Modeling morphological changes by tsunami Induced currents

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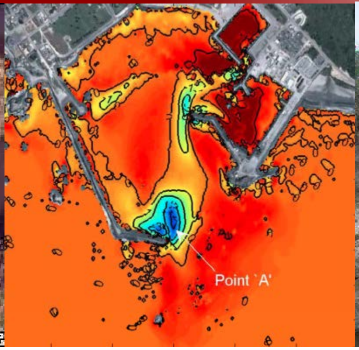
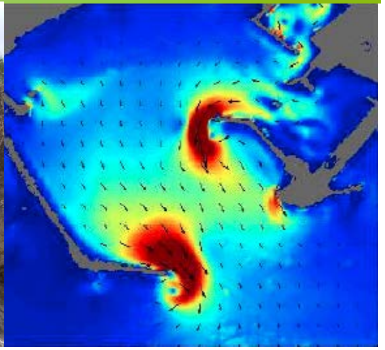
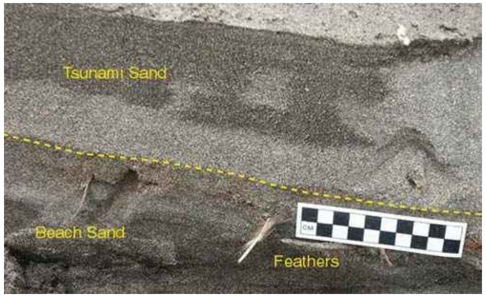




Online presentation at EGU General Assembly 2020

Motivation

- Tsunamis have wide-spread and profound effects across the ocean.
- Among those, morphodynamic changes were found in harbor areas where significant strong currents occurred.(e.g., Tsunamiites)
- Tsunami physics in the nearshore area tend to be much complex due to the existence of **turbulence sources**(e.g., bottom boundary layer, wave-breaking).
- **Prediction of morphological processes** associated with **tsunami-induced currents** are highly challenging.



Outlines

- ***Objectives***
  - Develop a numerical solution to predict complex morphodynamic processes in the nearshore.
- ***Strategy***
  - *Set-up modeling tools by integrating sub-module such as*
    - *Hydrodynamic model*
    - *Sediment transport model*
    - *Morphodynamic model*
  - Finite volume method coupled w/ HLL Riemann solver
  - Sensitivity tests on parameters included in closure models
- ***Scopes***
  - 1. Model development
  - 2. Validations : Dam-break flows, Breaking solitary waves(1D/2D)
  - 3. Application

1. Model Development

Model Equations

- Hydrodynamic model : Boussinesq-type equations with rotational terms

$$\frac{\partial H}{\partial t} + \frac{\partial H \hat{u}_i}{\partial x_i} + (\mathcal{M} + \mathcal{M}^\nu) = \frac{e-d}{1-p}$$

Erosion/deposition

$$\frac{\partial H \hat{u}_i}{\partial t} + \frac{\partial H \hat{u}_i \hat{u}_j}{\partial x_j} + gH\frac{\partial \zeta}{\partial x_i} + H\left(\mathcal{D}_i + \xi_i + \mathcal{D}_i^\nu + \xi_i^\nu\right) + \hat{u}_i(\mathcal{M} + \mathcal{M}^\nu) - H\frac{\partial}{\partial x_j}\left(\nu_t^h \frac{\partial \hat{u}_i}{\partial x_j}\right) + H\frac{\partial}{\partial x_i}\left(\nu_t^v \frac{\partial \hat{u}_j}{\partial x_i}\right) + \frac{\tau_i^b}{\rho} + HF_i - HR_i = -\frac{(e-d)\hat{u}_i}{1-p}$$

Turbulent dissipation

Wave-breaking/BSM

- Sediment Transport Model

$$\frac{\partial H\overline{c}}{\partial t} + \frac{\partial H\overline{c}\hat{u}_i}{\partial x_i} = \frac{\partial}{\partial x_i}\left(K_h H \frac{\partial \overline{c}}{\partial x_i}\right) + e - d$$

- Morphodynamic Model

$$\frac{\partial h}{\partial t} = \frac{e-d}{1-p}$$

Closures

- Erosion and Deposition Fluxes

$$e = \varphi\left(\theta - \theta_c\right)\left(\overline{u}_i \overline{u}_i\right)^{0.5} H^{-1} (D_{50})^{-0.2} \qquad d = \alpha \bar{c} w_0$$

- Bed-induced Turbulent Eddy Viscosity(Smagorinsky's)

$$\nu_t^h = \left(C_s \Delta x_i\right)^2 \sqrt{2\mathcal{S}_{ij}\mathcal{S}_{ij}}$$

- Wave breaking (Kennedy et al.(2000))

$$R_i = \frac{1}{H}\left[\frac{(1+\delta_{ij})}{2}\frac{\partial}{\partial x_j}\left\{\nu_b \frac{\partial\left(H\hat{u}_i\right)}{\partial x_j}\right\} + \frac{|\epsilon_{ij}|}{2}\frac{\partial}{\partial x_j}\left\{\nu_b \frac{\partial\left(H\hat{u}_j\right)}{\partial x_i}\right\}\right]$$

- Turbulence Backscattering Model(Hinterberger et al.(2007))

$$F_i = C_b \frac{\sqrt{\hat{u}_j \hat{u}_j}}{H}\sqrt{\frac{\nu\sqrt{C_f}}{\Delta t}} r_i$$

Numerical Methods

- Leading order terms :

  - 4^{th} order MUSCL-TVD scheme by Yamamoto & Daiguji(1993) incorporated with approximated HLL Riemann Solver

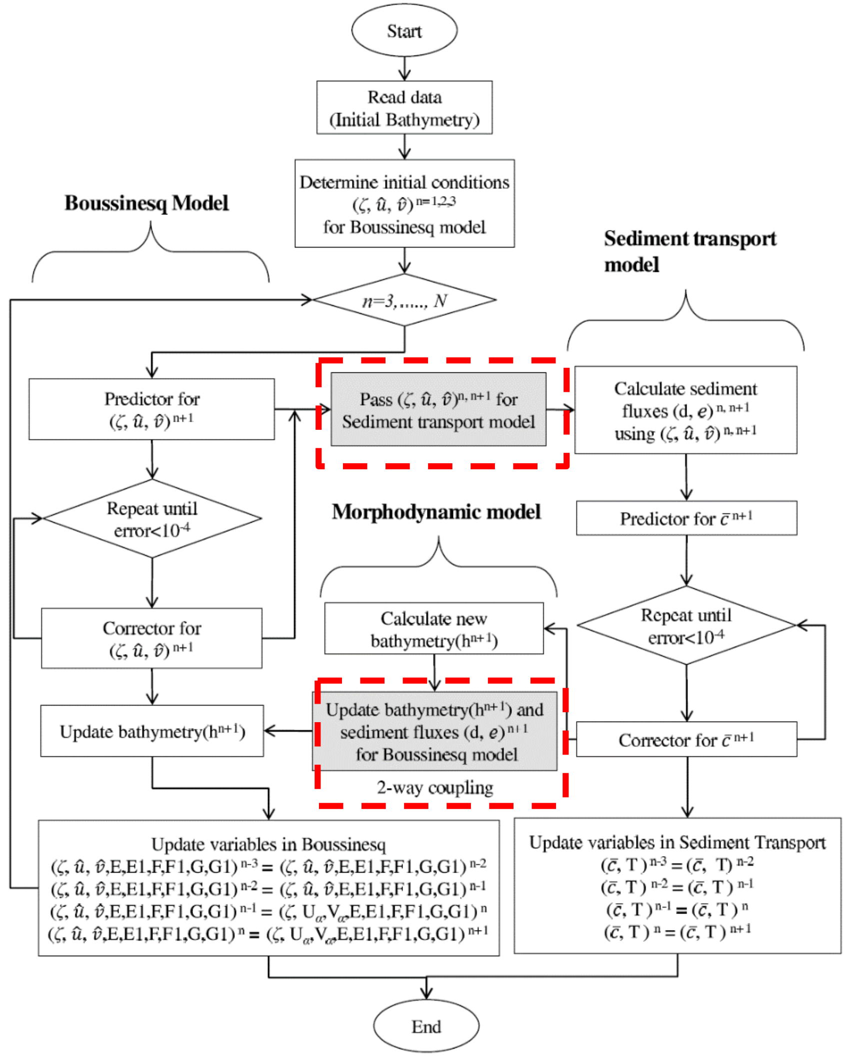
- Higher order terms :

