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*The State of the Art and Science of Coastal Engineering*

# Validation of Sand-Mud Mixture Transport Model with Field and Flume Experiments

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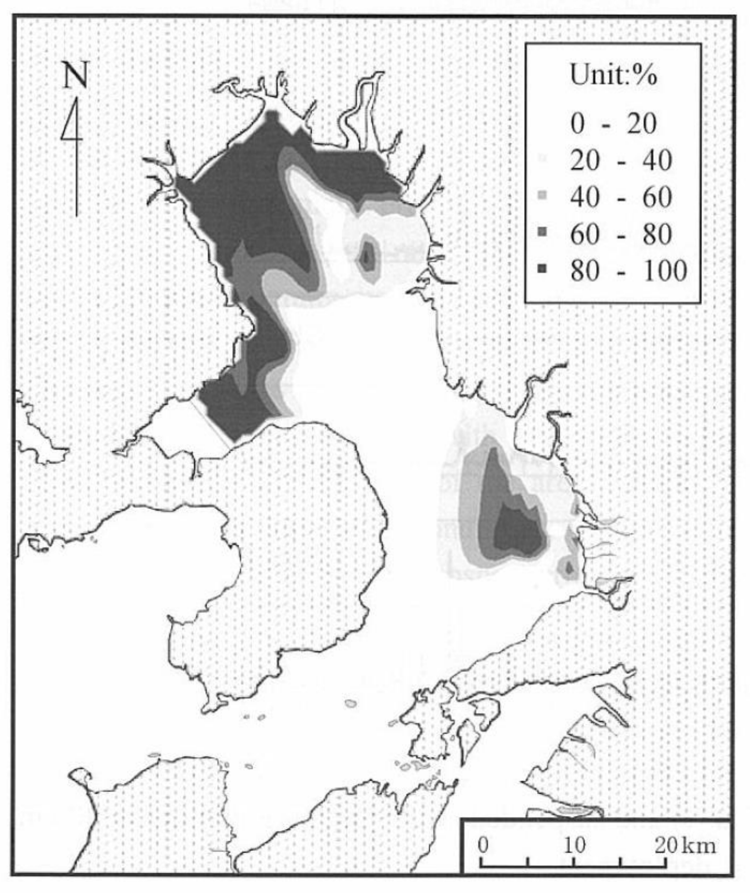
# Introduction

- In estuaries and coasts, sand-mud mixtures are often observed.
- Mud content has an important role in erosion behavior of mixed beds (e.g., Mitchener and Torfs, 1996).

↓

- Simple (linear) combination of transport models for pure sand and mud (ST + MT models).
- Sand-mud mixture transport model (SMMT model) considering erosion process of sand-mud mixture (e.g., Chesher & Ockenden, 1997; van Ledden, 2003)

required for better prediction of bed evolution in estuaries and coasts




Distribution of mud content in the Ariake Bay（Nakagawa, 2003）

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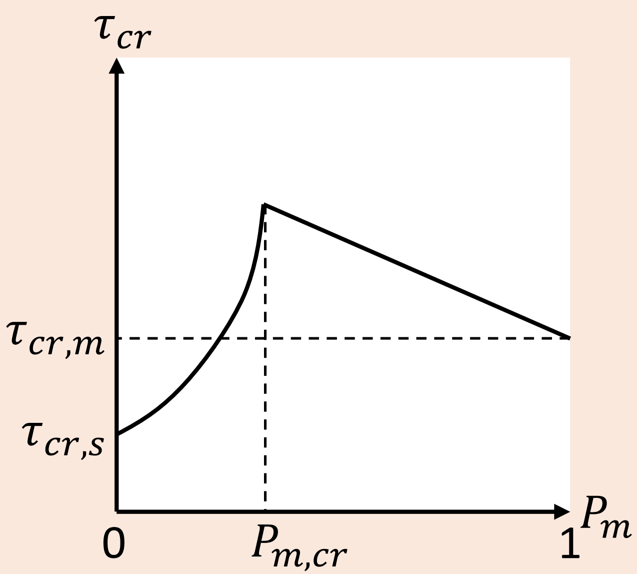
# *Sand-Mud Mixture Transport (SMMT) model*

- Critical shear stress $\tau_{cr}$ of sand-mud mixture (van Ledden, 2003)
  - $\tau_{cr}$ is assumed to vary between pure sand ($\tau_{cr,s}$) and mud ($\tau_{cr,m}$) depending on mud content ($P_m$), but with a critical value ($P_{m,cr}$).

$$\tau_{cr} \begin{cases} = \tau_{cr,s}(1+P_m)^{\beta}, & if\ P_m < P_{m,cr} \\ = \dfrac{\tau_{cr,s}\left(1+P_{m,cr}\right)^{\beta} - \tau_{cr,m}}{1-P_{m,cr}}(1-P_m) + \tau_{cr,m}, & if\ P_m \geq P_{m,cr} \end{cases}$$

| | |
|---|---|
| $\tau_{cr,s}$ | : critical shear stress for pure sand |
| $\tau_{cr,m}$ | : critical shear stress for pure mud |
| $P_{m,cr}$ | : critical mud content |
| $\beta$ | : dimensionless parameter |



# *Sand-Mud Mixture Transport (SMMT) model*

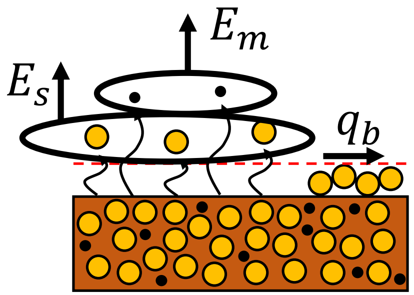
- Erosion formulations of sand-mud mixture (van Ledden, 2003)

***if*** $\boldsymbol{P_m < P_{m,cr}}$ ⇨ **Non-cohesive regime**

van Rijn's formulations

$$q_b = \left(1 - \frac{P_m}{P_{m,cr}}\right) \times 0.5 u_* d_{50} D_*^{-0.3} \left(\frac{\tau_b}{\tau_{cr}} - 1\right)$$

$$E = \underbrace{(1 - P_m) \times w_s \cdot 0.015 \frac{d_{50}}{a} D_*^{-0.3} \left(\frac{\tau_b}{\tau_{cr}} - 1\right)}_{E_s} + \underbrace{P_m \times M \left(\frac{\tau_b}{\tau_{cr}} - 1\right)}_{E_m}$$

