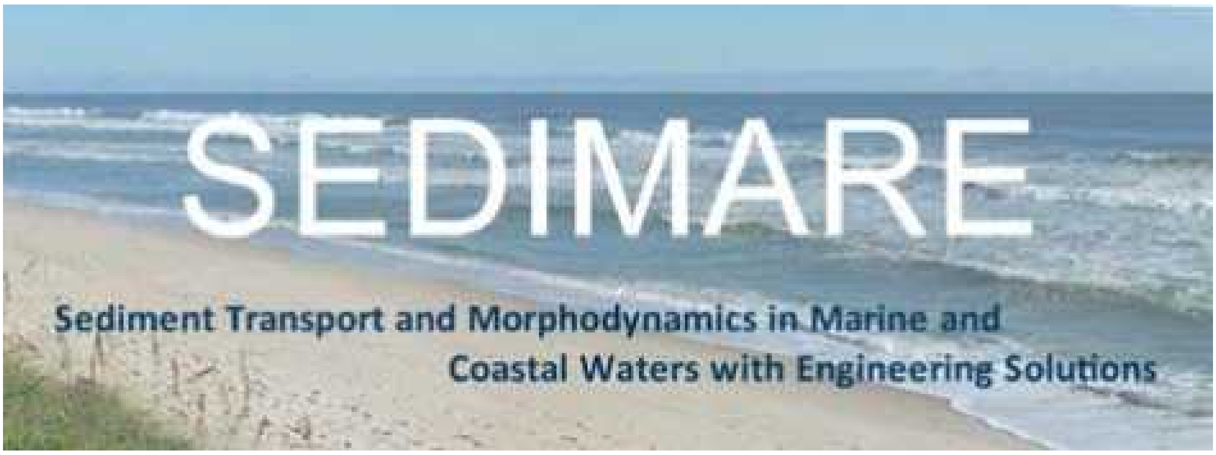

Project Number: 101072443

3rd NETWORK TRAINING SCHOOL

Deliverable 4.4

Dissemination level: PU - Public

Prepared by:

Javier López Lara, FIHAC Principal Investigator in SEDIMARE

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Document Information

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LOPEZ LARA JAVIER - DNI 16577795Q

Firmado digitalmente por LOPEZ LARA JAVIER - DNI 16577795Q
Fecha: 2025.03.19 14:19:29 +01'00'

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1. Program

The SEDIMARE "3rd Training School" was organized by Fundación Instituto de Hidráulica Ambiental de Cantabria (FIHAC)[1], in Santander (Spain), on 11-13 March 2025. Local organizers were Prof. Javier López Lara and Silvia Fernández Rodicio (EU Projects Department). The event was attended in person by all DCs, with the exception of DC Van Thi To Nguyen, who was conducting her experiments in Aberdeen during that time.

The SEDIMARE meeting consisted of:

- **PROJECT REVIEW & SCIENTIFIC EXCHANGE MEETING**
    - PhD progress presentations
    - Supervisory Board meeting
- **TRAINING SCHOOL**
    - This training school will consist of seminars with topics related to "effective monitoring techniques", "building adaptive capacity for resilient coast" and "coastal zone management - examples and best practices"

Day 1 – Tuesday 11 March

Morning

8:45 Walk-in

9:00-9:30 Welcome by **PI Javier López Lara (IHCantabria)**

9:30-10:30 KEYNOTE 1 – *"Shoreline Evolution Modeling"* by **Camilo Jaramillo (IHCantabria)**

10:30 Coffee Break

11:00-13:05 DCs presentations (15 min presentation + 10 min discussion)

11:00-11:25 **DC Buckle Subbiah Elavazhagan**

11:25-11:50 **DC Jowi Miranda**

11:50-12:15 **DC Nasim Soori**

12:15-12:40 **DC Nishchay Tiwari**

12:40-13:05 **DC Muhammed Said Parlak**

13:05 Lunch

Afternoon

14:00-15:00 Presentation of *"COMMONCOAST: A common coast to cherish – capping climate change"* by **Jara Martínez (IHCantabria)**

15:00-15:15 Presentation of SEDIMARE LinkedIn page by **DC Jowi Miranda**

15:15-16:15 Supervisory Board meeting

Evening

20:00 Project social dinner – ***Restaurante ABRA Sardinero (Plaza Brisas, 1, Santander)***

[1] Also known as "IHCantabria".

Day 2 – Wednesday 12 March

Morning

8:45 Walk-in

9:00-10:00 KEYNOTE 2 – "*Sediment transport in vegetated ecosystems*" by **María Maza (IHCantabria)**

10:00 Coffee Break

10:30-12:00 DCs presentations (15 min presentation + 10 min discussion)

10:30-10:55 **DC Van Thi To Nguyen** (online)

10:55-11:20 **DC Siyuan Wang**

11:20-11:45 **DC Eloah Rosas**

12:00-13:00 Interactive session with FIHAC PhD students by **Andrea Costales, Lucas de Freitas and Arnau García (IHCantabria)**

13:00 Lunch

Afternoon

14:00-14:45 Presentation of IHCantabria and visit to its facilities by **Javier López Lara (IHCantabria)**

14:45-15:55 Practical issues regarding the field trip on Day 3 by **Silvia Fernández (IHCantabria)**

15:55-16:30 DCs presentations (15 min presentation + 10 min discussion)

15:55-15:20 **DC Saeed Osouli**

15:20-15:45 **DC Ioannis Gerasimos Tsipas**

15:45-16:05 **DC Quan Nguyen**

16:05-16:30 **DC Evangelos Petridis**

16:30 End of the SEDIMARE 3rd Training School

Day 3 – Thursday 13 March

Morning

11:30-14:15 Field trip by **Camilo Jaramillo (IHCantabria)** – El Puntal, Somo and Loredo (Cantabria)
Meeting point: ***Palacete del Embarcadero (Calle Muelle de Calderón, 0, Santander)***

2. Presentations

The theme of the 3rd Network Training School was "Advanced Integrated Coastal Zone Monitoring and Management".

The keynote presentations by invited speakers, as well as the presentations of all the DCs, are shown in the next pages.

“Shoreline Evolution Modeling”

(Invited Speaker Camilo Jaramillo, IHCantabria)

SHORELINE EVOLUTION MODELING

CAMILO JARAMILLO CARDONA

IHcantabria

UC

Coastal Management and Engineering Group

March, 2025

Index

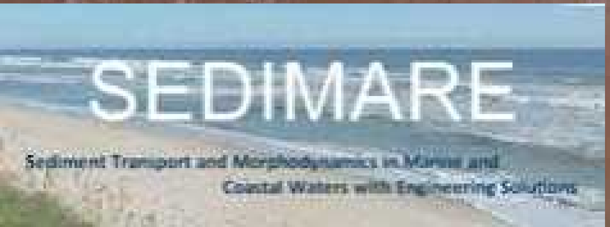
1 **Introduction**

2 **PhD thesis**

3 **Applications**

4 **IH-SET**

5 **GESEM**



IH cantabria

UC

Coastal Management and Engineering Group

March, 2025

MOTIVATION

- **Many coastal inhabitants** → More than 66% of the global population lives within 100 km of coastlines (Biausque *et al.*, 2016).

- **Sandy beaches are facing erosion and accretion**

→ Mentaschi et al. (2018) made a global shoreline variability analysis. They found that the overall surface of eroded land is about twice the surface of gained land.

→ Luijendijk et al., (2018) estimated that 24% of the world's sandy beaches are eroding at rates exceeding 0.5 m/yr

- **From climate change**
  - Sea level rise → Church et al. (2013).
  - Increase in storm intensity and frequency → Reguero et al. (2019) found an increase in global wave power as a consequence of oceanic warming.


Cartagena de Indias, Colombia


Somo, Spain


Santander, Spain

MOTIVATION

- **Many coastal inhabitants** → More than 66% of the global population lives within 100 km of coastlines (Biausque *et al.*, 2016).

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  - Sea level rise → Church et al. (2013).
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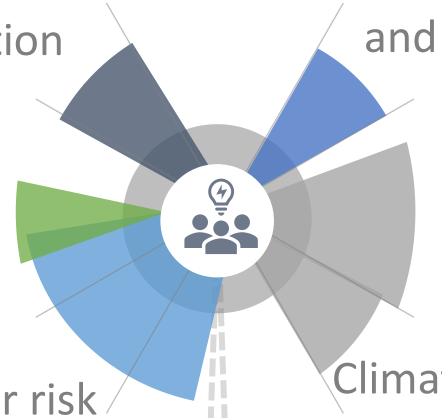
Introduction



Need to predict coastal changes and variability

Need for accurate shoreline modeling

Introduction

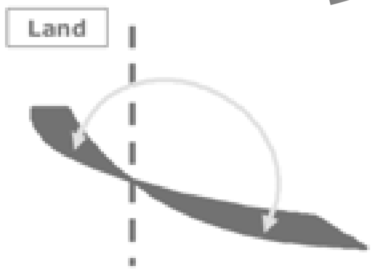
Planform

"Longshore"

Beaches

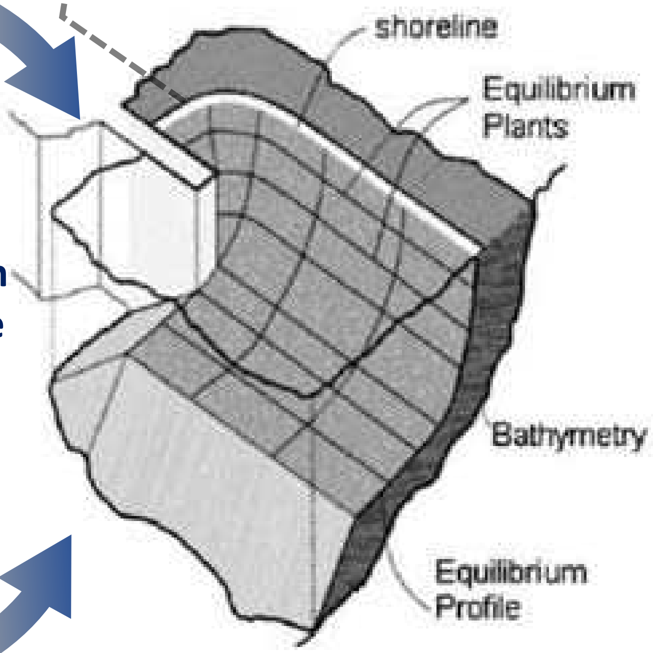
Profile

"Cross-shore"



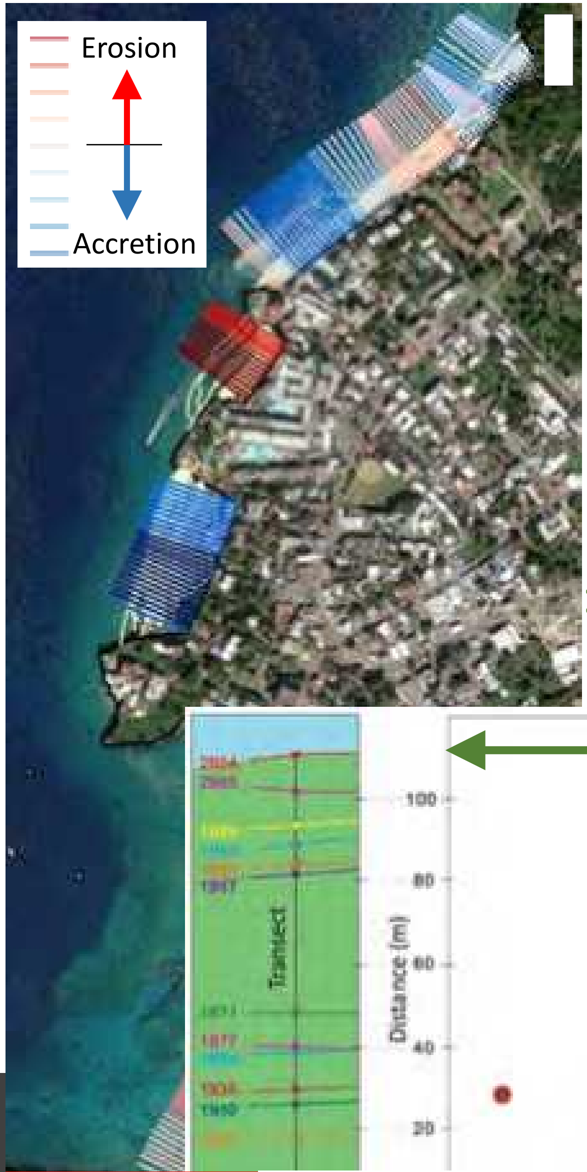
The **shoreline variability** is a reliable indicator to describe the global beach change at different spatial-temporal scales (Smith and Bryan, 2007).