  - Cell-centered Finite Volume Method by Lacor(2004)

- Time marching :

  - 3^{rd} order Adams-Bashforth predictor and
  - 4^{th} order Adams-Moulton corrector

Flow Chart

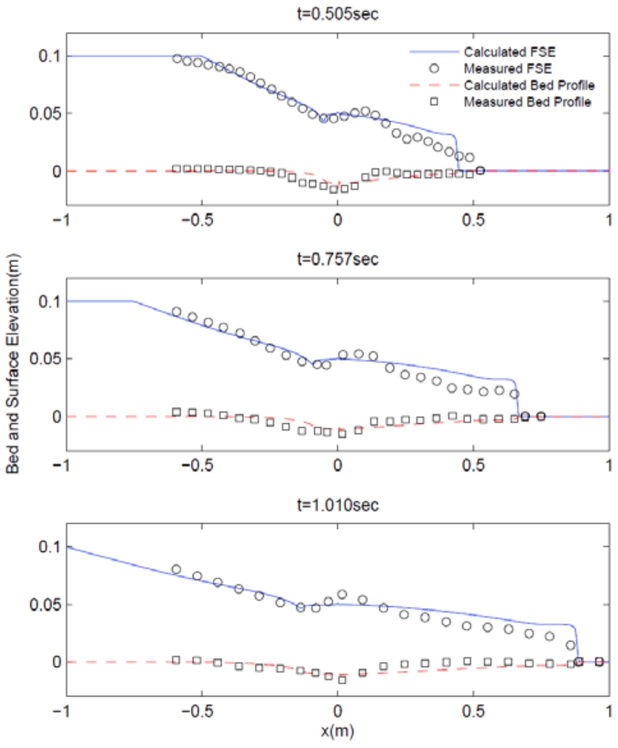


Two way coupling

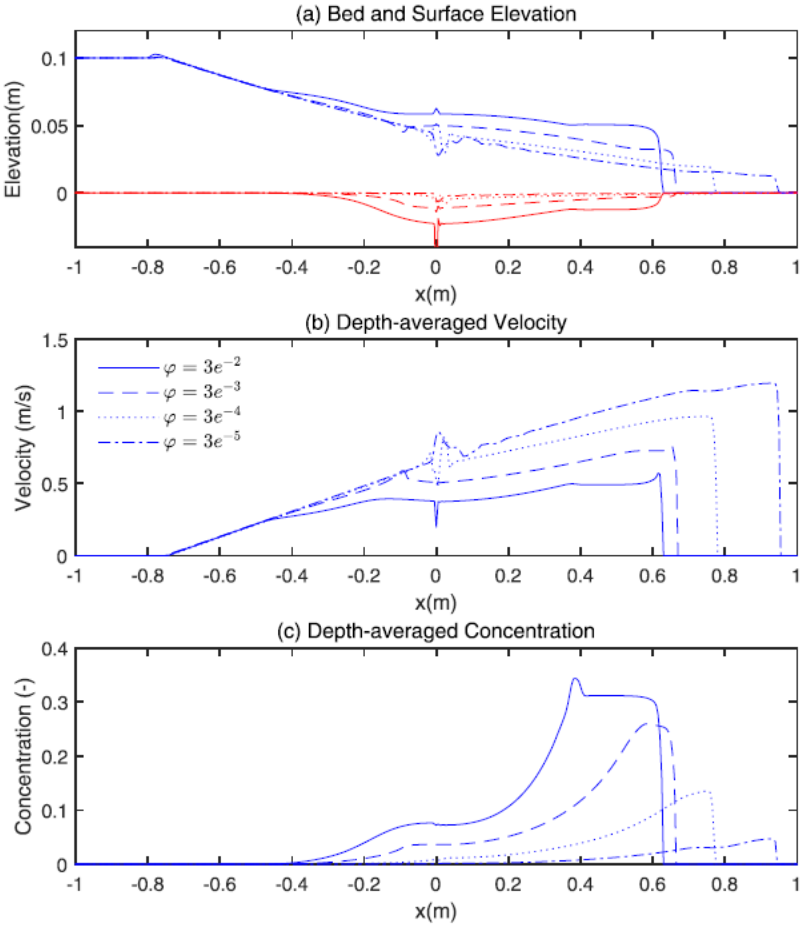
2. Model Validations

Validations : Case 1

