Large Vessel and Debris Transport due to Tsunami-Induced Currents

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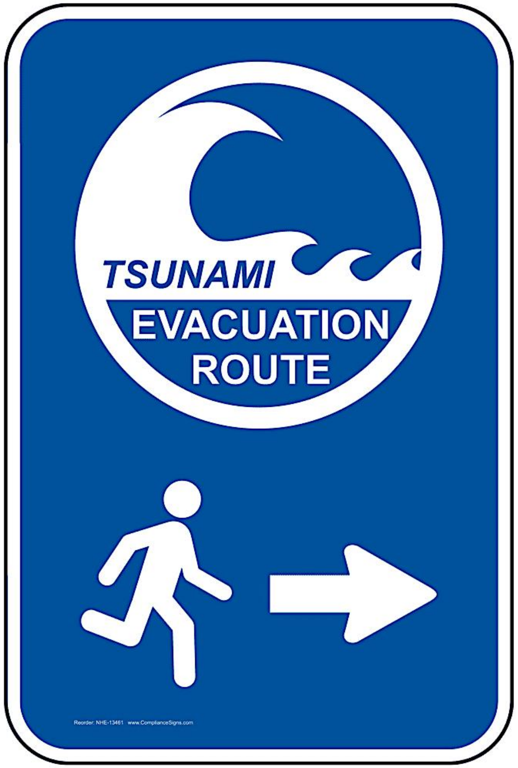
Outline

Large vessel and Debris Transport due to Tsunami Currents



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Tsunami Current Induced Hazards

No/Little Inundation → Primary damage mechanism → ▪Able to pick-up and move very large objects

Crescent City – California (2011)

Oarai – Japan (2011)

Our Purpose

Develop a model

- Motion of the Large Vessels & Small Craft/Debris Transport
- Flow-Vessel Interaction
- Built-in Collision Model

Hydrodynamic Model

Method Of Splitting Tsunamis (MOST)

- Non-linear Shallow Water (NSW)
- Used extensively tsunami hazard assessment studies
- Depth-averaged -> 2 HD

Hydrodynamic Model

Vessels are included as horizontal pressure disturbances

$$u_t + uu_x + vu_y + gh_x = gd_x - \tau_{bx} - \frac{1}{\rho}\frac{\partial P_0}{\partial x}$$

$$v_t + uv_x + vv_y + gh_y = gd_y - \tau_{by} - \frac{1}{\rho}\frac{\partial P_0}{\partial y}$$

Form Drag

Hydrodynamic Model

Vessels are included as horizontal pressure disturbances

$$u_t + uu_x + vu_y + gh_x = gd_x - \tau_{bx} - \frac{1}{\rho}\frac{\partial P_0}{\partial x}$$

$$v_t + uv_x + vv_y + gh_y = gd_y - \tau_{by} - \frac{1}{\rho}\frac{\partial P_0}{\partial y}$$

