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## **AN OPEN VISUALIZATION TOOL (OPENVT) FOR MESH BASED WATER MODELS**

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Several numerical models for water related problems have been developed worldwide. The open visualization tool (OpenVT) provides the functions of visualizing results from a suite of modeling systems, regardless of their data structures. Available file formats for visualization include netCDF, NEFIS, domain range time series binary files and individual ASCII files. OpenVT integrates the OpenGL library for better performance of frame display frequency. The capabilities of OpenVT are displayed in real hydro-systems for a hydrodynamic coastal problem, a water quality simulation and a dam break problem. The limitations on publishing OpenVT are presented as well and the task for the future development.

### **1. INTRODUCTION**

Development of computers allowed for solution of equations describing water related phenomena. Numerical models have been used for solutions and are based on discretization of the computational domains in various manners. Historically the approaches in discretization uses meshes to represent the computational domains. Any value of a solution function is expressed at the nodes of the discretization mesh. A lot of data is generated in the process of obtaining a solution at a mesh point. All these results are easily interpretable by specialists if they are represented in graphical format. The process of presenting solutions of a problem in a graphical format is known as post-processing. Numerical models developed for solution of water related problems may differ a lot in their post-processing capabilities. Usually each numerical model possesses its own data formats and visualization tools. Meanwhile, the computer power has also been greatly upgraded, hence size of outputs from numerical simulation models becomes much larger and more complex. The requirement of efficient visualization tools for large data sets is currently an issue posed to software developers.

Many existing numerical models are published as open source or commercial packages. Examples of open source models are: Delft3D developed by Deltares, OpenFOAM an open source CFD toolbox produced by ESI-OpenCFD, TELEMAC which provides an integrated suite of solvers for free-surface flow. Examples of commercial packages are MIKE developed by Danish Hydraulic Institute (DHI), ANSYS from ANSYS Inc. Each of the previous listed tools has its own numerical engine solver and visualization tools that are made available to the user. For example Deltares has a quick plot toolbox which is provided as a Matlab component. This quick plot toolbox can visualize results from Delft3D, D-FLOW and TELEMAC output files. However such a tool is not easy to use when result data sets are large, because of the used programming language used, which gives relatively slow performance. Moreover it is not

possible to display multiple simulation results simultaneously in the same screen window. This is a major drawback, especially when comparison of multiple simulations, which have different resolutions, is required. All of these listed issues pointed to the need of developing an open visualization tool (OpenVT) that tries to solve these challenges.

Present paper presents an open source OpenVT tool, that has functions for loading and visualizing multiple output results from a suite of modeling systems. Deltares modeling software suites are presented as examples for demonstrating the capabilities of the tool. The tool offers functions for multi-plots and simple analysis of several variables within the same window.

The paper is structured in five parts, first the introduction followed by the description of OpenVT. Example cases of the use of OpenVT are presented in section three. Section four of the paper presents the conclusion, limitations and possible future developments of the tool.

## 2. OpenVT DESCRIPTION

OpenVT is a desktop application fully developed under Windows environment by using Intel Visual Fortran and OpenGL library. OpenVT has three main capabilities that are not present in the available post-processing tools; efficiency in updating and rendering of results data sets; capability to work with different data formats; and possibility to make multi-plots of different simulation scenarios.

Fortran 95 was the developing environment for OpenVT, because of the capabilities of the programming environment, as detailed further. Fortran is a general-purpose, imperative programming language and it is suited to perform scientific computations, as highlighted by *Backus et al.* [1]. For the graphical interface, OpenVT integrates OpenGL library as the graphic rendering solution. OpenGL is the most widely adopted graphics standard with high visual quality and performance, and it suits the purpose of visualization under a GNU environment, *Shreiner [2]*

Currently the tool has been tested for the visualization of results of software developed by Deltares. Different data formats can be uploaded in the same environment, which is very useful for qualitative model comparisons. OpenVT has implemented the following data formats:

- NEFIS, which are data files with result outcomes from Delft3D. Delft3D is a flexible integrated modeling suite. It is able to simulate in time and two- and three-dimensional space water hydrodynamics along with sediment, ecology and water quality. Flow results are presented per groups of cells and elements in a NEFIS file structure. There are two types of flow model results; point-based and grid-based output [3].
- ASCII files, which contain results coming from SOBEK, an integrated modeling suite for flood forecasting, optimization of drainage systems, control of irrigation systems, river morphology and surface water quality, etc. Result data of this suite is saved in a set of ASCII files with the name of the variable [5]. In this case, square grid is set for model simulation, however the results are stored as changes in the stored variables at each time step. This reduces notably the output file size for fine spatial resolutions.
- NetCDF: The network common data format, of D-FLOW, is a set of interfaces for array-oriented data access library. NetCDF library has the advantages of self-describing, portable, scalable, appendable, sharable and archivable. It supports C, Fortran, C++, and other languages [4]. The main characteristic of D-FLOW is the use

of unstructured grids. Due to the binary nature of NetCDF files, challenges needed to be overcome in the development of OpenVT.

