6th International Conference on Hydroinformatics - Liong, Phoon & Babovic (eds)

COASTAL HYDRODYNAMIC FORECAST SYSTEM

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This paper describes an integrated computerized system facilitating the computational forecast of tidal hydrodynamics in Singapore Strait. The governing core of the system is the Model INTegrator (MINT), used for manipulation of 4-D (time & space) data, launching the hydrodynamics and relevant water quality modules, and on-line visualization. MINT is the universal-platform and model-independent environment for data pre- and post- processing and model management. The developed computational and visualization technologies are being extended to internet-based nowcast and forecast services. Communications of MINT, models and model parameters utilize XML language, for which a simple Fortran parser is developed; while storage of original and computed 4-D data employs the worldwide used netCDF standard. Usage of Java technologies and open source standards, like XML and netCDF, ensures easy exchange of data with other models, and makes MINT a platform independent. Standard looking intuitive GUI allows an easy control of complex computational tasks.

Keywords: Hydrodynamic model, forecast, internet, platform independent, XML, parser, netCDF, GUI, Java.

1. INTRODUCTION

The ability to forecast conditions of natural systems is important feature of decision making, and is essential part of a planning process. Weather forecast, for instance, from a guessing science has become everyday routine service, widely available via all sort of modern media including internet. In spite of expected numerous benefits, coastal forecast is less developed worldwide. The forecast provides an important information for planning and safety of commercial maritime transport. Many forms of coastal recreational activities, including fishing and sailing, require advance prediction of sea state (waves and currents). In accidents, timely information on wind and circulation patterns improve search and rescue efficiency and could significantly increase chances of surviving. Knowledge of currents and pollutant dynamics in coastal zones is an essential part of coastal management and environmental impact assessment during chronic and acute spills. In recent years, with significant improvement of computational power, accuracy and reliability of hydrodynamic models, operational forecast is becoming an indispensable part of a national planning. Combined with modern computer and communication technologies, accurate nowcast and forecast of hydrodynamic parameters could be made available to ordinary users almost instantly.

There are several available hydrodynamics internet forecast services, which represents hydrodynamic information in different ways. It can be simple tables of highest and lowest tides, such as Costa Rica tide forecast (http://www.costarica.com/Home/Weather/Tides/) or tidal time series plots in certain predefined points, such as Texas Water Development Board forecast/hindcast (http://hyper20.twdb.state.tx.us/data/bays_estuaries/tides.html). Another one type of internet forecast systems provides static or dynamic picture of hydrodynamic situation in certain water column. Systems of that kind, for example, are Wind & Wave Nowcasts & Forecasts for the Great Lakes (http://www.crh.noaa.gov/grr/marine/windwave.php) and Monitoring, Forecasting and Information system for the Greek seas POSEIDON (http://www.poseidon.ncmr.gr/poseidon_mainframe4.html), based on POM.

This paper presents recent TMSI efforts in creating of operational hydrodynamic forecast model. The customized general purpose circulation model is integrated and controlled by Model INTegrator (MINT) user environment. The Java-written interface is responsible for post- and pre- processing of model data and parameters. Data exchange and storage utilizes universal platform independent standards, like XML and netCDF. A brief description of hydrodynamic modeling aspects in Singapore Strait is outlined. Finally, a MINT-based internet forecast system is presented.

2. MODEL INTEGRATOR (MINT)

In spatial-oriented model integration systems two major types of coupling are distinguished: loose and tight [4]. Loose coupling is a method of integration in which common files are used as an exclusive mean of data exchange between otherwise independent GIS and environmental modeling systems. Using this approach, GIS components serves as a pre- or post- processor to the modeling system. Typically all that is needed is a simple interface and perhaps some common file format conversion methods. In one’s turn, tight coupling involves a common user interface to system components, common data structures and model integration through reciprocal accessible procedures. The GIS and modeling components exchange data via shared resources, such as files, network connections, etc. In these terms, MINT is a hybrid of both approaches, because it does utilize common file structure and similar Graphic User Interface (GUI) for different kinds of model, but doesn’t provide integration at the level of functions. From MINT point of view a numerical model is a black box with understandable input and output structure, which also sends back some tracing information on the performed task status. This configuration utilizes both, advantages of a relatively tightly coupling, and a transparency of a partially integrated system. In a contrast to tightly coupled systems, which are closed to other models, MINT can integrate any required numerical model.