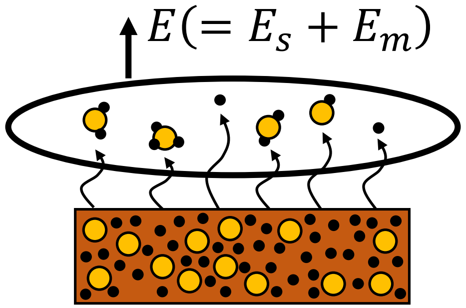



***if*** $\boldsymbol{P_m \geq P_{m,cr}}$ ⇨ **Cohesive regime**

empirical law for mud erosion

$$q_b = 0$$

$$E = \underbrace{(1 - P_m) \times M \left(\frac{\tau_b}{\tau_{cr}} - 1\right)}_{E_s} + \underbrace{P_m \times M \left(\frac{\tau_b}{\tau_{cr}} - 1\right)}_{E_m}$$



# Objectives

van Ledden's formulation

$$\tau_{cr} \begin{cases} = \tau_{cr,s}(1+P_m)^{\beta}, & if\ P_m < P_{m,cr} \\ = \dfrac{\tau_{cr,s}\left(1+P_{m,cr}\right)^{\beta} - \tau_{cr,m}}{1-P_{m,cr}}(1-P_m) + \tau_{cr,m}, & if\ P_m \geq P_{m,cr} \end{cases}$$

$\tau_{cr,s}$ : critical shear stress for pure sand
$\tau_{cr,m}$ : critical shear stress for pure mud
$P_{m,cr}$: critical mud content
$\beta$ : dimensionless parameter

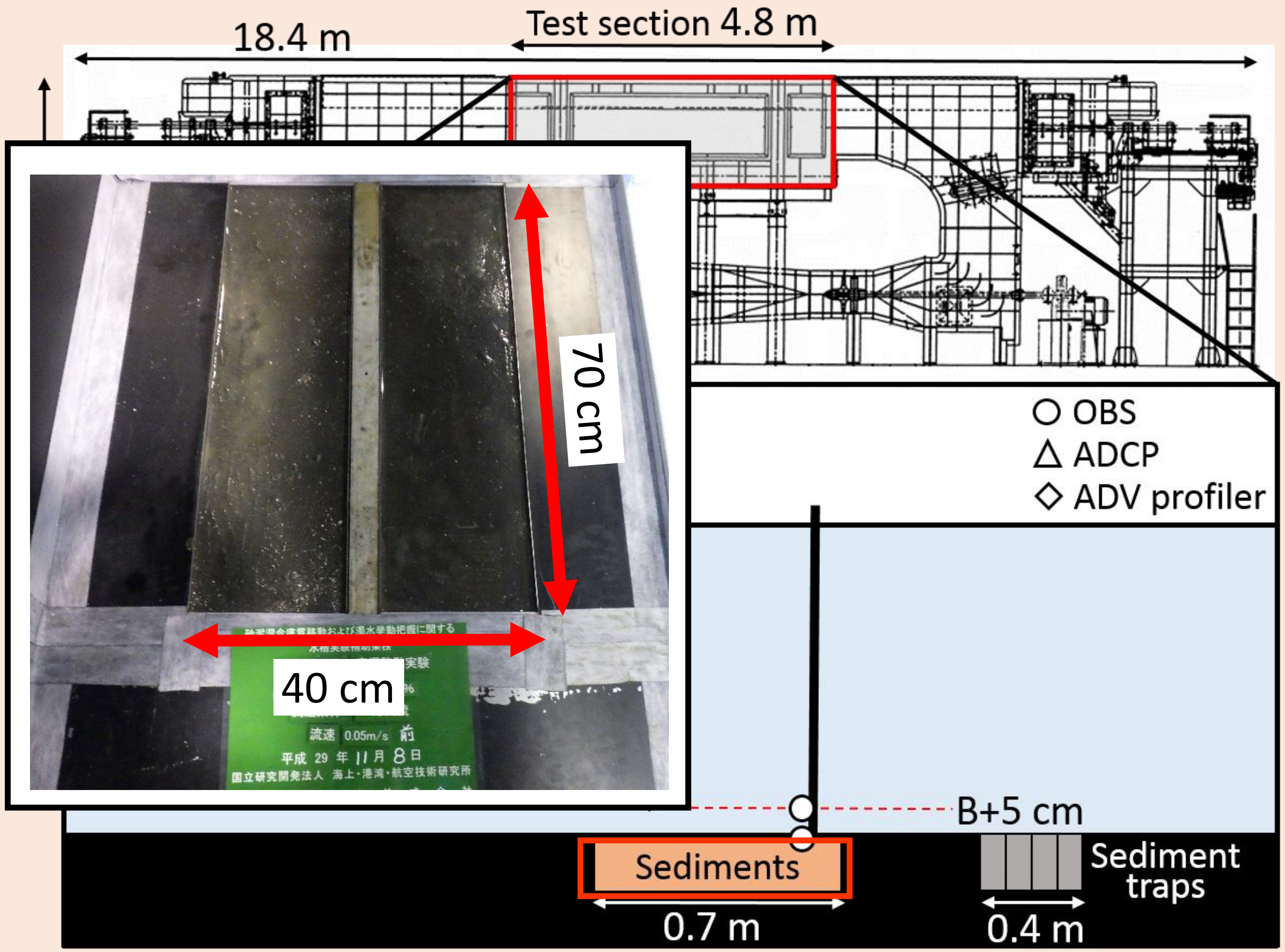
= ???

These parameters are required for $\tau_{cr}$

- Calibration and validation of SMMT model with flume experiments
- Sediment transport simulation in a field with SMMT model