- *CASE1 : 1D Dam Breaking over a Movable Bed (Fraccarollo and Capart [2002])*

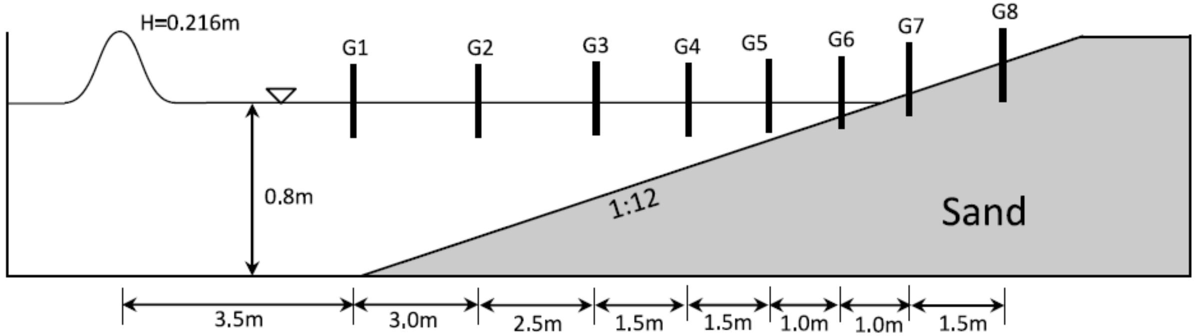


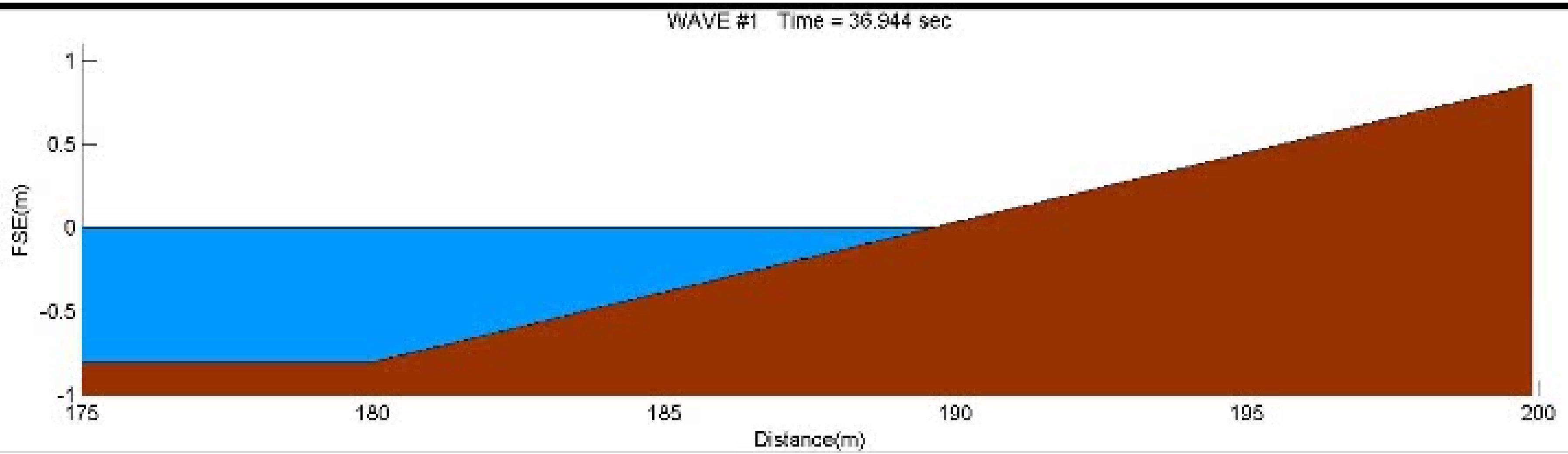
Sensitivity tests on φ



Validations : Case 2

- *CASE2 : Breaking Solitary Waves on Sloping Beach*
  (Kobayashi and Lawrence [2004])





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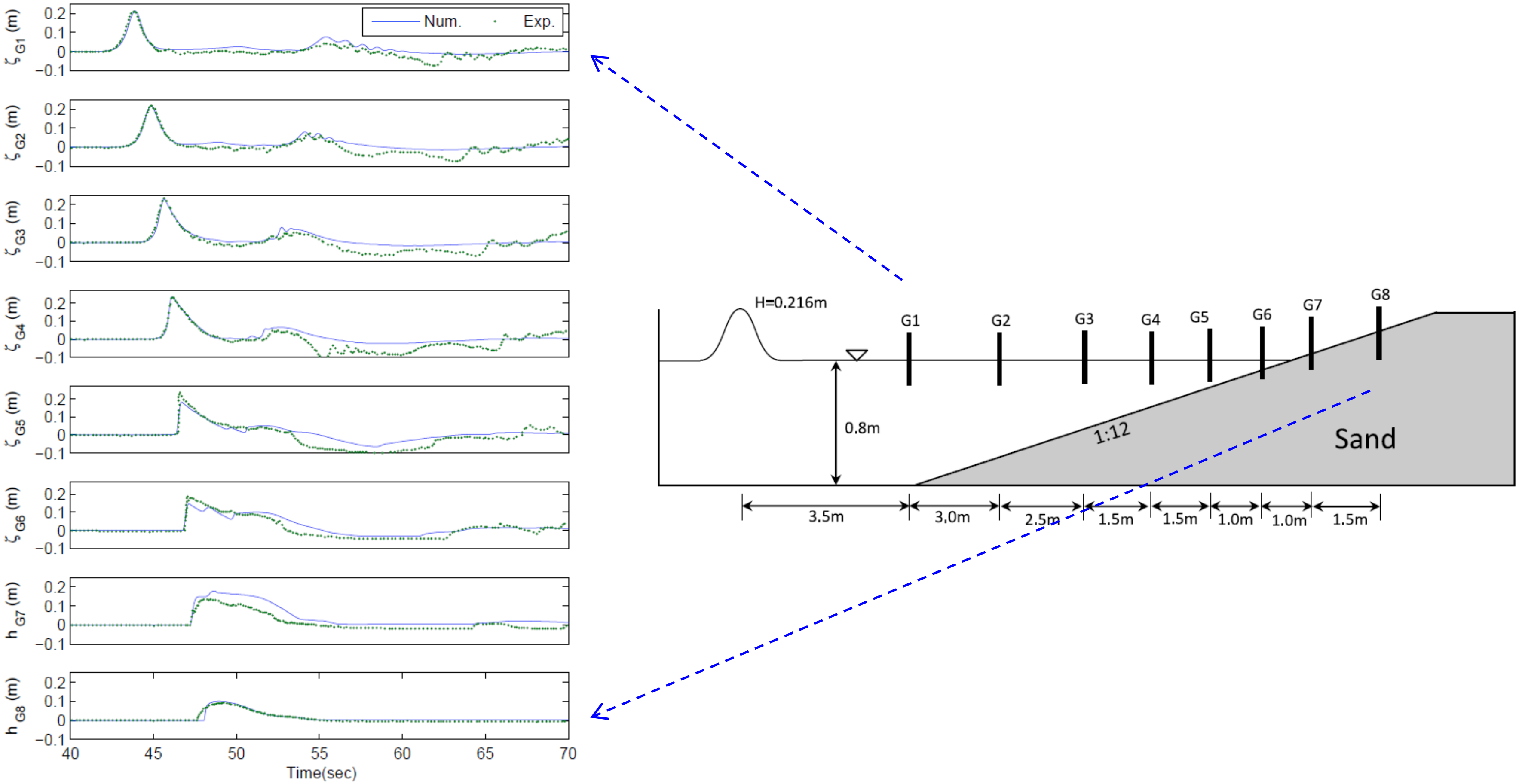

