A development of two-way coupling model between wave overtopping-induced surface flow and backflow of sewer systems in coastal cities

Junbeom Jo

Sooyoul Kim, Nobuhito Mori

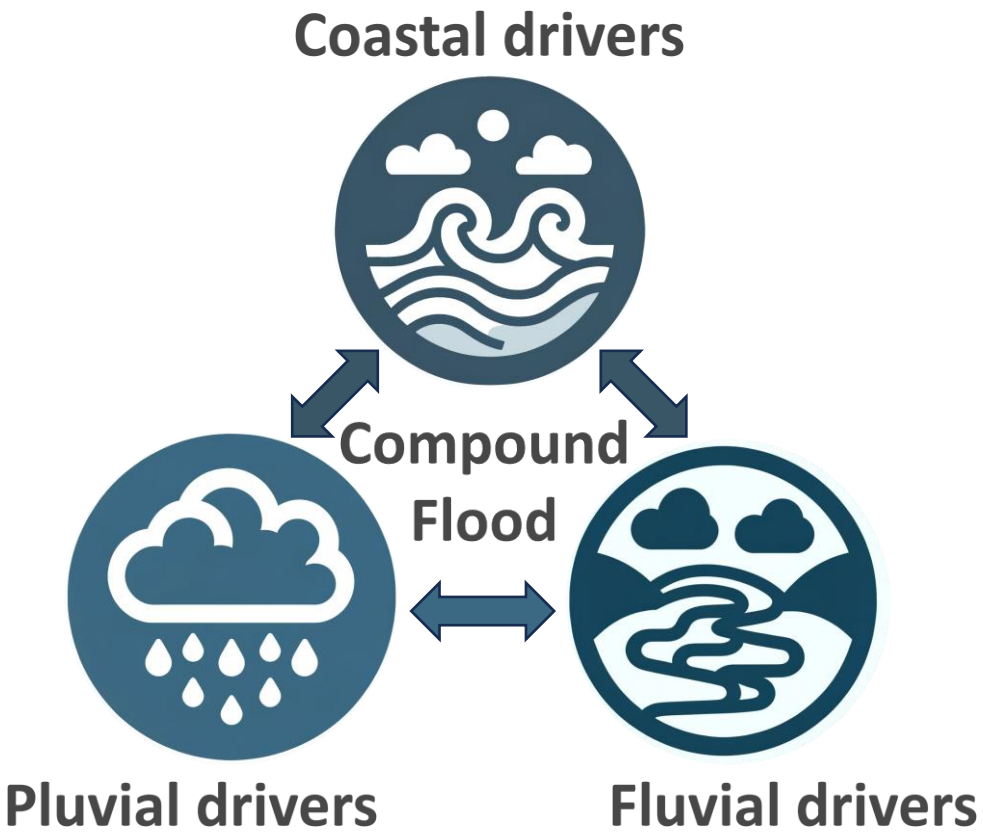
Coastal Disaster Risk Research Laboratory

Disaster Prevention Research Institute

KYOTO UNIVERSITY

京都大学

Why Do We Need Fully Coupled Models for Flood Simulation?



Coastal Urban Flooding is driven by complex interaction.

✗ **Conventional (One-way) Models:**

- Ignore feedback effects among flood drivers and oversimplify real dynamics

✓ **Fully Coupled (Two-way) Models:**

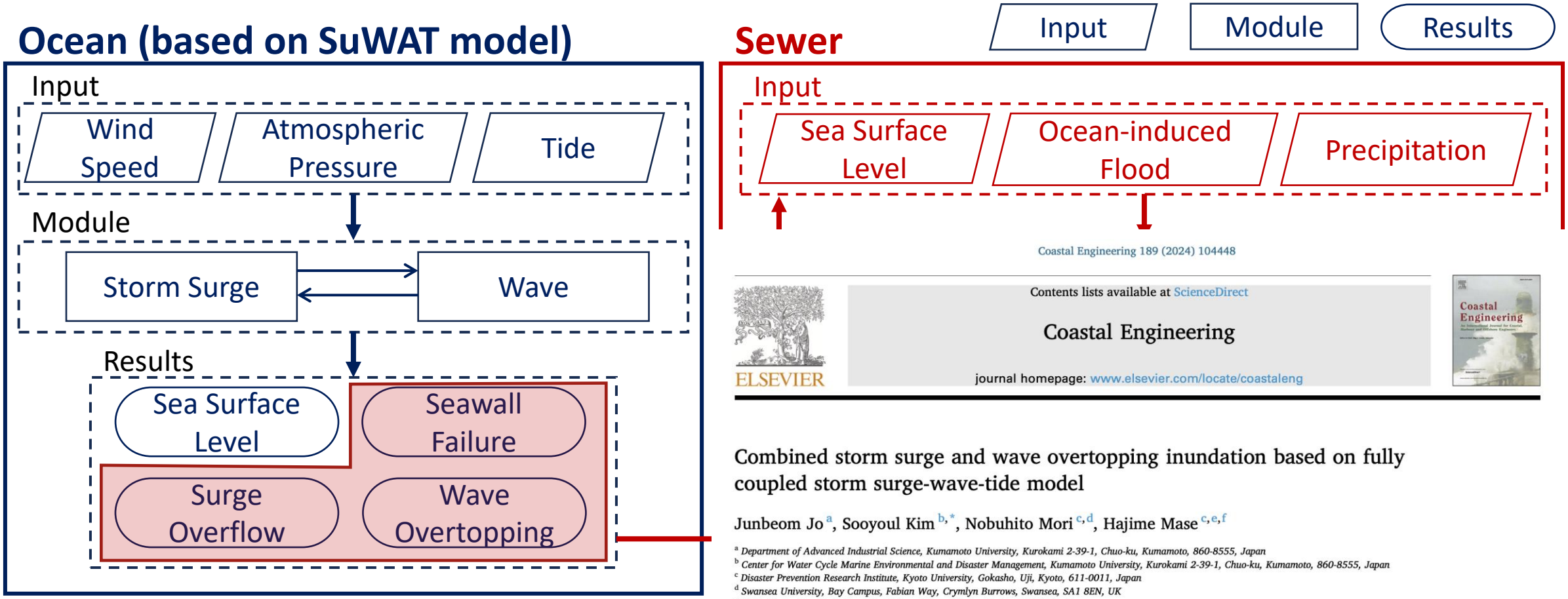
- Capture bidirectional interactions between Coastal-Pluvial-Fluvial drivers

What Happens Without Coupling?

- Can lead to both over- and underestimation of compound flood risk

One-way models cannot account for real flood dynamics.

Flowchart for Fully Coupled Flood Model



Coastal Engineering 189 (2024) 104448

Contents lists available at ScienceDirect

Coastal Engineering

journal homepage: www.elsevier.com/locate/coastaleng

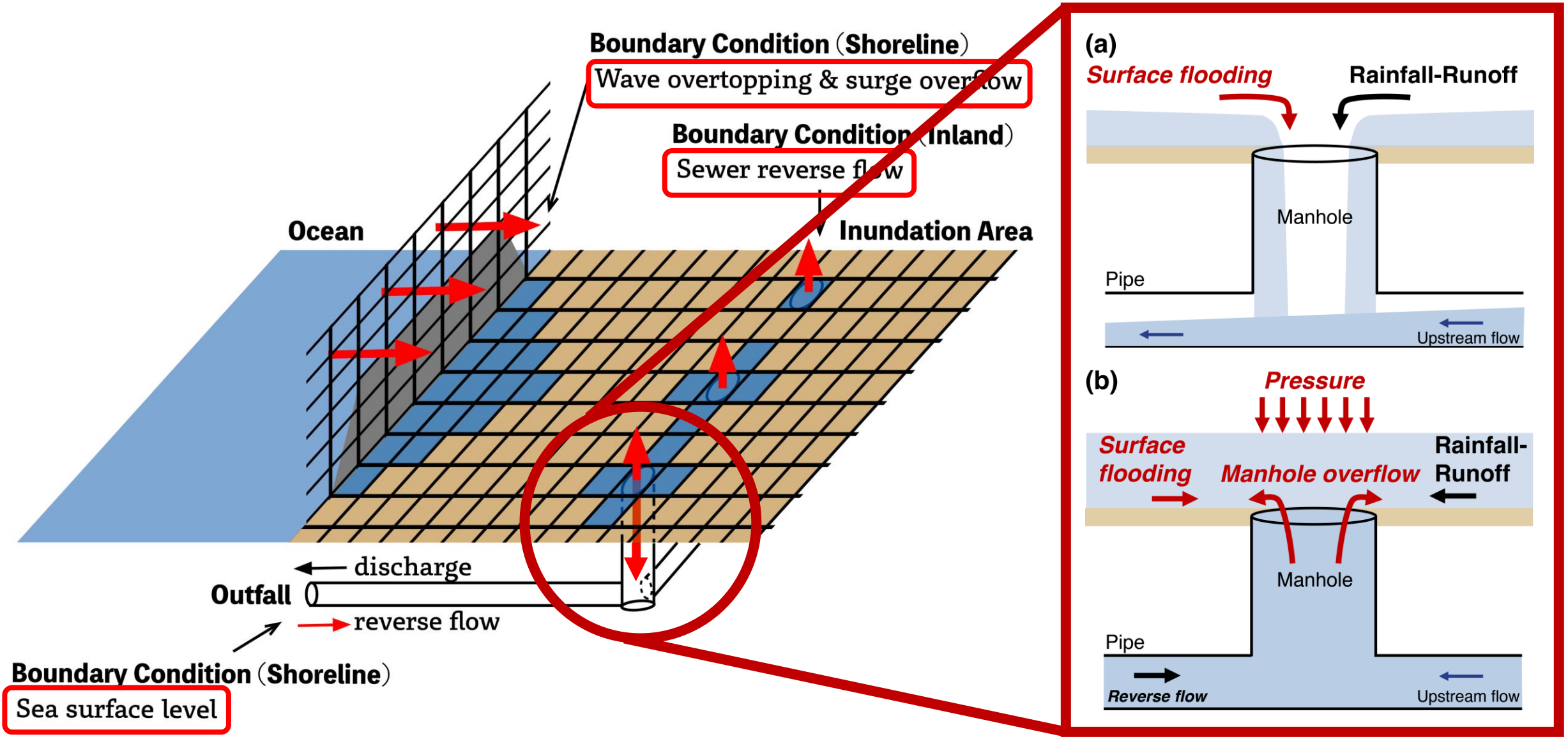
Combined storm surge and wave overtopping inundation based on fully coupled storm surge-wave-tide model