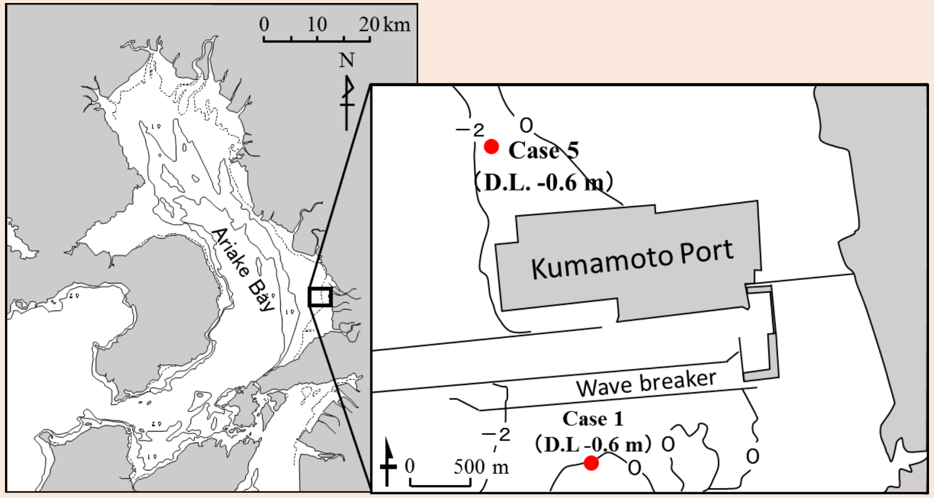
*Parameter calibration of SMMT model*

# ■ Erosion tests with annular flume in PARI



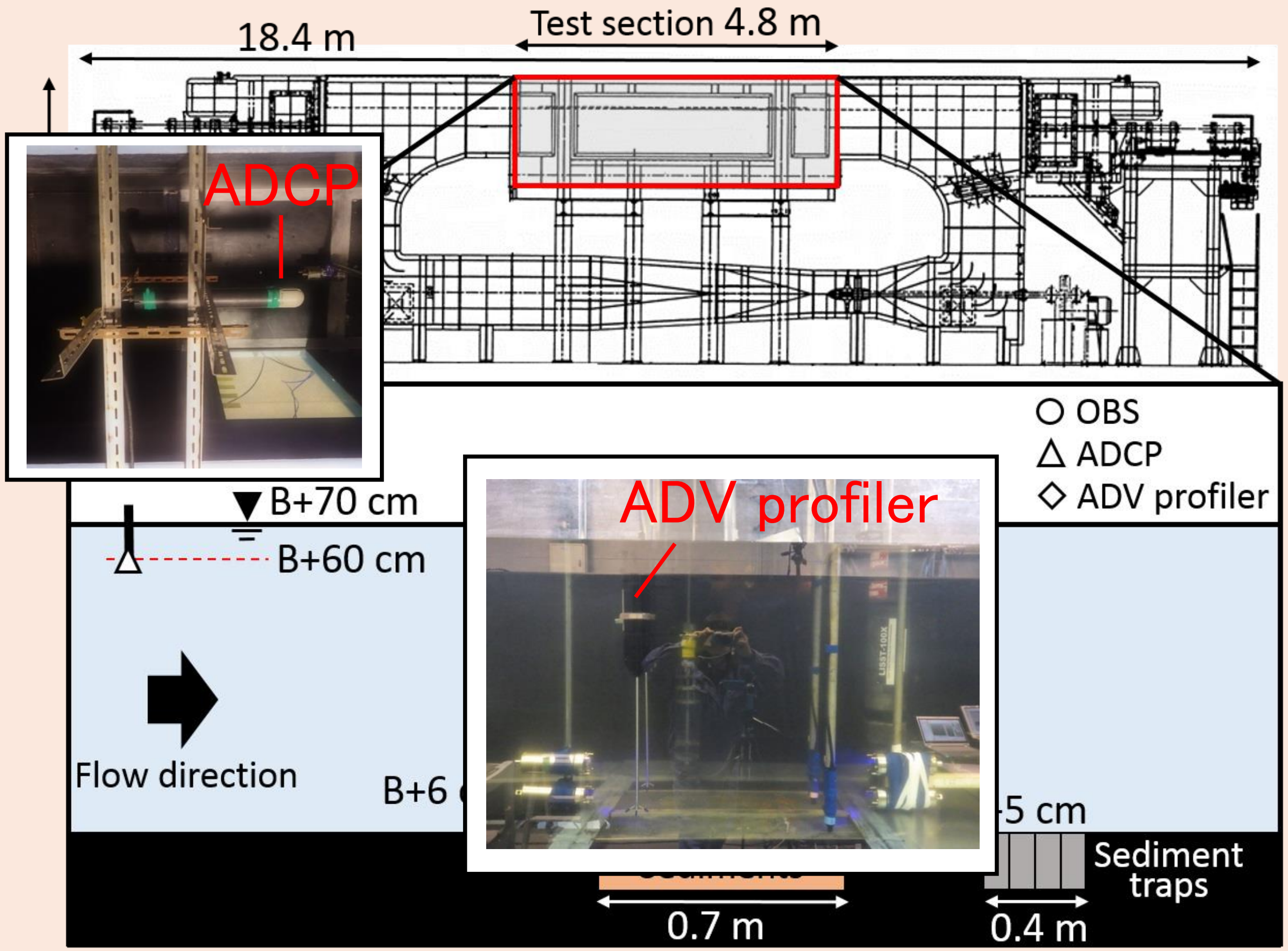

## ➢Bed properties

| Case | $P_m$ (%) | $d_{50}$ (μm) | Bed type |
|---|---|---|---|
| 1 | 4.9 | 248.4 | natural |
| 2 | 19.3 | 218.4 | homogeneous |
| 3 | 25.2 | 210.8 | 〃 |
| 4 | 40.2 | 142.5 | 〃 |
| 5 | 80.2 | 29.0 | natural |



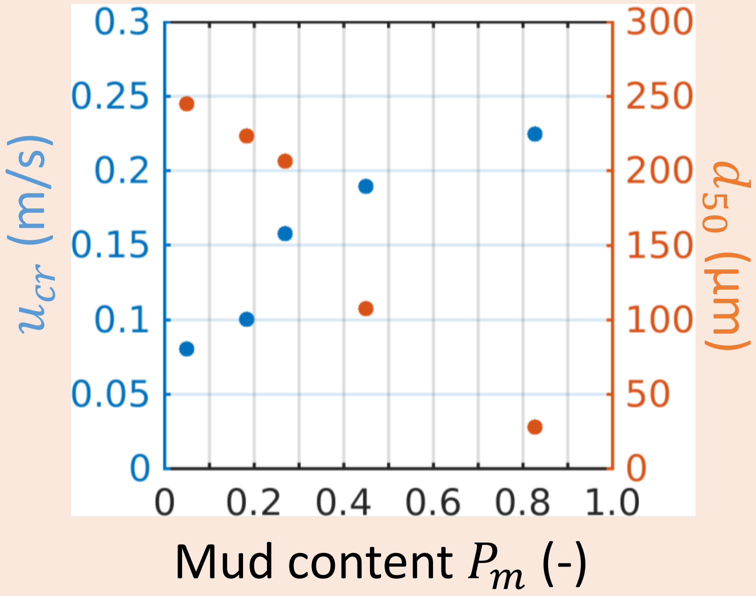
*Parameter calibration of SMMT model*

# ■ Erosion tests with annular flume in PARI




## ➢ Forcing condition

- **4 grades** of steady **unidirectional flow**
- **Depth-averaged velocity $\overline{U}$** measured by ADCP
- **Critical near-bottom velocity $u_{cr}$** ($z = B + 5\ mm$) measured by ADV profiler