The multi-plot feature in OpenVT includes two and four subplots in the same window. However the distribution of these subplots is fixed. The maximum number of simulation results can be displayed is two. The grid size and time step of each scenario can be different based on the simulation purposes. In addition, a simple analysis module is integrated in OpenVT for quick comparison, which is plotted in the lower row.

### 3. VIZUALIZATION USING OpenVT

Several result data files were used to test OpenVT tool, from which three are selected and presented below. The first case is considering the results obtained from a model of the San Francisco Bay area using D-FLOW for calculation of the hydrodynamics of the flow in the area. The sediment of the same estuary was simulated using Delft3D-DELWAQ. Second example case is a water quality model for algae bloom in the Taihu lake, China. Finally, an example of how flooding event over a DEM is displayed as a comparison of flooding extent with different grid resolutions.

#### 3.1 Visualising results from sediment transport

Suspended sediment transport in the San Francisco Estuary was modeled taking into account three sources of sediments. Results of DFLOW hydrodynamic model are given in NetCDF files, which are later used by DELWAQ (Delft3D-water quality model) to simulate the sediment transport. The two models represent different processes, using data input described by different meta data formats, that are stored in different structures.

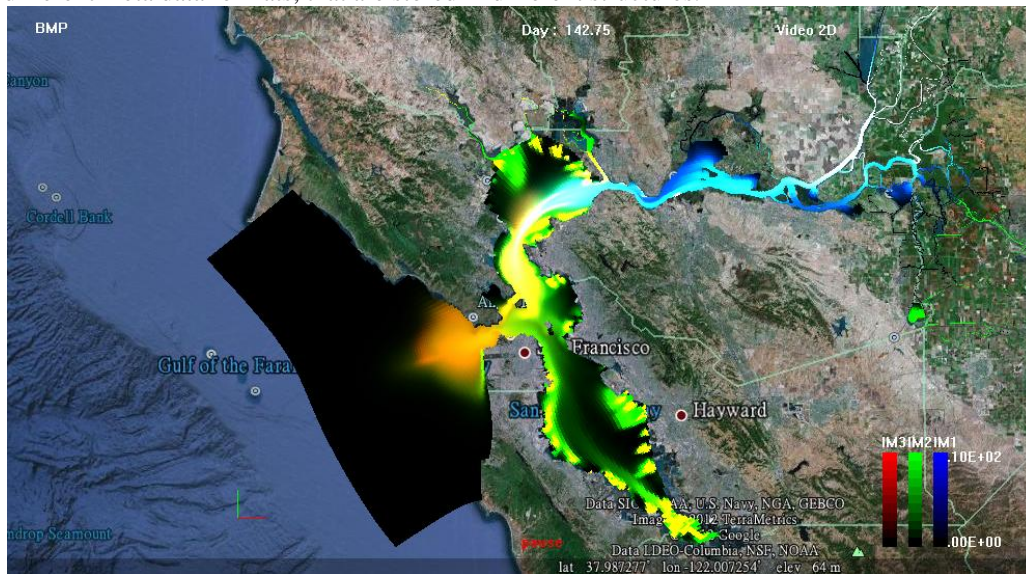


Figure 1. Visualization of suspended sediment concentration in San Francisco Estuary, USA

OpenVT is capable to visualize together the mixture of these data sources. The three primary colors (red, green, blue) are used to represent each sediment source with its own granulometry. The combined concentration is calculated in OpenVT by linear interpolation of the three defined primary colors, Figure 1 shows an example of suspended sediment concentration in the San Francisco Estuary.

### 3.2 Visualizing results of water quality models

Simulation of the Taihu lake (China) on its eutrophication status and behavior for algae bloom is done using the Delft3D hydrodynamic tool, which outputs simulation results in files in NEFIS format.

OpenVT is used to make comparisons between different scenarios of model set-up. The multi-plot function capability of OpenVT set up a maximum of 4 multi-plots in the viewport. In the case of algae bloom in Taihu lake, two cases are selected to be presented and correspondingly two subplots are used to show the results of the simulation for lake velocity. A third subplot is used to display a simple analysis of the two selected simulated scenarios. Figure 2 shows this set-up; i.e. two selected scenarios on the top row and the difference calculated by OpenVT on the lower row.

Grid size, time- and space step, as well as simulation time are the same for both analyzed scenarios, however there are cases when result files may contain results of simulations with different time steps and different time. In general computational grid is the same, but given that hydrodynamic simulations are easily influenced by the boundary conditions, the capability of multi-plot of different scenarios can be carried out in OpenVT.