Junbeom Jo [a], Sooyoul Kim [b,*], Nobuhito Mori [c,d], Hajime Mase [c,e,f]

[a] Department of Advanced Industrial Science, Kumamoto University, Kurokami 2-39-1, Chuo-ku, Kumamoto, 860-8555, Japan
[b] Center for Water Cycle Marine Environmental and Disaster Management, Kumamoto University, Kurokami 2-39-1, Chuo-ku, Kumamoto, 860-8555, Japan
[c] Disaster Prevention Research Institute, Kyoto University, Gokasho, Uji, Kyoto, 611-0011, Japan
[d] Swansea University, Bay Campus, Fabian Way, Crymlyn Burrows, Swansea, SA1 8EN, UK
[e] Hydro Technology Inst., Co., Ltd., Nakanoshima, Kita-ku, Osaka, 530-6126, Japan
[f] Toa Corporation, 3-7-1, Nishi-shinjuku, Shinjuku-ku, Tokyo, 163-1031, Japan

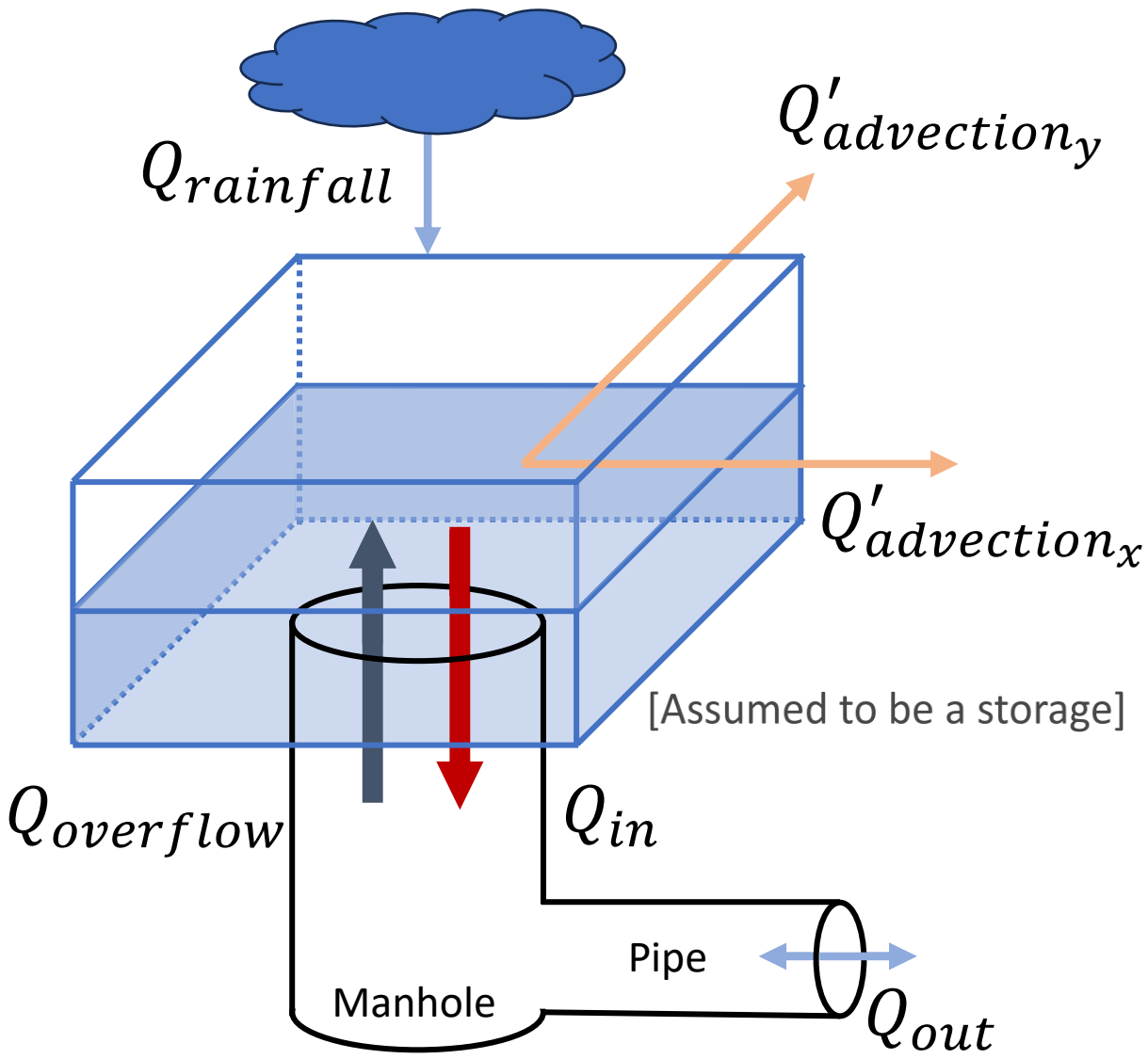
- The fully coupled model was developed based on the **Ocean-induced flood model**.
- **Sewer flow module** was integrated for dynamic data exchange at each time step.

Framework of Fully Coupled Flood Model



京都大学

Schematic Diagram for Flow Exchange



- Continuity equation (1D)

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0$$

t : time
A : cross-sectional area
Q : flow rate
H : hydraulic head
S_f : friction slope
h_L : local energy loss

- Momentum equation (1D)

$$\frac{\partial Q}{\partial t} + \frac{\partial (Q^2/A)}{\partial x} + gA\frac{\partial H}{\partial x} + gAS_f + gAh_{\mathrm{L}} = 0$$

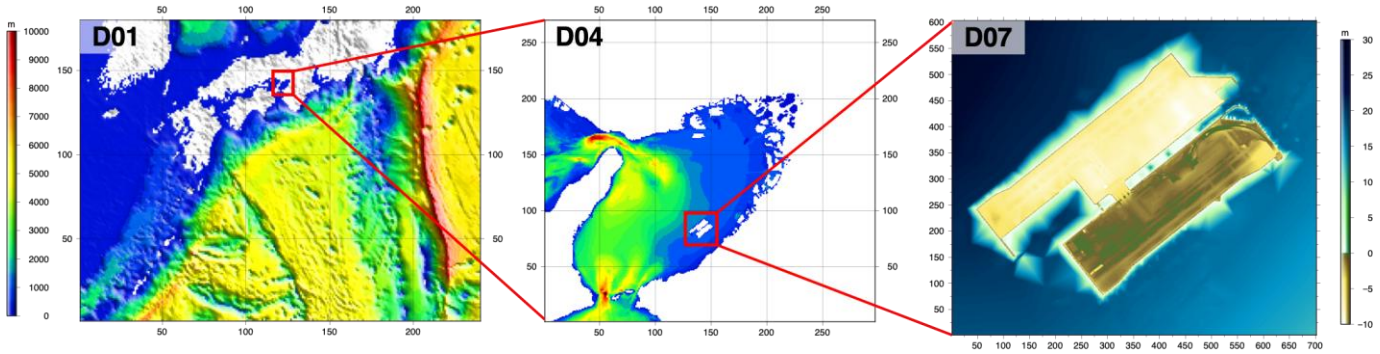
- Flow rate change in the sewer system (1D-2D)

$$\Delta \boldsymbol{Q} = Q_{overflow} + \boldsymbol{Q_{inflow}} + Q_{pipe}$$

$$\boldsymbol{Q_{inflow}} = Q_{rainfall} + \boldsymbol{Q'_{advection_x}} + \boldsymbol{Q'_{advection_y}}$$

Flow exchange **from 1D to 2D**
Flow exchange **from 2D to 1D**
Flow in **1D**
Flow in **2D**

Study Area and Bathymetry: Kansai Airport, Japan



< Bathymetry for Grid refinement >

Flood drivers (by TC Jebi(2018)):

- Wave overtopping of seawalls
- Localized seawall failure
- Sewer-induced reverse flow of seawater and rainwater

Domain	Grid Size	Refinement Ratio
D01	7200 m	-
D02	2400 m	1:3
D03	810 m	≈ 1:3
D04	270 m	1:3
D05	90 m	1:3
D06	30 m	1:3
D07	10 m	1:3

Time step determination (CFL condition)