Form Drag

Skin Friction

Bottom Stress

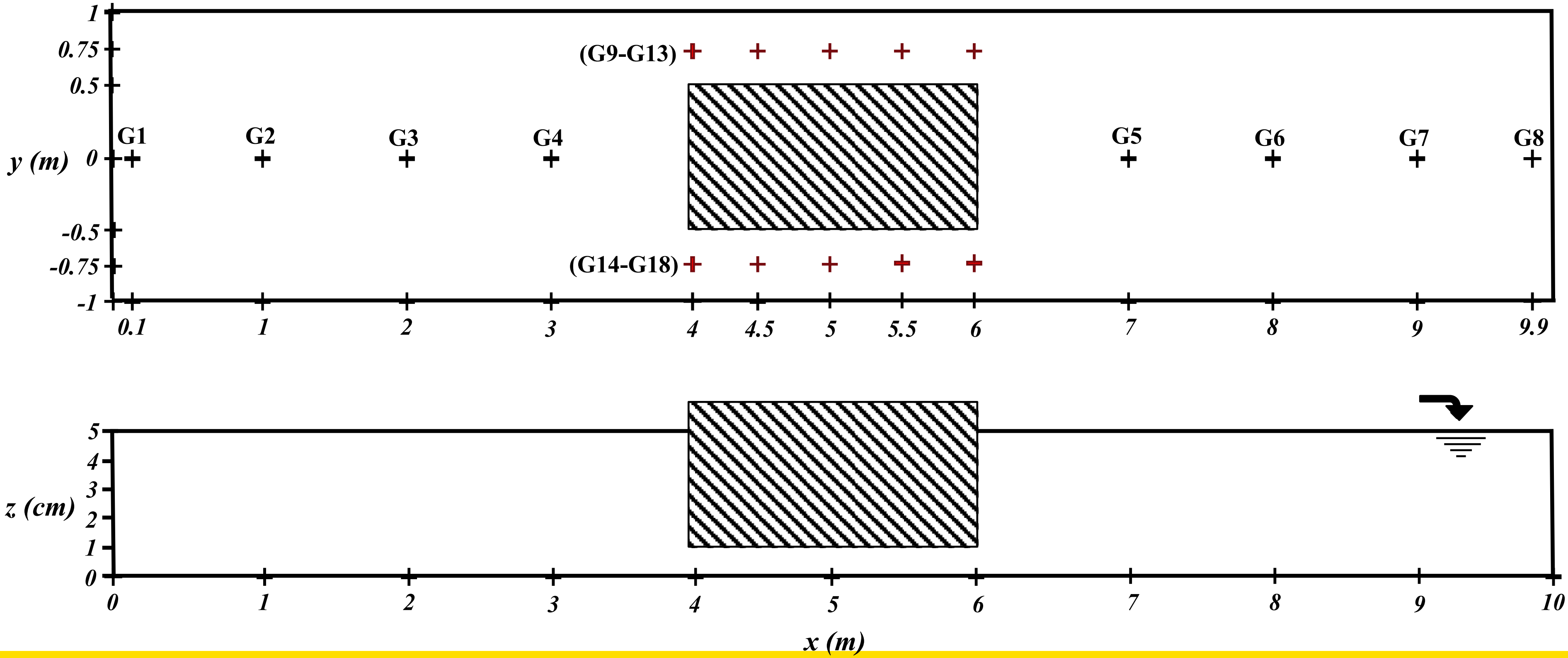
Friction Coefficient

Model Validation – OpenFOAM®

Flow past a floating rectangular block

80% Submerged

Constant discharge of 0.1 m/s

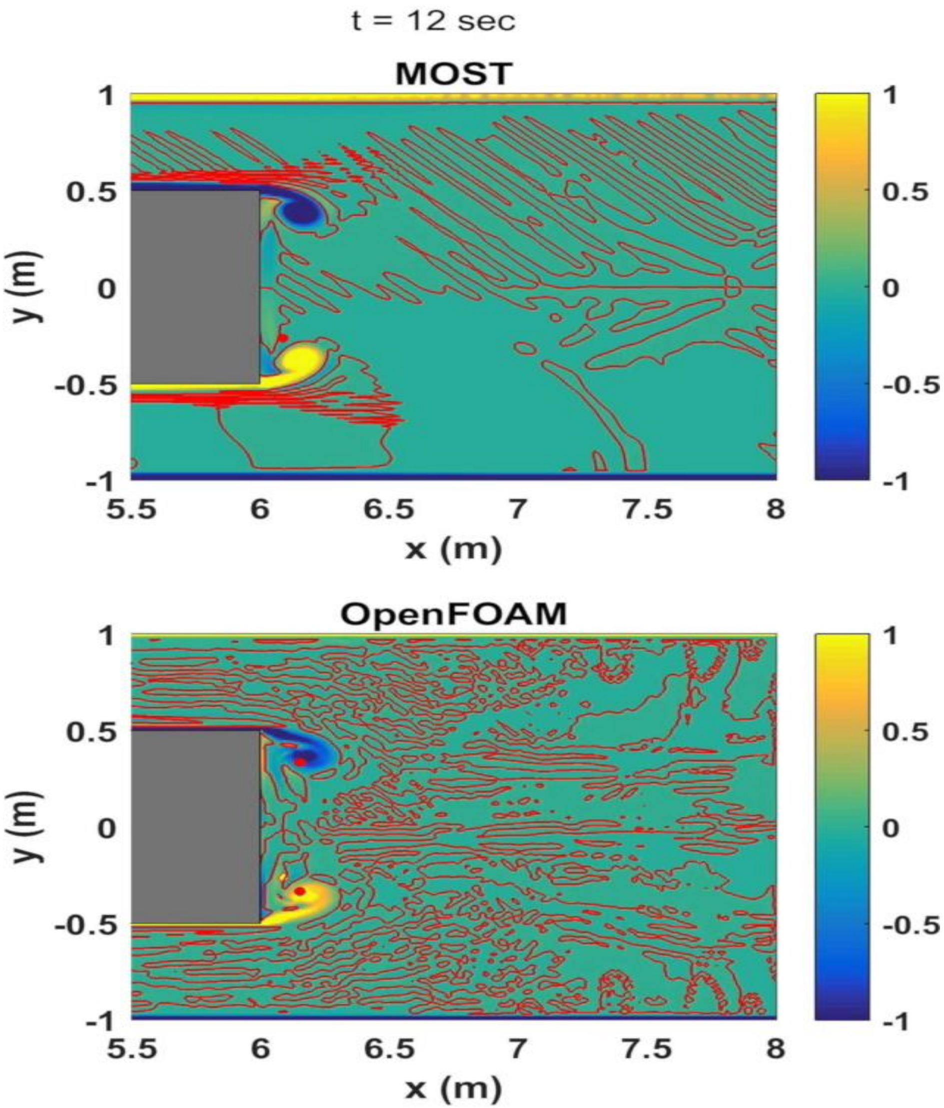


Model Validation – OpenFOAM®

MOST

Vorticity Maps (1/s)