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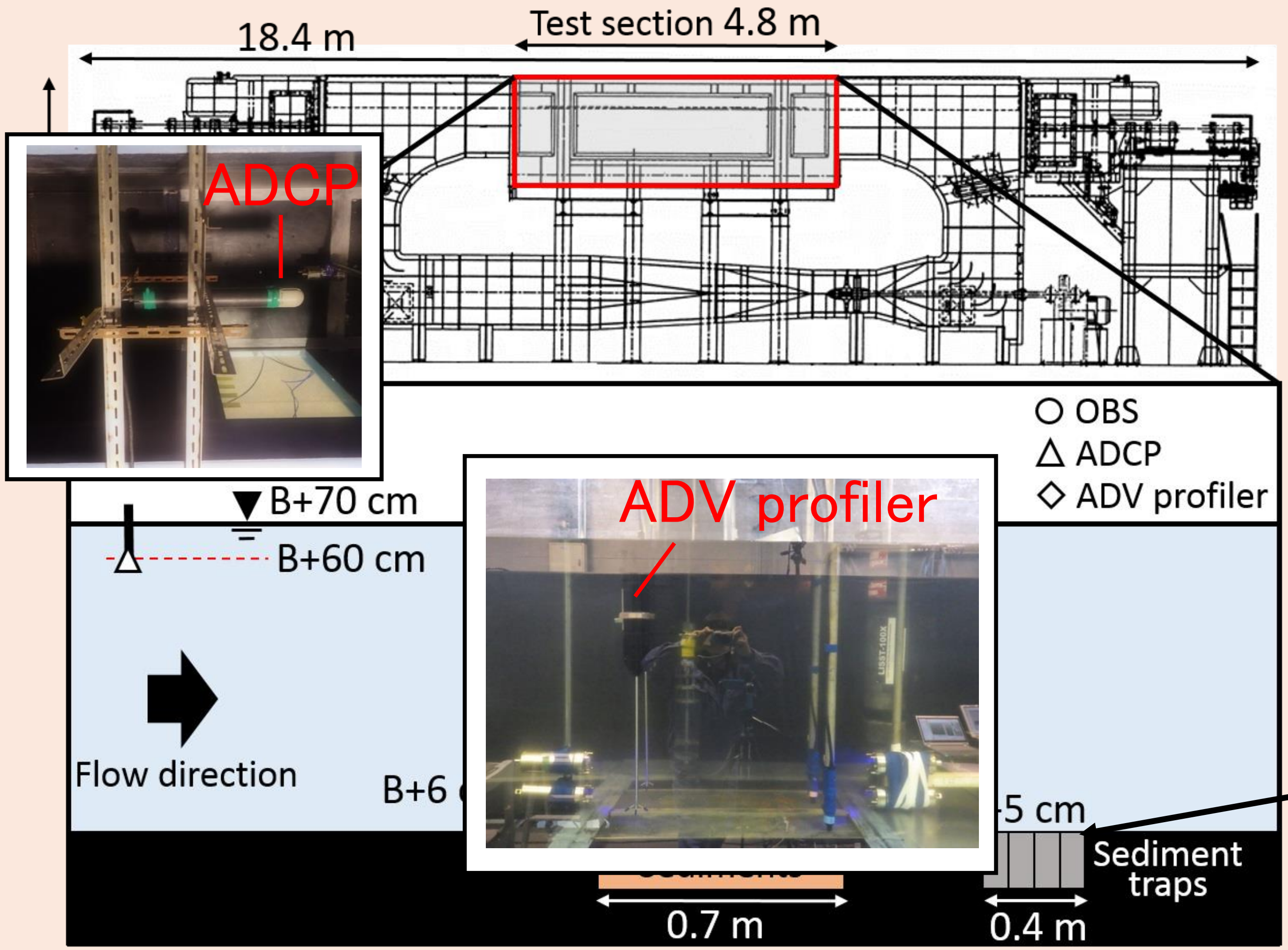
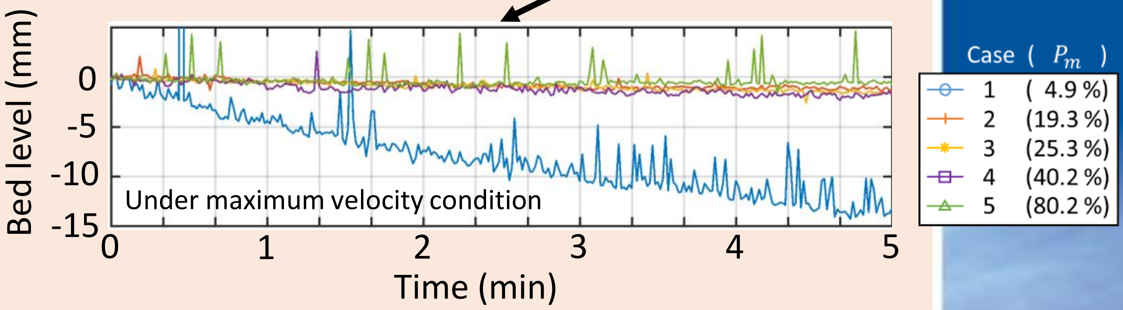
*Parameter calibration of SMMT model*