Both the **beach profile and the planform** are linked



Three-dimensionality of the processes

Complex phenomenon



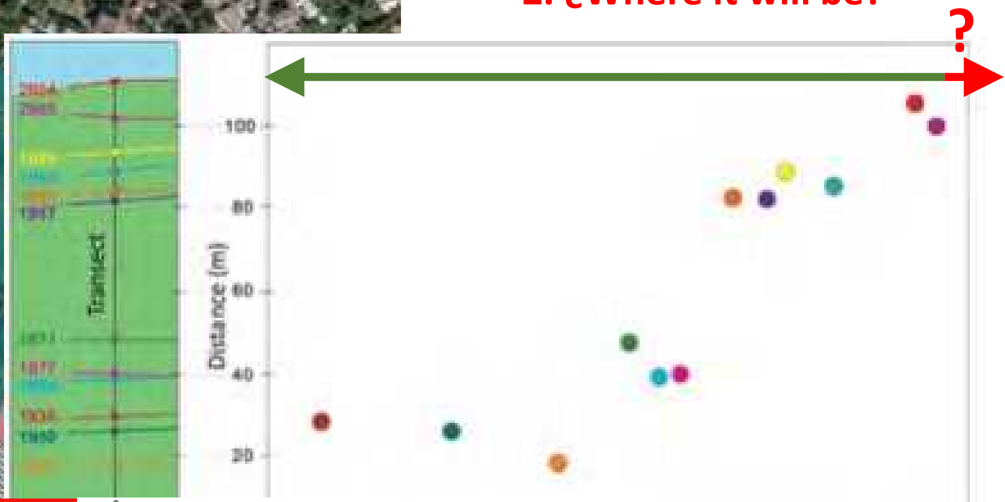
Knowing the **shoreline evolution**

- Estimate erosion trends
- Regulate coastal development
- Design protection works
- …

We need to know:

1.¿Where the shoreline has been?

2. ¿Where it will be?

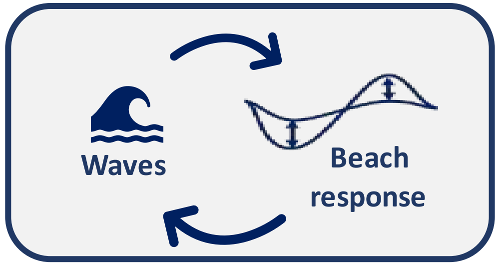


Modified from DSAS manual

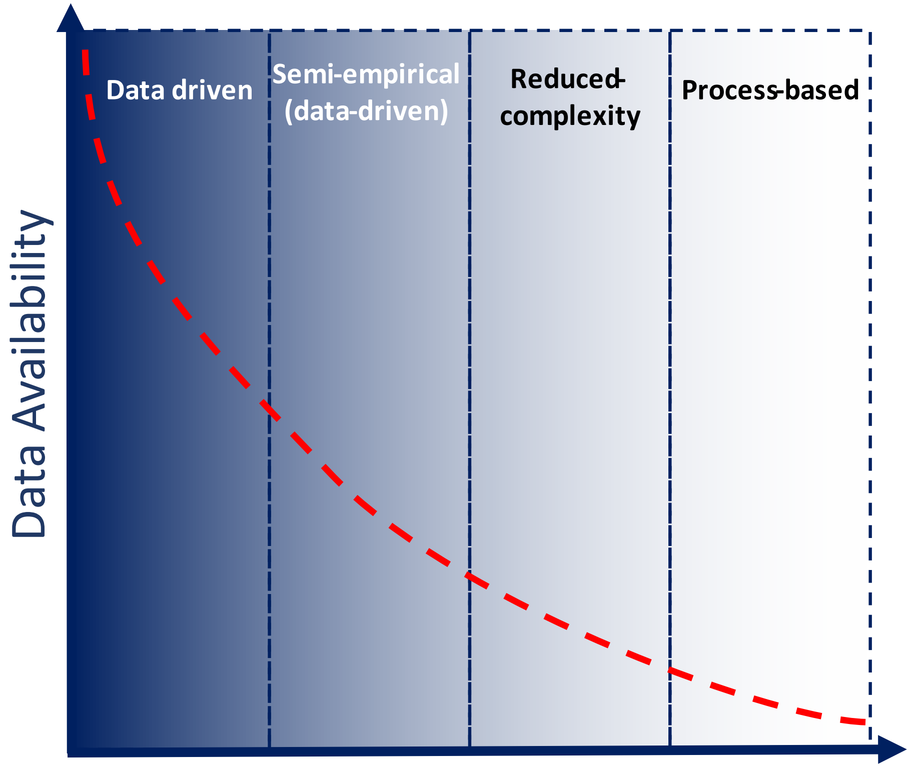
DATA

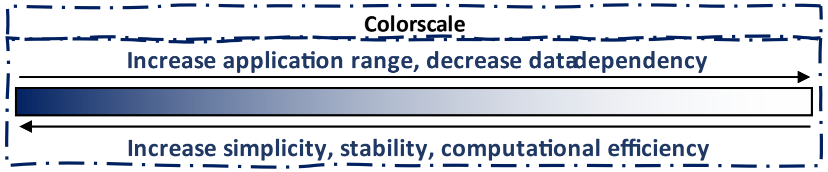
Shoreline modeling

Data driven
Semi-empirical



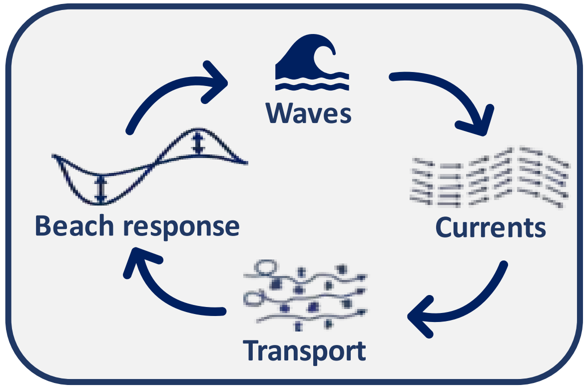
Short- to long-term



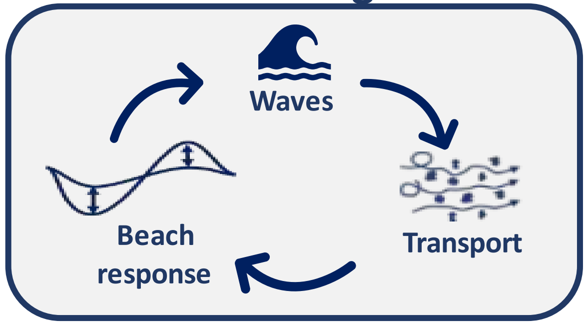


Modified from Hunt et al. 2023

Process-based
Short- to mid-term



Reduced-complexity
Short- to long-term

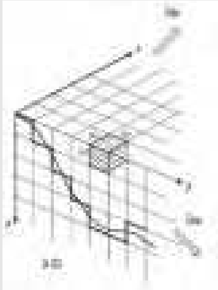


Introduction

→ *The shoreline variability has been estimated through multiple evolution models*

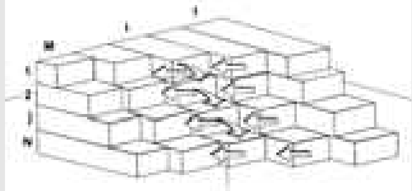
3D models

de Vriend et al. 1993;
Nicholson et al. 1997;
Lesser et al. 2004; …



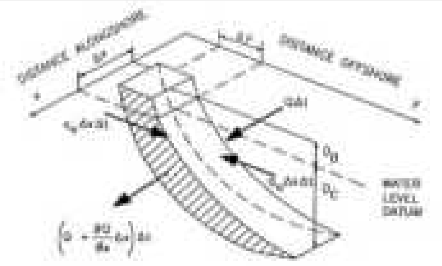
Multiline shoreline models

Bakker, 1970;
Perlin and Dean, 1979; 1983; Hanson and Larson, 2000; …



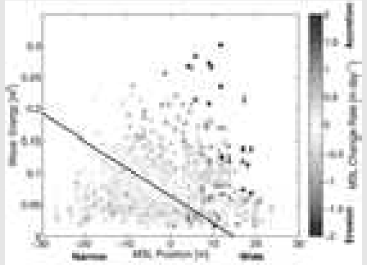
One-line shoreline models

Pelnard-Considere, 1956;
Hanson and Kraus, 1991;
Dabees and Kamphuis, 1998; …



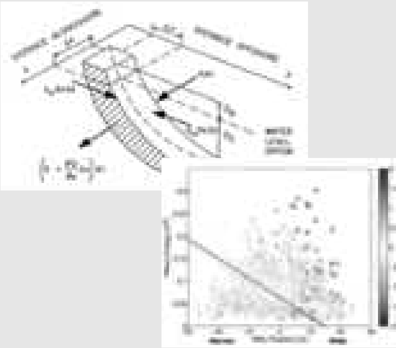
Equilibrium shoreline evolution models

Miller and Dean, 2004;
Yates et al., 2009;
Davidson et al., 2013;
Castelle et al., 2014;
Jara et al., 2015; …