Validations : Case 2

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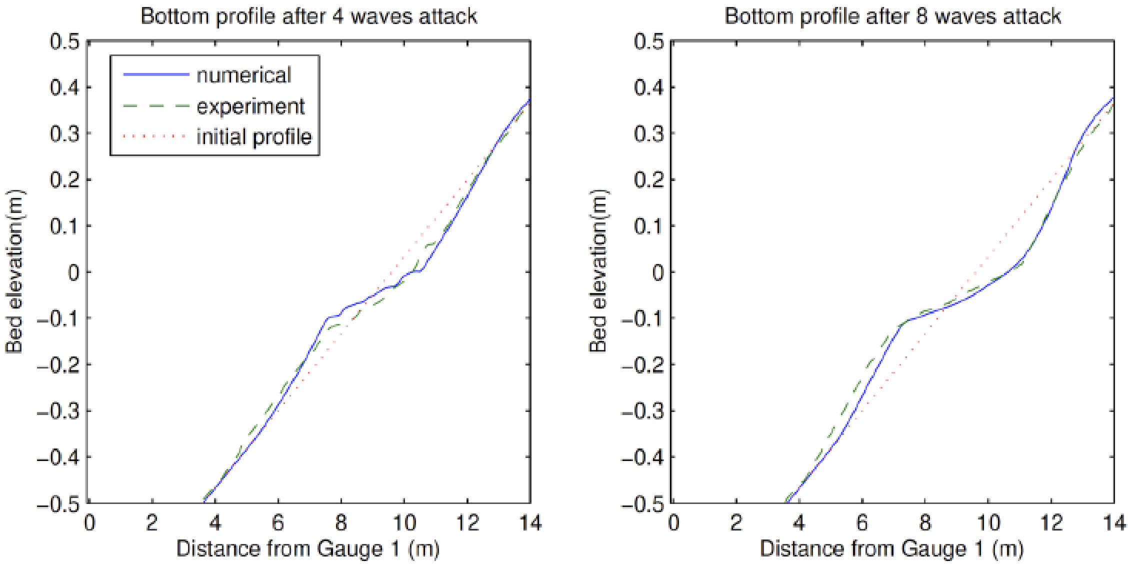
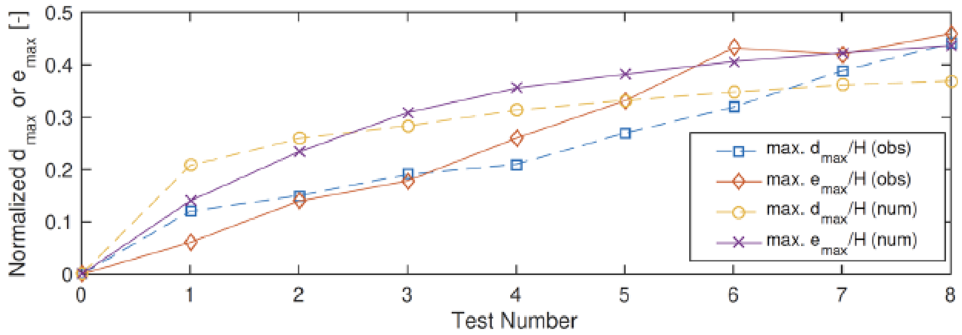
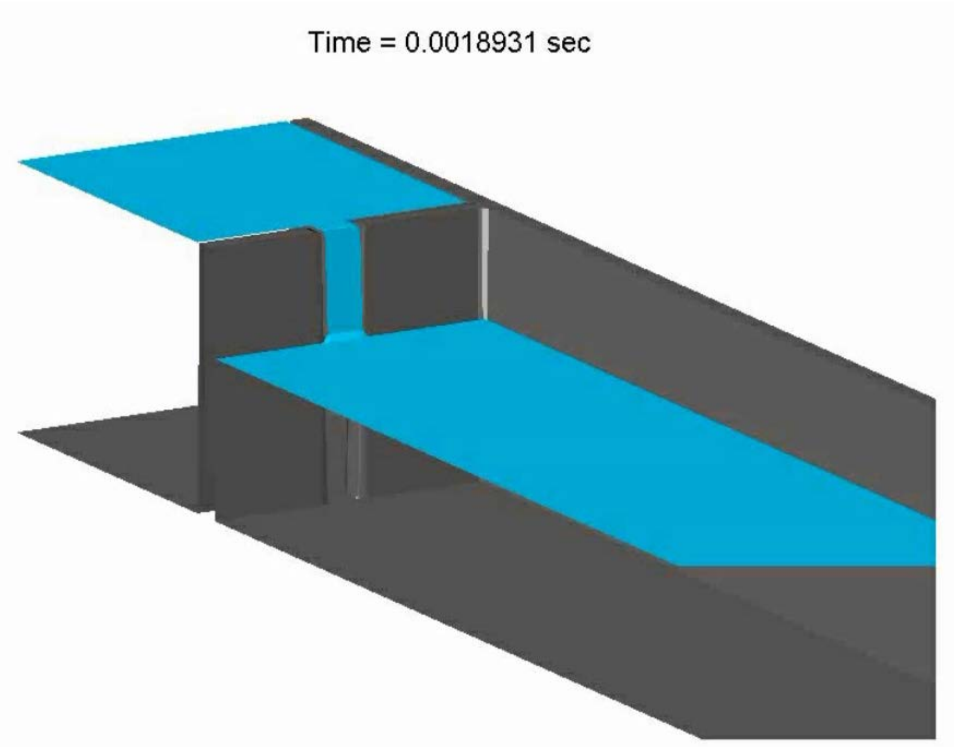


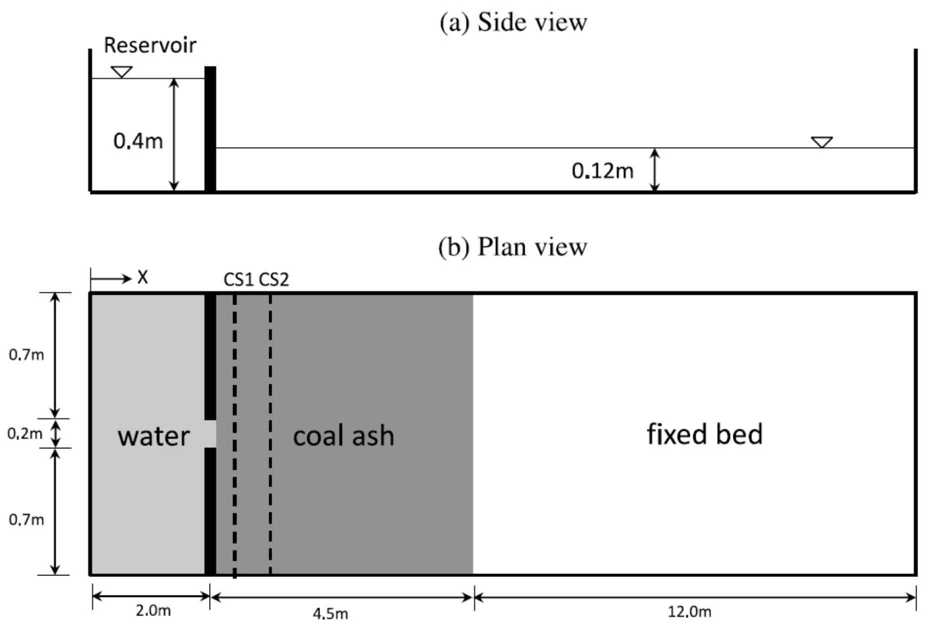


A significant erosion process at the foreshore may be explained by the strong backwash current initiated when a solitary wave retreats.

Validations : Case 3

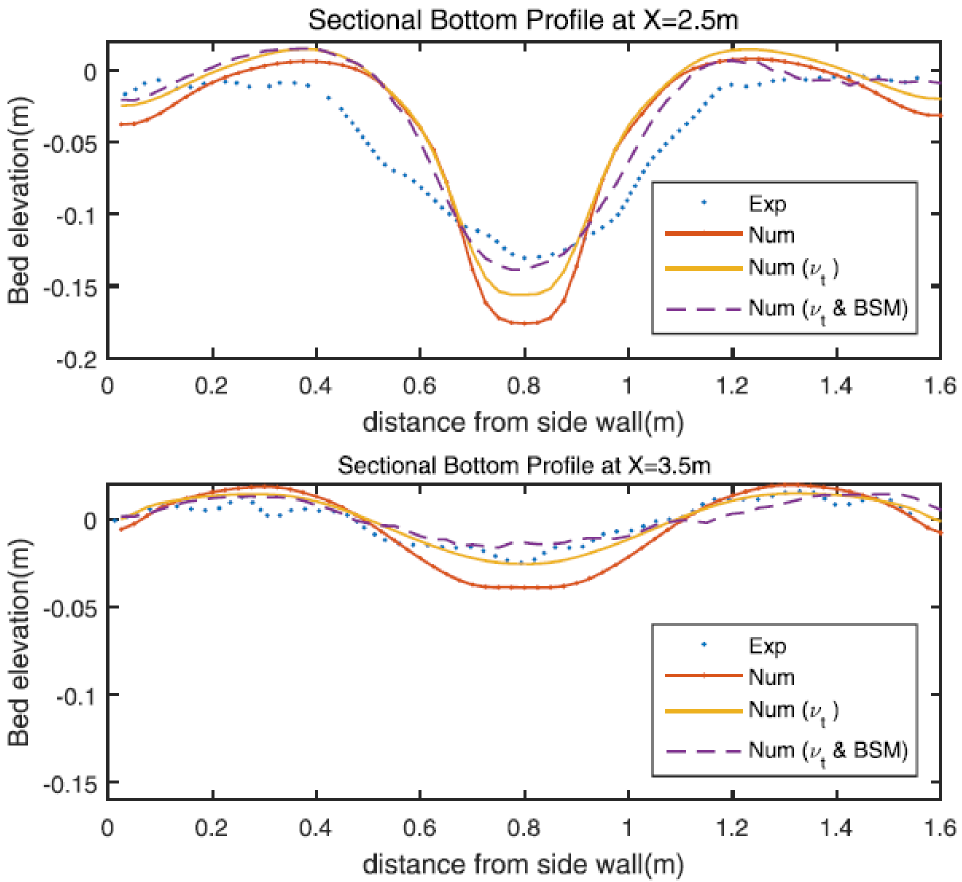
- *CASE3 : Dam-Break Flow through a Partial Breach*