# ■ Erosion tests with annular flume in PARI

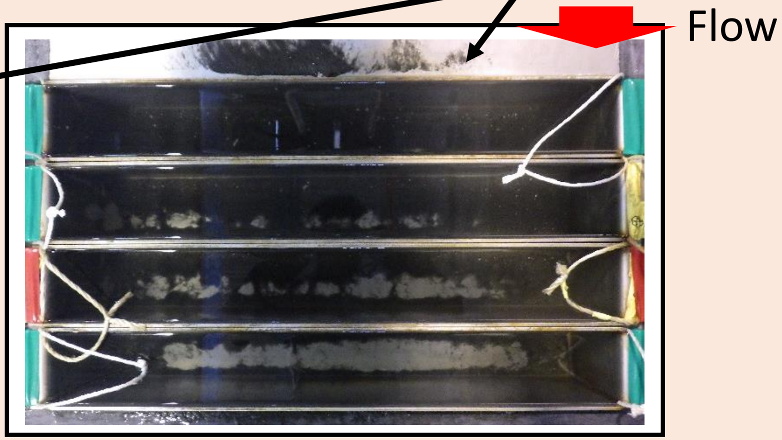



## ➢Quantify erosion behavior

- **Erosion rate** calculated with **Bed level** measured by ADV profiler

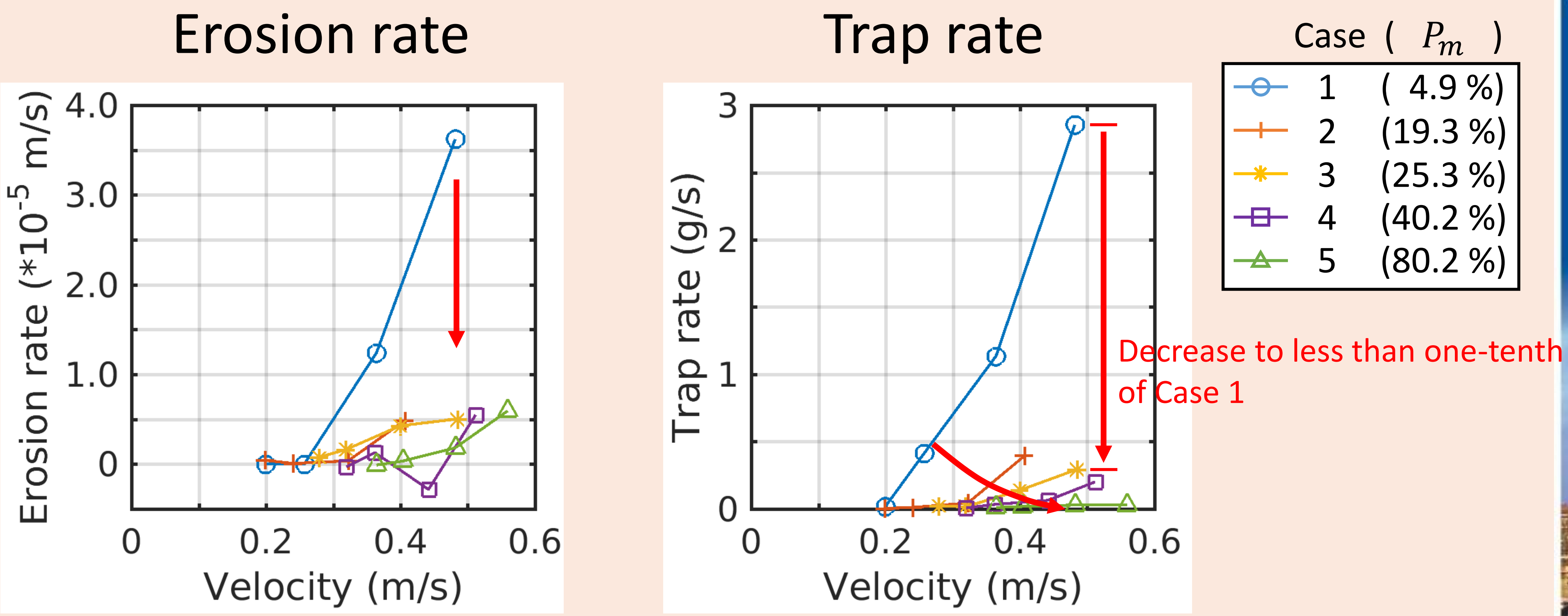



- **Trap rate** measured with **Dry weight of sediments** trapped into Sediment trap



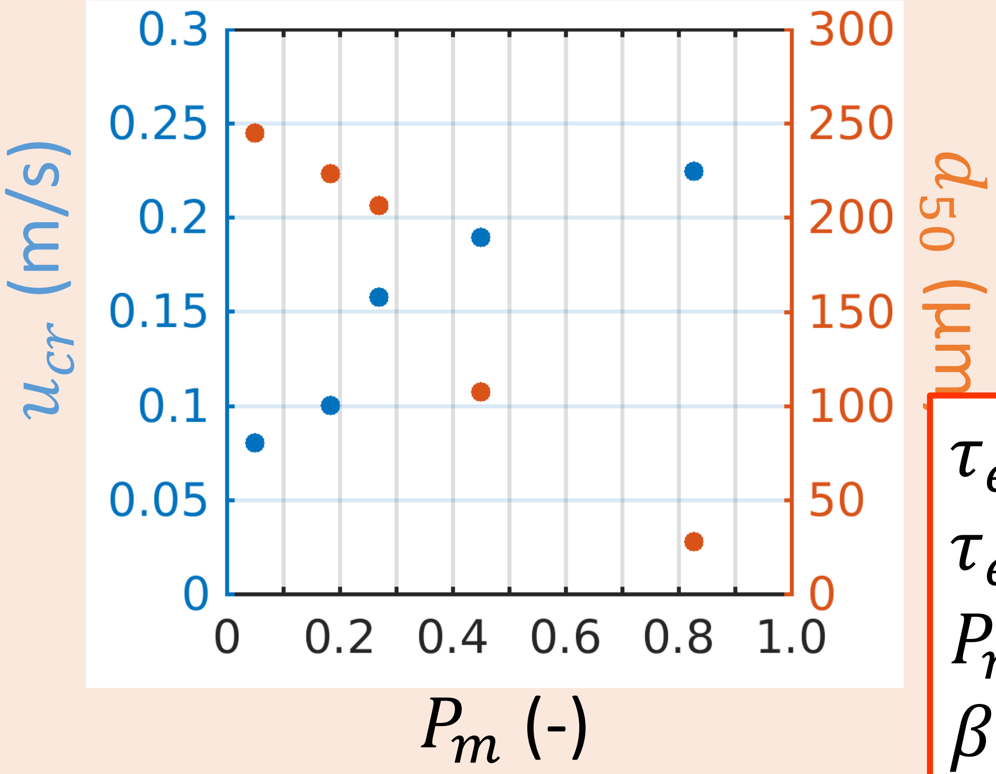
## *Parameter calibration of SMMT model*

### ■ Experimental results




- Erosion rate and trap rate significantly decrease due to addition of mud.
- Trap rate (due to mainly bedload) in Case 3-5 decrease to less than one-tenth of that in Case 1.

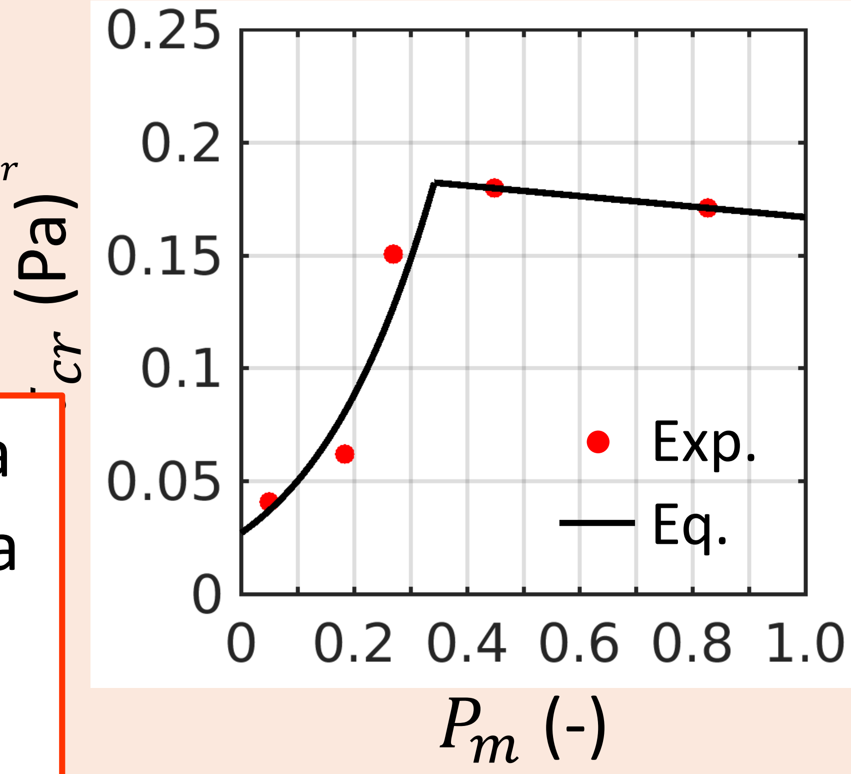
## ■ Calibration of $\tau_{cr}$ with experimental result