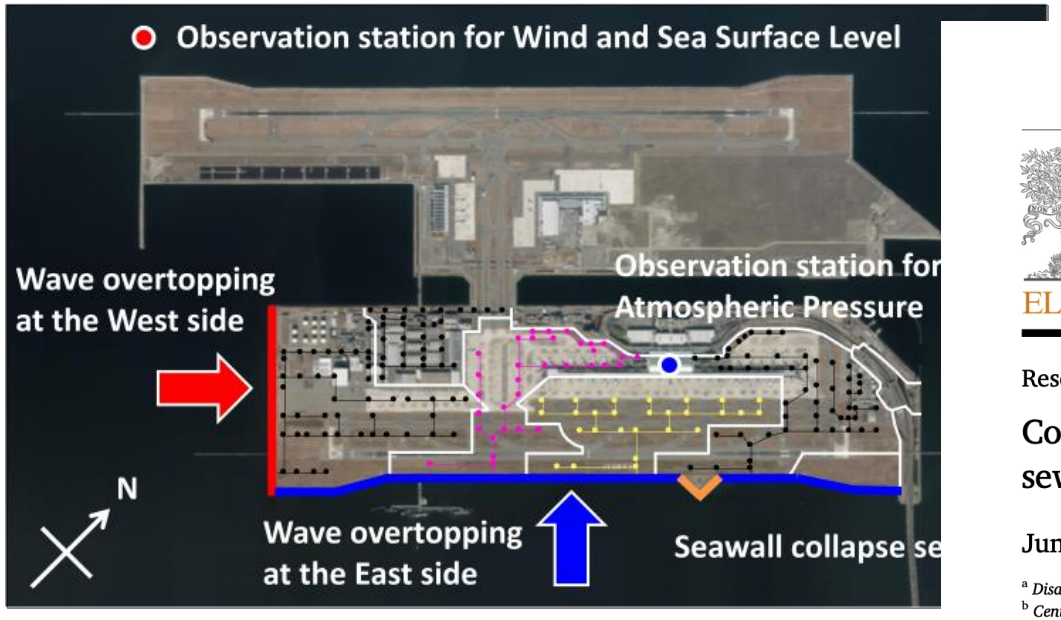
$$\mathrm{CFL} = u_x \frac{\Delta t}{\Delta x} \leq C_{max}$$

$C_{max} = 1$
u_x : the velocity ($= \sqrt{2gh_x}$)
Δt : the time step
Δx : the grid size

0.4 s was determined.

京都大学

Study Area and Bathymetry: Kansai Airport, Japan



Flood drivers (by TC Jebi(2018)):

- Wave overtopping of seawalls
- Localized seawall failure
- Sewer-induced reverse flow of seawater and rainwater

Journal of Hydrology 661 (2025) 133698

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Research papers

Coastal and pluvial compound flooding of surge, wave, tide, rainfall-runoff, sewer flow, and seawall failure at coastal urban areas

Junbeom Jo [a,*], Sooyoul Kim [b], Jungsoo Kim [c], Nobuhito Mori [a,d,e]

[a] Disaster Prevention Research Institute, Kyoto University, Gokasho, Uji, Kyoto 611-0011, Japan
[b] Center for Water Cycle Marine Environmental and Disaster Management, Kumamoto University, Kurokami 2-39-1, Chuo-ku, Kumamoto 860-8555, Japan
[c] Department of Civil Engineering, Bucheon University, Bucheon 14623, South Korea
[d] Typhoon Science Technology Research Center, Yokohama National University, Yokohama 240-0067, Japan
[e] School of Engineering, Swansea University, Swansea SA1 8EN, UK

ARTICLE INFO

This manuscript was handled by Y. Huang, Editor-in-Chief, with the assistance of Jing-Cheng Han, Associate Editor

Keywords:
Surge-wave-tide interaction
Sewer system reverse flow
Surface rainfall-runoff
Multi-hazard assessment
Compound flooding

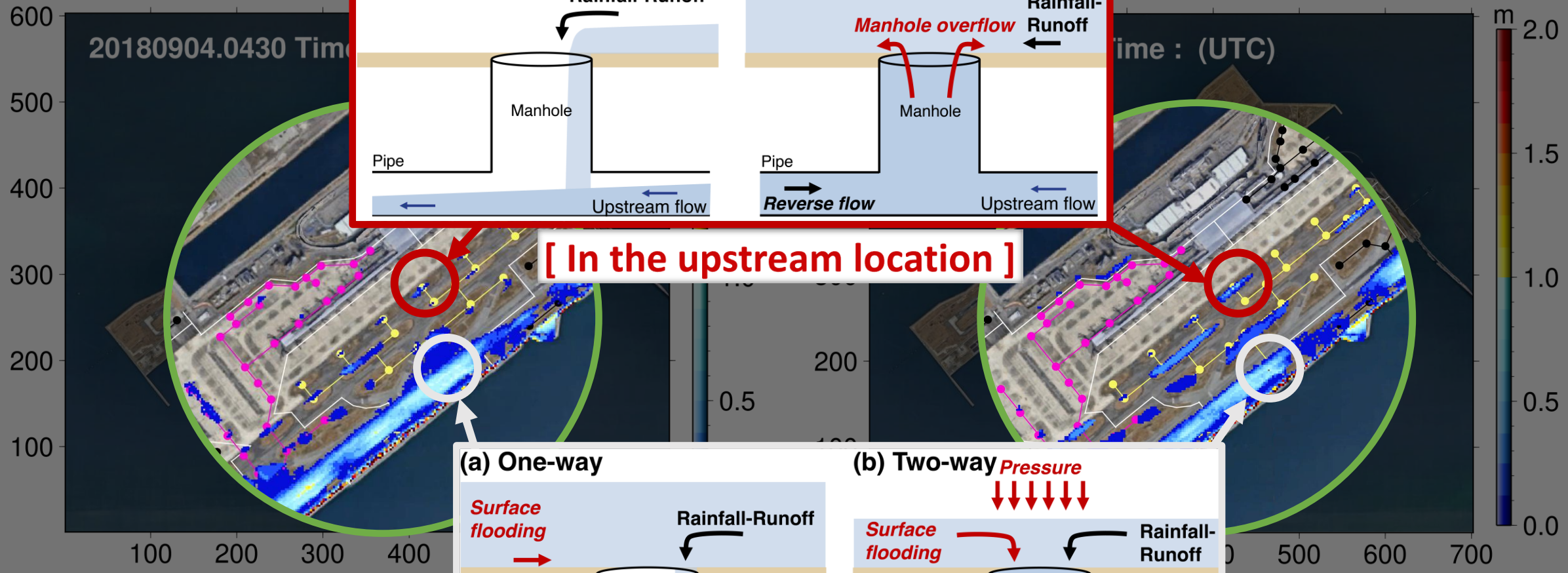
ABSTRACT

This study examines the compound storm surge, storm surge and sewage flooding at Kansai International Airport during Typhoon Jebi in 2018 using the SuWAT model, which integrates storm surge, tides, waves, wave over-topping, and pluvial processes. The findings for Typhoon Jebi case indicate that wave overtopping was the primary contributor to the flooding, accounting for 90.8% of the total flood volume, followed by seawall failure (7.5%) and sewer reverse flows (1.7% and 0.26% from seawater and rainwater, respectively). The multi-process coupled model demonstrated greater accuracy in flood depth estimations compared to a simple summation of individual components, underscoring the significance of accounting for interactions among flood drivers. The study highlights the need for integrating multiple flood mechanisms to improve hazard assessment in coastal urban areas. It suggests future enhancements, such as two-way coupling between surface inundation and sewer dynamics, to understand complex flooding processes further and develop better disaster hazard reduction strategies.

Reproducing Jebi-induced compound flooding using one-way coupling model

京都大学

Effect of Two rn and Timing



(a) One-way
Rainfall-Runoff
Manhole
Pipe
Upstream flow

(b) Two-way *Pressure*
Rainfall-Runoff
Manhole overflow
Manhole
Pipe
Reverse flow
Upstream flow

[In the upstream location]

(a) One-way
Surface flooding
Rainfall-Runoff
Manhole
Pipe
To downstream
Upstream flow

(b) Two-way *Pressure*
Surface flooding
Rainfall-Runoff
Manhole
Pipe
To downstream
Upstream flow

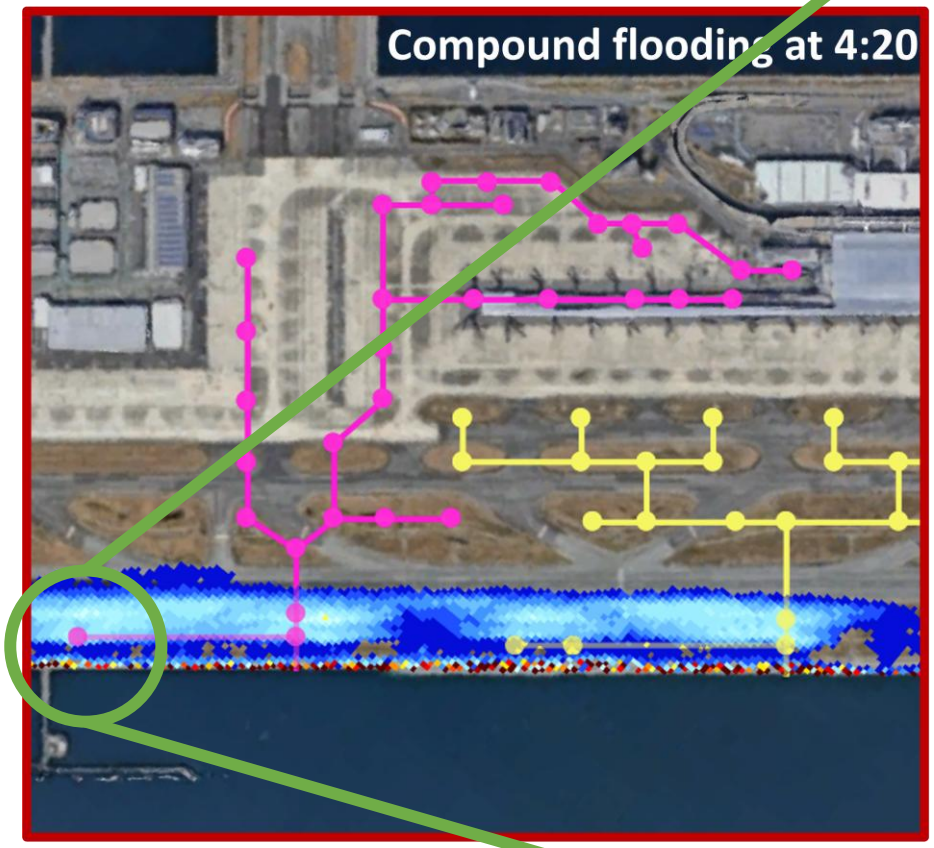
[In the downstream location]