Figure 1 represents a MINT structure and scheme of interaction between the GUI and the model, showing the following major modules: Visualization, Configuration controller, and Launch controller. Visualization module combines set of independent components for input and output data visualization and editing. Configuration controller allows user to specify model parameters, and save them in XML files, accessible by the numerical model. Launch controller allows user to run a specific model as a separated thread, takes care of the process during running time, and closes the thread once the assigned task is completed.

MINT performs two major tasks: working with models and data visualization. At the initial stage, when user chooses a required model, MINT parses related model definition section from the MINT configuration file, and dynamically generates respective Configuration controller. Visualization components for each kind of source data dynamically upload and take their place according to the model definition part. At this stage one may change model parameters using intuitive interface, and check data consistency on-a-fly. Once all parameters are specified, user can start simulation via Launch controller. Output results can be viewed within the same GUI after the simulation is completed.

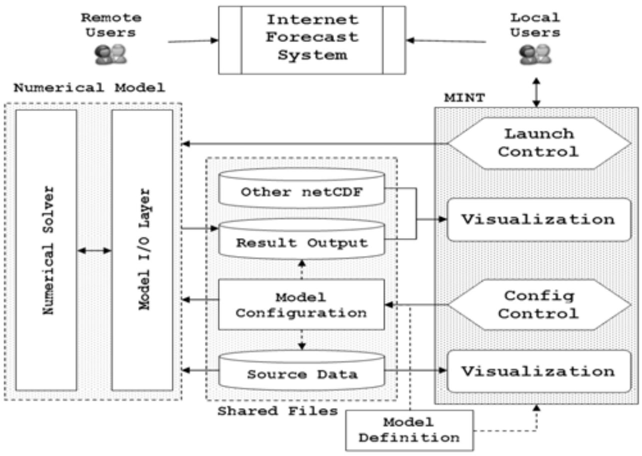

Figure 1. Communication between MINT and the model.

3. DATA EXCHANGE

Interaction of Programs using XML

MINT is written in Java language, whereas a typical numerical model utilizes Fortran or another high-level programming language. MINT controls itself and a numerical model via parameters grouped in configuration XML (eXtensible Markup Language) files. XML is a simple and extremely flexible platform-independent text format, allowing usage of tree-like structures for description of elements. An element may have a set of attributes, in the form of key-value pairs, and may contain other elements, text, or mixture of them. An element may refer to other elements via special attributes, thereby allowing an arbitrarily graph structure to be designed. The document structure is flexible enough to elaborate any possible set of parameters, allowing fast search, removal or addition of required parameters. The structure of an XML document does not require additional regulations beyond those laid out by XML specifications. XML by itself is deeply integrated into the Java system, providing rich utilities to work with different kind of XML parsers, including low-level SAX (Simple API for XML) parser, or high-level DOM (Document Object Model) parse-tree API.

Simple API for XML in Fortran

In order for the hydrodynamic forecast model to access parameters stored in XML configuration files, a generic SAX parser is developed. The parser is written in Fortran language and could be utilized within any Fortran program. The basic function of the parser is to retrieve XML elements or attributes from the configuration file, regardless their positions and order in the file. The parser supports reading of integers, logical, strings, as well as single- and double- precision real values or 1-D arrays from XML attributes. Basic error handling and syntax validation are included. High level functions in the parser are directly called by the model's I/O subroutines, while low level functions are automatically invoked by high level functions to handle syntax validation, errors and adjustment of XML strings (such as removal of meaningless blank space, for instance). To call upon the parser, several subroutines are written in I/O layer of the forecast model, where each subroutine is responsible for handling of separate tasks, such as description of boundary conditions, managing of result files, specification of simulation parameters, etc. The retrieved information is stored in operational memory of the forecast model, and processed at appropriate time later. Figure 2 shows schematic flow of user settings from MINT GUI to the hydrodynamic model.