$$\tau_{cr} = \rho u_*^2$$

$$u_* = 0.121 \left(\frac{d_{50}}{z_{cr}}\right)^{\frac{1}{7}} u_{cr}$$

$\tau_{e,s}$ = 0.0269 Pa
$\tau_{e,m}$ = 0.1668 Pa
$P_{m,cr}$ = 0.3425
$\beta$ = 6.4845

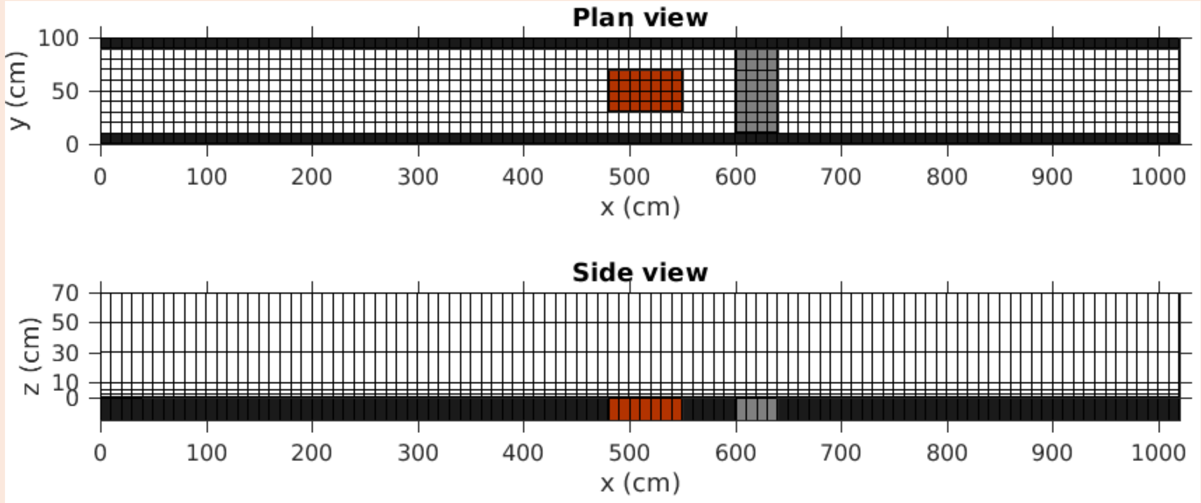



van Ledden's formulation for $\tau_{cr}$

$$\tau_{cr} \begin{cases} = \tau_{e,s}(1+P_m)^{\beta}, & if\ P_m < P_{m,cr} \\ = \dfrac{\tau_{e,s}(1+P_{m,cr})^{\beta} - \tau_{e,m}}{1-P_{m,cr}}(1-P_m) + \tau_{e,m}, & if\ P_m \geq P_{m,cr} \end{cases}$$

# ■ Numerical configuration and domain

- Erosion rate and trap rate are simulated with the present SMMT model.
- The simulated results are compared with experimental ones to validate the model.




Numerical domain

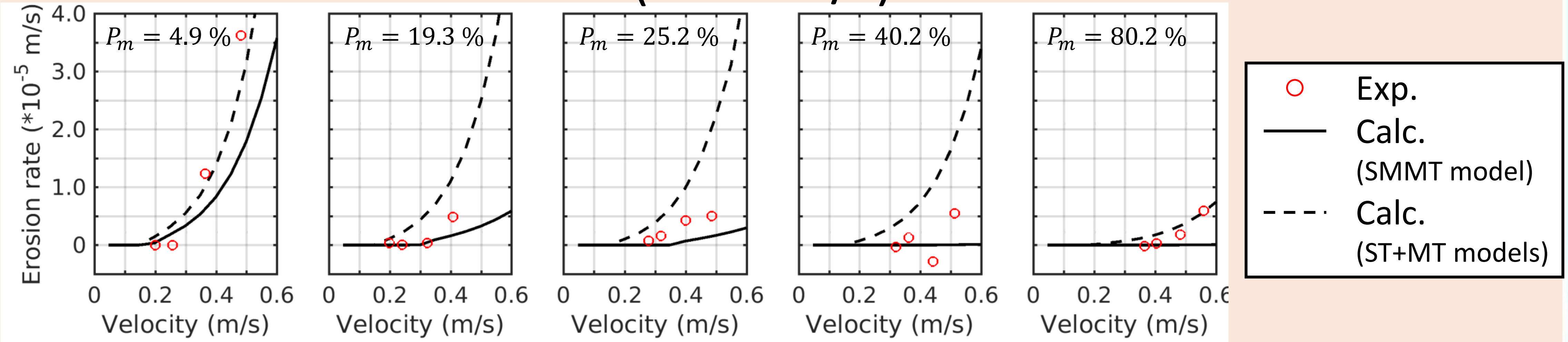
## Numerical configuration

| | | |
|---|---|---|
| Numerical domain | X | 10 m |
| | Y | 0.8 m |
| | Z | 0.7 m |
| Grid size | dx, dy | 0.1 m |
| | dz | 0.2, 0.2, 0.2, 0.05, 0.03, 0.02 m |
| Forcing condition | | Unidirectional flow |
| Mud content | $P_m$ | Experimental values |
| Median diameter for sand | $d_{50,s}$ | 250 µm |
| mud | $d_{50,m}$ | 15 µm |
| Critical mud content | $P_{m,cr}$ | 0.3425 |
| Critical shear stress for pure sand | $\tau_{e,s}$ | 0.0269 Pa |
| mud | $\tau_{e,m}$ | 0.1668 Pa |
| Dimensionless parameter | $\beta$ | 6.4875 |
| Erosion coefficient for mud | $M$ | 0.02 kg/m$^2$/min |

