Prediction of Overbank Flows with Coupling 1D Flash Flood Routing Model and 3D Coastal Ocean Model

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Taiwan is located at the intersection of the Euro-Asian continent and the Pacific Ocean, and it suffers from typhoons during summer and fall seasons. Annual rainfall: 2500mm
Introduction

Over the past years, Taiwan has experienced several severe flood disasters involving major river basins. One of the important features is the overtopping of levees at upriver reaches due to extremely heavy rainfall during typhoons events.

Typhoon Nair (2001)
Introduction

- It is common practice to apply different modeling system for coastal waters and river system in hydrodynamic modeling community. 3D models are designed for the horizontal and vertical variability in coastal waters, while 1D river models are designed to accurately represent complicated river geometries.
To deal with the complicated river and coastal ocean interaction, a 3D coastal ocean model coupled with a 1D river system model is proposed for simulating the overbank discharge hydrographs under Typhoon Kalmaegi (2008) hit central Taiwan.

Schematic diagram of the coupling of 1D-3D models.
The Wu River system includes the mainstem of Wu River and main tributaries, Fazi River, Dali River, Han River, and Maoluo River.

The drainage basin covers 2026 km², the total channel length is 117 km, and the mean channel slope is 0.01.

The peak discharge of 100-years flood is 21000 m³/s.

Mean tidal range at the Wu River mouth is 3.8 m. The M₂ tide is the primary tidal constituent at the mouth.
Methodology

◆ 3D coastal ocean model

\[
\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0
\]

\[
\frac{\partial \eta}{\partial t} + \frac{\partial}{\partial x} \int_{H_R - h}^{H_R + \eta} u \, dz + \frac{\partial}{\partial y} \int_{H_R - h}^{H_R + \eta} v \, dz = 0
\]

\[
\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z} = f v - \frac{\partial}{\partial x} \left\{ g (\eta - \alpha \varphi) + \frac{P_a}{\rho_o} \right\}
\]

\[
- \frac{g}{\rho_o} \int_z^{H_R + \eta} \frac{\partial \rho}{\partial z} \, dz + \frac{\partial}{\partial x} \left( K_{m_v} \frac{\partial u}{\partial z} \right) + F_{m_x}
\]

\[
\frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + w \frac{\partial v}{\partial z} = - f u - \frac{\partial}{\partial y} \left\{ g (\eta - \alpha \varphi) + \frac{P_a}{\rho_o} \right\}
\]

\[
- \frac{g}{\rho_o} \int_z^{H_R + \eta} \frac{\partial \rho}{\partial y} \, dz + \frac{\partial}{\partial y} \left( K_{m_v} \frac{\partial v}{\partial z} \right) + F_{m_y}
\]

◆ Free surface elevation and water velocity equations are based on the Boussinesq approximation.

◆ The shallow water equations are solved by finite-volume/finite-difference semi-implicit Eulerian-Lagrangian algorithm to enhance computational efficiency.
Methodology

◆ 1D flood river routing model

\[ \frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} - q_1 + q_2 = 0 \]  Continuity eq.

\[ \frac{\partial Q}{\partial t} + \frac{\partial}{\partial x} \left( \frac{Q^2}{A} \right) - gA \left( S_o - \frac{\partial Y}{\partial x} - S_f \right) - q_1V_1 + q_2 \left( \frac{Q}{A} \right) = 0 \]  Momentum eq.

◆ 1D flood routing model is based on the dynamic wave theory of the Saint-Venant equations which consist of 1D continuity and momentum eqs.
Methodology

◆ Overtopping flow module

To calculate the overtopping flow, the weir formula was adopted and incorporated into 1D flood river routing model.

Schematic representation for overbank in the river.
Methodology

◆ Concept of 1D-3D coupling

An explicit coupling approach was adopted.

At each time step, the 1D model sends calculated discharge values to the 3D model which in turns provides calculated water level values to the 1D model.

Conceptual approach of explicit coupling between 1D and 3D models.
Methodology

◆ Model Implementation

The modeling domain in horizontal plane covers 48kmx65km in the coastal sea. The model meshes consist of 603 polygons and 372 grids. Ten layers in vertical direction were used.

In the Wu River system, the model includes 310 transects for 1D model.
The local bottom roughness \( Z_0 \) in 3D model and Manning friction coefficient \( n \) in 1D model are to be determined through calibrated and verified procedures.

Two typhoon events, Typhoon Krosa (2007) and Typhoon Sinlaku (2008), were used for model calibration.

Typhoon Jangmei (2008) was used for model verification.
Typhoon Krosa (2007)
## Model evaluation

### Statistical errors of simulations for four typhoon events

<table>
<thead>
<tr>
<th>Typhoon</th>
<th>Taichung Harbor</th>
<th>Wu River Bridge</th>
<th>Limin Bridge</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AME (m)</td>
<td>RMSE (m)</td>
<td>AME (m)</td>
</tr>
<tr>
<td>Krosa (2007)</td>
<td>0.126</td>
<td>0.155</td>
<td>0.076</td>
</tr>
<tr>
<td>Sinlaku (2008)</td>
<td>0.100</td>
<td>0.126</td>
<td>0.095</td>
</tr>
<tr>
<td>Jangmi (2008)</td>
<td>0.108</td>
<td>0.124</td>
<td>0.052</td>
</tr>
<tr>
<td>Kalmaegi (2008)</td>
<td>0.103</td>
<td>0.129</td>
<td>0.158</td>
</tr>
</tbody>
</table>

Note: AME: Absolute Mean Error; RMSE: Root Mean Square Error.

Through the model calibration and verification procedures, we adopted 0.9 cm for local bottom roughness ($Z_o$) in the coastal sea area.

The values range from 0.028 to 0.075 for the Manning friction coefficient ($n$) used in the Wu River system.
Model applications

During July 17-19, 2008, Typhoon Kalmaegi brought more than 630mm of rainfall in three days and caused severe inundation in the TaiChung City which resulted from flooding and overtopping flows in Wu River system.

Therefore this typhoon event was applied to model the overtopping flows.
Typhoon Kalmaegi (2008)
Model applications

Typhoon Kalmaegi (2008)
Model applications
Model applications
Model applications

- The most overbank locations occurred at the upper reaches of Wu River system.
Conclusions

◆ A coupling 1D river model and 3D coastal ocean model was developed and applied to calculate overtopping flows during typhoon period.

◆ The numerical model has been well calibrated and verified with observed water levels using the data collected from three typhoon events.

◆ The model was then used to model the overtopping flow hydrographs when Typhoon Kalmaegi (2008) attacked Taiwan.
Acknowledgements

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Thanks you!