$\begin{aligned}\frac{\partial h\bar{v}}{\partial t}+\frac{\partial h\bar{v}^2}{\partial y}+\frac{\partial h\bar{u}\bar{v}}{\partial x}=f\bar{u}h-gh\frac{\partial\eta}{\partial y}-\\ \frac{h}{\rho_0}\frac{\partial p_a}{\partial y}-\frac{gh^2}{2\rho_0}\frac{\partial\rho}{\partial y}+\frac{\tau_{sy}}{\rho_0}-\frac{\tau_{by}}{\rho_0}-\frac{1}{\rho_0}\\ \left(\frac{\partial S_{yx}}{\partial x}+\frac{\partial S_{yy}}{\partial y}\right)+\frac{\partial}{\partial x}\left(hT_{xy}\right)+\frac{\partial}{\partial y}\left(hT_{yy}\right)+hv_sS\end{aligned} \tag{4}$$

The average flow velocity along the water depth direction is defined by the following equation:

$$h\bar{u}=\int_{-d}^{\eta}udz,h\bar{v}=\int_{-d}^{\eta}vdz \tag{5}$$

Where η is Riverbed elevation; u,v is velocity component in the direction x,y; u_s,v_s is average water flow velocity in the direction x,y; f is coriolis force coefficient; ω is Earth's rotational angular velocity; φ is local latitude; g is gravitational acceleration; S is flow generated by source and sink terms; $\tau_{sx},\tau_{bx},\tau_{sy},\tau_{by}$ is components of the surface wind stress and riverbed bottom friction stress along the direction x,y; T_{ij} is lateral stress terms.

The boundary condition treatment in the MIKE 21 includes open boundaries, closed boundaries, and dry-wet boundaries. Under open boundary conditions, water flow is allowed to enter and exit the boundary region. For closed boundaries, all velocity components perpendicular to the boundary are set to zero, defining a no-slip boundary. In dry-wet boundary conditions, the cells are classified as dry, semi-dry, or wet, with the conditions being satisfied as: $h_{dry}<h_{flood}<h_{wet}$ (Hu, X. W., 2024).

3 EXPERIMENTS

3.1 Two-Dimensional Flow Field Calculation

The Fujiangsha Waterway is located opposite the Zhangjiagang Port area.In this study, MIKE 21 is used to construct a two-dimensional hydrodynamic numerical model for the river section where the Fujiangsha Waterway is located. The river section is approximately 43 km long. The computational range of the model is shown in the figure 6.

Figure 6: Model computation range.

In constructing the model computational grid, it is necessary to extract the riverbank and water depth data. In this study, ArcGIS Pro was used to extract riverbank and water depth data from the S-57 charts. Given the characteristics of the river channel, an unstructured triangular mesh grid was employed. The grid near the riverbanks and islands was refined, while the grid in the center of the river was coarser, ensuring the model’s stability and improving computational efficiency. The computational grid consists of 1,277 nodes, which is shown in the figure 7.

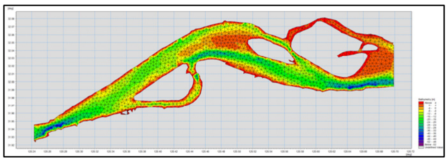


Figure 7: Model grid division.

The MIKE 21 model adopts a cold start for its initial conditions. The upper and lower boundary conditions are defined as water level boundaries, with the boundary format varying over time and along the boundary. In this study, the default value of 0.28 is used for the eddy viscosity coefficient. The Manning coefficient is selected to control the bed roughness, set to 32 in this study. The time step is set to 300 seconds, with results output every 30 minutes. The model's computational results are shown in the figure 8.

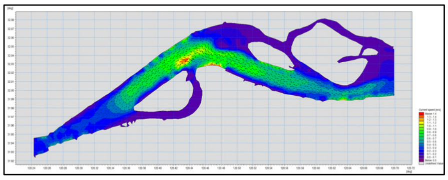


Figure 8: Model computation results (time interval of 4).

3.2 S-111 Data Generation and Visualization

Based on the results from MIKE 21, this study uses a script to perform interpolation and gridding of flow velocity and direction data, generating surface current data files compliant with the S-111 standard. The domain of the regular grid is defined by the latitude range from about 31.93 N to 32.08 N and the longitude range from about 120.24 E to 120.70 E, with a grid resolution of 0.001. The interpolation method is used to map irregularly distributed data points onto a regular latitude-longitude grid. Subsequently, the gridded data is further processed to generate a surface current data file in HDF5 format. The interpolated data file is loaded, and the flow velocity and direction data are reconstructed into two-dimensional arrays. Geographic boundaries, resolution, and grid dimensions are then defined, ensuring consistency with the settings in the interpolation step. The resulting S-111 surface current is shown in the figure 9.

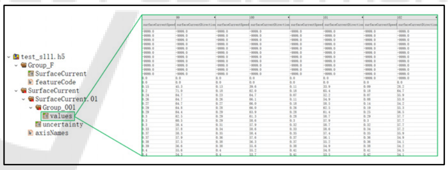
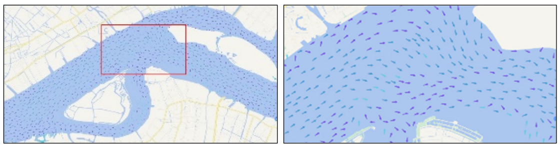


Figure 9: Generated S-111 surface current data.

Based on the Cesium platform, this study develops a frontend platform for data reading and visualization, allowing complex current velocity and direction data to be presented in an intuitive manner. The platform reads the HDF5 files, parses the current velocity and direction data into two-dimensional arrays, and converts them into vector format. The display of arrows is defined according to the S-111 surface flow product specifications, including parameters such as color, size, and direction. The visualization of the S-111 surface current is shown in the figure 10.



(a) (b)

Figure 10: Visualization of S-111 surface current data (a) and its zoom-in (b).

4 CONCLUSIONS

This study focuses on the Fujiangsha and successfully generates surface current data compliant with the S-111 standard, based on the S-100 framework and the Mike 21 hydrodynamic model. The data is visualized using Cesium for intuitive display. The research results demonstrate that the integration of standardization and visualization techniques provides a clearer representation of the hydrological characteristics in complex water areas, offering support for improving channel management and navigation safety. However, it should be noted that the S-100 standard has not yet been officially implemented, and the current study area lacks validated observational data. Future research could refine the MIKE 21 model parameters using actual hydrological measurements when available, thereby enhancing the accuracy of simulation results. The standardized data processing framework and visualization scheme proposed in this study have demonstrated applicability to compliant hydrological data, which may serve as a reference for establishing operational systems in standardized maritime environments.

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