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AUTOMATIC LINKING AND FAST CALCULATION METHODS OF 1D/2D COUPLED MODEL

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***Abstract**: In order to use 1D/2D coupled model for flood prediction in a large area, we propose automatic linking and fast calculation methods. For fast calculation, we propose the Dynamic Domain Defining Method (Dynamic DDM), which defines the calculation domain to include wet cells and to exclude dry cells during the simulation. Because of the nearly optimal calculation domain, the calculation time is significantly reduced. For automatic linkage generation, we propose the Floodplain –River –Overflow Gluing (FROG) method. It defines a cell in the 2D model as either left or right side of a river, and connects it to the same side of the levee line in the 1D river model. The coupled model generated by the FROG method accurately simulated a flood disaster occurred in Takayama City (Japan). We applied the proposed methods for Kawasaki City (Japan). The 1D model is applied to the two river systems with 2 main rivers and 15 tributaries, and the 2D model is applied to the city (143 km^2). The FROG method generates 14,287 linkages between 1D and 2D models. The system working on a PC simulates a 27 hours event in less than 10 minutes. We conclude that the proposed methods are suitable for flood prediction.*

***Keywords**: 1D/2D coupled model; Dynamic Domain Defining Method (Dynamic DDM); Floodplain –River –Overflow Gluing (FROG) method; DioVISTA® Flood Simulator.*

1. INTRODUCTION

Recently, various coupled models composed of one-dimensional (1D) river model and two-dimensional (2D) inundation model are successfully applied to simulate river flooding and inundation (e.g., Lin et al., 2006, Leandro et al., 2009). In addition, sophisticated simulation software for the coupled model (e.g., Rungø and Olesen, 2003) is available. Because of the high accuracy and high productivity of the coupled model, the coupled model is expected to be more common. However, the coupled model is not applicable for real time prediction, because it requires a long computational time to calculate the 2D model. In addition, generating links between 1D and 2D models by manual is time-consuming (and costly). Therefore introducing the coupled model for a large area with many rivers is unrealistic.

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We propose two methods: (1) fast calculation method named Dynamic Domain Defining Method (Dynamic DDM) in order to forecast river water level and inundated area using the coupled model, and (2) automatic linkage generation method named the Floodplain –River – Overflow Gluing (FROG) method in order to introduce the coupled model for a large area. In this paper, we explain the two methods in Section 2. We show a use case of the methods in Section 3. We present conclusions in Section 4.

2. PROPOSED METHODS

2.1 Software Architecture

Because the proposed methods use modeling and geospatial information, we develop a four-dimensional (4D) global geographic information system (GIS) and a modeling engine. Our software product, the DioVISTA® Flood Simulator, consists of Windows-based graphical user interfaces, 4D global GIS engine and modeling engine (Fig. 1). The Dynamic DDM is applied to the inundation model, and the FROG method is applied to the River-Inundation connector. These methods also use the GIS engine to convert coordinates and fetch geospatial data.