OpenFOAM®

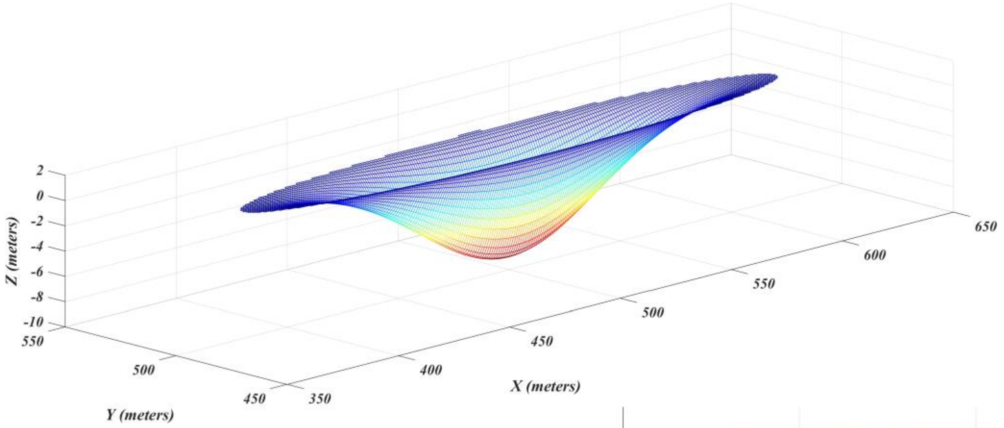


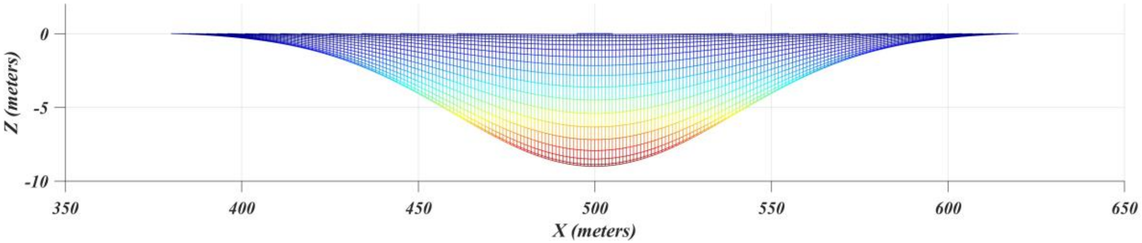
Collision Model

Analytical method solves linear equations

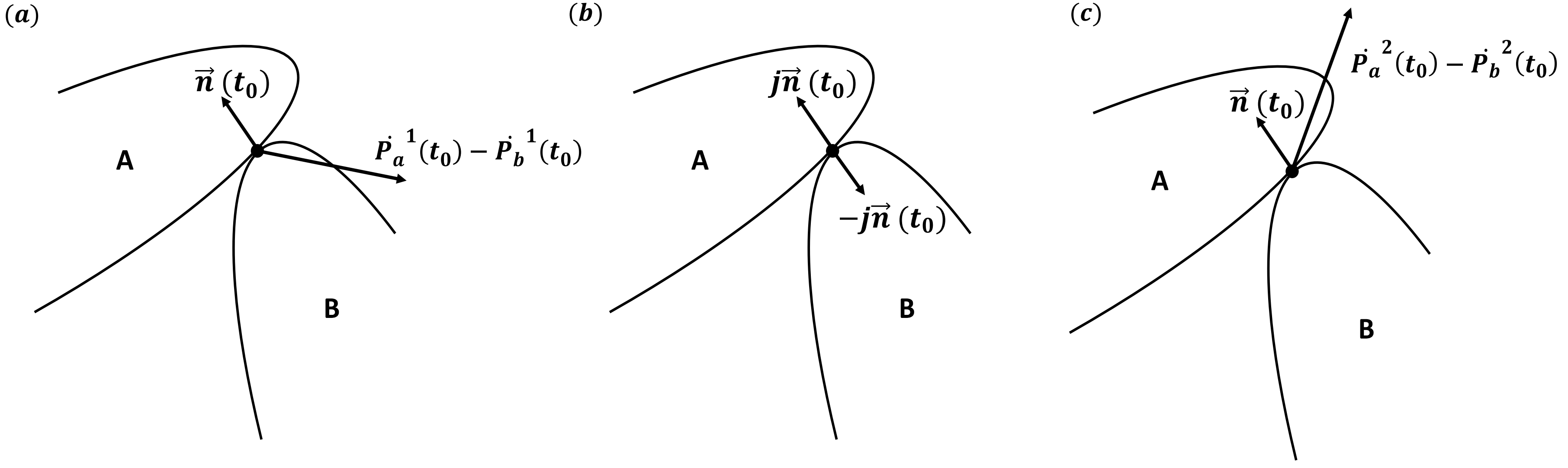
Conservation of momentum and impulse (J)

Evaluate the collisions between ellipses





Collision Model

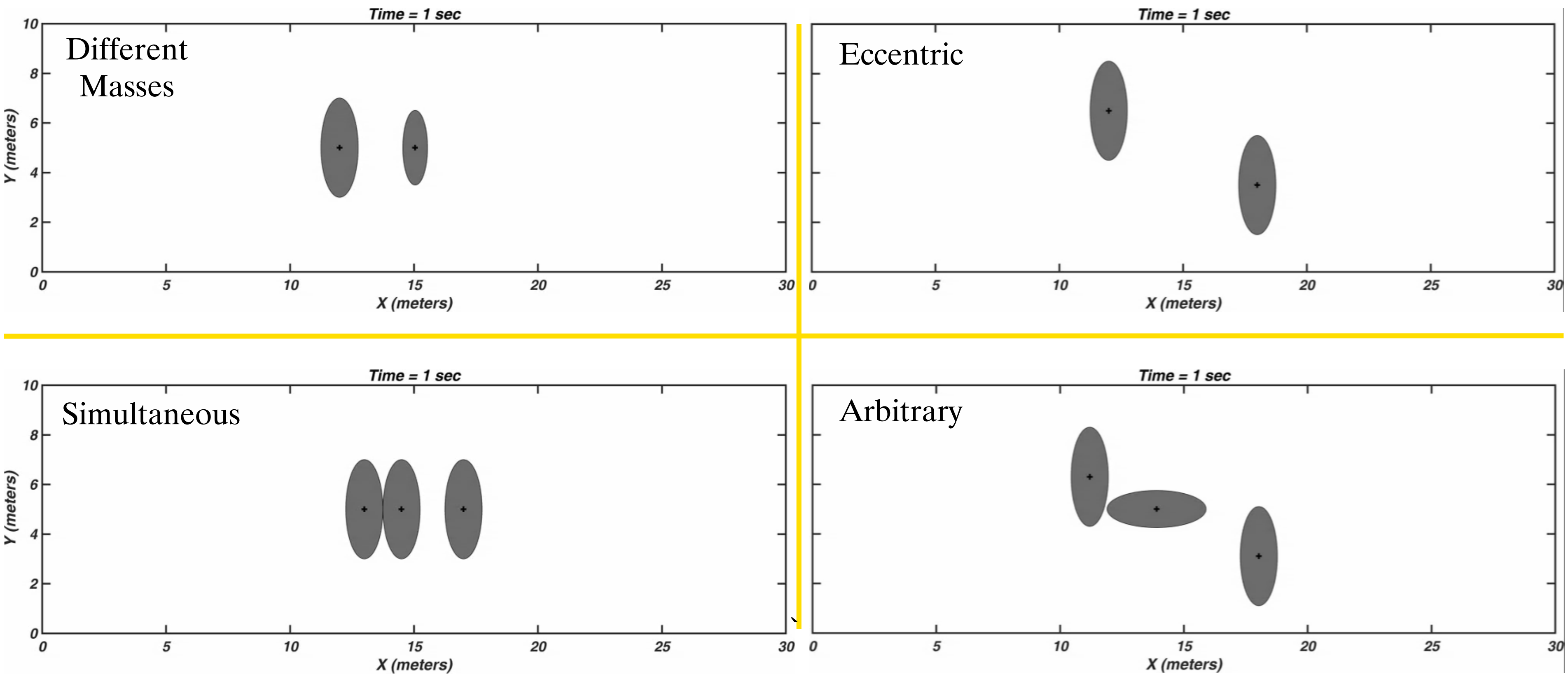


$$v_{rel} = \left(\dot{p_a}(t_0) - \dot{p_b}(t_0)\right) \cdot \vec{n}(t_0)$$

$$v_{rel}^1 = -\beta v_{rel}^2 \quad 0 \leq \beta \leq 1$$

$$j = -\frac{-(1+\epsilon)v_{rel}^1}{\left(\frac{1}{M_a} + \frac{1}{M_b} + \vec{n}(t_0) \cdot \left(\frac{r_a\, x\, \vec{n}(t_0)}{(I_{zz})_a}\right) x\, r_a + \vec{n}(t_0) \cdot \left(\frac{r_b\, x\, \vec{n}(t_0)}{(I_{zz})_b}\right) x\, r_b\right)}$$