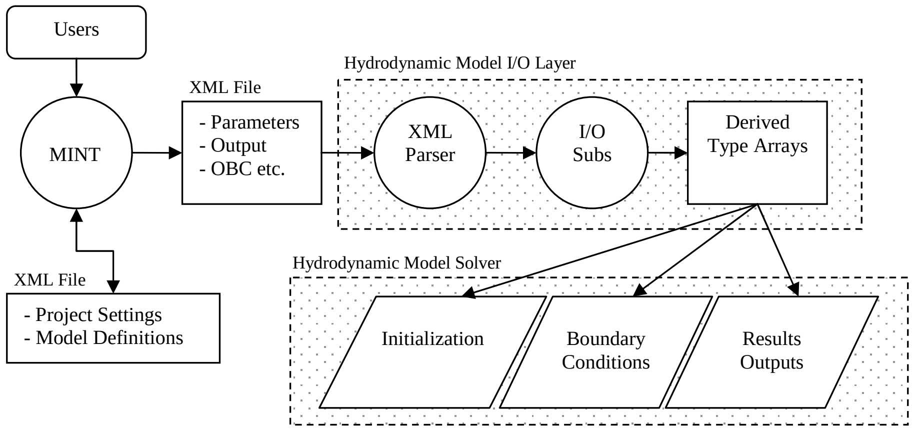

Figure 2. Schematic flow of user-specified data to the model.

Storage and Sharing of Information using NetCDF

NetCDF (Network Common Data Form) is an interface for array-oriented data access and a library that provides an implementation of the interface. The interface is developed under the Unidata program (http://www.unidata.ucar.edu/packages/netcdf/) funded by National Science Foundation (NSF) of USA. NetCDF has been utilized to store input data and computational results of the forecast model.

NetCDF library allows for an easy cross-platform exchange of data among numerical models, user interfaces, pre- and post- processing tools. Availability of netCDF libraries in a source and binary forms for Fortran, Java, and many other programming languages ensures wide access and sharing of data. To enhance data exchange with other systems or research groups, format of netCDF files in the system is drafted in a strict conformation to the Climate and Forecast (CF) Metadata Conventions. The format is also compatible with Ferret and Matlab. NetCDF files used in the MINT system contain all necessary descriptions of the data and model; it supports multiple concurrent access, analysis, and visualization by other models and programs.

Data Storage and Access

During simulations using the 3-D hydrodynamic model, a large amount of data is generated, which are used later for analysis and visualization, or by other models, such as water quality or particle tracking. For instance, a typical output file for the continuous 5 days tidal current simulation in Singapore Strait may well exceed a few gigabyte (GB). Since it is difficult to work with the large files, and since netCDF has a file size limit of 2 GB without Large File Support (LFS), several methods have been implemented to make the storage and access operations more flexible. Firstly, the file format is using the fact that a certain portion of the 4-D (time & space) numerical results is meaningless, like description of flow characteristics at inland grid nodes. Using user-defined filtering criteria, the original 4-D data can be converted uniquely in 2-D (time & space) format with the attached index array. In the Singapore Strait hydrodynamic forecast model this method could reduce file size by 80%. Secondly, the forecast model is capable of writing series of netCDF files according to user-selected criteria, such as file size or record period. The filtering criteria and order of files in the series is stored in the same netCDF file(s). Figure 3 shows a schematic diagram of data storage and access utilizing the two methods.