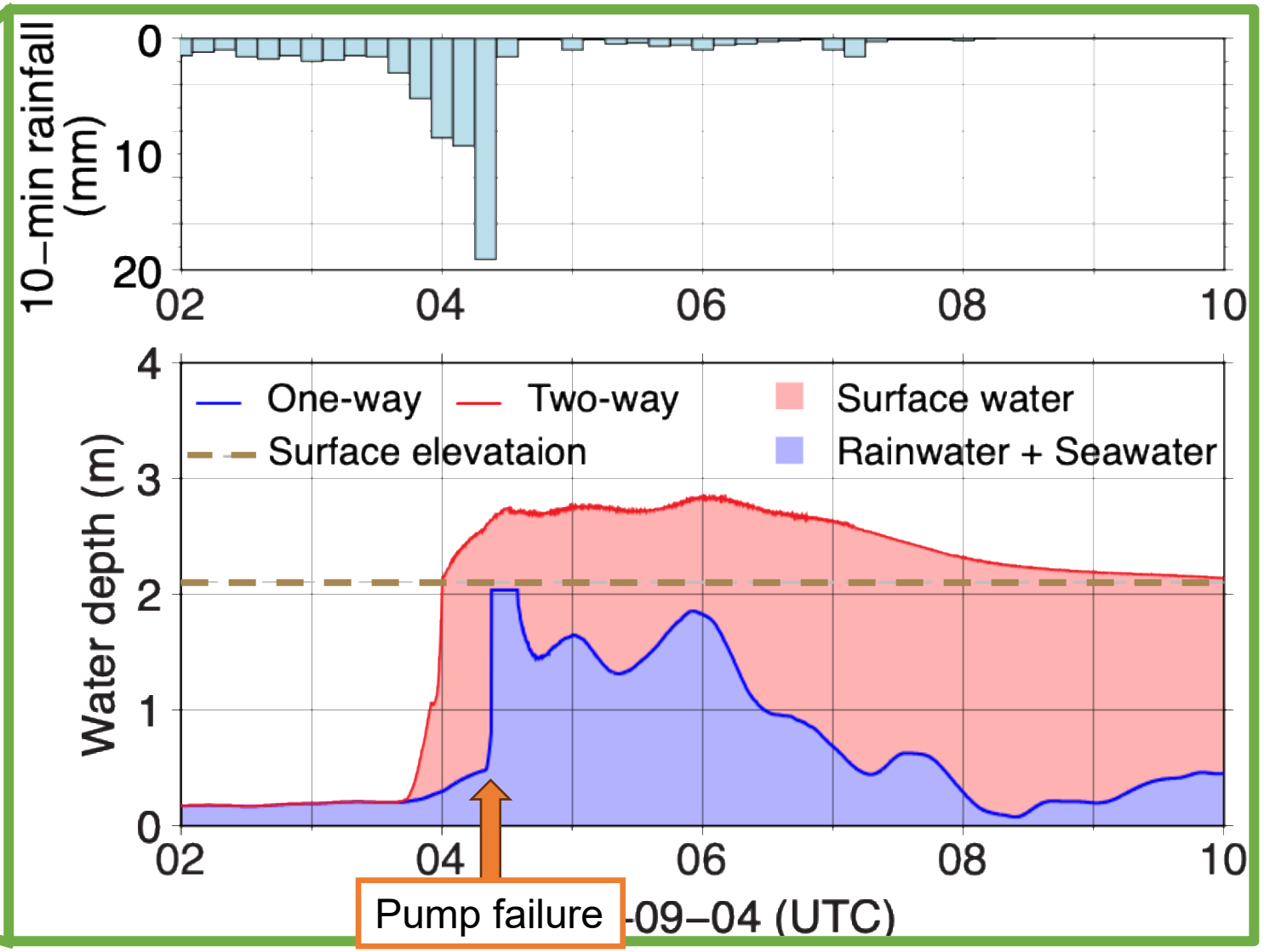
< One-way coupli upling case >

- The coupling method nd timing.
- These impacts were d eas.

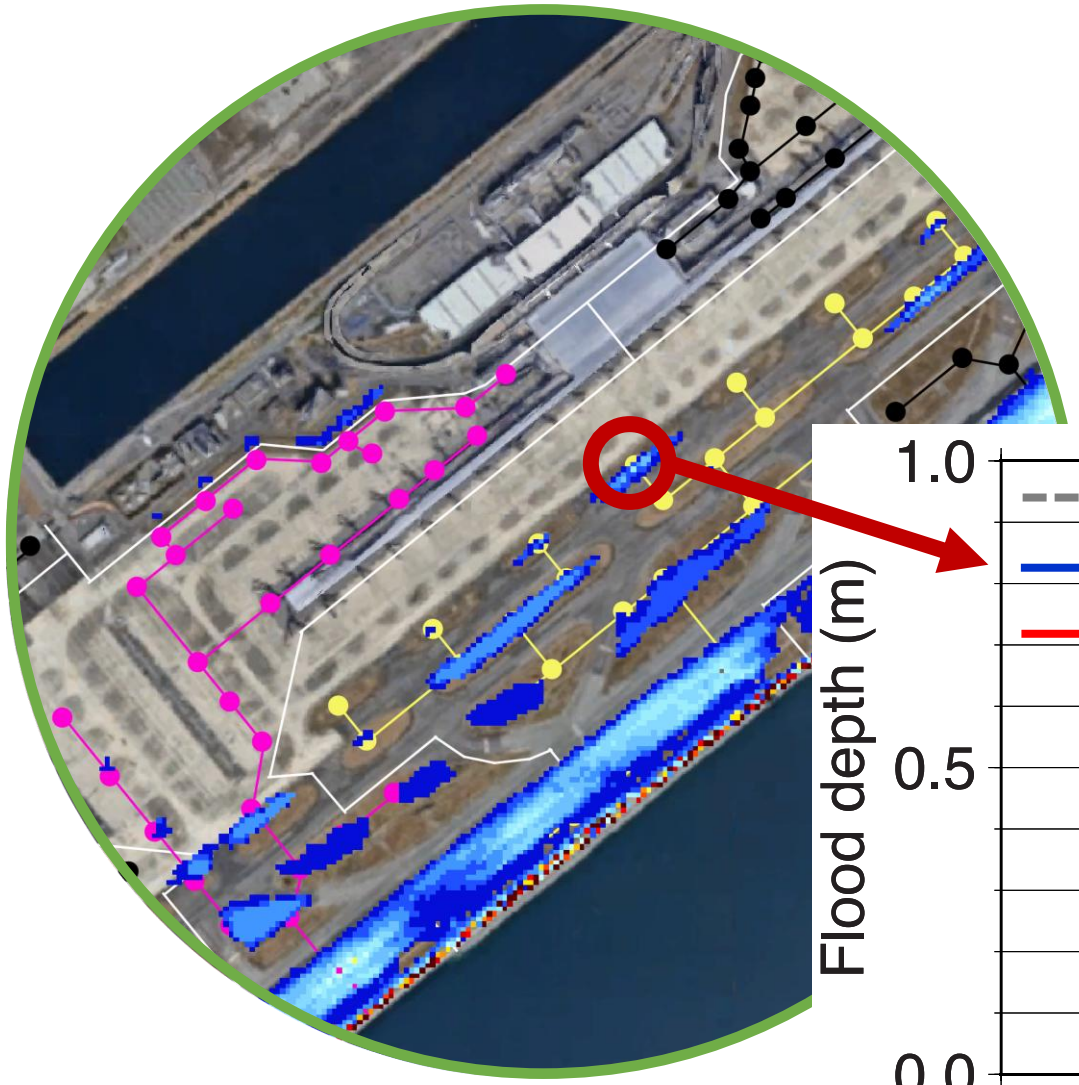
京都大学

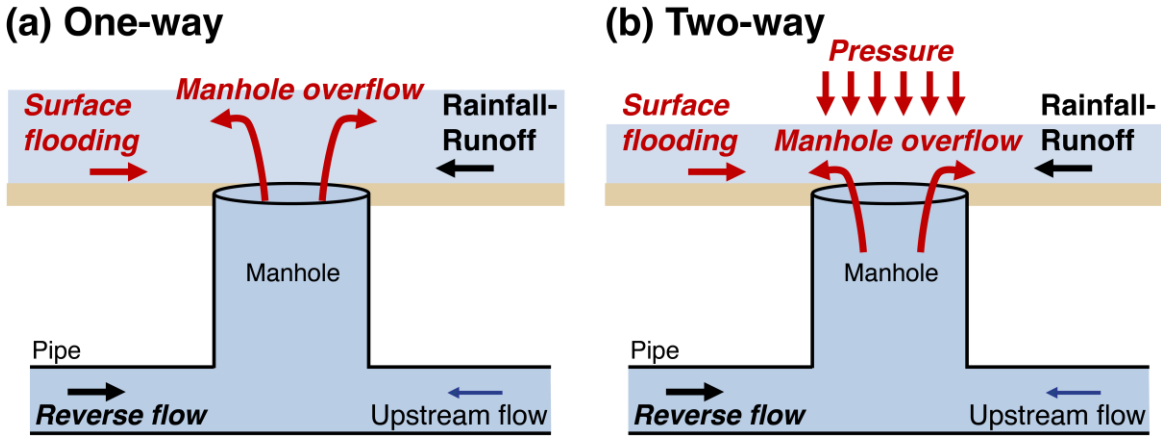
Effect of Two-way Coupling on **Manhole Water Depth**