Collision Model - Experiments



Equations of Ship Motion

Based on the linear model

Includes added mass and damping

Current forces -> Empirical drag formulation

Forces due to ship's controls are excluded

$$(m - X_{\dot{u}})\,\dot{u} = X_u u + X'$$

$$(m - Y_{\dot{v}})\,\dot{v} + Y_{\dot{r}}\dot{r} = Y_v v + (Y_r - mu)r + Y'$$

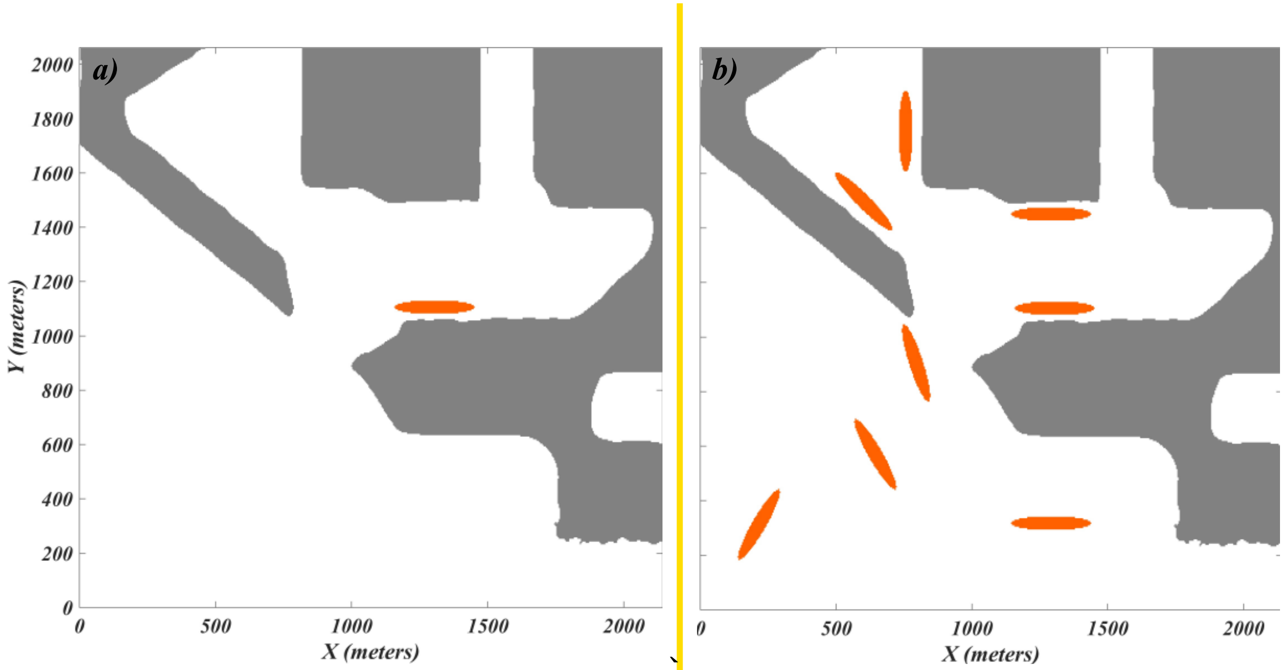
$$(I_{zz} - N_{\dot{r}})\dot{r} - N_{\dot{v}}\dot{v} = N_v v - N_r r + N'$$