Validations : Case 3

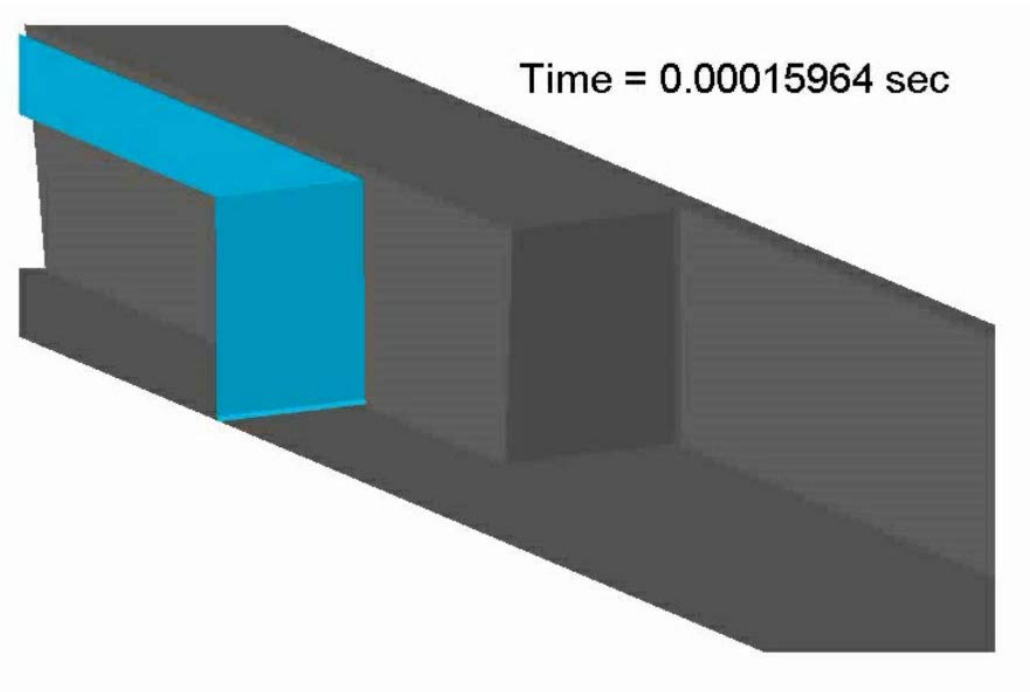
- *CASE3 : Dam-Break Flow through a Partial Breach*

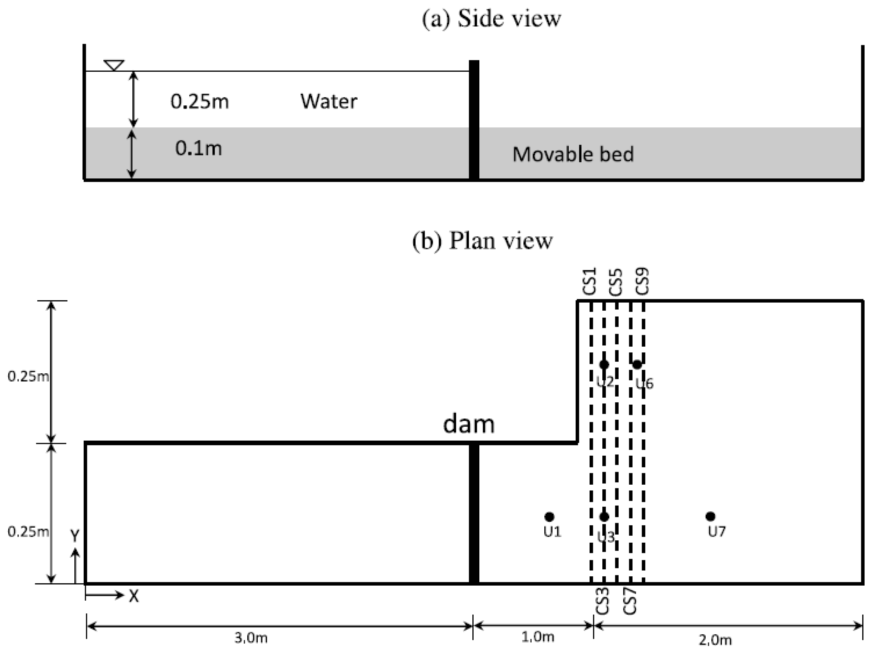


Reasonable agreement found when including turbulence effects, while the calculations overestimated the peak erosion depth at CS1.

Validations : Case 4

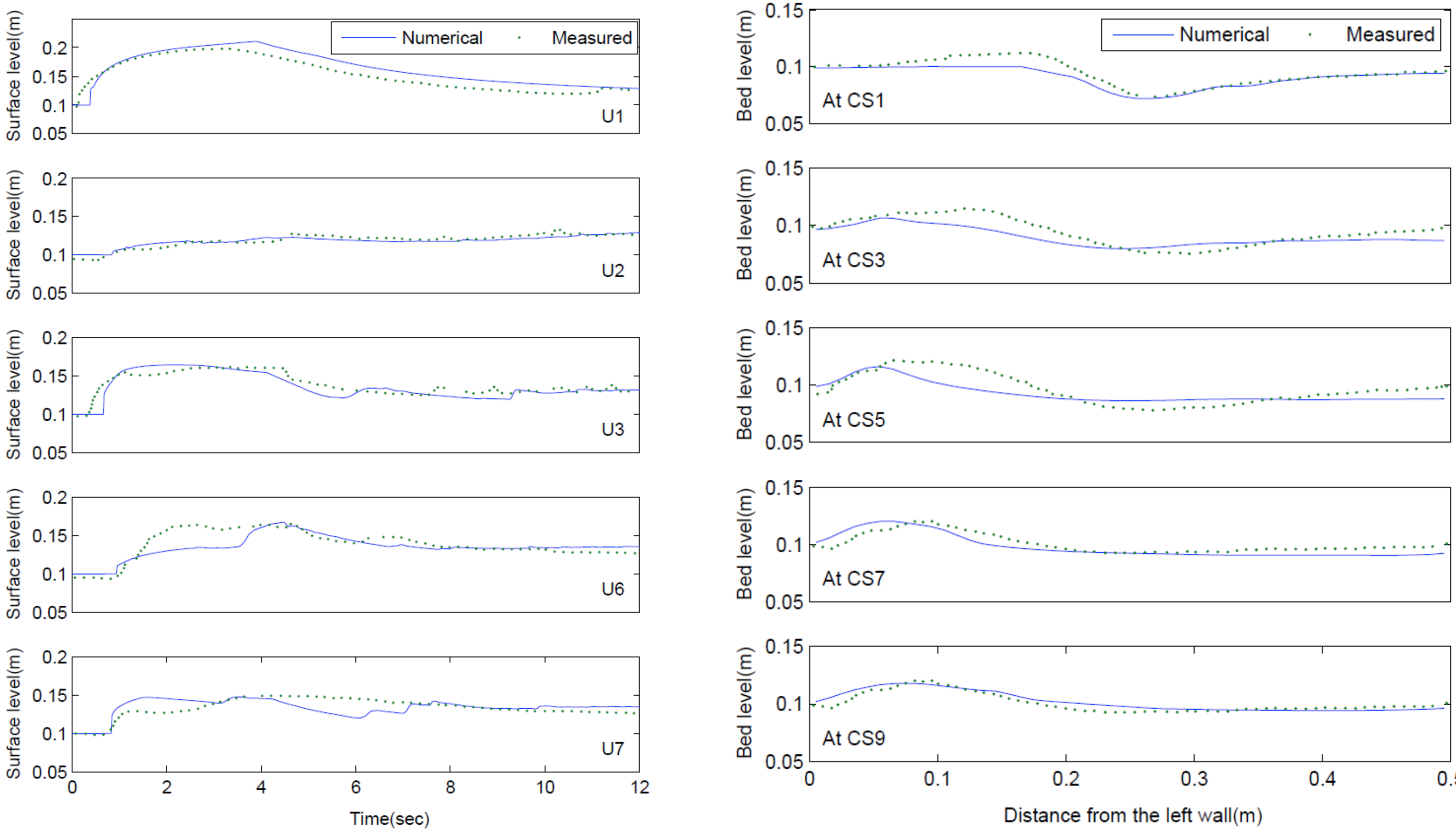
- *CASE4 : Dam-Break Flow over a Movable Bed Channel with Sudden Enlargement*