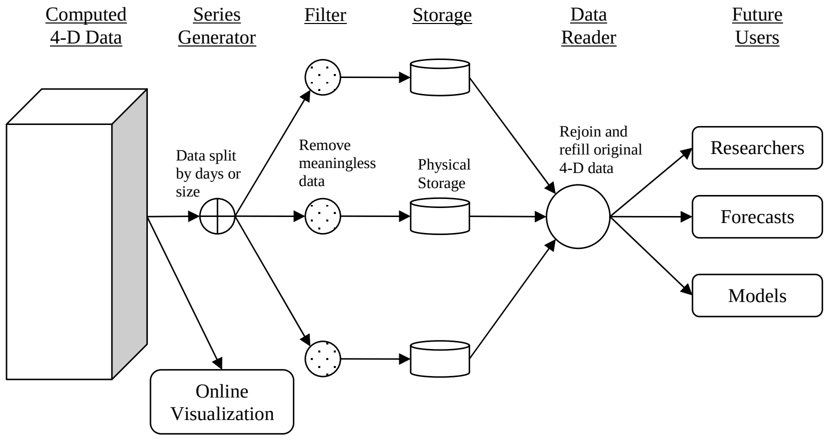

Figure 3. Computed data processing structure.

4. HYDRODYNAMIC MODEL

Numerical model of hydrodynamic forecast is based on the 3-D sigma coordinate Princeton Ocean Model (POM) [5]. POM is a so-called “primitive equation circulation model” that contains a second-order turbulence model. Originally used for oceanic scale hydrodynamic modeling, the model has in recent years been applied to coastal water problems, including Singapore Strait [1]. In order to increase the computational time-step, POM uses a time-splitting technique which allows for separate explicit approximation of derivatives along (coarse resolution) horizontal coordinates and (fine resolution) vertical coordinate. This feature permits forecast computation of adequate resolution within reasonable time in most single-processor PC-based computers. The model is written in a fixed form Fortran language.

Enhancements have been made to the model boundary conditions module to better adapt it to the Singapore Strait simulation [2] [3]. Based on field observations, open boundaries of the model have been aligned to observed incident angles of tidal waves from South China Sea and Malacca Strait. Alignment of the boundaries enables more accurate prediction of coastal circulation in the limited domain. Since the coastal circulation of Singapore Strait is controlled by astronomical tides and Asia-Australia monsoons, tidal elevations are prescribed at open boundaries as the main driving force. Prediction of tidal elevations is obtained from harmonic analysis using tidal prediction software [6]. The forecast model could then predict coastal hydrodynamics of Singapore

Strait for any given period. Figure 4 shows the coverage and open boundaries of the forecast model.

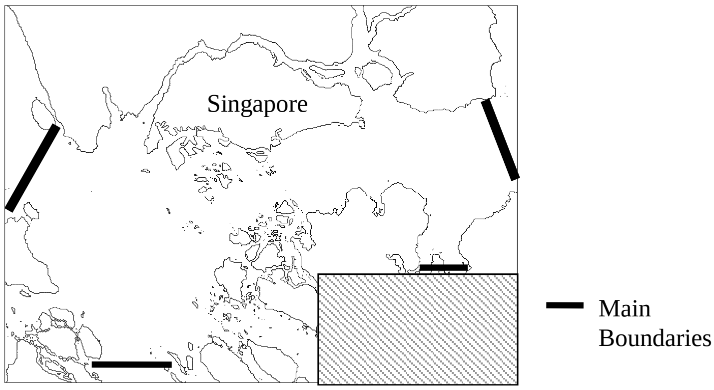

Figure 4. Domain and boundaries of Singapore Strait hydrodynamic model.

To follow up the coastal developments, it is important to ensure up-to-date bathymetry in the forecast system. The bathymetry database contains data collected in various forms from different sources. In order to produce gridded bathymetry, the data are filtered to obtain the relevant portions for that particular forecast period. Then, a 2-D triangle based linear interpolation is performed to obtain the gridded data. Manual adjustment or other techniques (e.g. diffusion and smoothing) are applied when the data are incomplete or inadequate for modeling purpose. After appropriate adjustment according to numerical masks of hydrodynamic model, the bathymetry data are stored in netCDF format for common use.