Combined models

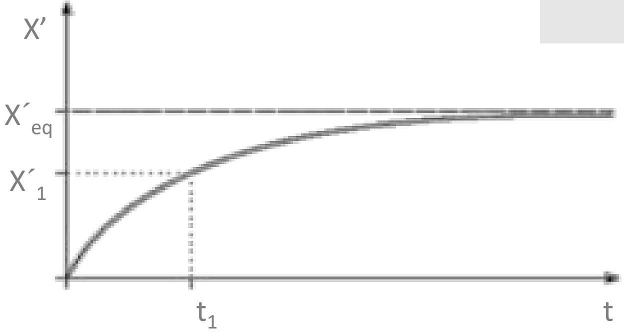
Vitousek et al., 2017;
Robinet et al., 2018;
Antolínez et al. 2019; …



$$\frac{dX'(t)}{dt} = K' \cdot \Delta X'$$

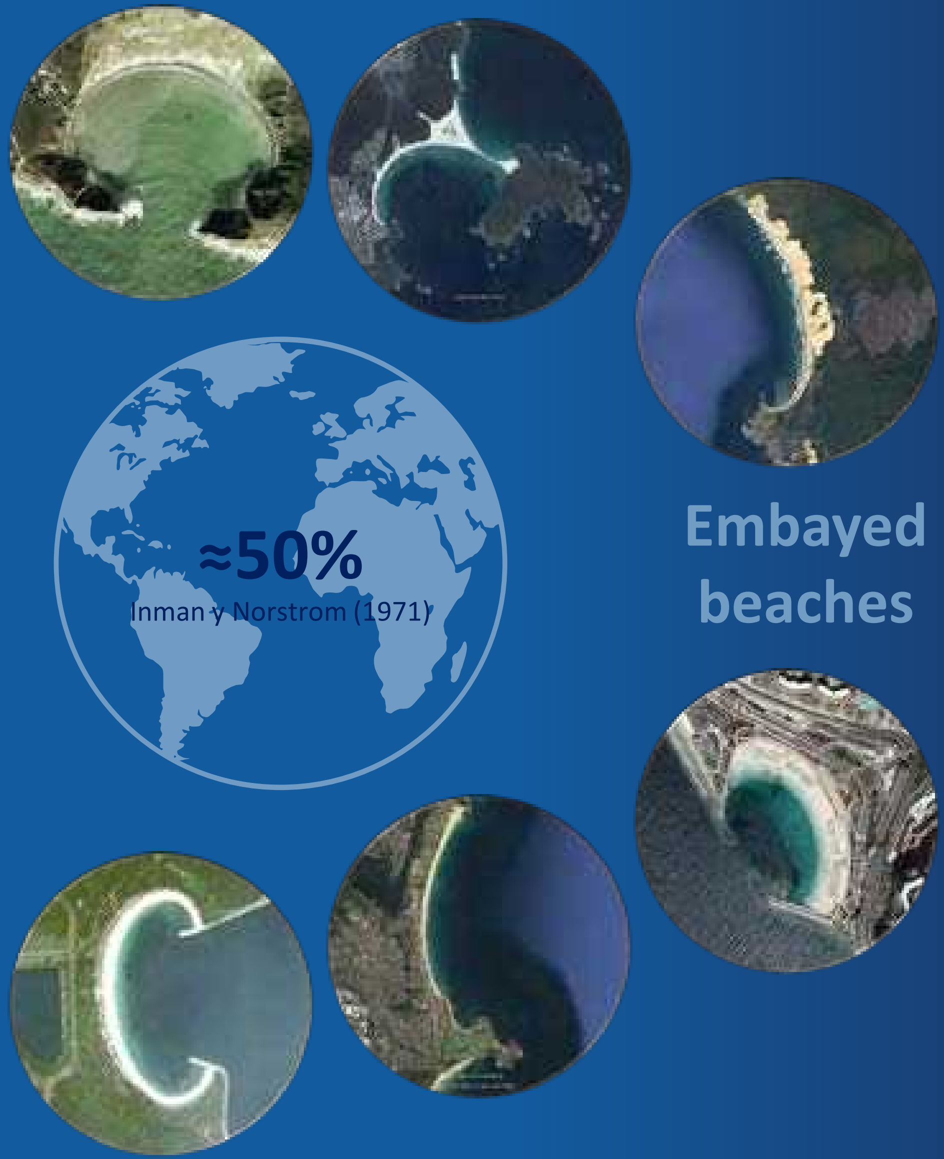
- K': f(wave conditions/ beach morphology)
- $\Delta X'$: Disequilibrium between current conditions and a theoretical equilibrium

$$\Delta X' = X' - X'_{eq}$$

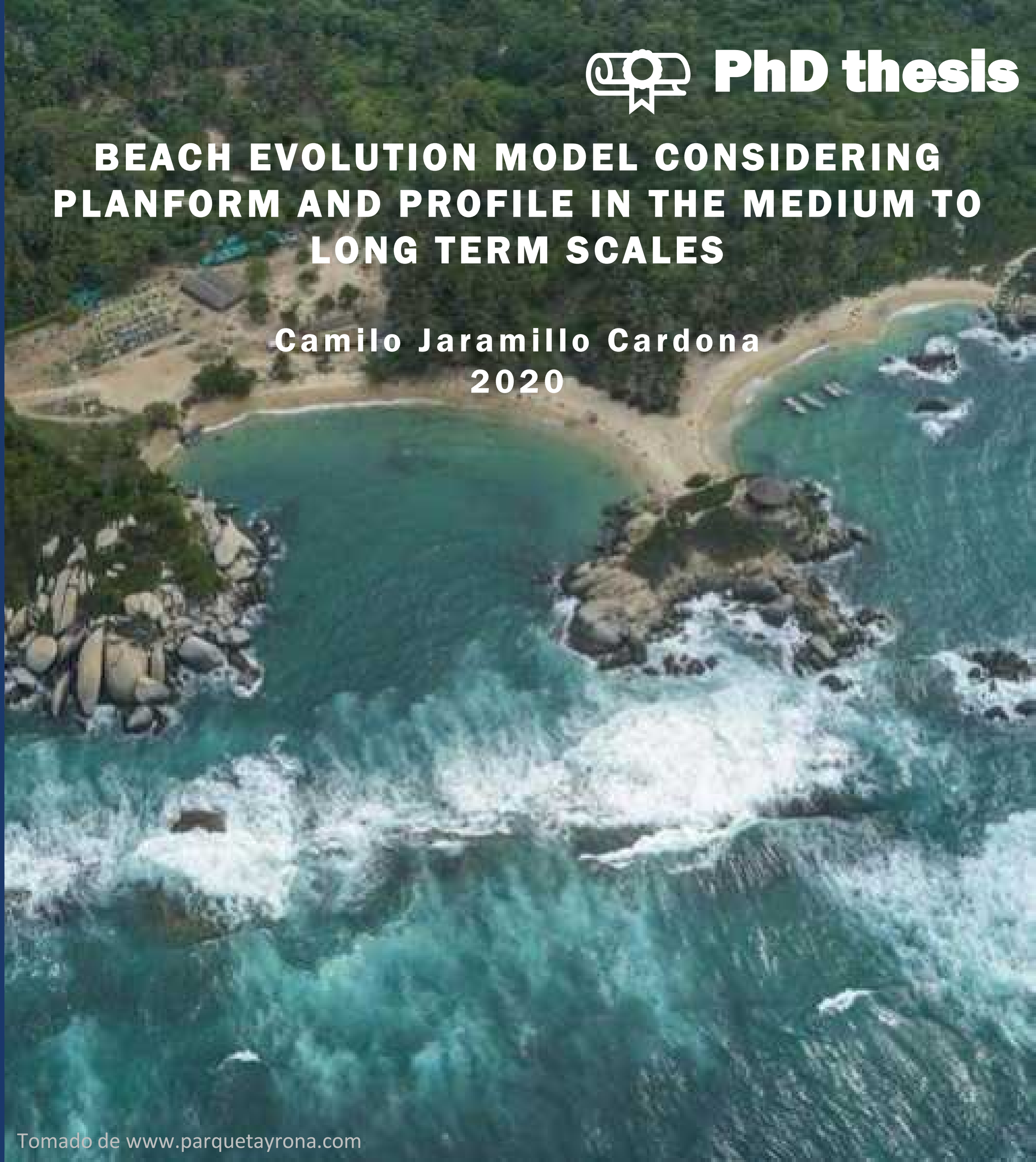


1 2 3 4 5

Shoreline evolution modeling – Camilo Jaramillo Cardona



Embayed beaches



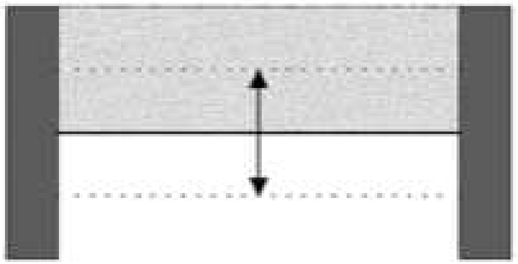
PhD thesis

BEACH EVOLUTION MODEL CONSIDERING PLANFORM AND PROFILE IN THE MEDIUM TO LONG TERM SCALES

Camilo Jaramillo Cardona

2020

Tomado de www.parquetayrona.com

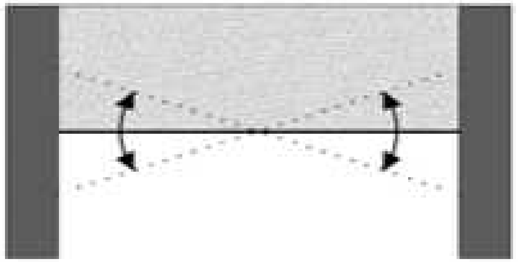


Cross-shore migration

Equilibrium-based shoreline evolution models

- Wright et al. (1985)
- Kriebel and Dean (1993)
- Miller and Dean (2004)
- Yates et al. (2009)
- Davidson and Turner (2009)
- Davidson et al. (2010)
- Long and Plant (2012)
- Davidson et al. (2013)
- Castelle et al. (2014)
- Splinter et al. (2014)
- Jara et al. (2015)
- **Jaramillo et al. (2020)**

Equilibrium condition
Jara et al. (2018)
- Through a function of the shoreline position
- Through a weighted average of the preceding conditions

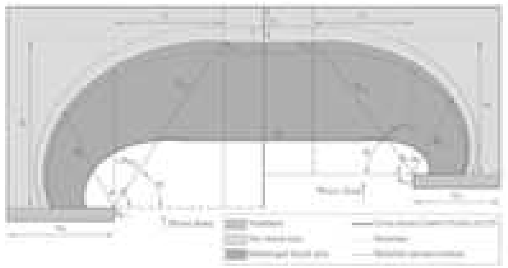


Beach rotation

- Turki et al. (2013)
- Blossier et al. (2015)
- Blossier et al. (2017)
- **Jaramillo et al. (2021a)**

Other models (morphological parameters)

- Madsen and Plant. (2001) → **Beach slope**
- Ludka et al. (2015) → **Beach profile state**
- Prodger et al. (2016) → **Sediment grain size**
- Blossier et al. (2017) → **Barline**