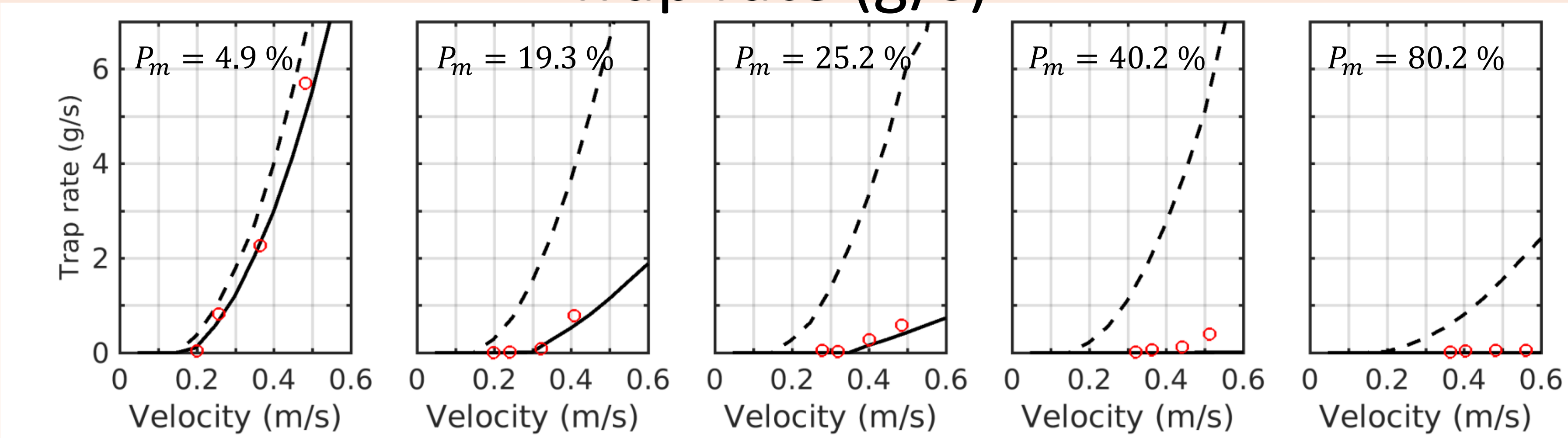
*Validation of SMMT model with flume experiments*

## ■ Simulated results

### Erosion rate (*10^-5 m/s)




### Trap rate (g/s)

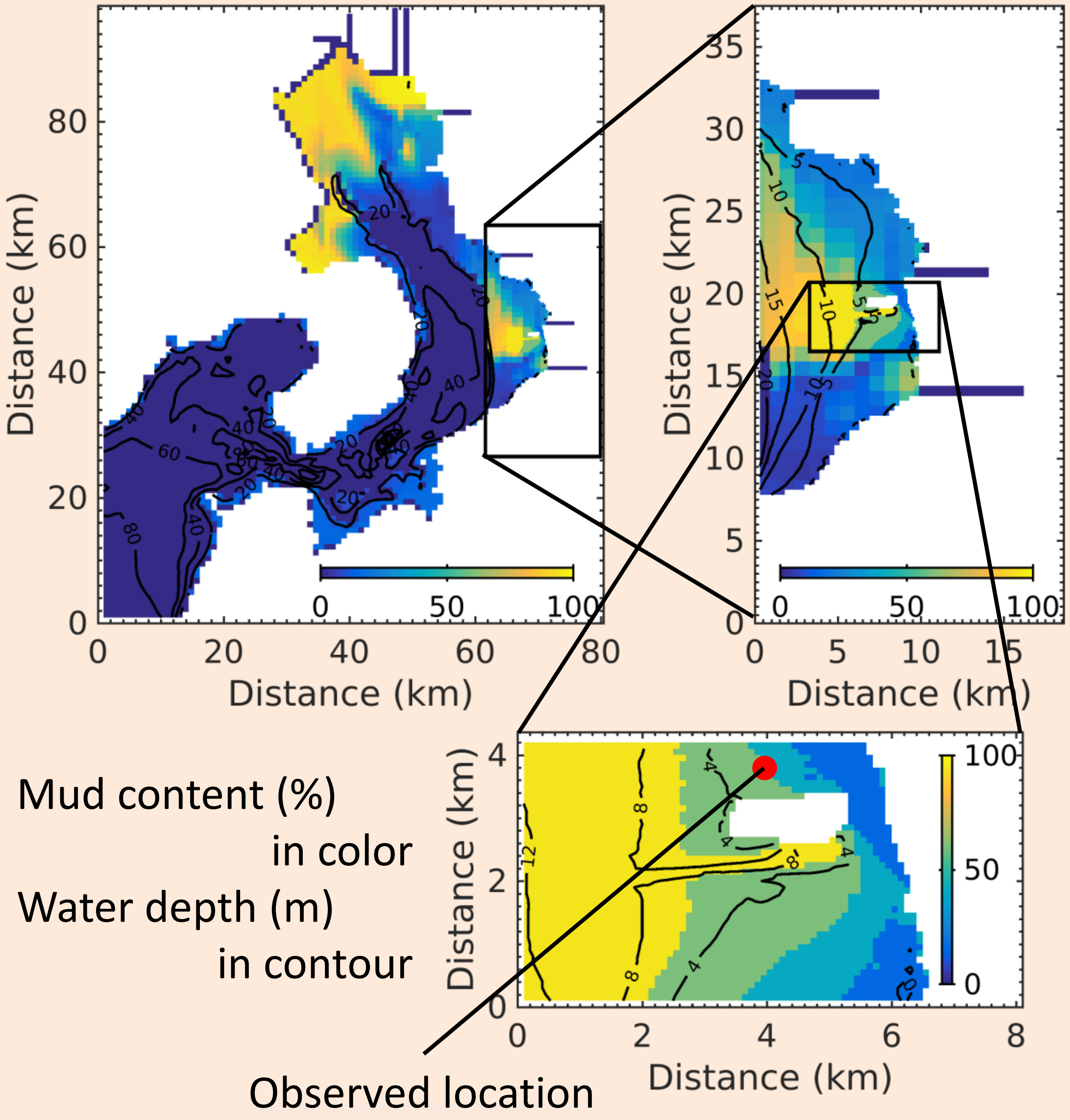


# ■ Numerical configuration and domains

- Intertidal area around Kumamoto Port are targeted, because sand-mud mixtures are formed there.