5. INTERNET-BASED HYDRODYNAMIC FORECAST

While MINT currently provides only local full-feature access to the forecast system, the next step of a wide interactive usage via internet is under development. A trial limited-feature hydrodynamic forecast for the Singapore Strait is currently available at PORL's web-site: www.porl.nus.edu.sg/forecast/index.jsp. Once accessed, the page generates a snapshot figure of forecasted surface currents in Singapore Strait. The same MINT modules are used for the internet-based forecast due to the application of Java Servlet Pages (JSP) as a basic server technology (Figure 5). Request from a user comes to Servlet Container (based on JSP parser Tomcat, for instance), and then to the JSP system, which controls snapshot preparation of pre-computed current velocities (Figure 6). Higher resolution full-feature forecast service is available upon request.

6. CONCLUSIONS

An integrated environment MINT is coupled with the 3-D hydrodynamic model to develop a hydrodynamic forecast system. XML data format has been used as a medium to exchange most important parameters within the system, while netCDF is used for storing and sharing of large multi-dimension data. The system currently is implemented to allow direct user access, and a pilot version of remote internet access is being developed. Although, the first version of the system is released, a lot of developments have either been planned, or are currently being performed to improve it further. For instance, currently user obtains only static figure representing tidal velocity prediction at the time of access; in the future, animation of the specified period will be available. The MINT system will be expended to include water quality models.

ACKNOWLEDGEMENTS
The research is sponsored by A*STAR research grant. Help of colleagues from the Tropical Marine Science Institute and partner organizations is highly appreciated.

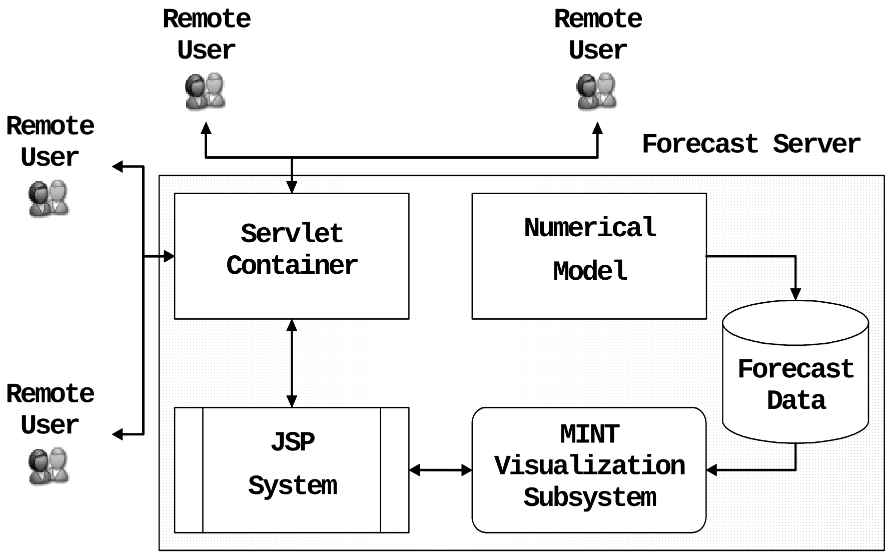

Figure 5. Internet forecast system.

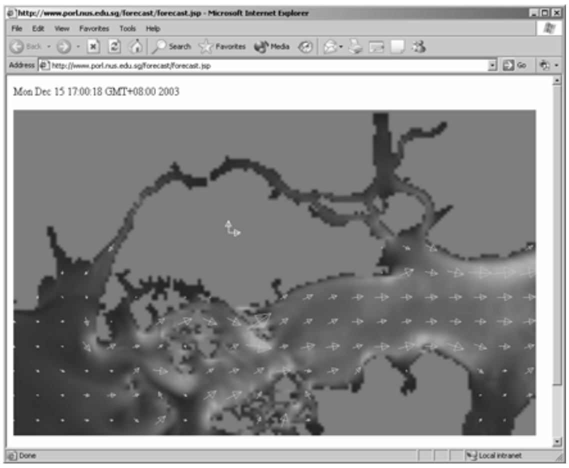

Figure 6. A sample of web-forecast, viewed in an internet browser.

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