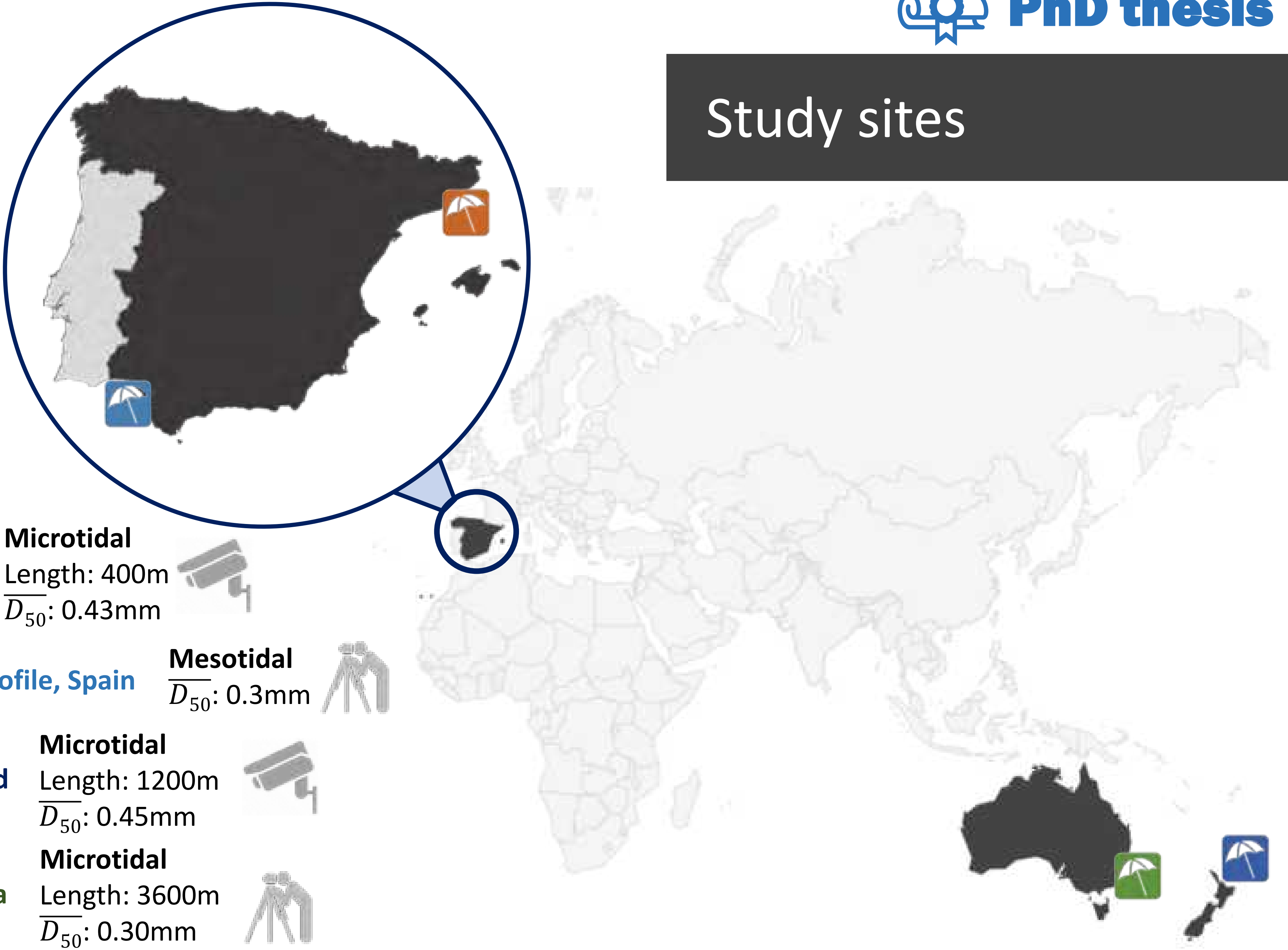


Cross-shore + longshore

Combined or hybrid models

- Vitousek et al. (2017)
- Robinet et al. (2018)
- Antolínez et al. (2019)
- Tran and Barthélemy, (2020)
- **Jaramillo et al. (2021b)**
- Alvarez-Cuesta et al. (2021a,b)
- de Santiago et al. (2021)
- Abdelhady and Troy, (2023)

Study sites



Nova Icaria Beach, Spain
Microtidal
Length: 400m
$\overline{D}_{50}$: 0.43mm

Campo Poseidón beach profile, Spain
Mesotidal
$\overline{D}_{50}$: 0.3mm

Tairua Beach, New Zealand
Microtidal
Length: 1200m
$\overline{D}_{50}$: 0.45mm

Narrabeen Beach, Australia
Microtidal
Length: 3600m
$\overline{D}_{50}$: 0.30mm

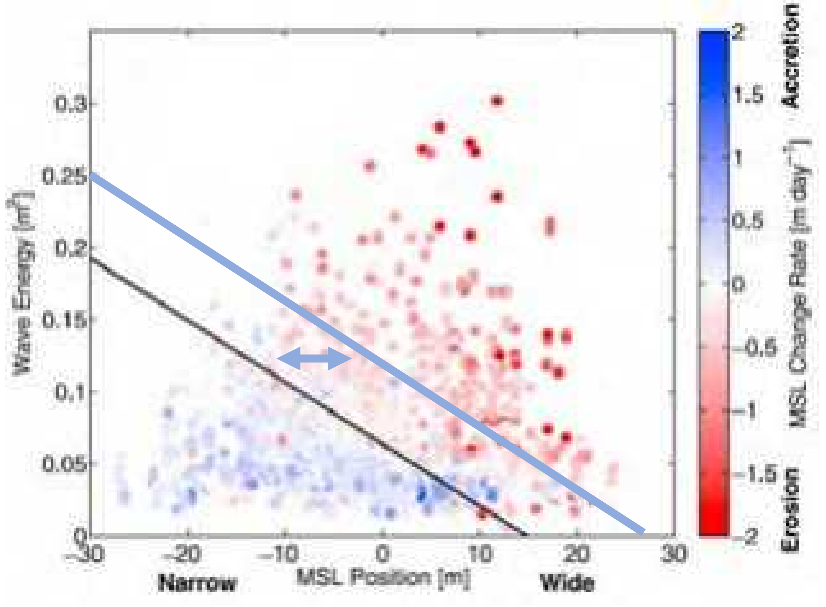
Equilibrium cross-shore shoreline evolution model

Yates et al. (2009) / Jaramillo et al. (2020)a

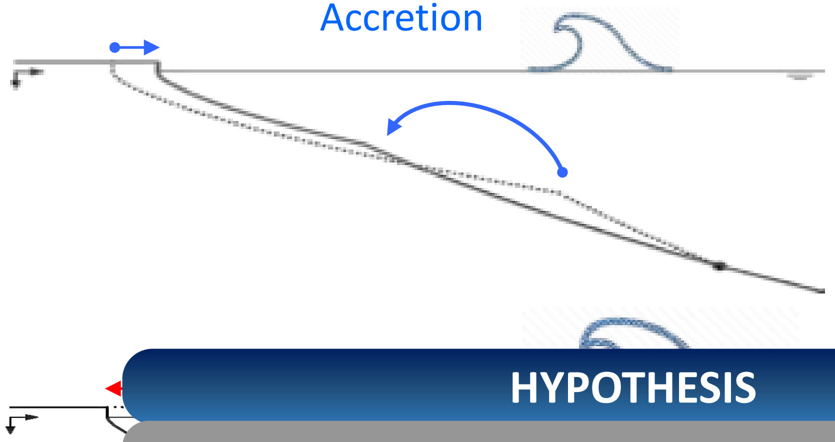
"YA09 model"

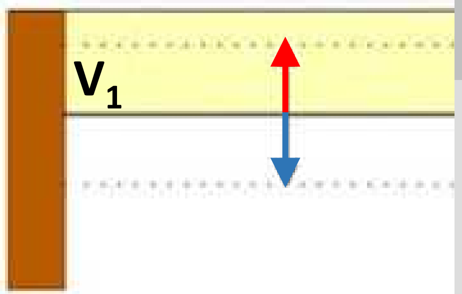
$$\frac{\partial S(t)}{\partial t} = C^{\pm} \cdot E^{1/2}(E - E_{eq})$$

$$S_{eq} = \frac{E-b}{a} + v_{lt} * t$$



Model parameters (a, b, $C^{\pm}$ and v_{lt})



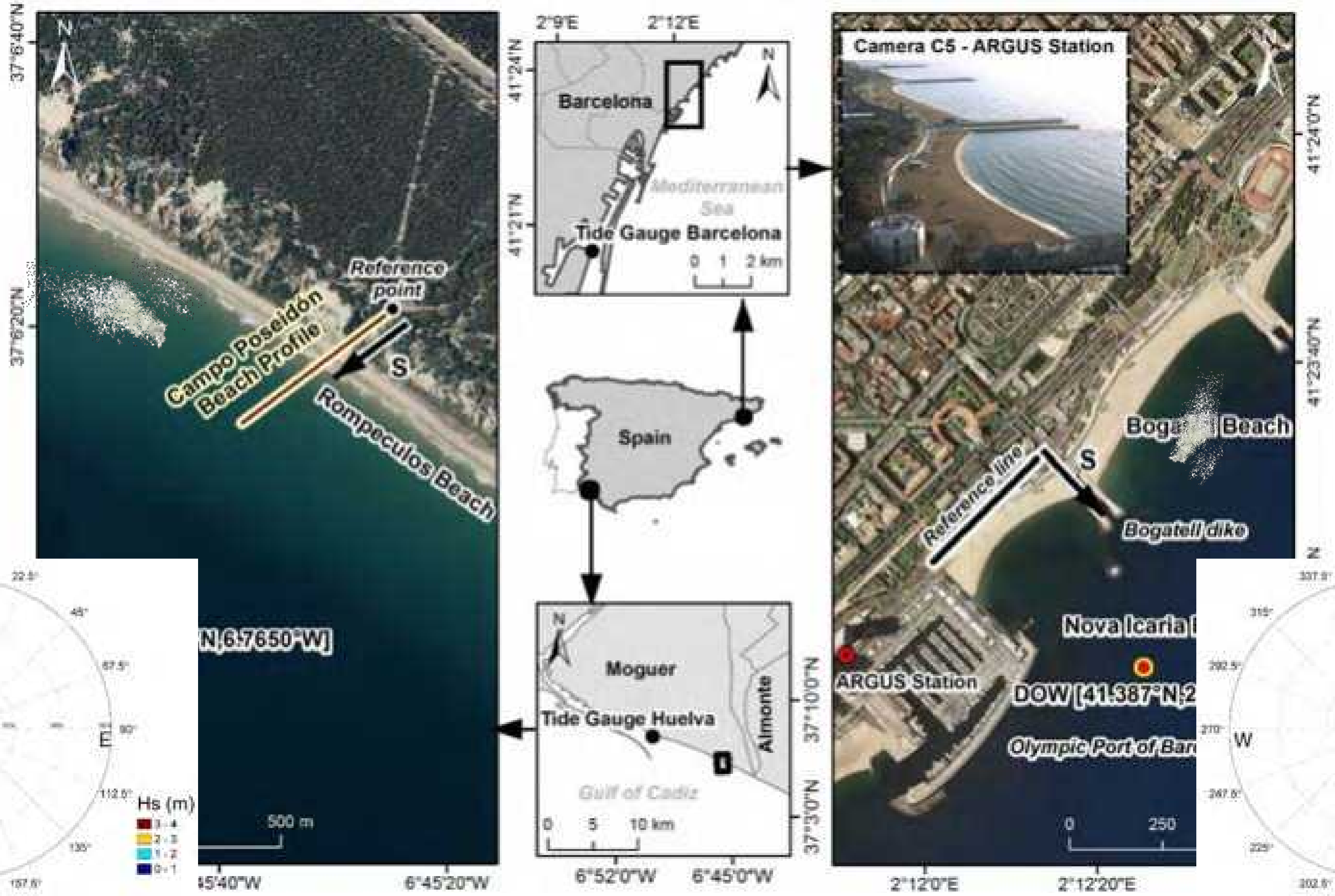


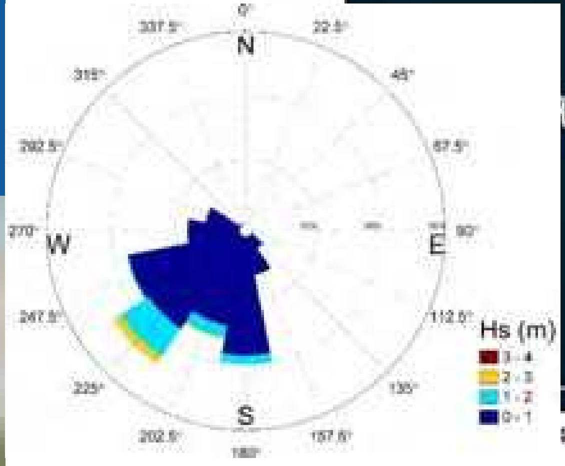
HYPOTHESIS

- The **shoreline variability** responds mainly to the magnitude of the **incident energy.**
- The model is applicable to beaches that are subject to **net sediment gain or loss.**
- The **parameters $C^{+/-}$** remain constant during the simulation.
- The model **does not include** an additional term for **tidal range.** However, as recommended by Castelle et al. (2014), in meso- / macrotidal environments it is preferable to evaluate a high contour of the beach profile, to avoid rising bar and berm dynamics.