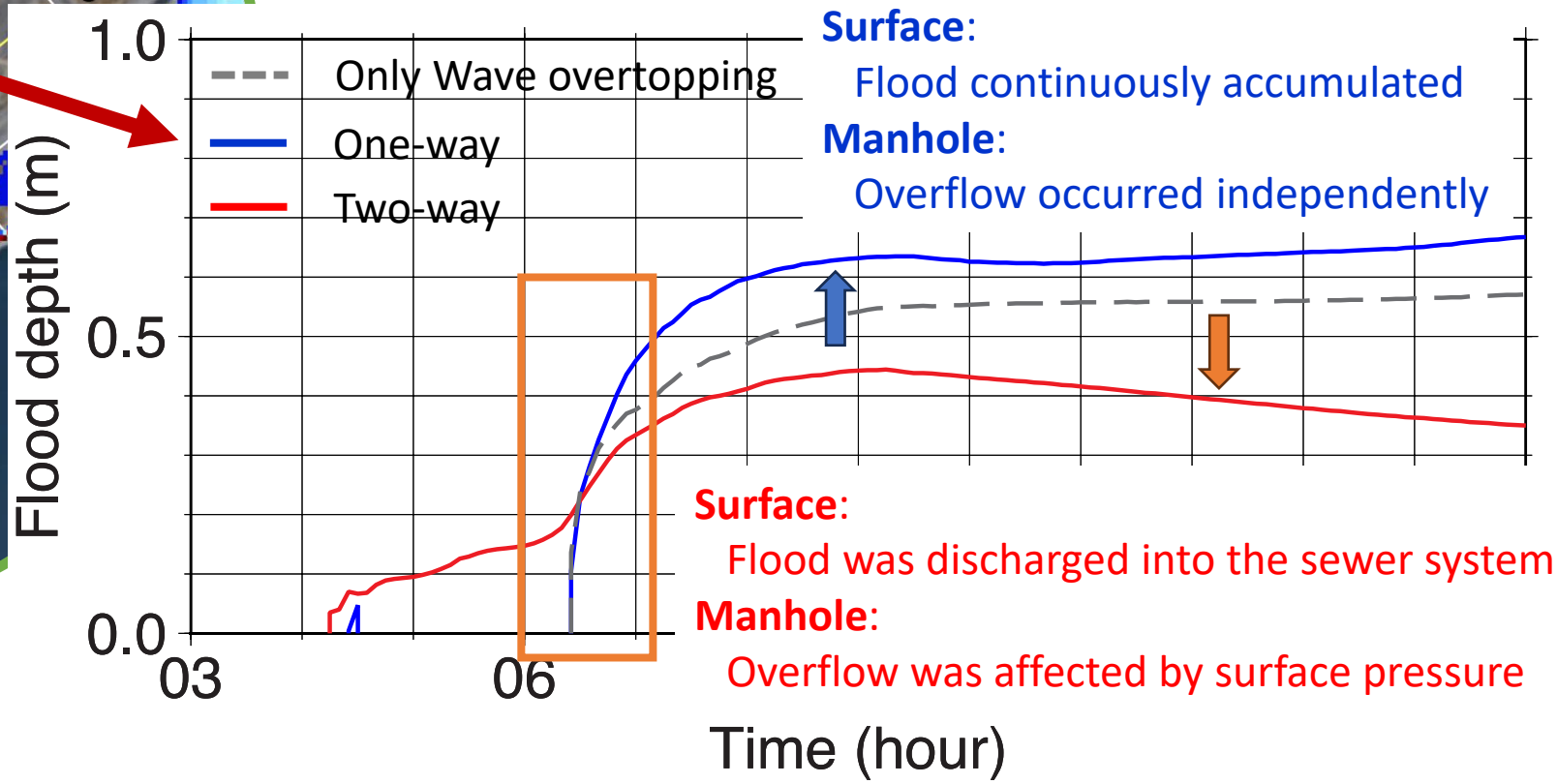




Effect of Two-way Coupling on **Surface Flood Depth**







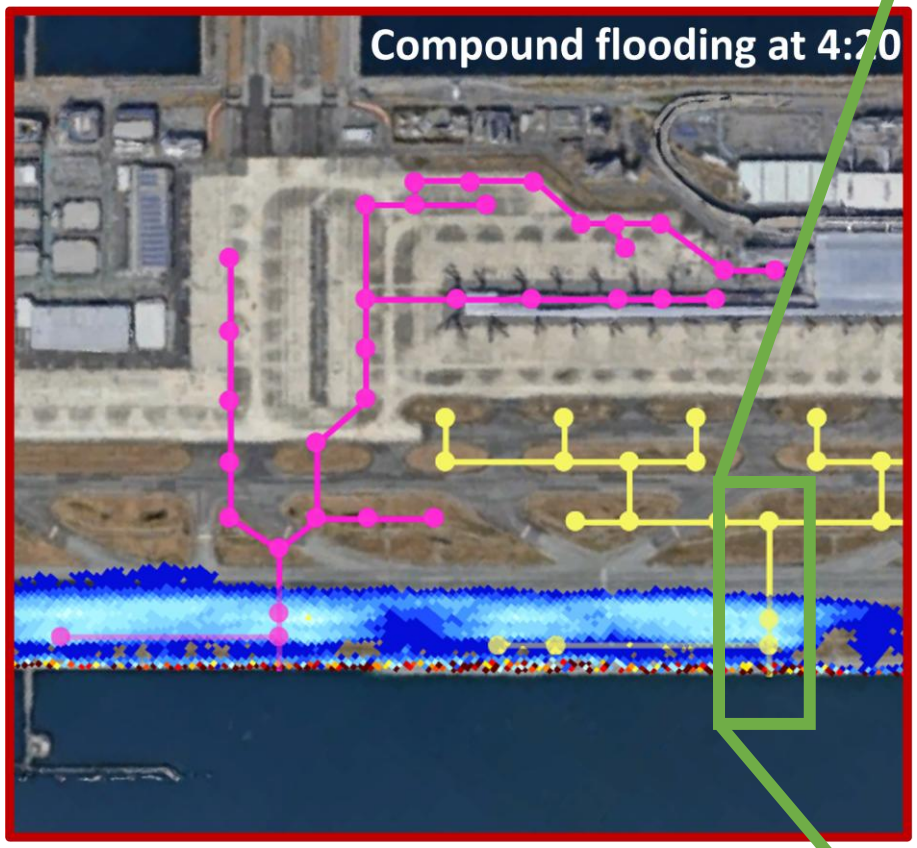
Surface:
Flood continuously accumulated

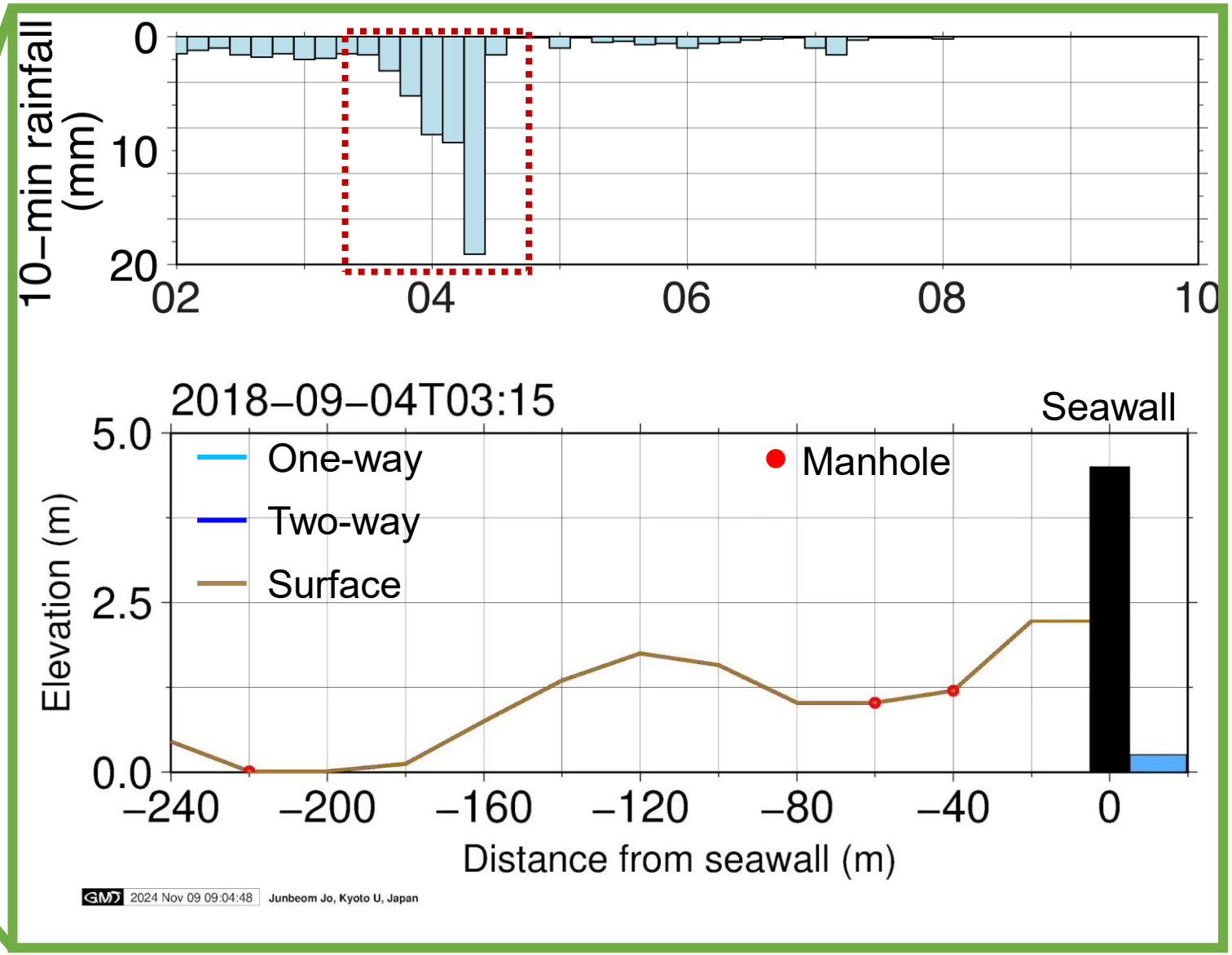
Manhole:
Overflow occurred independently

Surface:
Flood was discharged into the sewer system

Manhole:
Overflow was affected by surface pressure

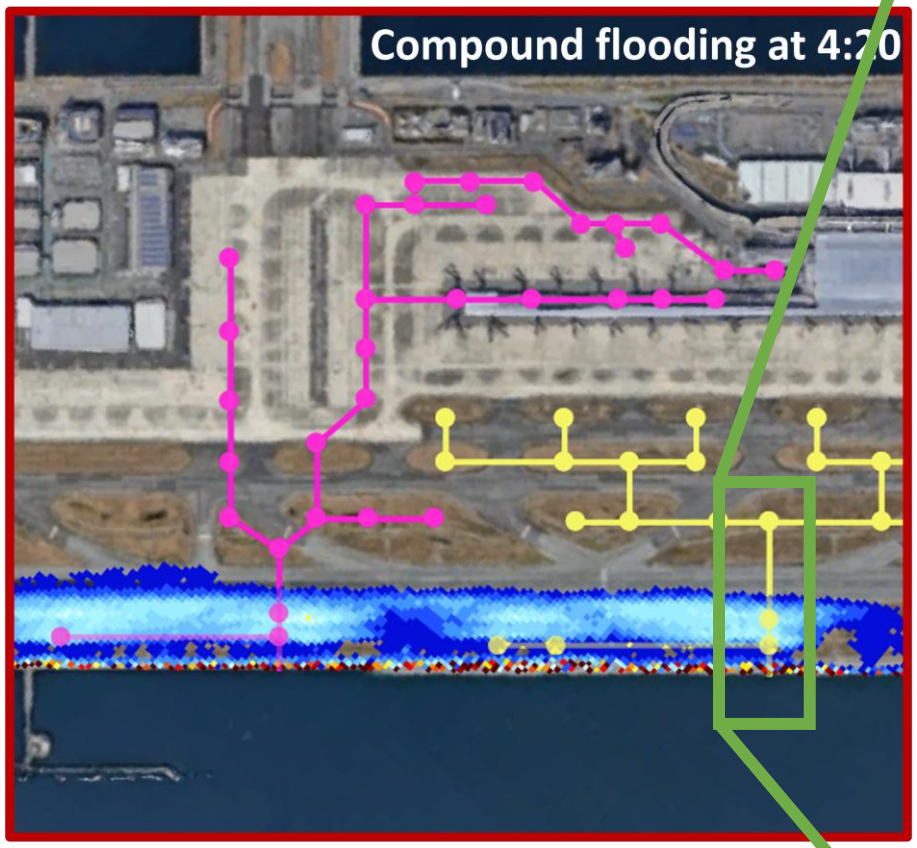
Flood Depth Variation Along Profile Line: **Start of Flooding**