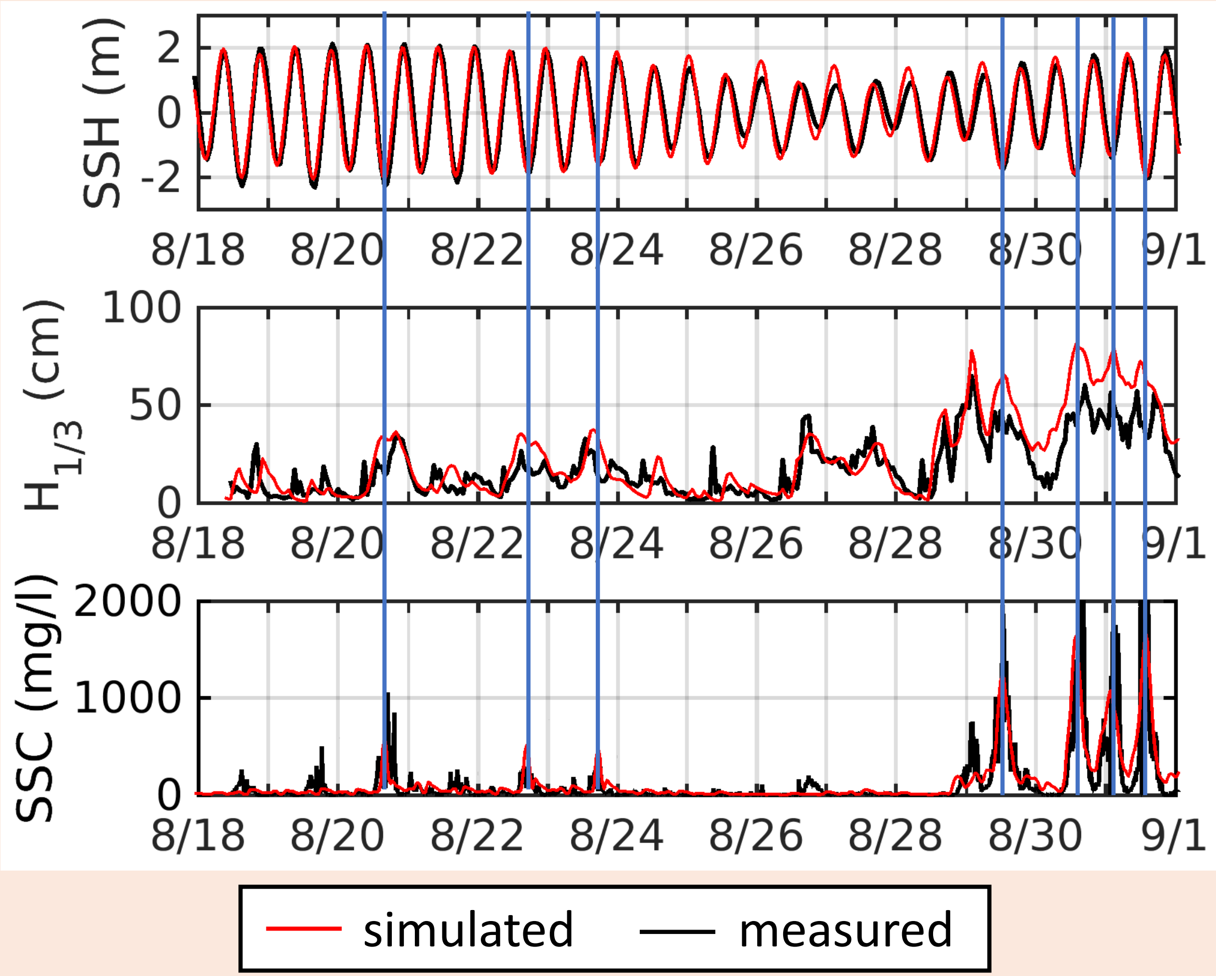
Numerical configuration

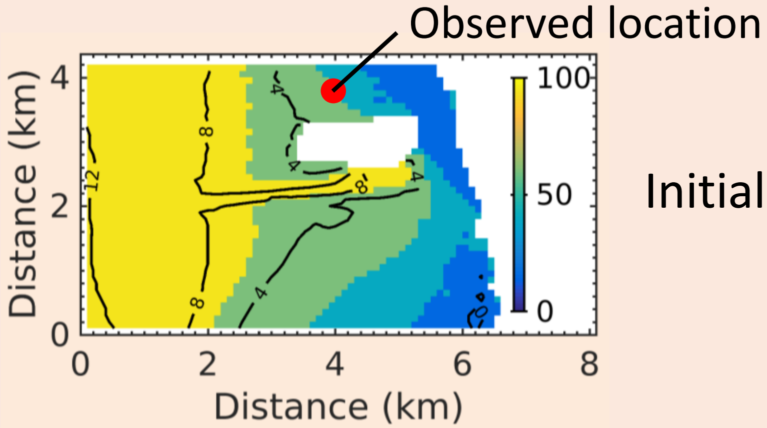
| | |
|---|---|
| Computational period | Aug.18 – Sep.1 in 2016 |
| Horizontal resolution | L1:900 m (90*100 grids)<br>L2:300 m (62*124 grids)<br>L3:100 m (79*43 grids) |
| Vertical layers | 10 level layers |
| Tides | 5 major constituents (M2, S2, K1, O1, N2) |
| Waves | Computed by SWAN |
| Other forcing factors | None |



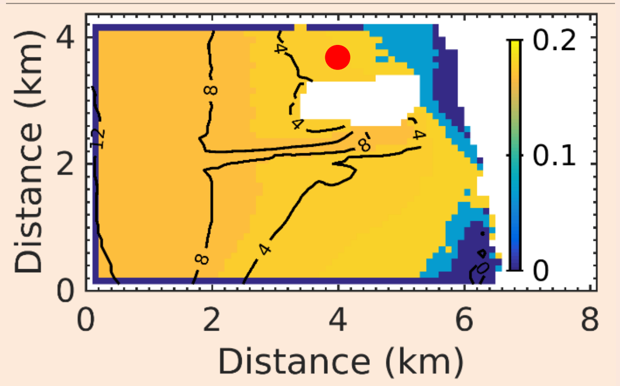
## ■ Simulated results

Simulated Tide level, Wave height, and SSC at observed location




Initial $P_m$ (%)




Initial $\tau_{cr}$ (Pa)

- The SMMT model can reproduce variation of SSC induced by combined tidal elevation and wind waves.

# Summary

- **Parameter calibration of SMMT model**
  - Increasing $\tau_{cr}$ from 5 to 45 % mud content (by 4.5 times)
  - Decreasing erosion rates from 5 to 25 % mud content
  - Parameters for $\tau_{cr}$ were obtained from experimental results.
- **Validation of SMMT model with flume experiments**
  - Good agreement with experimental results, quantitatively reproducing erosion behavior depending on mud content.
- **Numerical simulation in a field with SMMT model**
  - The present model can reproduce variation of SSC induced by combined tidal elevation and wind waves.