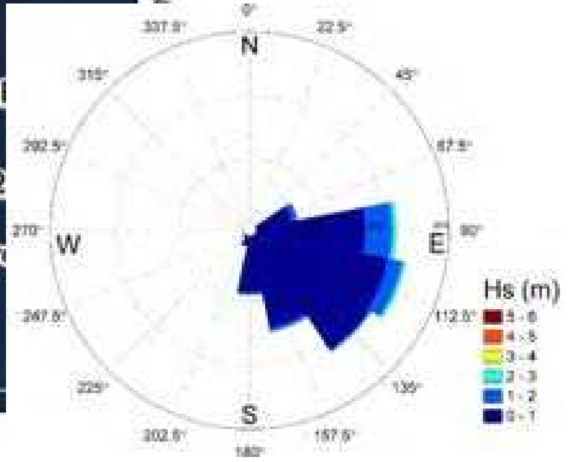
LOCATION OF SELECTED STUDY SITES

Campo Poseidón beach profile





Nova Icaria Beach



1 2 3 4 5

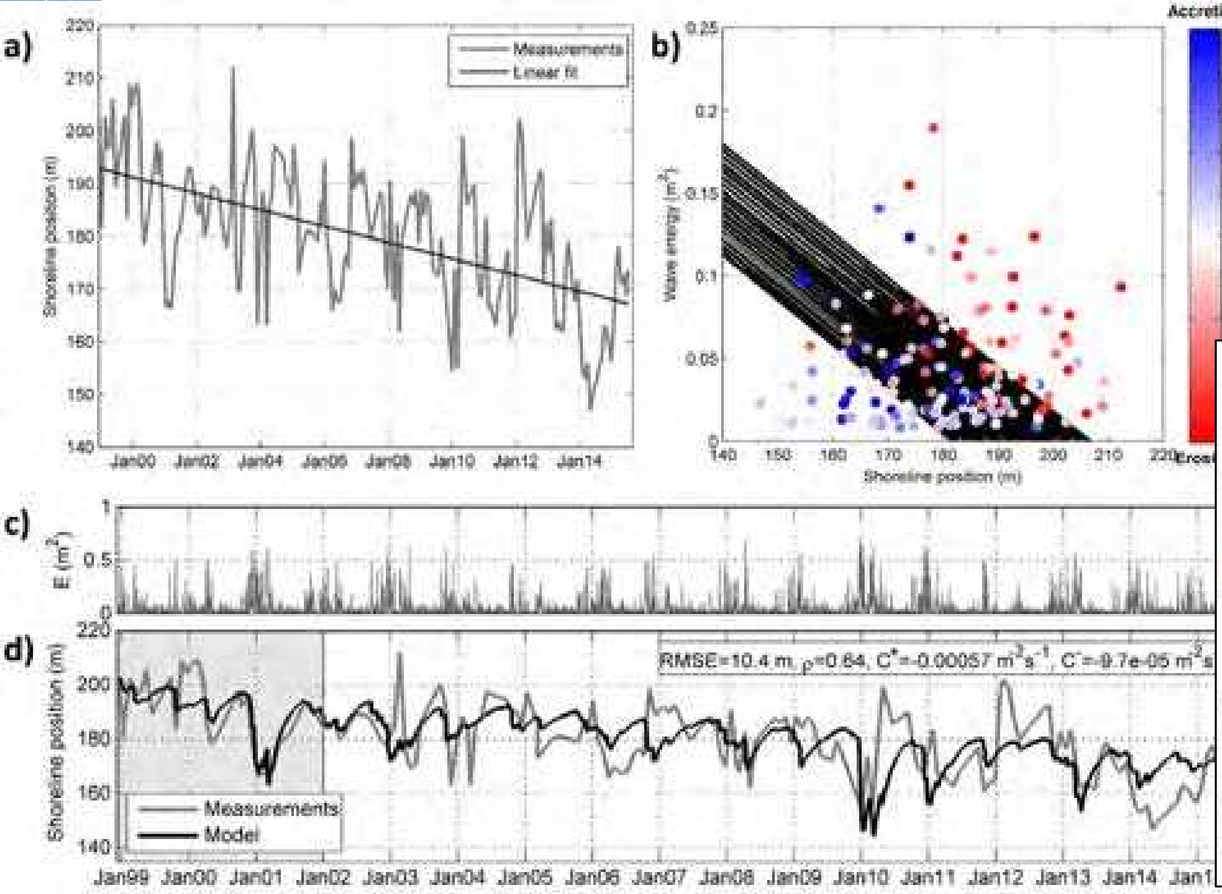
PhD thesis

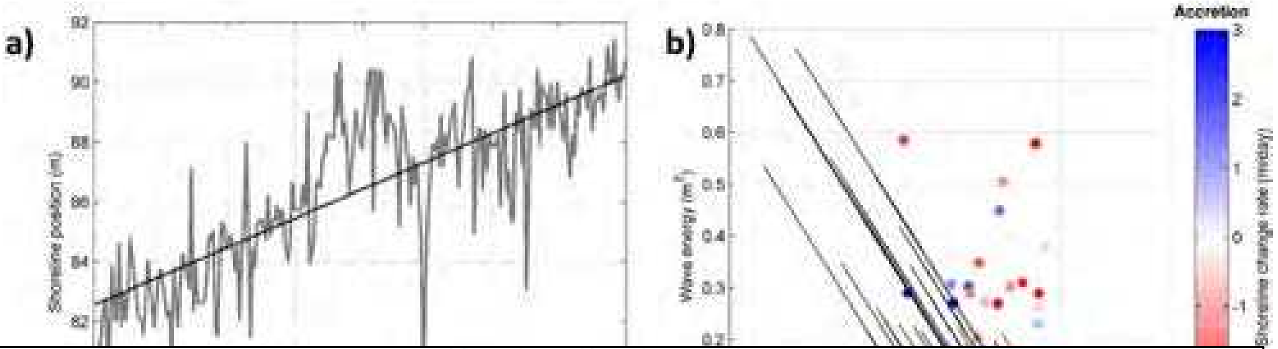
Equilibrium cross-shore shoreline evolution model

millo Cardona

Campo Poseidón beach profile, Spain
Mesotidal
$\overline{D_{50}}$: 0.43mm

Nova Icaria Beach, Spain
Microtidal
Length: 400m
$\overline{D_{50}}$: 0.43mm






Coastal Engineering 156 (2020) 103612

Contents lists available at ScienceDirect

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ELSEVIER

A shoreline evolution model considering the temporal variability of the beach profile sediment volume (sediment gain / loss)

Camilo Jaramillo*, Martínez Sánchez Jara, Mauricio González, Raúl Medina

Environmental Hydraulics Institute, Universidad de Cantabria, Avda. Isabel Torres, 15, Parque Científico y Tecnológico de Cantabria, 39011, Santander, Spain

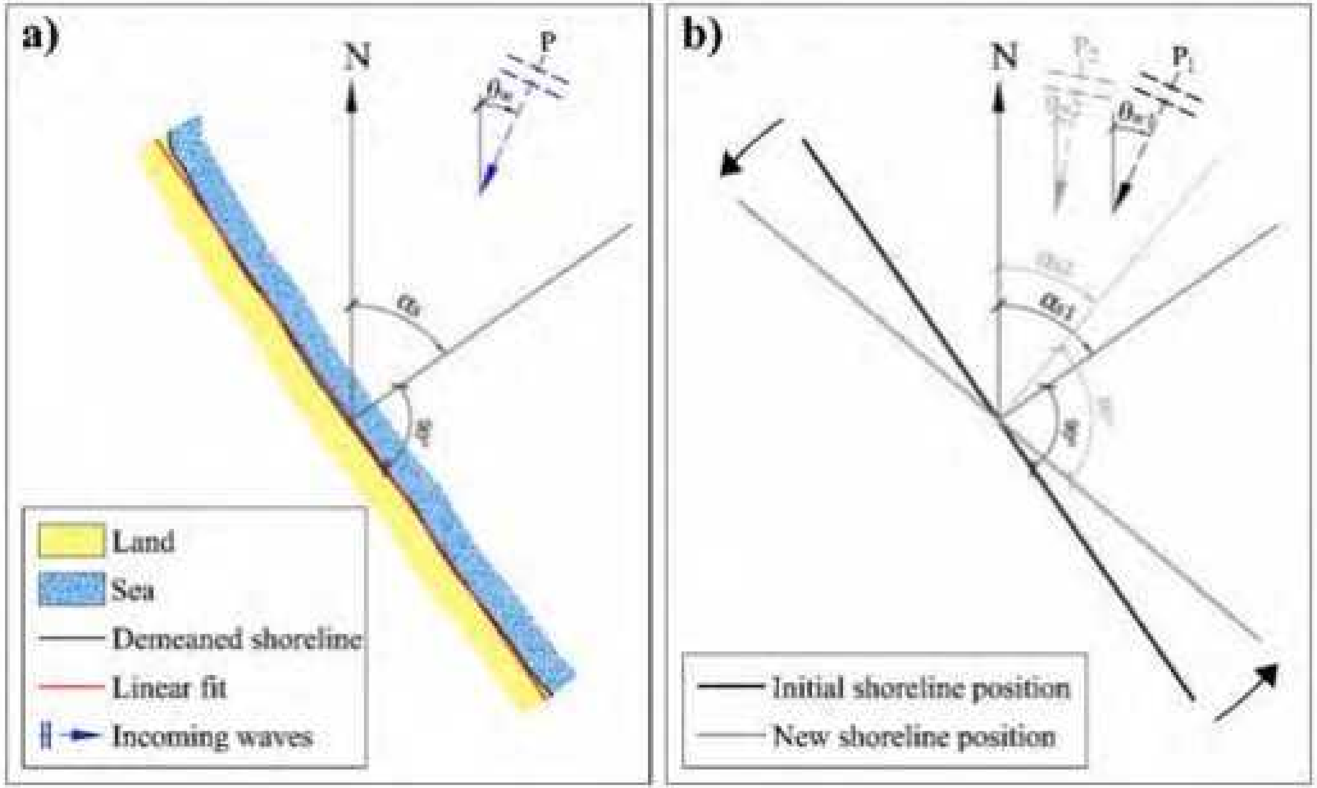
An equilibrium-based shoreline rotation model

$$\frac{d\alpha_s(t)}{dt} = L^{\pm} P \Delta\alpha_s(\theta)$$

$$\Delta\alpha_s(\theta) = \alpha_s - \alpha_{s_{eq}}$$

$\alpha s(t)$: shoreline orientation (°) at the time "t"
P: incident wave power (m^2s) → P= $Hs^2 \cdot Tp$
$L^{\pm}$: proportionality constants ($m^{-2}s^{-2}$) → L^{+}
$\Delta\alpha_s(\theta)$: shoreline orientation disequilibriu

$$\alpha_s(t) = \left(\alpha_{s_0} - \alpha_{s_{eq}}\right) e^{-L^{\pm}Pt} + \alpha_{s_{eq}}$$