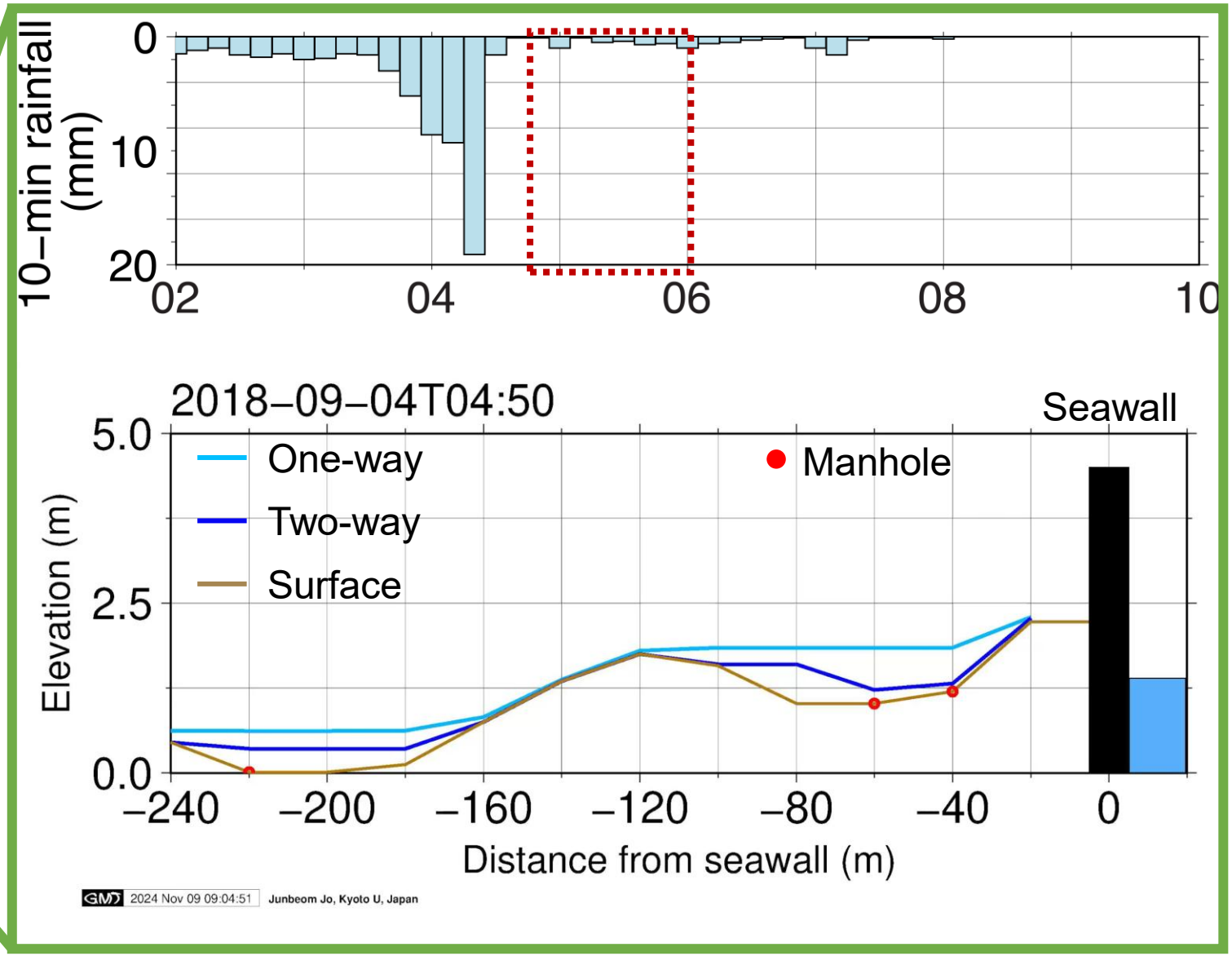




京都大学

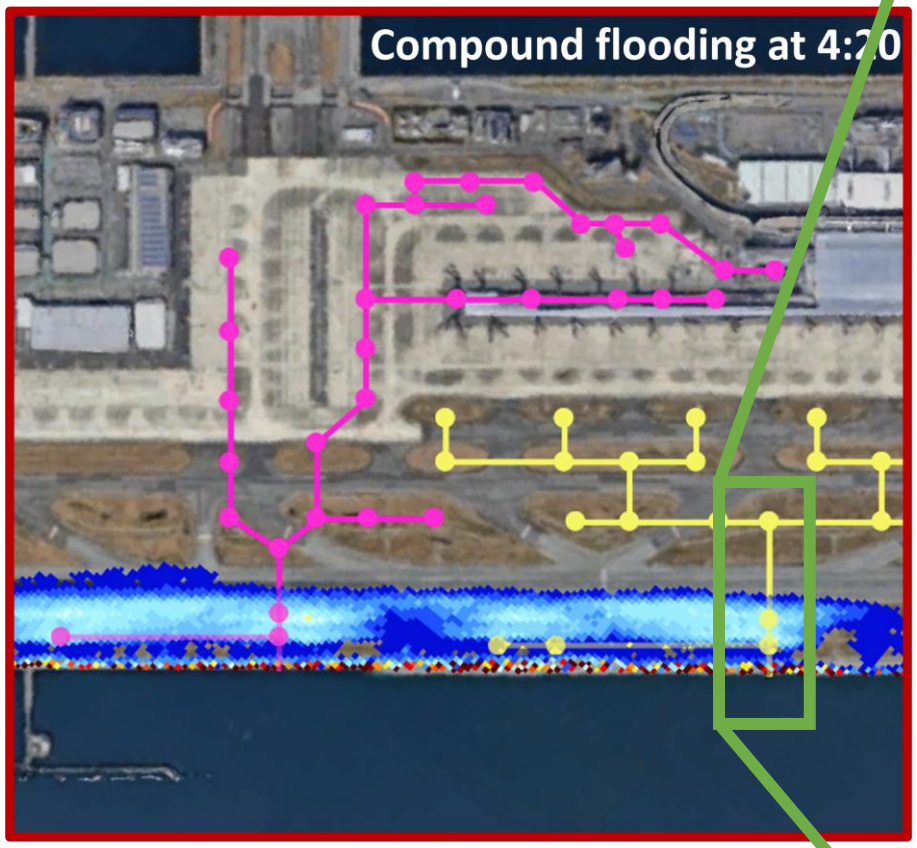
Flood Depth Variation Along Profile Line: **Peak of Flooding**

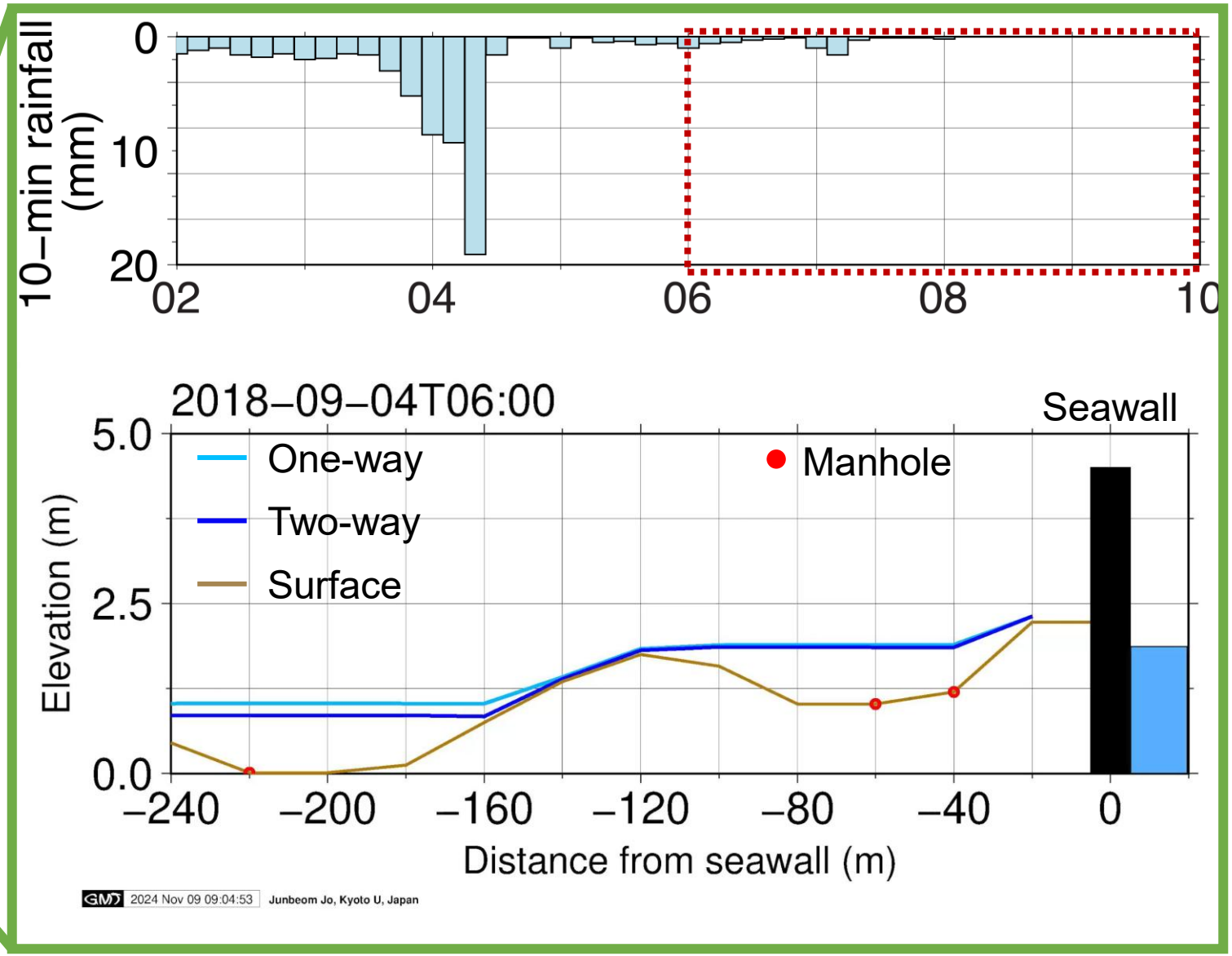




京都大学

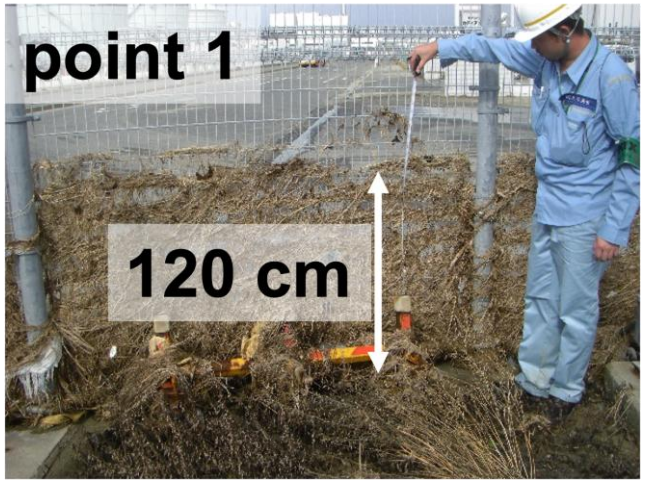
Flood Depth Variation Along Profile Line: **End of Flooding**