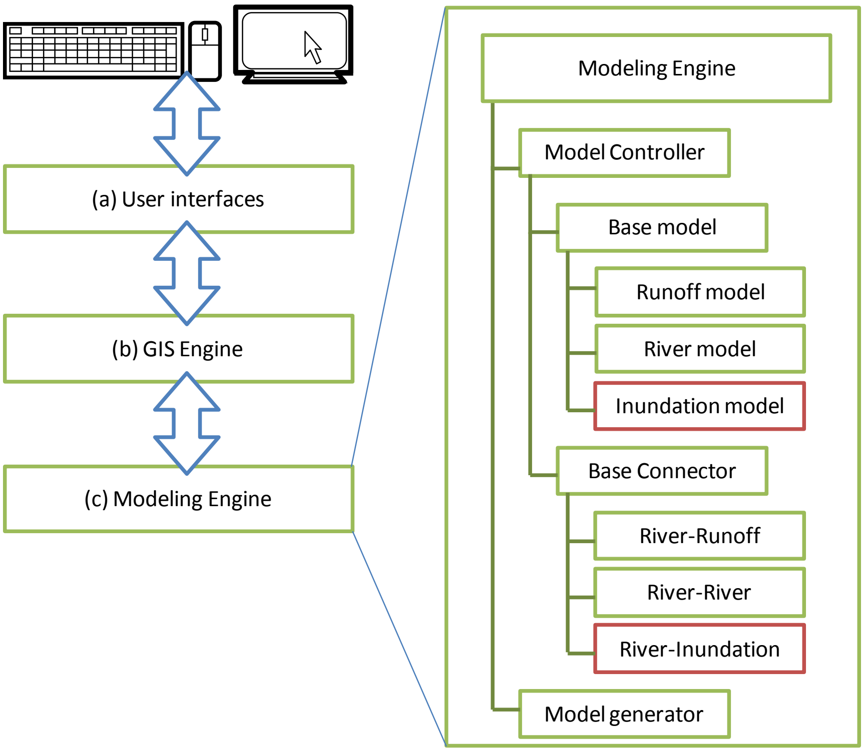

Fig. 1. Architecture of our flood simulation software

2.2 Dynamic DDM

Usual 2D inundation model with the 2D shallow water equations are conducted in the calculation domain (i.e., cells in the target area of the simulation). We need to solve the equations at flooded (wet) cells, and not need to at non-flooded (dry) cells. Because solving the equations takes a long calculation time, minimization of the calculation domain is important for faster processing.

In a conventional method (Fig. 2a), we must define the calculation domain in advance of the simulation. If the water reaches the boundary of the domain (Fig. 2a3), the simulation fails and we must simulate again after expanding the calculation domain. In the Dynamic DDM, (Fig. 2b) the calculation domain is automatically defined to include all wet cells and to exclude dry cells during the simulation. The modeling engine divides the entire space into sub-domains. In Fig. 2b, sub-domain consists of 4x4 cells. The modeling engine detects wet cells (Fig. 2b1), and loads the sub-domains in which those cells are included (Fig. 2b2). Data in the sub-domain is fetched from the GIS. The equations are solved only at the loaded sub-domains. Neighboring sub-domains are automatically loaded when the water reaches the current domain boundary (Fig. 2b3). A sub-domain will be unloaded when all the cells in the sub-domain become dry. Thus, the Dynamic DDM keeps nearly optimal calculation domain during the simulation.