Validations : Case 4

- *CASE4 : Dam-Break Flow over a Movable Bed Channel*



3. Model Applications

Applications

- *2011 Japan Tohoku Tsunami*

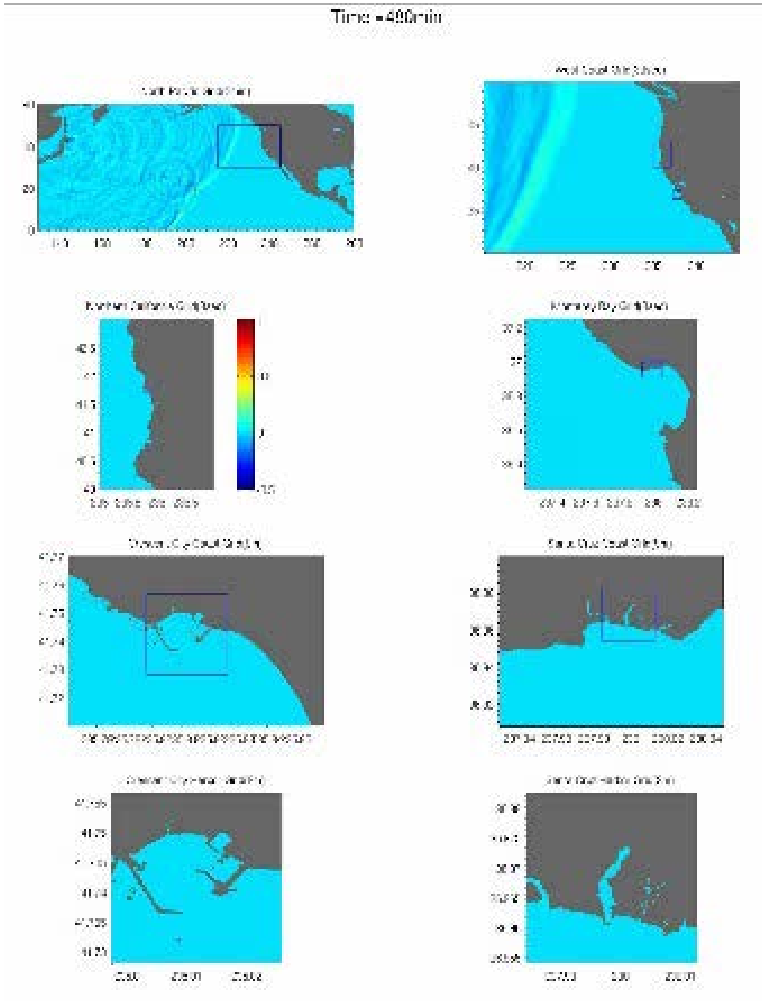
  - ***Simulation Result***
    Layer level 1-6 : SWE,
    Layer level 7-8 : Boussinesq)

  - Successful recreation of complex hydrodynamic process by tsunami waves at the nearshore harbor area.