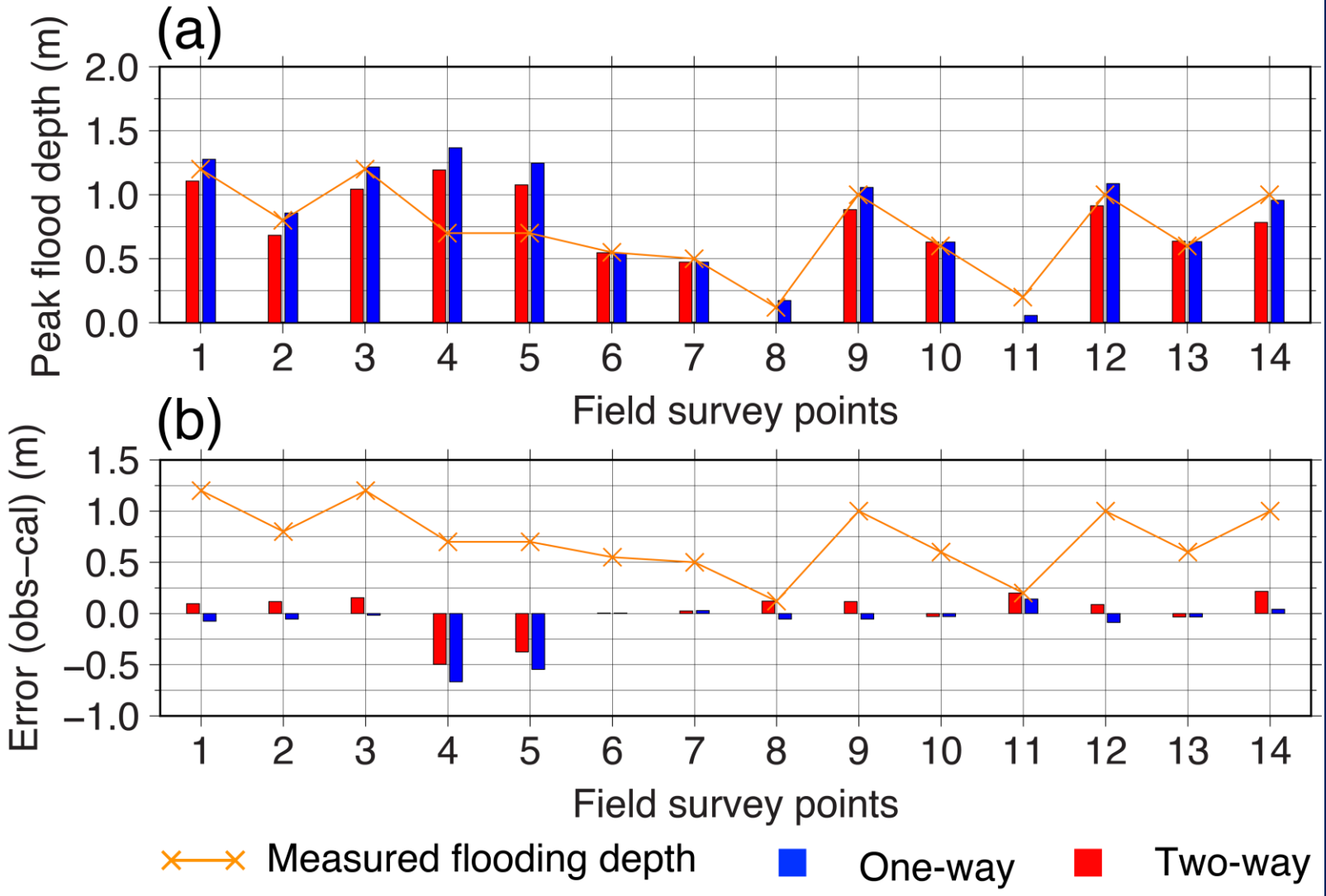


Peak Flood Depth Compared with Field Survey

< Location of field survey points >



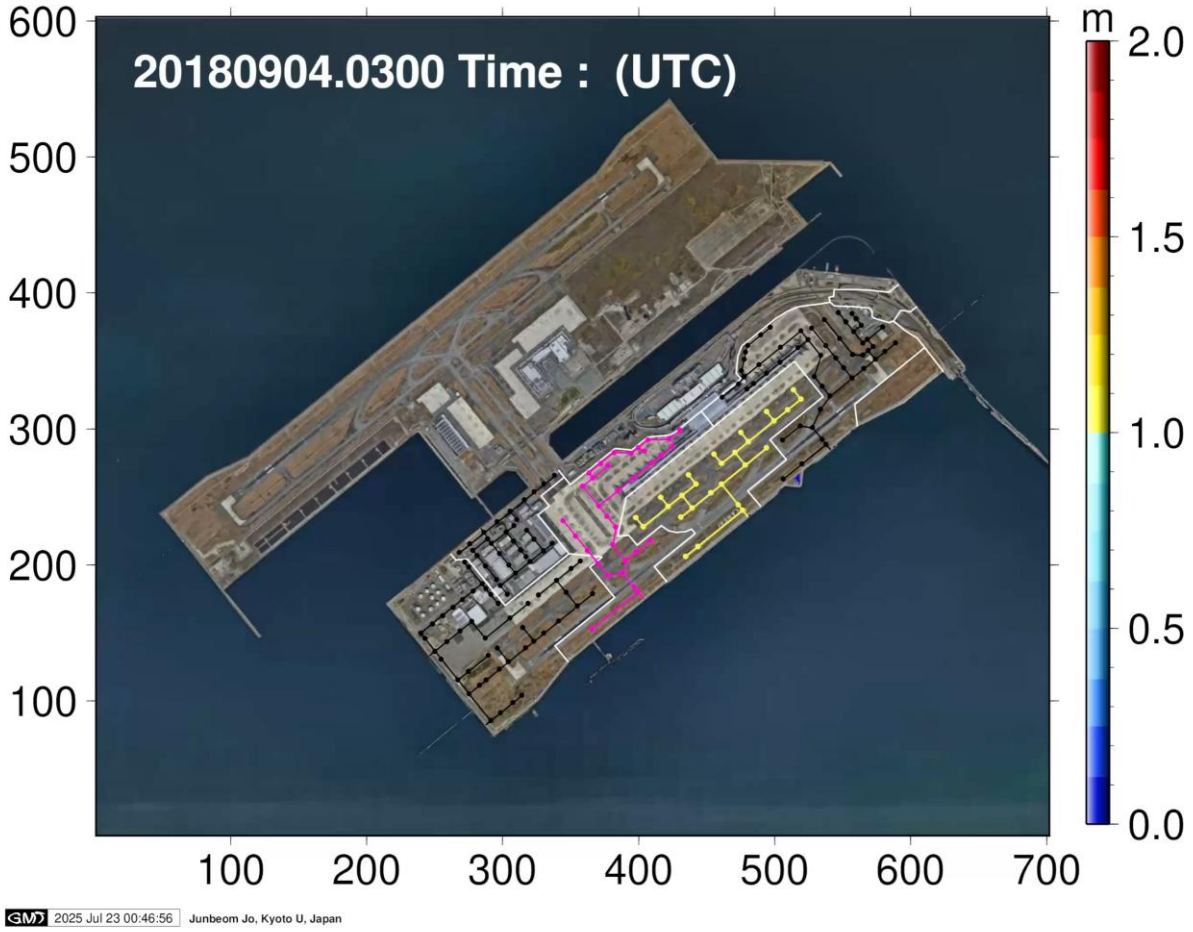
< Field survey overview >



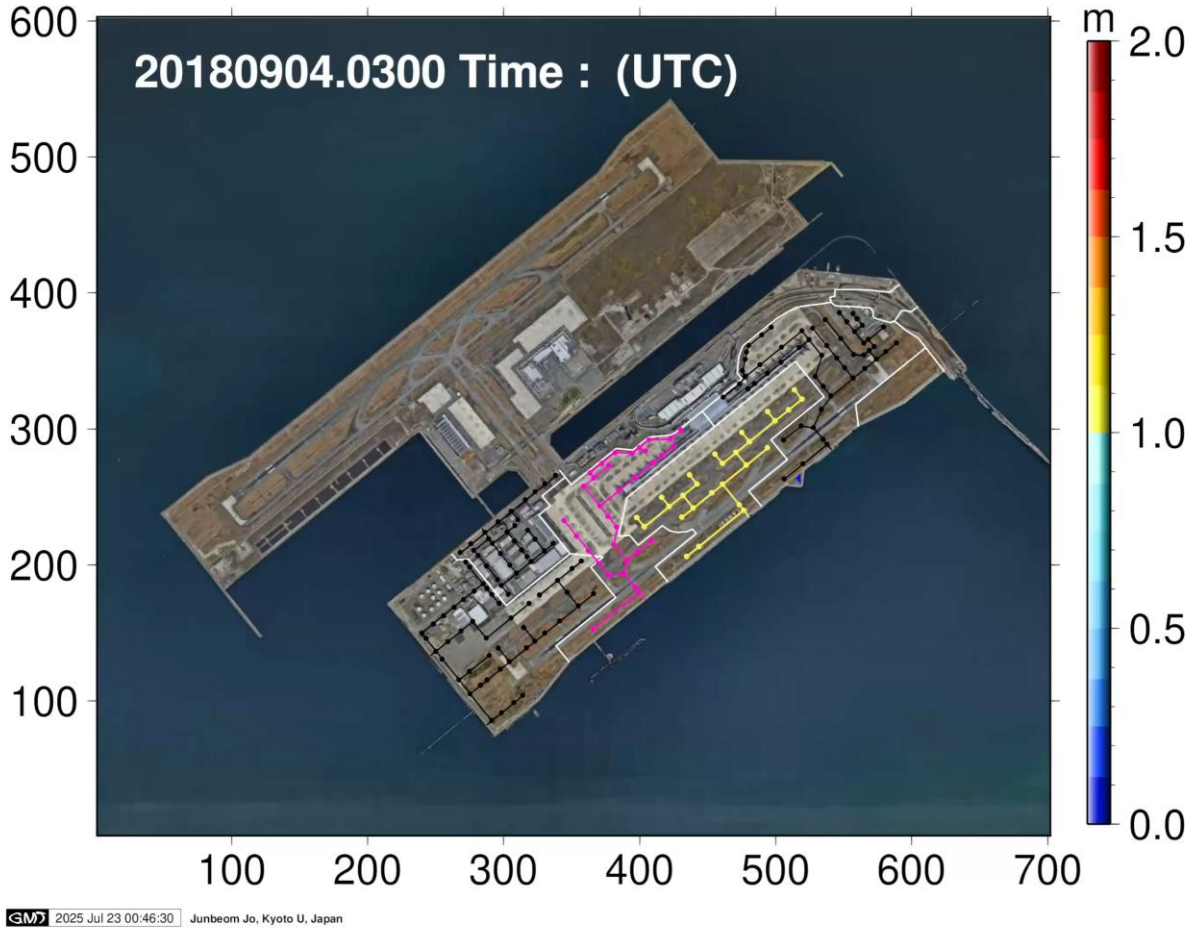
京都大学

One-Way vs **Two-Way** Flood Simulation

- Simulations based on identical forcing conditions – only the coupling differs.



< One-way coupling case >



< Two-way coupling case >

Conclusion

- The fully coupled flood model incorporating surface, ocean, and sewer systems was developed based on SuWAT model.
- The implementation of two-way coupling revealed complex flood dynamics, including:
  - ✓ Changes in the timing of flood
  - ✓ Redistribution of flood extent
  - ✓ Sewer reverse flow mechanisms
  - ✓ Drainage differences after the flood
- These results demonstrate the potential applicability of the proposed model for assessment of compound flood risk in coastal urban area.

Thank you for your attention

Junbeom Jo, Ph.D.

Postdoctoral Researcher

Email: jo.junbeom.56i@st.kyoto-u.ac.jp

KYOTO UNIVERSITY

京都大学