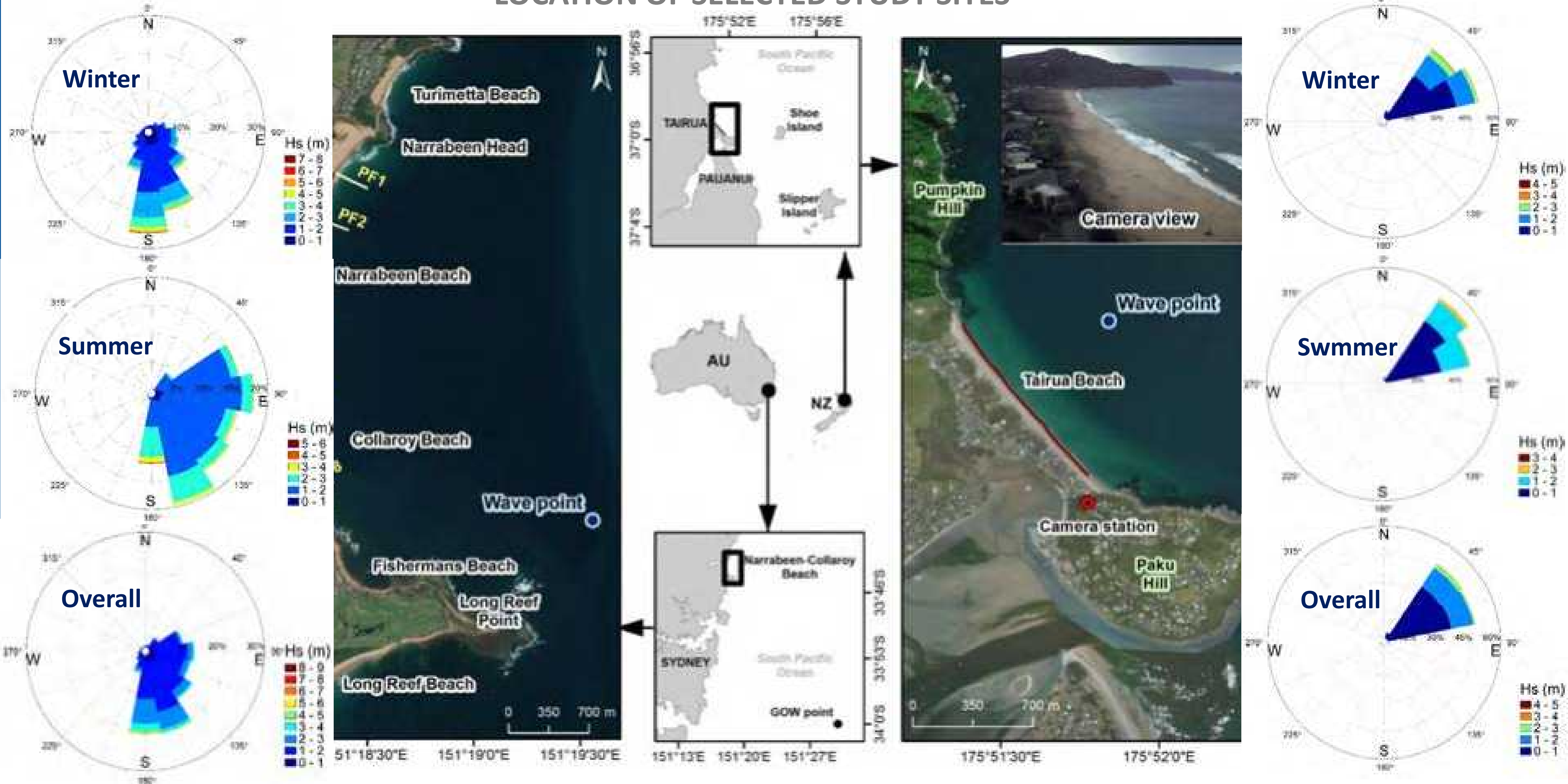


HYPOTHESIS

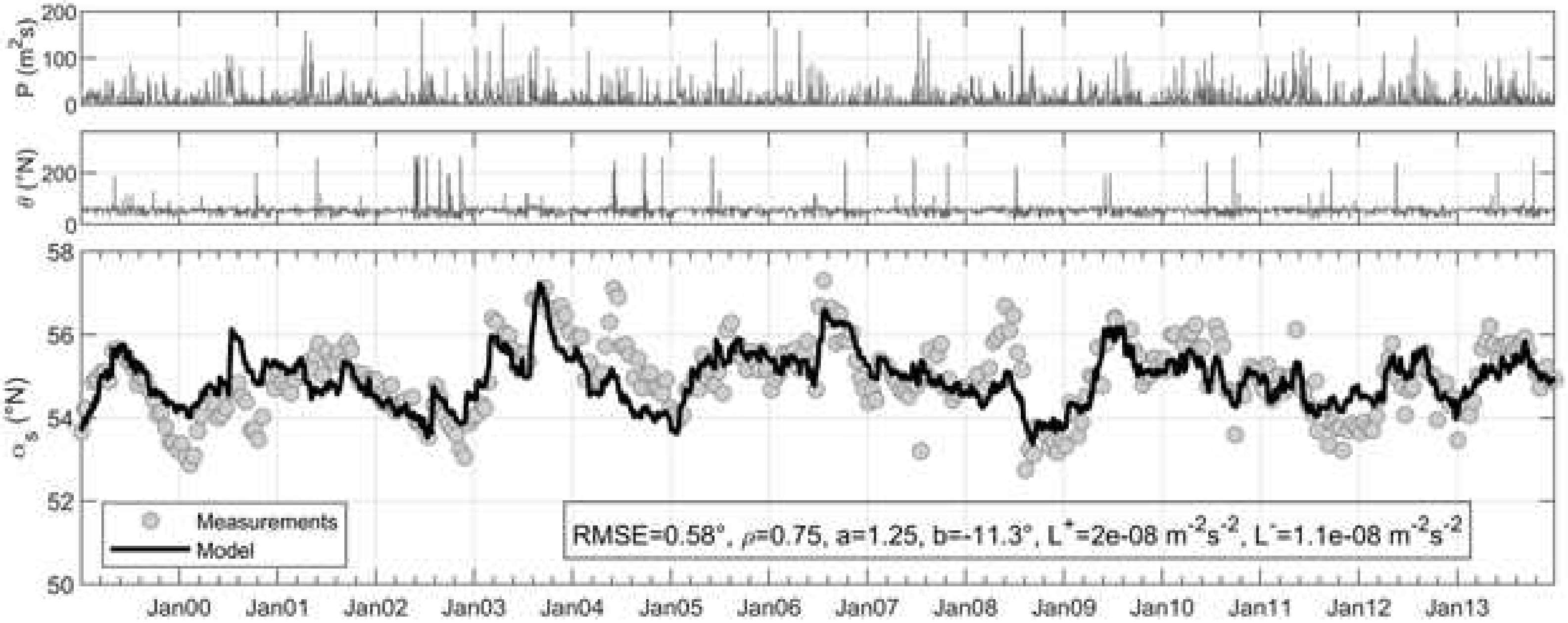
- The **beach rotation** is assumed to be **isolated from other beach movements**.
- The beach rotation mainly depends on the **energy and the directionality** of the incident waves.
- **A single wave point** is assumed as model forcing.
- The model does **not** account for **short-scale processes** (e.g. cusps, rips, etc.).
- The model does **not** explicitly include any additional parameter related to the **tidal range**.

Relationship ($< \theta >$ - α_s):
"Equilibrium Wave Direction Function, EWDF"