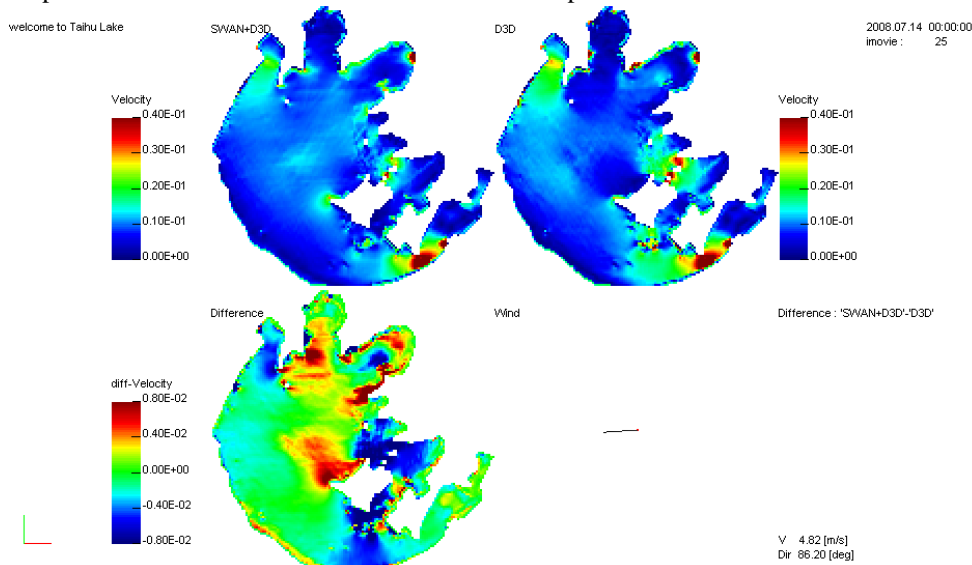


Figure 2. Depth average velocity in Taihu lake, China

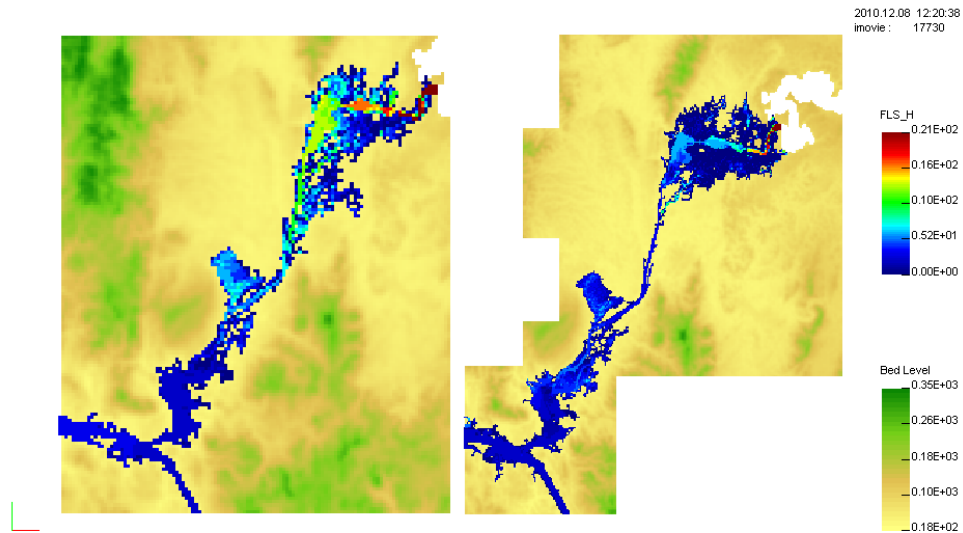


Figure 3. Visualizing results of flood extent for two computational grid sizes

### 3.3 Visualizing results from floods

One of the main issues to overcome by the use of the tool was its ability to load different scenarios of the same problem but for different grid resolution. Test cases of floods were run in SOBEK 1D2D over two different space discretization grids in order to see how they will affect flood extent. These two cases are plotted in OpenVT, for comparison purposes.

In figure 3 the left pane shows results of flood extent due to a dam break, over a grid with a cell size of  $100 \times 100 \text{ m}^2$ , while the right pane shows the solution results for same problem using a grid cell size of  $50 \times 50 \text{ m}^2$ . In hydrodynamic modeling, the time step is defined by CFL condition. Thus the time step of each case is also different. OpenVT creates a possibility for analysis of flood extent using water depth, which currently is not available in SOBEK or D-FLOW.

## 4. CONCLUSIONS, LIMITATIONS AND FUTURE DEVELOPMENTS

OpenVT is able to display backdrop images such as the ones obtained from GoogleEarth or different satellite images. It uses a third timeline in the computation of visualization and performing the time interpolations of results.

At this moment, OpenVT is not yet published as an open source, because of GNU license type. An alternative solution would be to move into open source solutions using NetBeans and GNU compilers. However, it is not possible to work in such environments with result files (or multiple result files) which adds up to more than 2Gb of memory. No solution is available so far, and it seems to be the main drawback migration of the current codes.

The possible future developments and extensions of OpenVT include: i) migration of the Intel Visual Fortran codes to GNU compiler collection, ii) integration of more mesh based data

types, iii) visualization of results from mesh free software and iv) improvement of the exited data storage scheme.

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