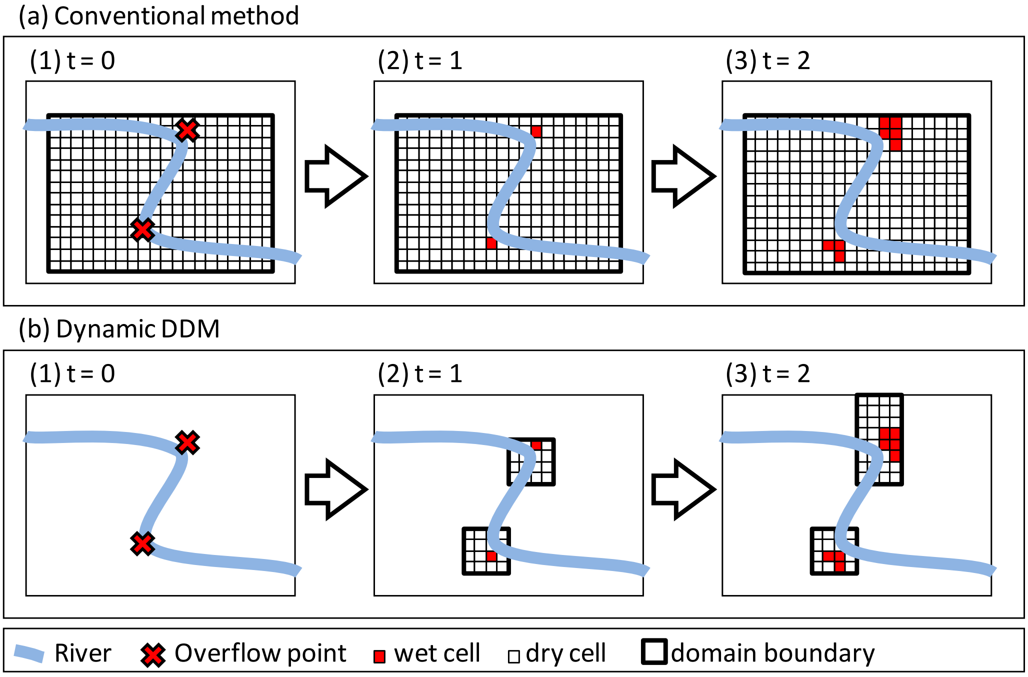

Fig. 2. Workflows of inundation models with (a) conventional method and (b) our Dynamic Domain Defining Method (Dynamic DDM)

The efficiency of the Dynamic DDM depends on the number of cells in a sub-domain. Usage of smaller sub-domain results in a better optimization of the calculation domain but more frequent access to GIS is required. Yamaguchi and Iwamura (2007) compared the calculation time of inundation simulation with 50 x 50 m cell for three size of sub-domain (16 x 16, 32 x 32, and 64 x 64 cells). They concluded that when flood area is 1 – 100 km^2 (400-40,000 cells), 32 x 32-cell sub-domain is most efficient. Therefore, we use the Dynamic DDM with 32 x 32-cell sub-domain.

The calculation time of the Dynamic DDM is nearly proportional to the number of wet cell, and not related to the size of target area of the simulation (Yamaguchi and Iwamura, 2007).

Even if the target area is large, the number of wet cell is zero at normal state in general, or few if any. Therefore, the Dynamic DDM is suitable for flood prediction in a large area.

2.3 FROG method

Since flows on floodplain are separated by a river, the 2D model must be separated by the 1D model. On the other hand, to generate linkage between the 1D and 2D models, left/right side of river must be connected to the same side of floodplain. While the left and right sides of the 1D model is defined by levee lines, those of the 2D model is not defined. Therefore, we can define a cell in the 2D model as both left and right side of the river (Fig 3a1). However, such cells make simulation unrealistic: even when a river overflows at either (left or right) side of the river, floodplain at the both sides of the river will be flooded.

The FROG method defines a cell in the 2D model as either left or right side of the river (Fig 3a2). The steps of the FROG method are as follows: (1) Set Markers on the 2D model's cells which intersect with a levee line. (2) Move Makers to the neighboring cell in the direction of overflowing flow. (3) Link the levee line and the cells with Marker. An example of the generated links by the FROG method is shown in Fig 3b.

A validation of the FROG method is conducted by Yamaguchi et al. (2008). They simulate the flood disaster occurred on Oct. 22, 2004 in Takayama City (Japan), and compared the simulated flooded area with site investigation (Fig. 4). Linkages between the 1D model with 10 m cell and the 2D model with 25 x 25 m cell are generated by the FROG method. Though the simulated flooded area (32.8 ha) is slightly larger than the site investigation (22.5 ha) in particular lower area, the west extent of flooded area in the left side of bank is accurately simulated.