Port of Long Beach

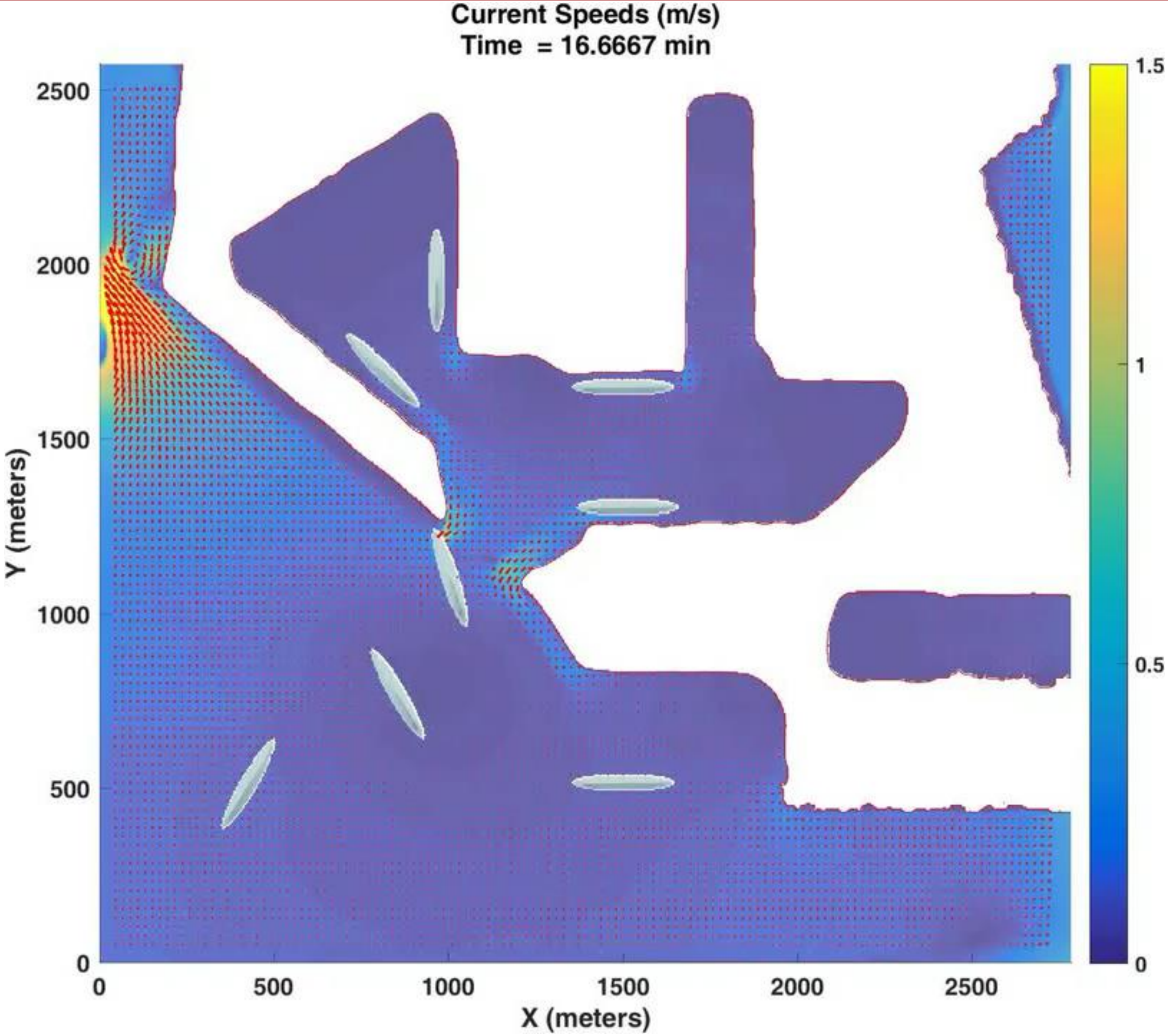
POLB – Simulation Set-up

M_w = 9.2 Earthquake in Alaska – Aleutians Subduction Zone

Two simulations with different number of vessels included



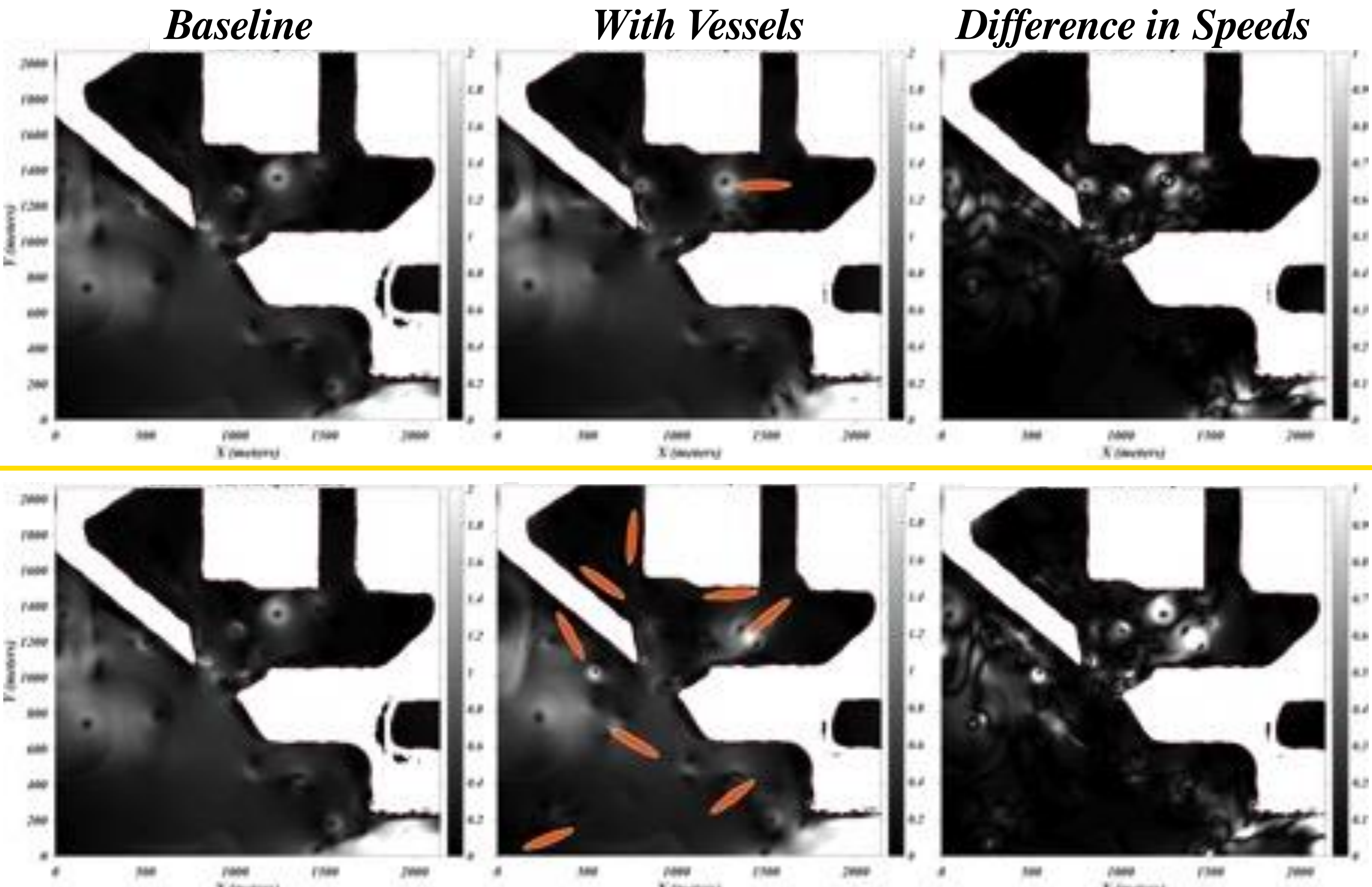
POLB – Multi Vessel Scenario



8 - Ships

- L = 305 m (~1000')
- B = 60 m (~195')
- Draft = 10 m (30')
- DW = 100,000 tons

POLB – Effect of Vessels



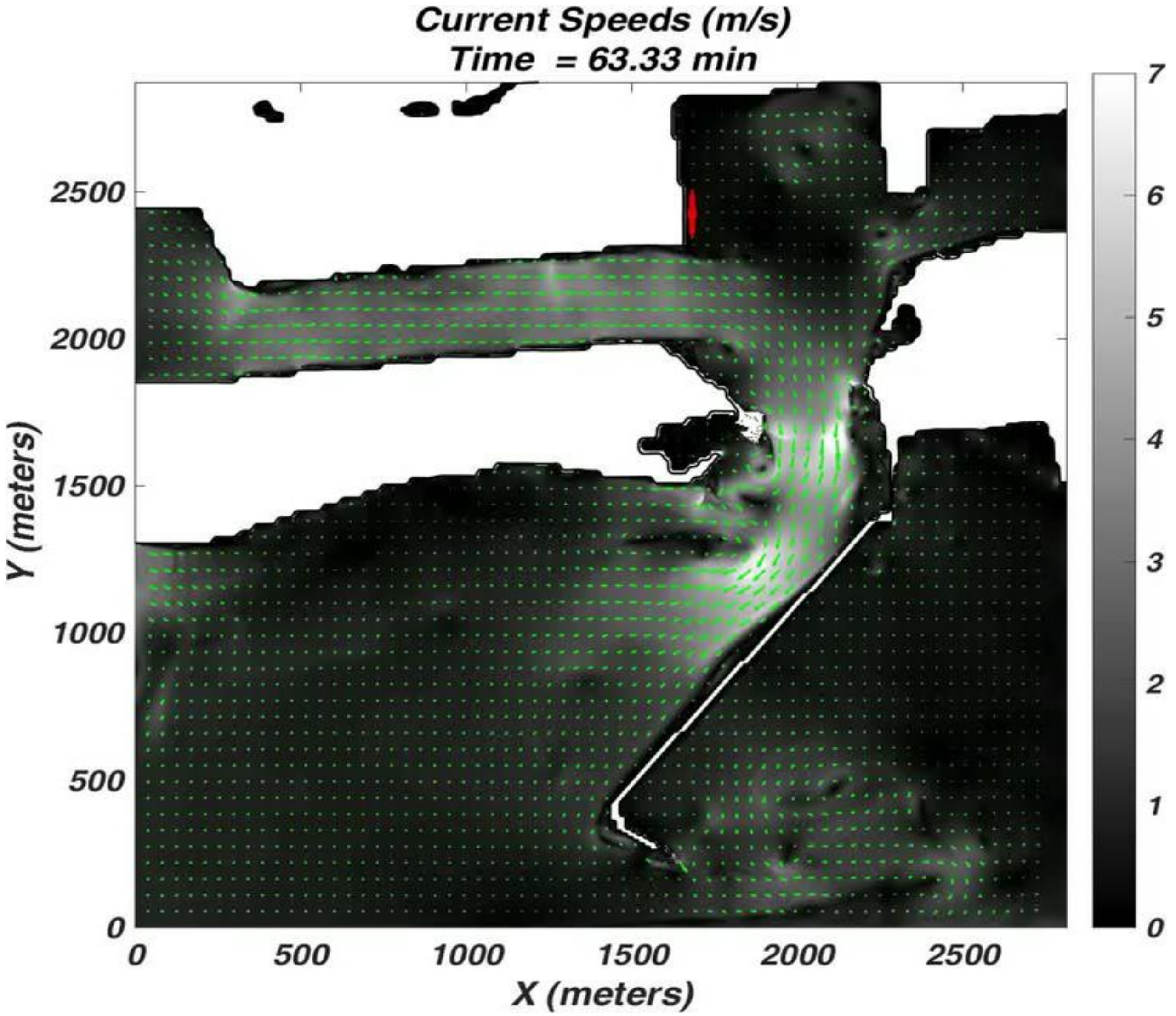
Ishinomaki Port

Ishinomaki Port

C.S. Victory

- L = 177 m (~580')
- B = 26 m (~85')
- Draft = 6.1 – 9 m (20-30')
- DW = 33,000 tons