  - Local focus : Crescent City Harbor, Santa Cruz Harbor

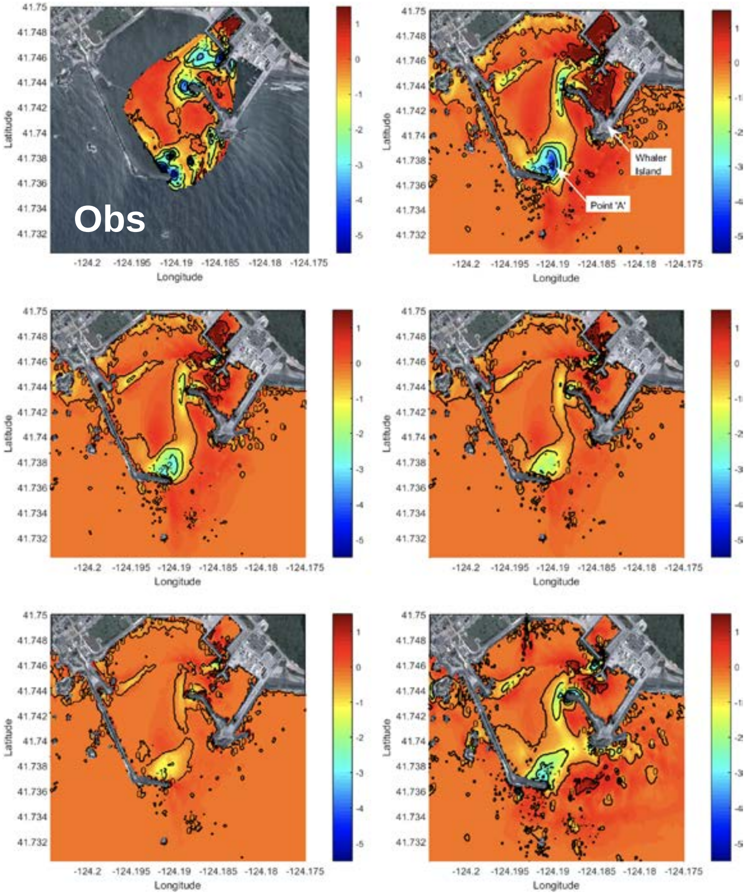
SWE Layers

Boussiensq Layers

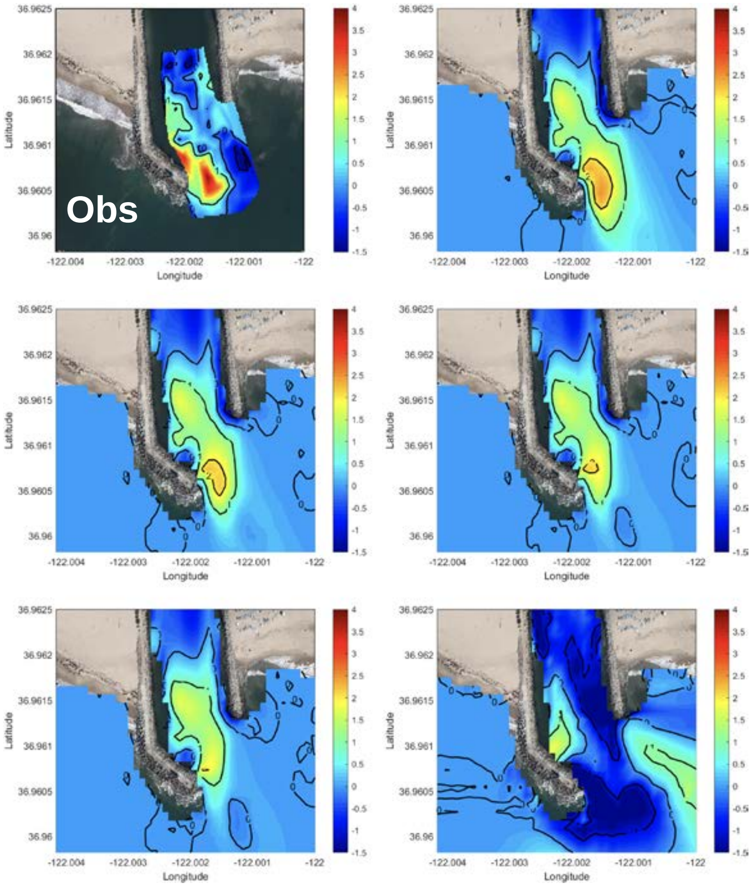


Applications

- Crescent City Harbor

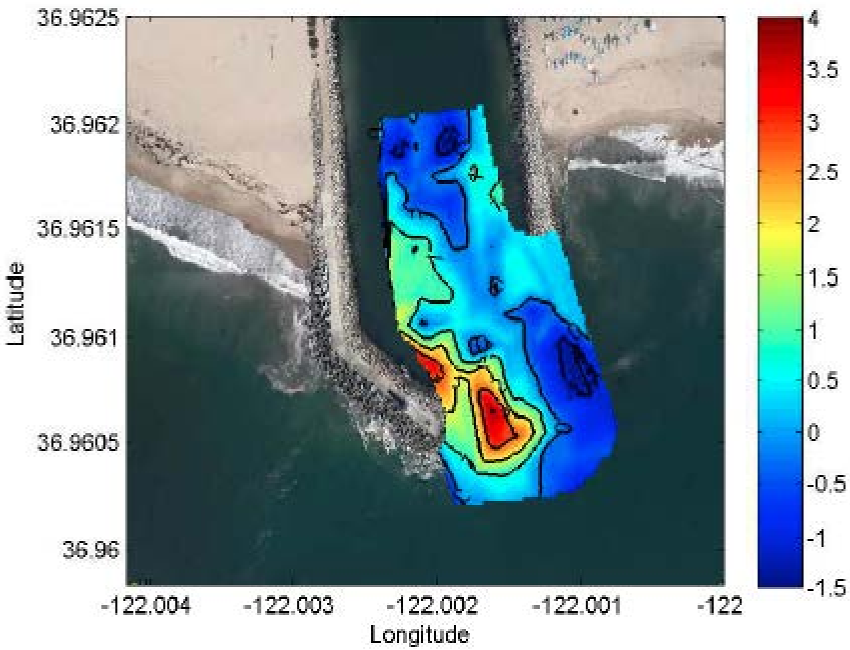


- Santa Cruz Harbor

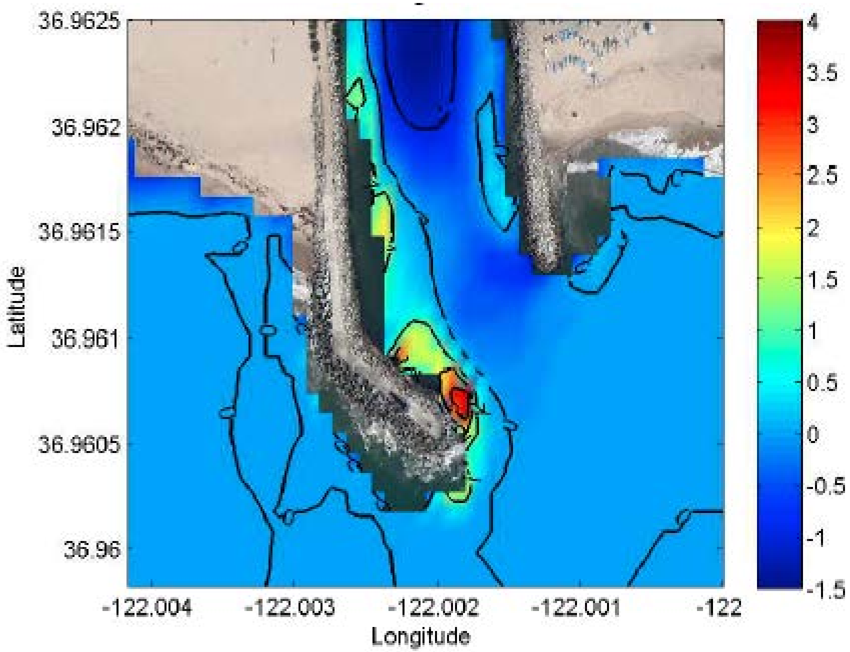


Applications

- Santa Cruz Harbor



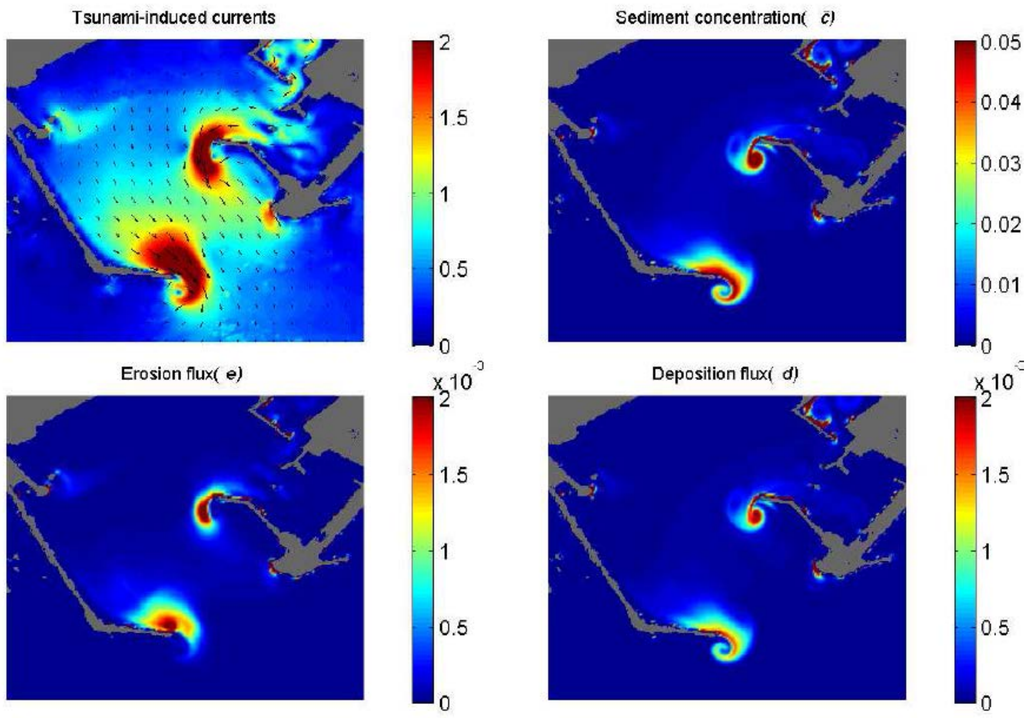
Observed data (Wilson et al.(2012))



Modeled results

Applications

- Numerical results of bathymetric changes in Crescent City Harbor at time t = 637 min since EQ.