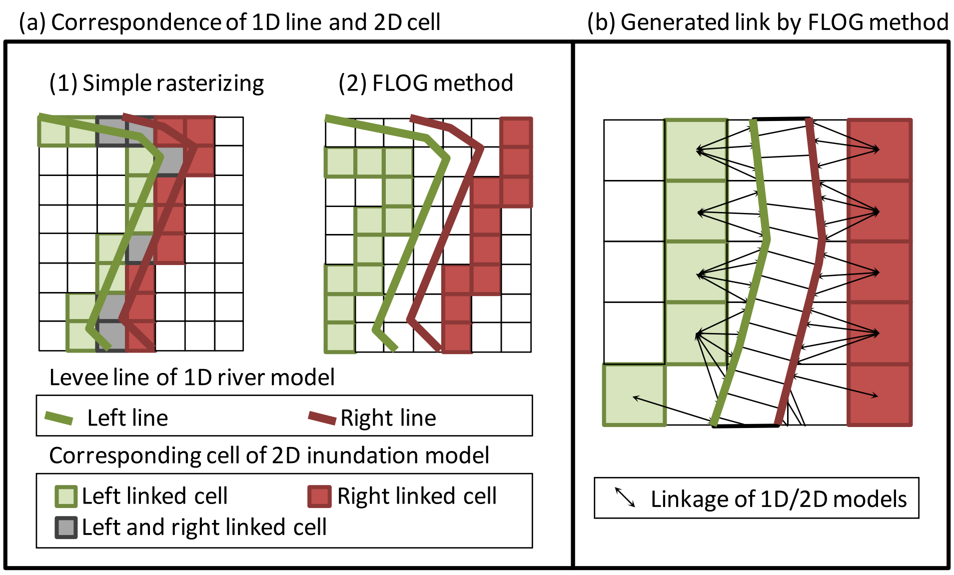

Fig 3. (a) Right and left levee lines and corresponding 2D cells of (1) simple rasterizing and (2) FROG methods, (b) an example of links automatically generated by FROG method.

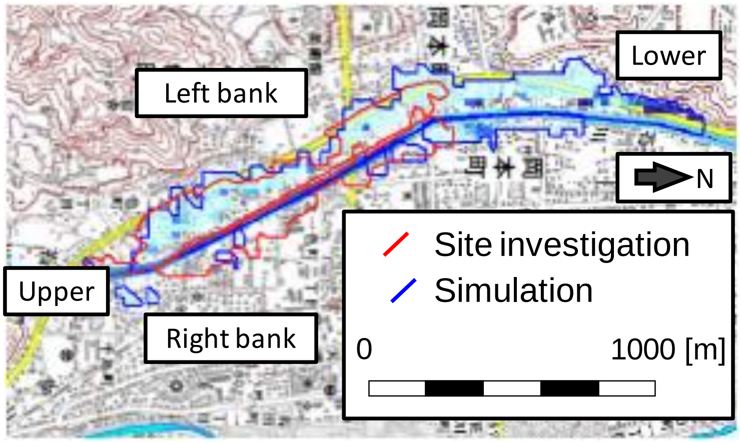

Fig. 4. Comparison of simulated flooded area and site investigation (Takayama City)

2. CASE STUDY

We applied the proposed methods to simulate floods in Kawasaki City (Fig. 5). The 1D model with 200 m cell is applied to two main rivers (Tama and Tsurumi Rivers) and with 100 m cell to 15 tributaries. Their total length is 192 km and the number of cell is 2,354. Surveyed cross section data is used for all rivers except for five tributaries (d, f, g, i, j in Fig. 5), where we apply estimate cross sections (trapezoid, upper width: 10 m, depth: 3 m). The 2D model with 50 x 50 m cells is applied to the entire city (143 km^2). The number of generated linkage between the 1D and 2D models is 14,287. In addition, a distributed runoff model with 100 x 100 m cell is applied to the catchment areas of Tama and Tsurumi Rivers (1,477 km^2).