Ishinomaki Port -



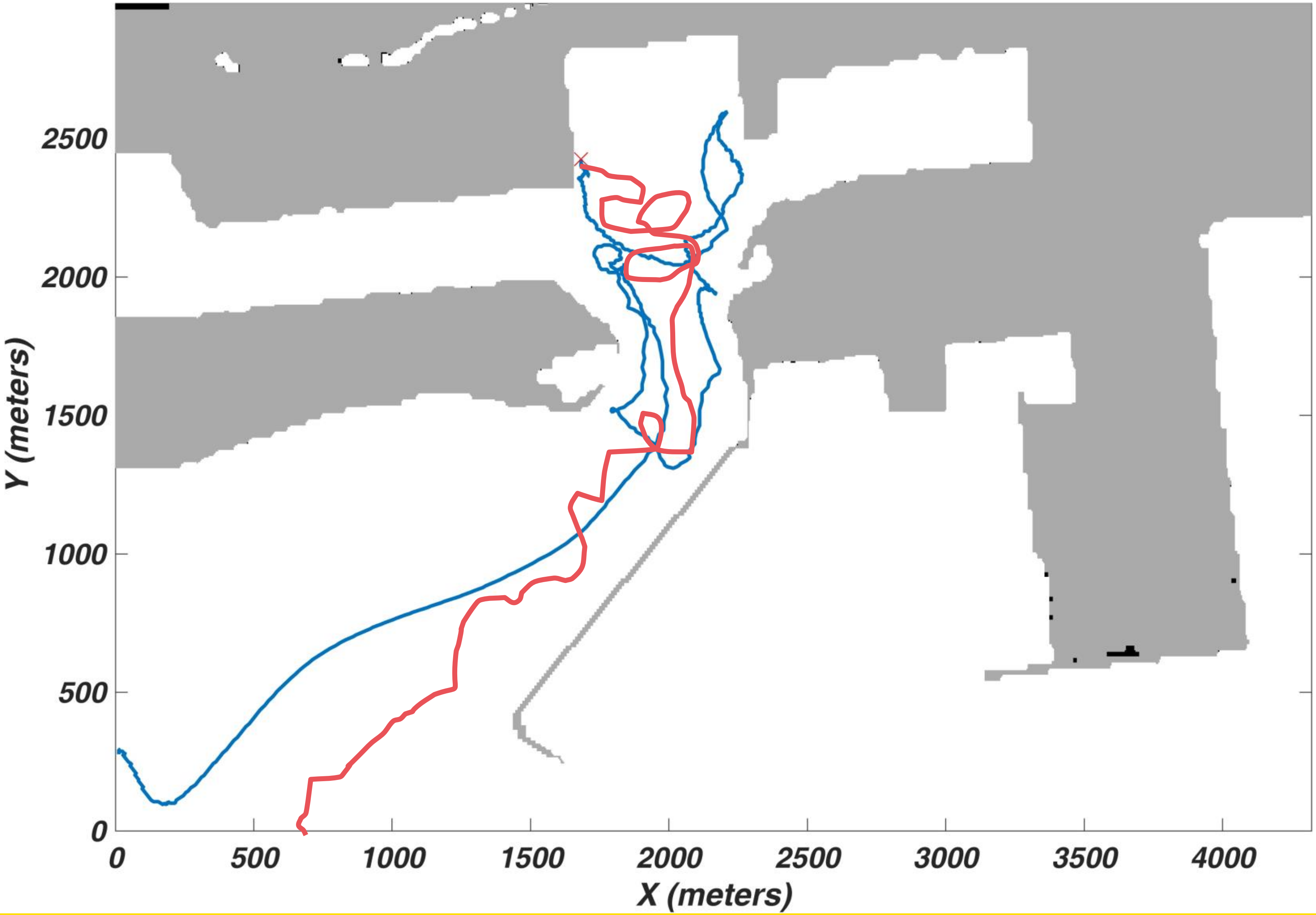
2011 Tohoku Tsunami

~5 m horizontal resolution

Released 65 min after the first arrival

Draft = 7.5 m (~25')