LOCATION OF SELECTED STUDY SITES

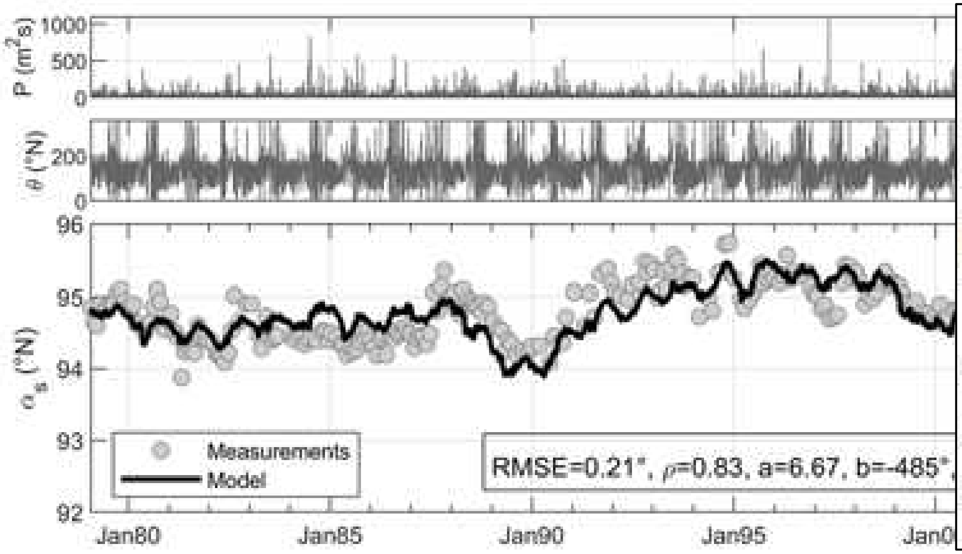


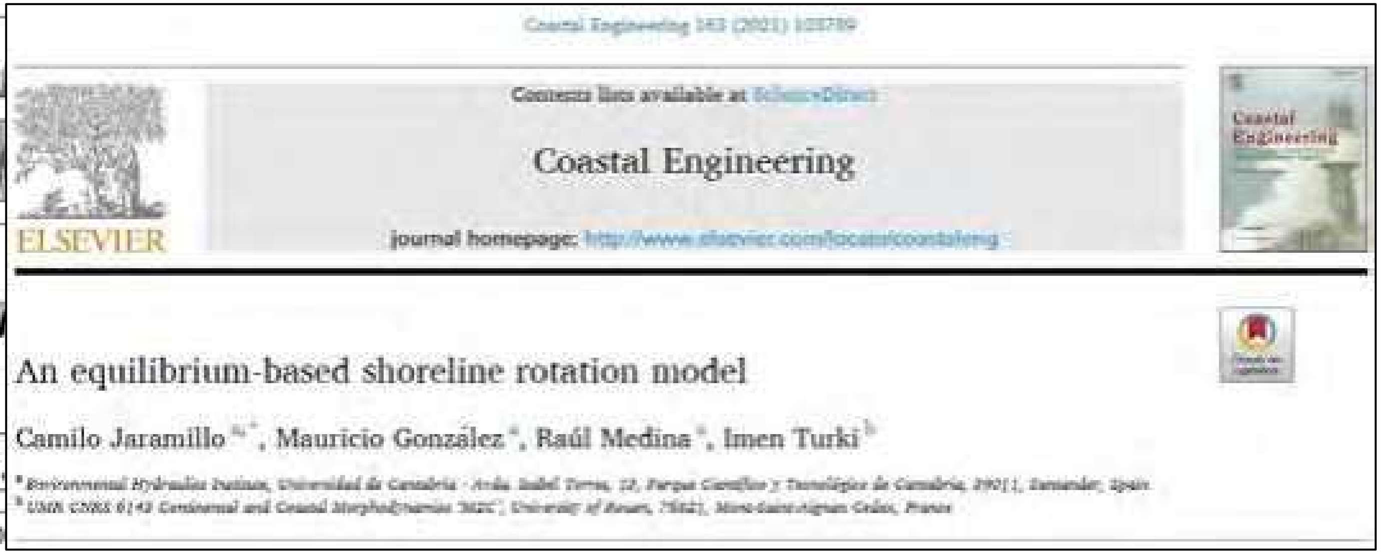
An equilibrium-based shoreline rotation model



Tairua Beach
~ 15 years

Tairua Beach, NZ
Microtidal
Length: 1200m
$\overline{D_{50}}$: 0.45mm




Coastal Engineering 163 (2021) 103789

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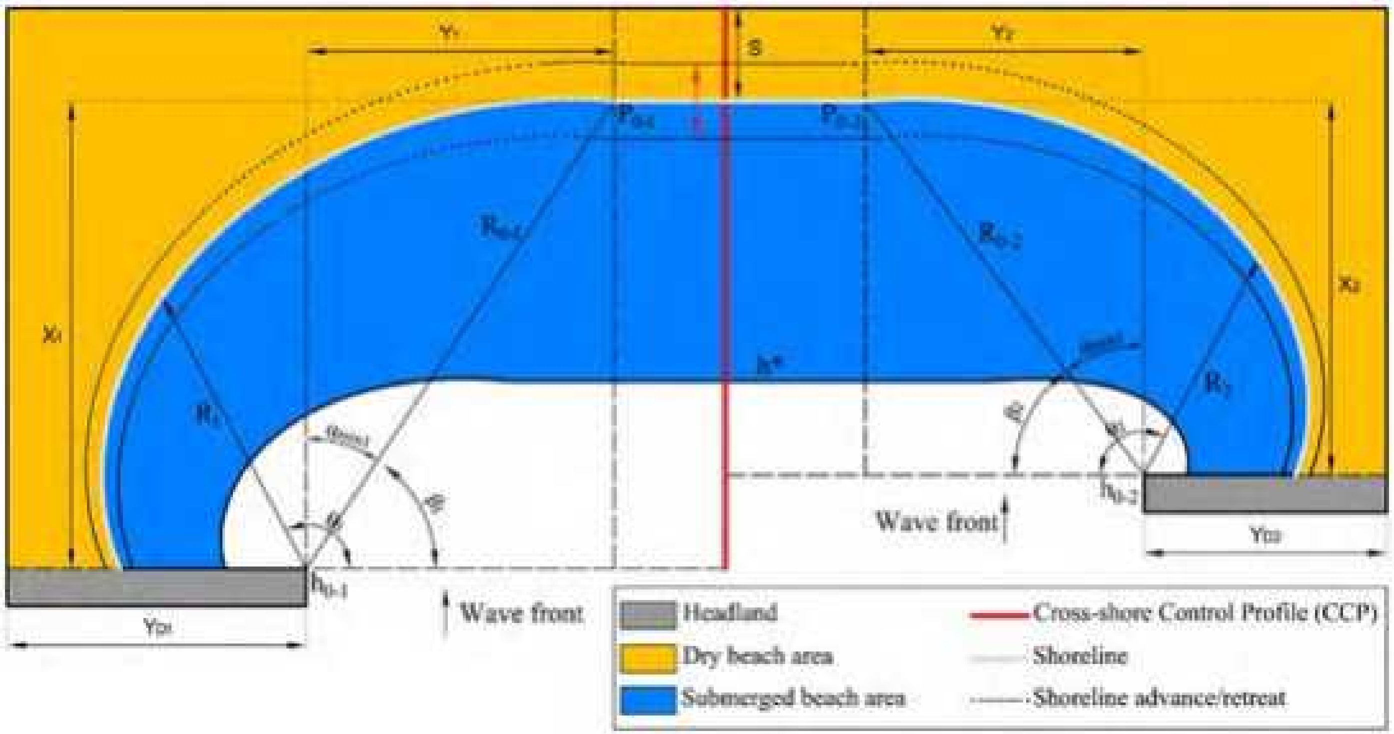
ELSEVIER

An equilibrium-based shoreline rotation model

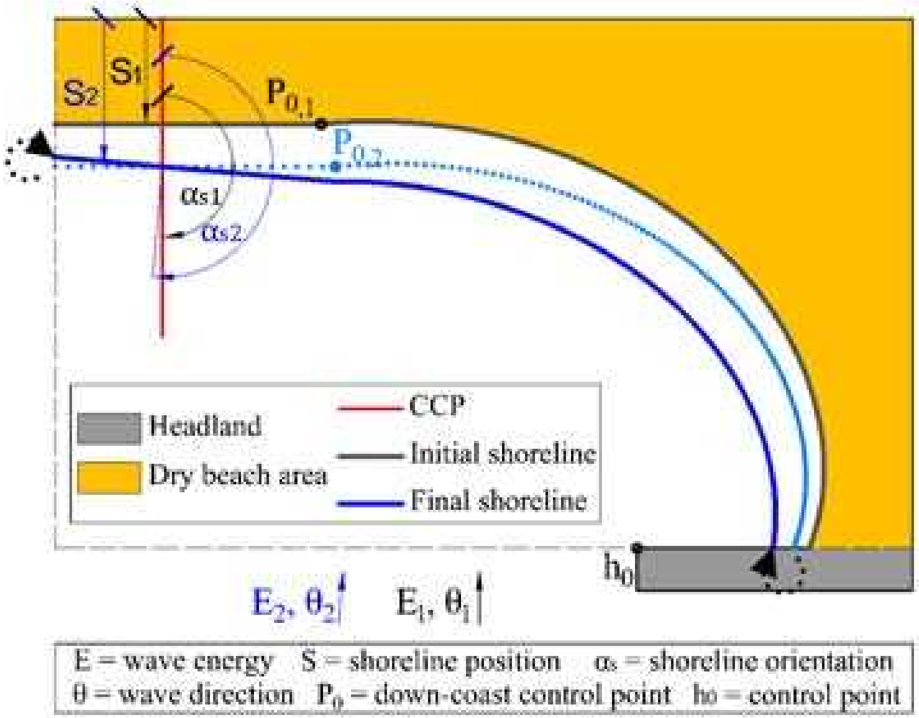
Camilo Jaramillo [a,*], Mauricio González [a], Raúl Medina [a], Imen Turki [b]

MOdel Of Shoreline Evolution (IH-MOOSE) **INTEGRATION**

Yates et al. (2009) / Jaramillo et al. (2020) + Hsu and Evans (1989)



+ Jaramillo et al. (2021a)



HYPOTHESIS

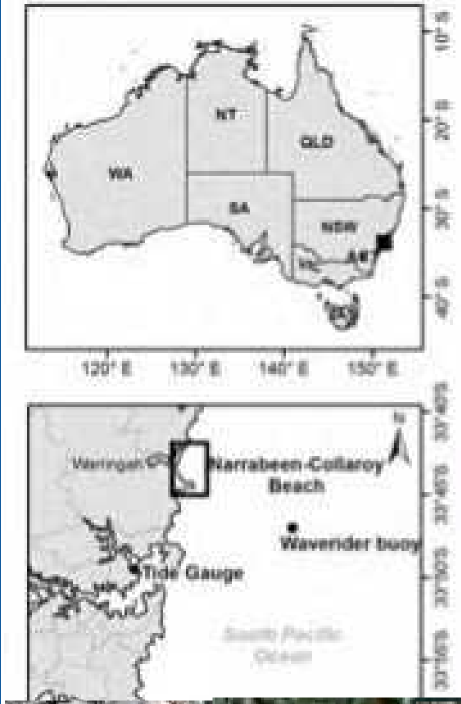
- The **beach profile** and **beach planform** tend to have an **equilibrium shape**
- The **beach profile** and **beach planform** are **linked**

APPLICABILITY

- **Embayed beaches** with parabolic shape

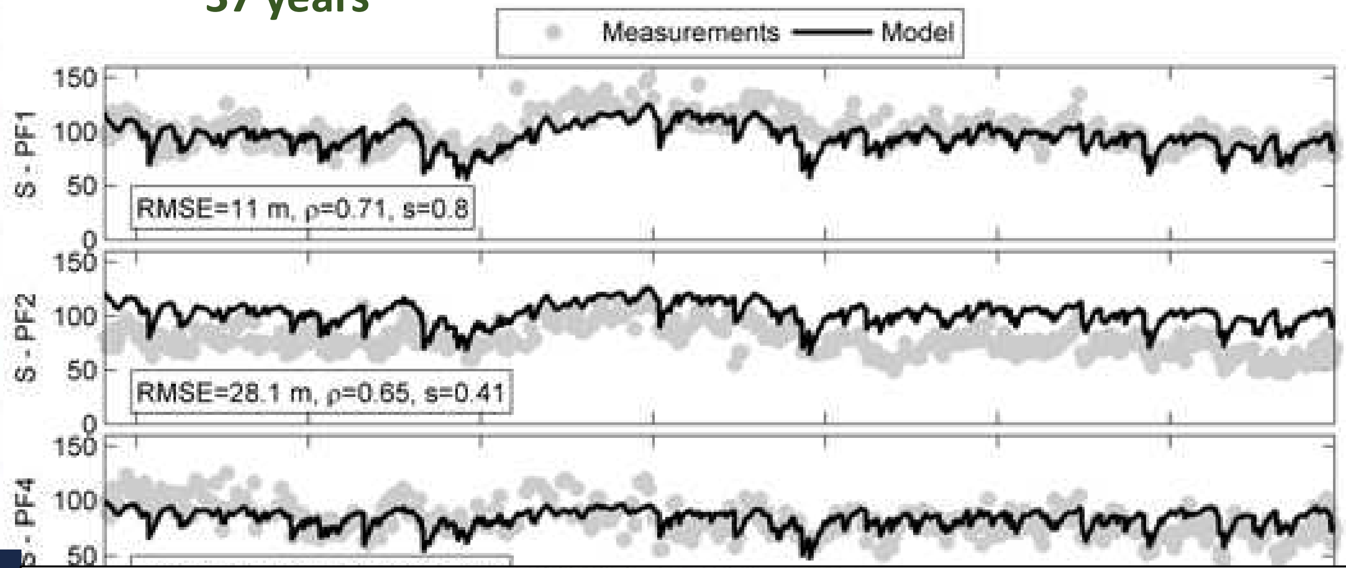
LIMITATIONS

- It is not considered **beach breathing**
- **Others**



Narrabeen Beach

37 years




Coastal Engineering 169 (2021) 103983

Contents lists available at ScienceDirect

Coastal Engineering

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

ELSEVIER

A shoreline evolution model for embayed beaches based on cross-shore, planform and rotation equilibrium models

Camilo Jaramillo*, Martínez Sánchez Jara, Mauricio González, Raúl Medina

Environmental Hydraulics Institute, Universidad de Cantabria - Avda. Isabel Torres, 15, Parque Científico y Tecnológico de Cantabria, 39011, Santander, Spain

01

Cross-shore model

We proposed an extension of a **cross-shore** shoreline evolution **model** considering the **time variation of the equilibrium energy function** (sediment gain / loss).