The strong current field formed by geometric contraction

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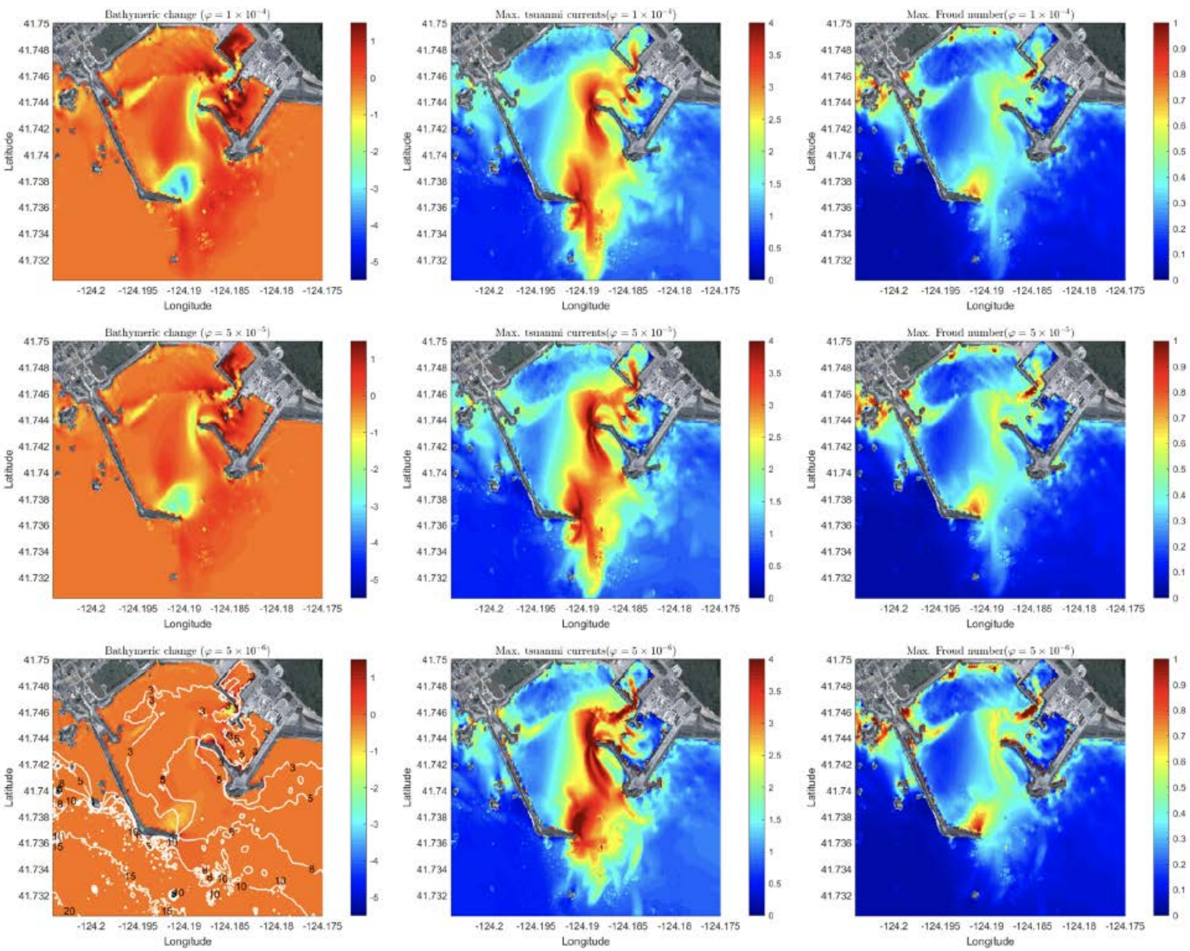
Very active sedimentation processes in the vicinity of the outer and inner harbour entrances

Applications

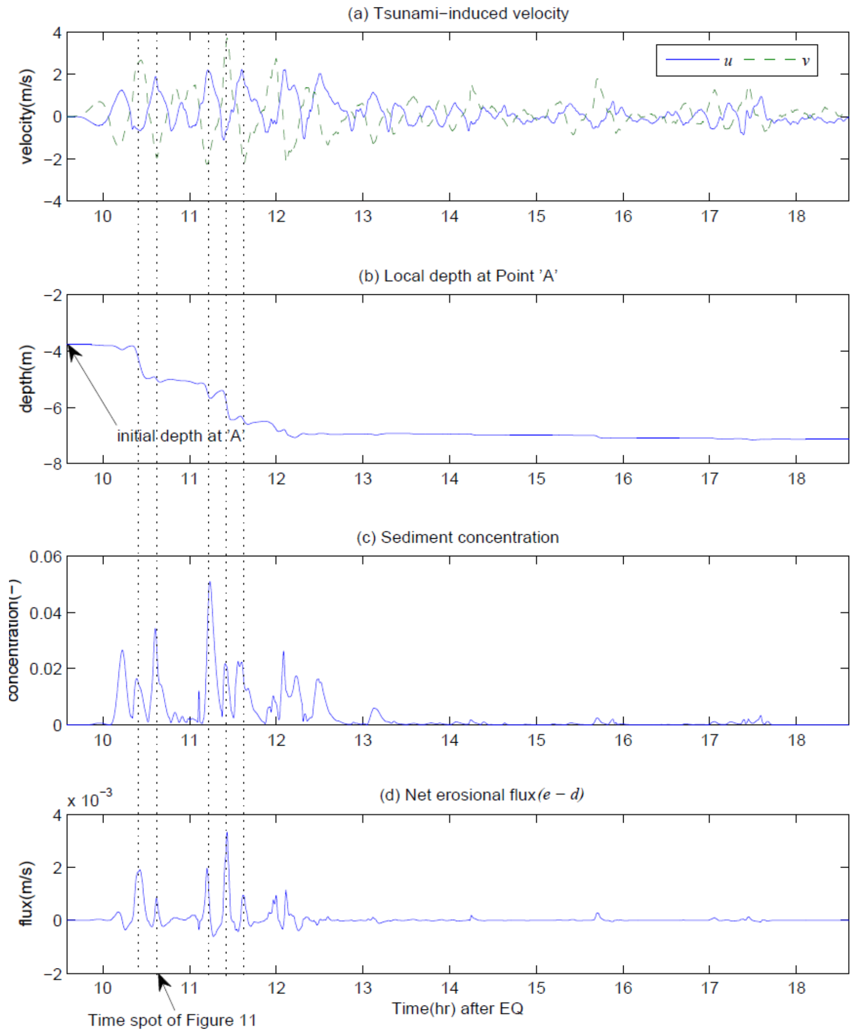
- Sensitivity tests on φ show that smaller $\boldsymbol{\varphi}$ produced less erosive sedimentation process
- Tsunami momentum is damped due to the strong interaction between surface processes and landforms, so the propagation gets retarded.



Applications

- Calculated time history at local point 'A'
  - (a) velocity
  - (b) local depth
  - (c) sediment concentration
  - (d) net erosion flux

- Coastal morphologic evolution is significant during the initial 3–4 hrs.
- Physics of tsunami-induced sedimentation is confined to a time scale of O(hours).



Conclusions

1. ***A numerical model to predict morphologic changes by tsunami-induced current is developed by coupling 'hydrodynamic-morphologic models.***
2. ***The model is validated through 1D and 2D sediment problems, with a comprehensive test on prametric sensitivity.***
3. ***Application to the real tsunami event(2011 Japan Tohoku Tsunami) revealed that***

"the simulated bathymetric changes provide good approximations to the observation as long as the parameters is properly chosen"