Ishinomaki Port – Model/Data Comparison

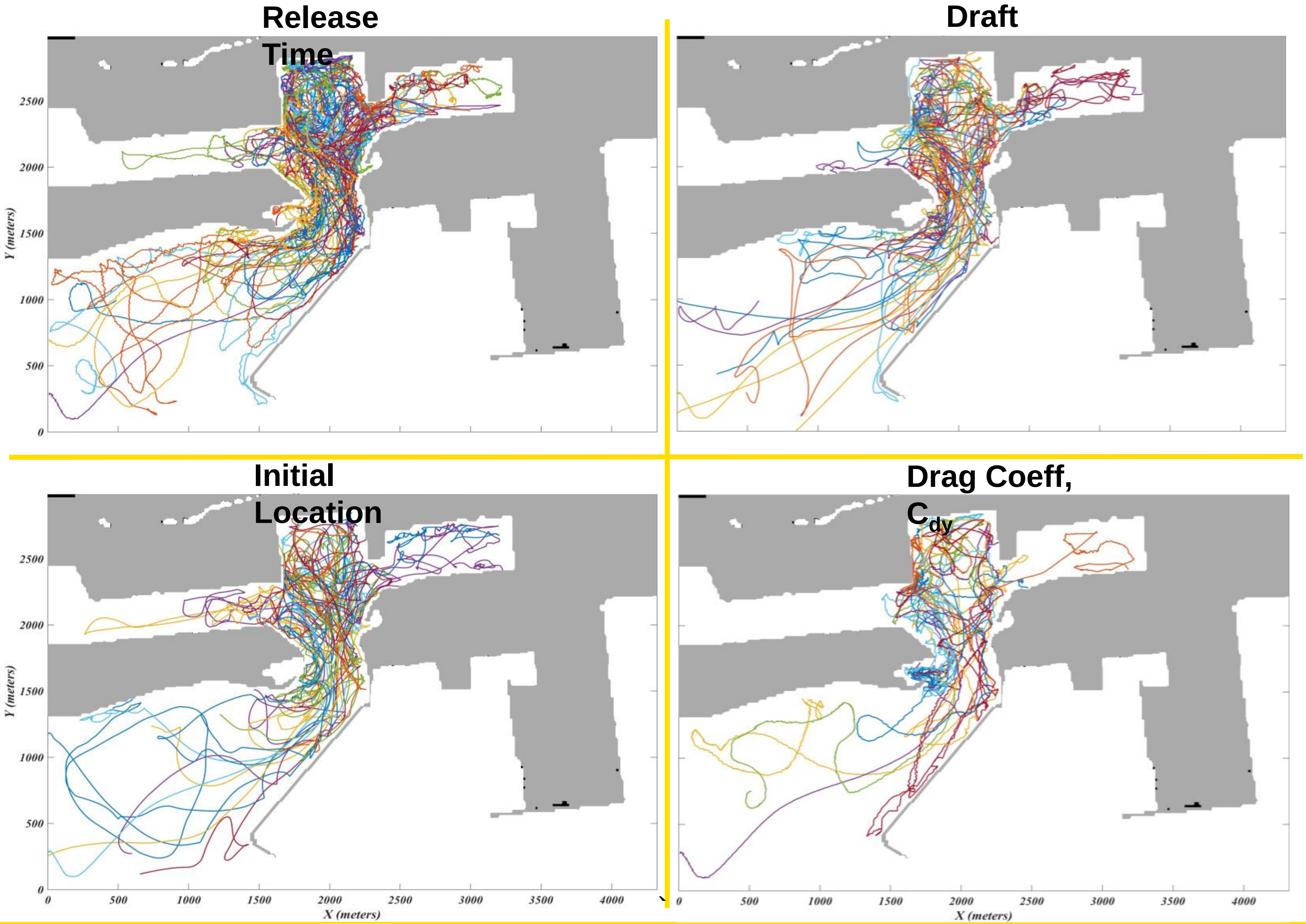


Ishinomaki Port – Sensitivity Analysis

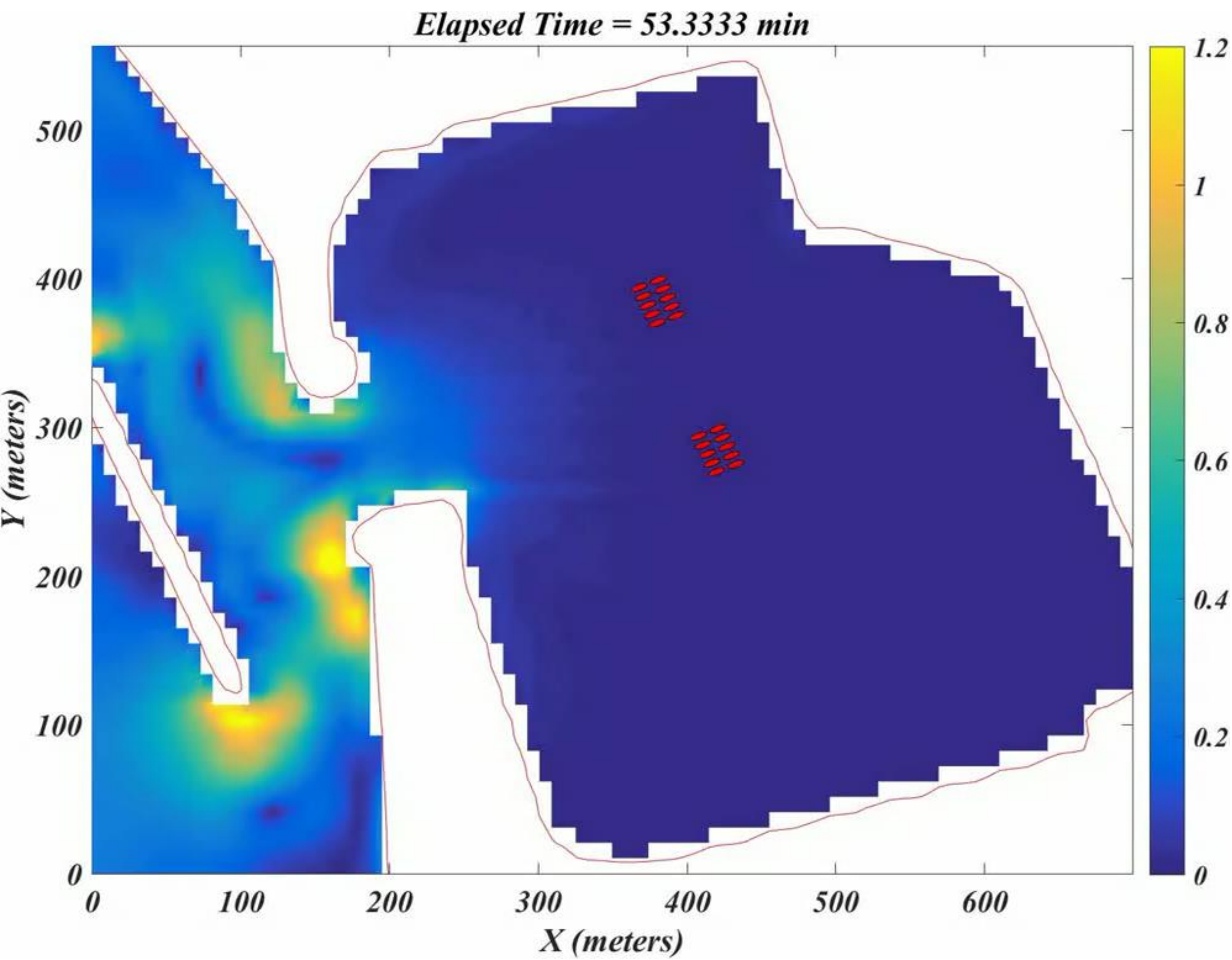
Sensitivity Analysis

Initial choice of parameters effect the model results?