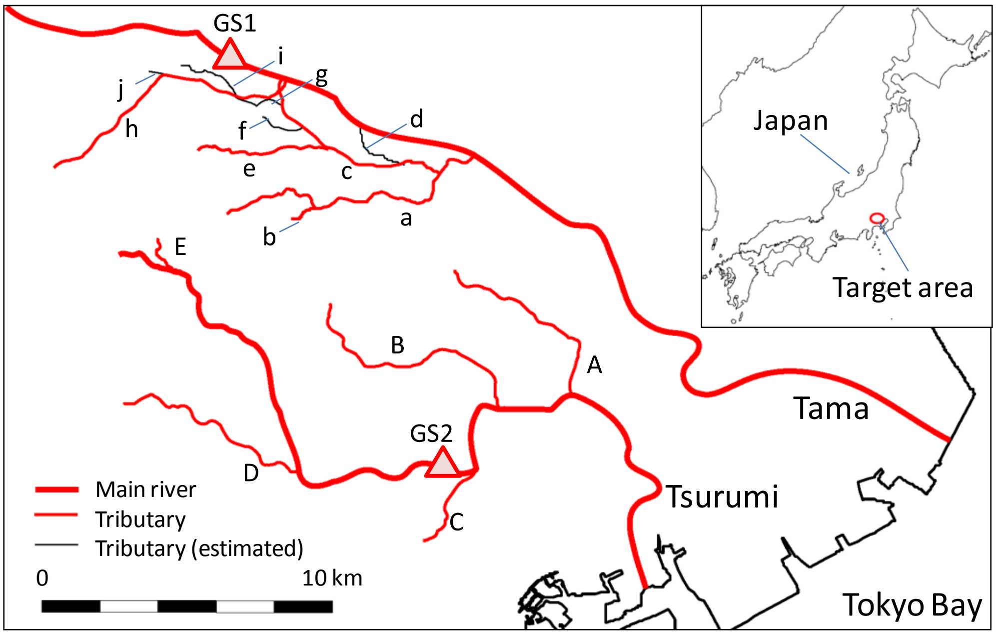

Fig. 5. Map of target rivers of flood simulation system
(a-j: Tama tributaries, A-E: Tsurumi tributaries, GS1 and GS2: Gauging station)