Ishinomaki Port – Sensitivity Analysis



Debris/Small Craft Transport



Berkeley Marina (CA)

2011 Tohoku Tsunami

20 Identical Boats

L = 11.7 m (37’)

B = 4 m (13.1’)

Conclusions

- Presented a model to predict large vessel transport model
- The interaction between the flow and vessels are significant
- Model results are very sensitive to the initial choice of parameters

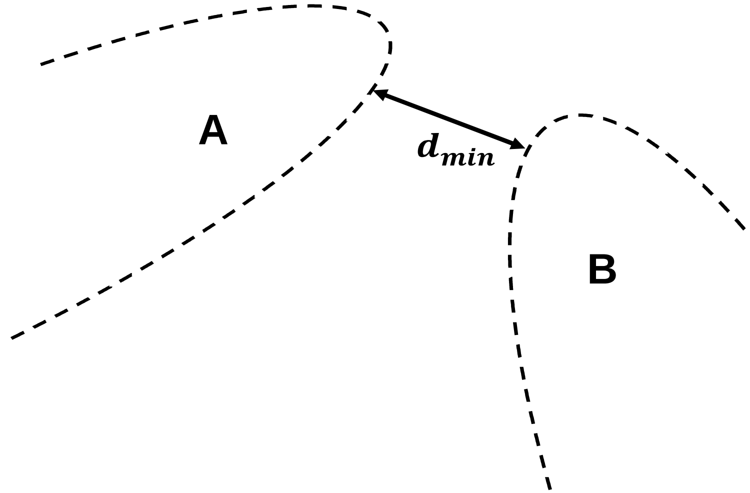
Future Works

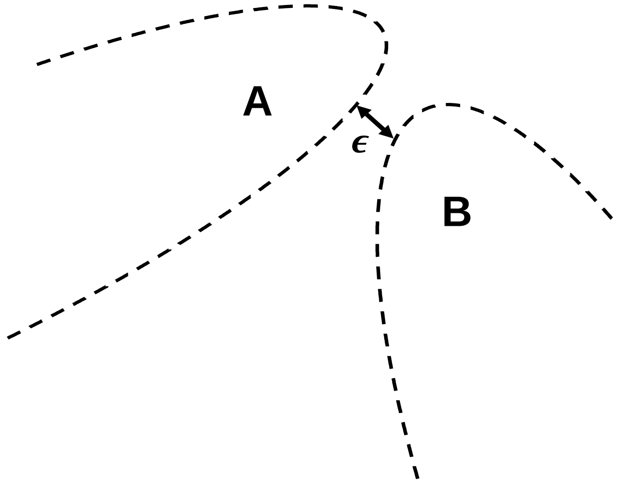
- Techniques to model the chaos in the system
- Can form the basis for a debris transport model

Acknowledgments

- Funded by California Geological Survey (CGS)
- Gökhan Güler for his support in OpenFOAM simulations
- Dr. Hiroshi Takagi for providing high-res DEM of the Ishinomaki Port

Collision Model - Detection





$$A = \{k_1, k_2, k_3, \ldots, k_n\} \text{ and } B = \{l_1, l_2, l_3, \ldots, l_n\}$$

$$d_{min}(A, B) = \min\{d(k_i, l_j)\}, \qquad i, j = 1,2, \ldots, n$$

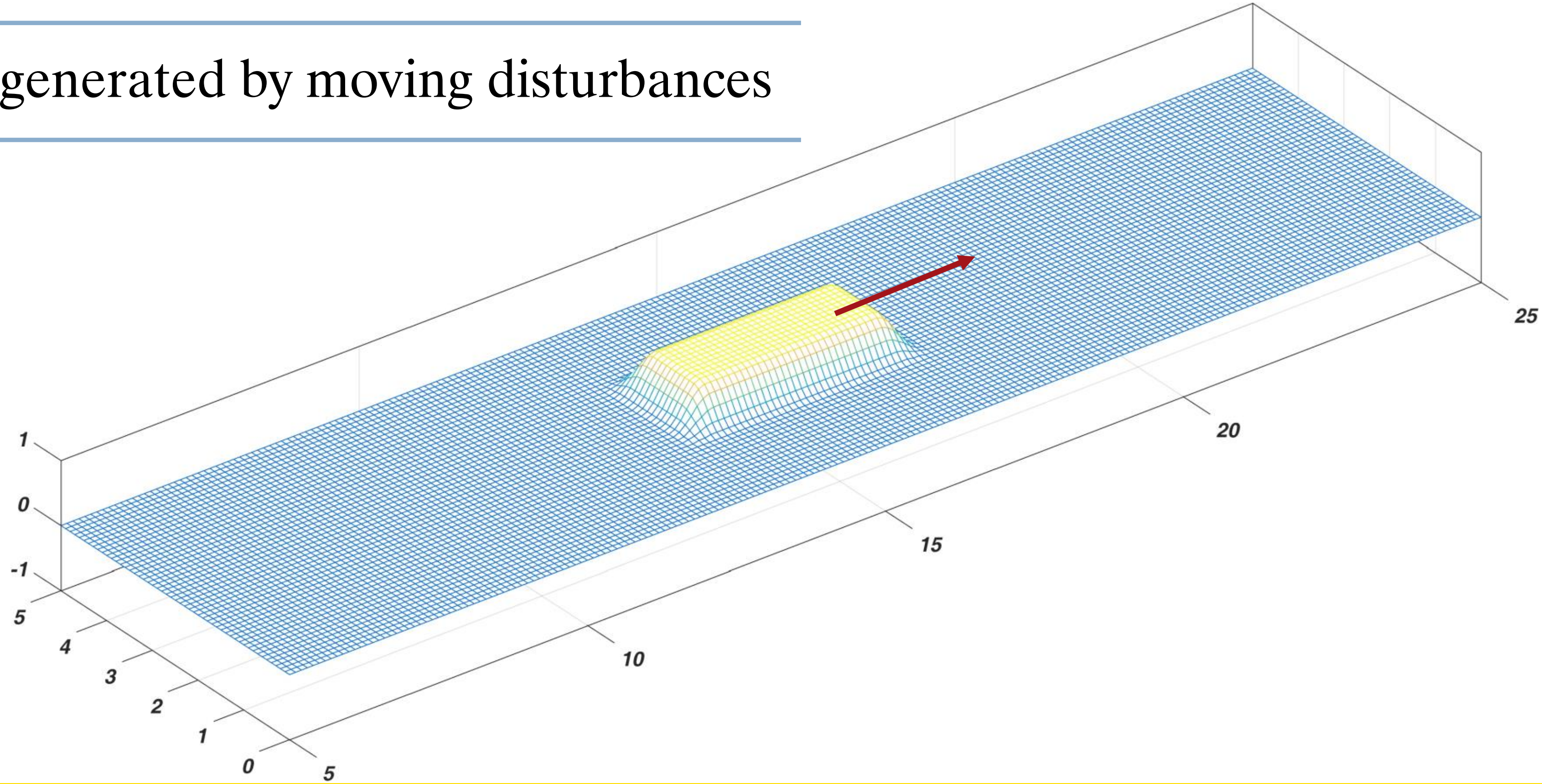
$$\boldsymbol{d_{min}(A, B) \leq \epsilon}$$

Model Validation

Ertekin et al., (1986)

3D, dispersive, rotational Green-Naghdi

Waves generated by moving disturbances



Model Validation

Disturbance moving with Fr = 1

65 m ahead

130 m ahead