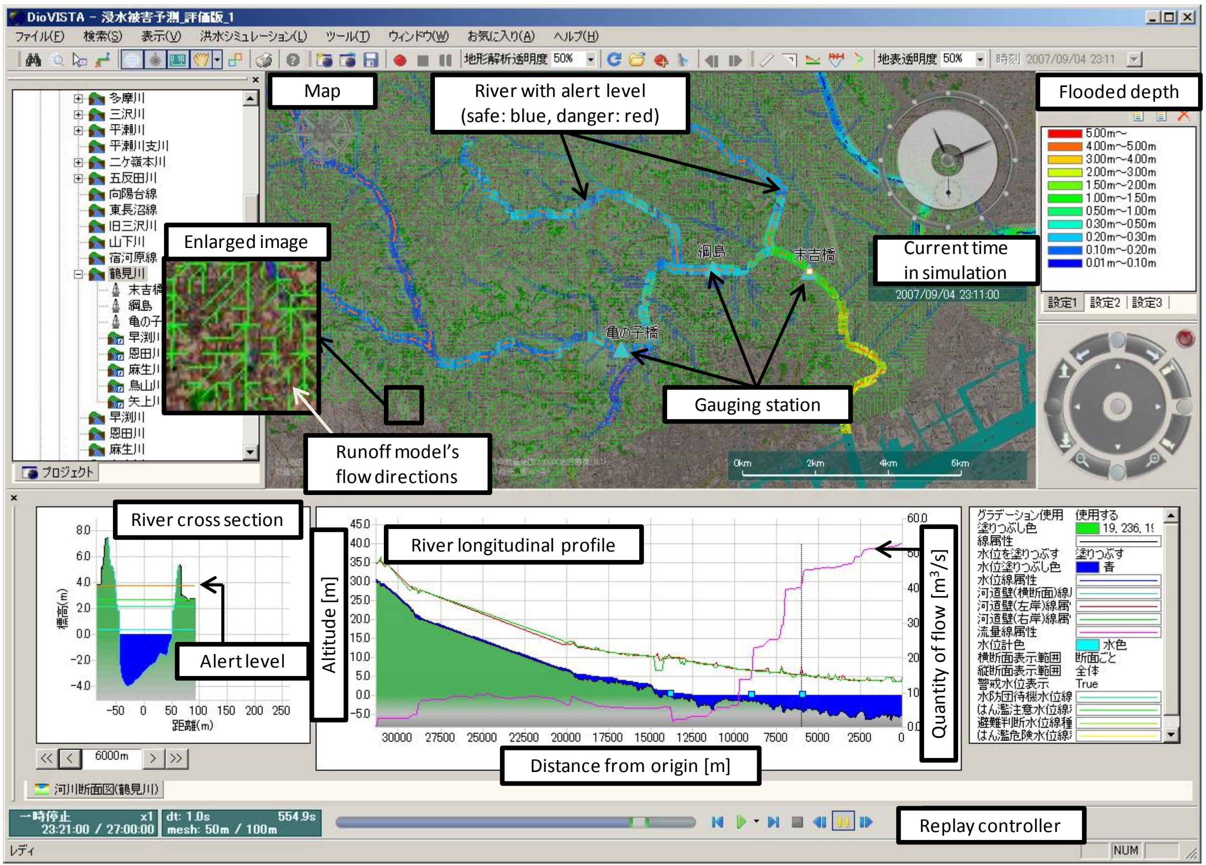

Fig. 6. Screenshot of flood simulation system

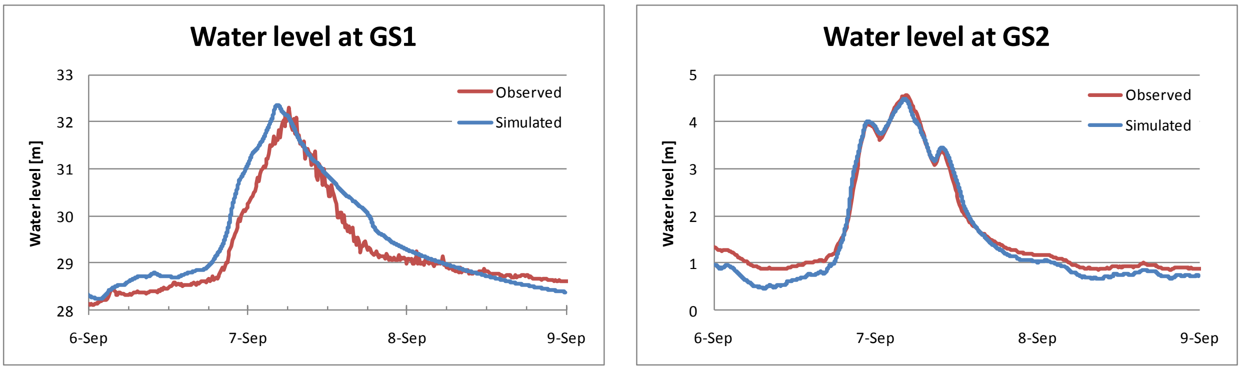

Fig. 7. Comparison of simulated and observed water level in Sep. 2007 at GS1 and GS2

The input data is precipitation data (3 hour forecast range, 1 km horizontal and 10 min temporal resolution) provided by Japan Weather Association. The output data is water level along the river and flood area if any (Fig. 6). The system working on a PC simulates a 27 hours event in less than 10 min. The short calculation time enable the system to update the prediction every 10 min, because the precipitation data is updated every 10 min. The system can also simulate user-defined what-if scenarios such as levee failure by adding the scenario to the latest simulated result. Comparison of simulated and observed water level in Sep. 2007 (Fig. 7) shows good correspondence. We conclude that the proposed methods are suitable for flood prediction.

4. CONCLUSIONS

In order to use 1D/2D coupled model for flood prediction in a large area, we propose automatic linking and fast calculation methods. Because our proposed methods use modeling and geospatial information, we develop software which consists of modeling and GIS engines. To reduce calculation time of 2D inundation model, optimization of calculation domain is effective. Because the Dynamic DDM defines the calculation domain to include wet cells and to exclude dry cells during the simulation, the calculation domain is nearly optimal and the calculation time is significantly reduced.

To generate linkage between 1D and 2D models, the FROG method defines a cell in the 2D model as either left or right side of a river. The coupled model generated by the FROG method accurately simulated a flood disaster occurred in Takayama City (Japan).

We applied the proposed methods for Kawasaki City (Japan). The 1D model is applied to the two river systems with 2 main rivers and 15 tributaries, and the 2D model is applied to the city (143 km^2). The FROG method generates 14,287 linkages between the 1D and 2D models. The system working on a PC simulates a 27-hour event in less than 10 min. We conclude that the proposed methods are suitable for flood prediction. The short calculation time enable the system to update the prediction every 10 min, because the precipitation data is updated every 10 min.

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