- The model has been successfully applied in **Nova Icaria Beach** an **Campo Poseidón beach profile**.

02

Rotation model

We proposed a new equilibrium-based empirical shoreline **rotation model** assuming that rotation movement is **induced by the incoming wave energy and direction**.

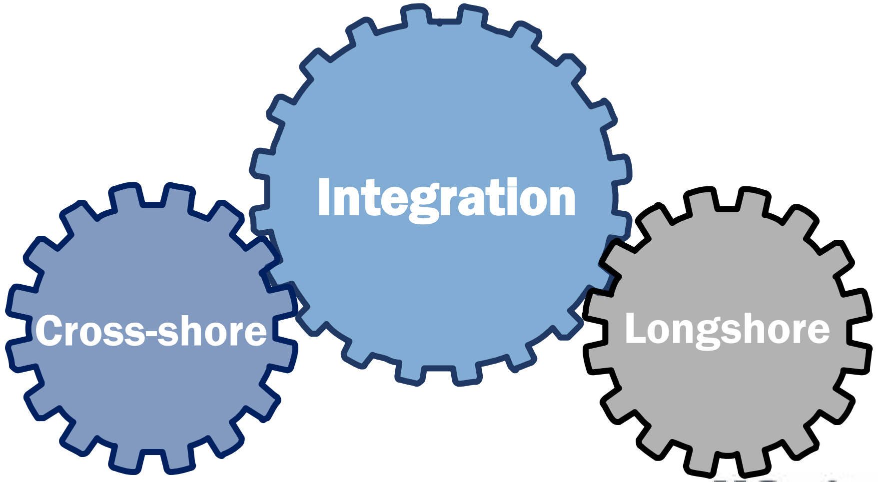
- The model has been successfully applied in **Tairua Beach** and **Narrabeen Beach**.

03

Integrated model

We proposed a new shoreline evolution model for embayed beaches based on **cross-shore, planform** and **rotation equilibrium models**. From a single monitoring beach profile, the model is able to obtain the evolution of the entire beach coastline.

- The model has been successfully applied in **Narrabeen Beach**.



Applications

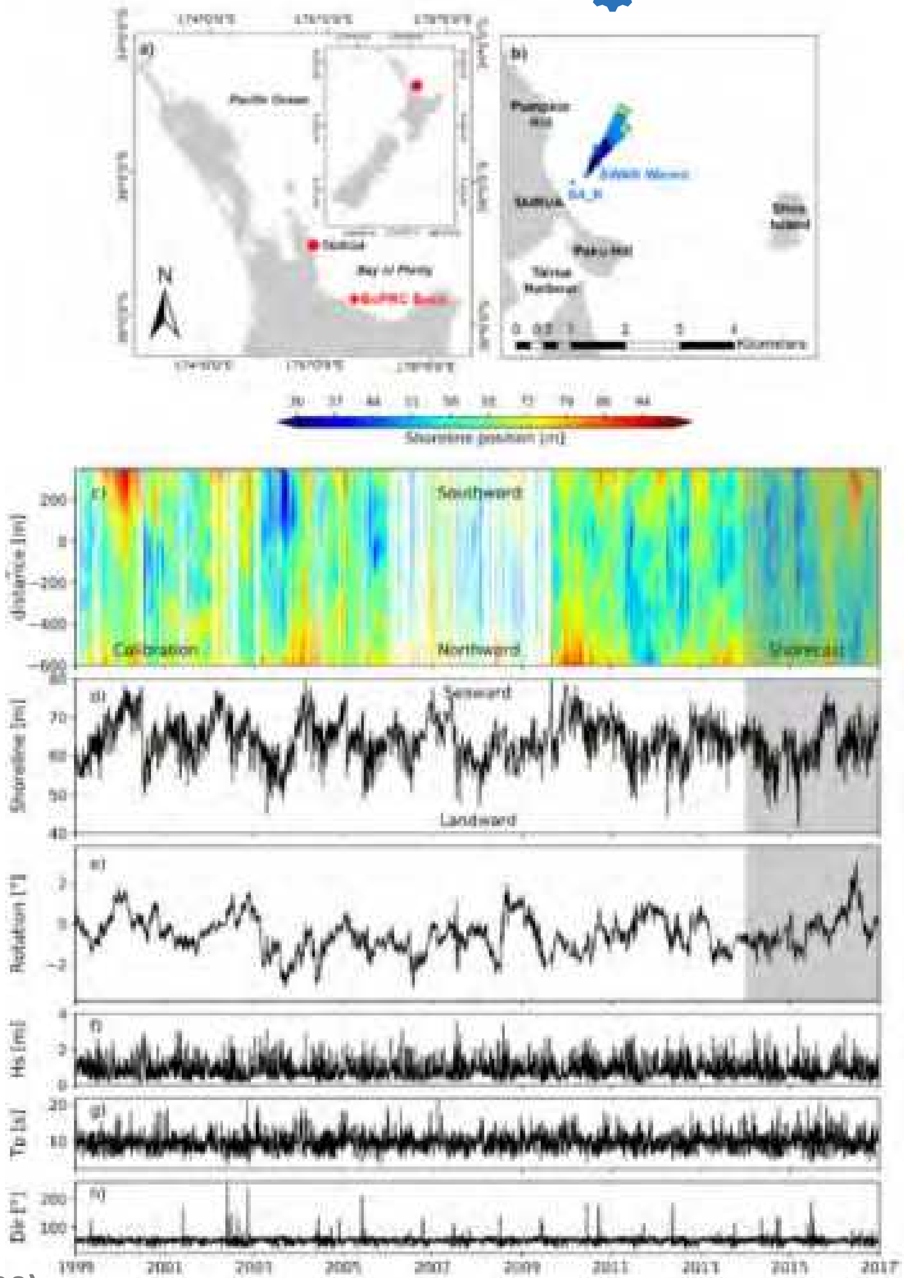
Shoreshop 1 (2018)

SCIENTIFIC REPORTS
natureresearch

OPEN

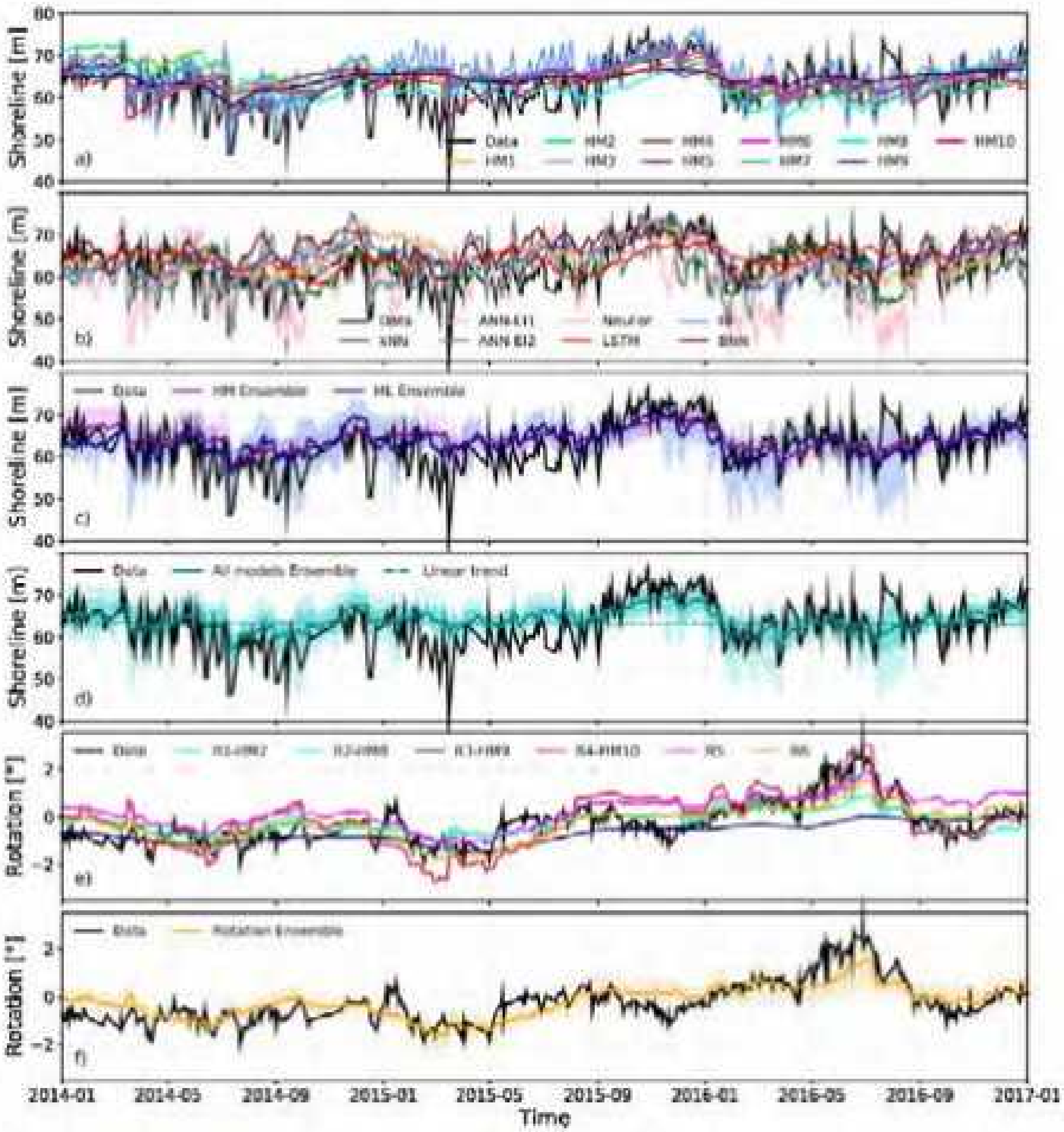
Blind testing of shoreline evolution models

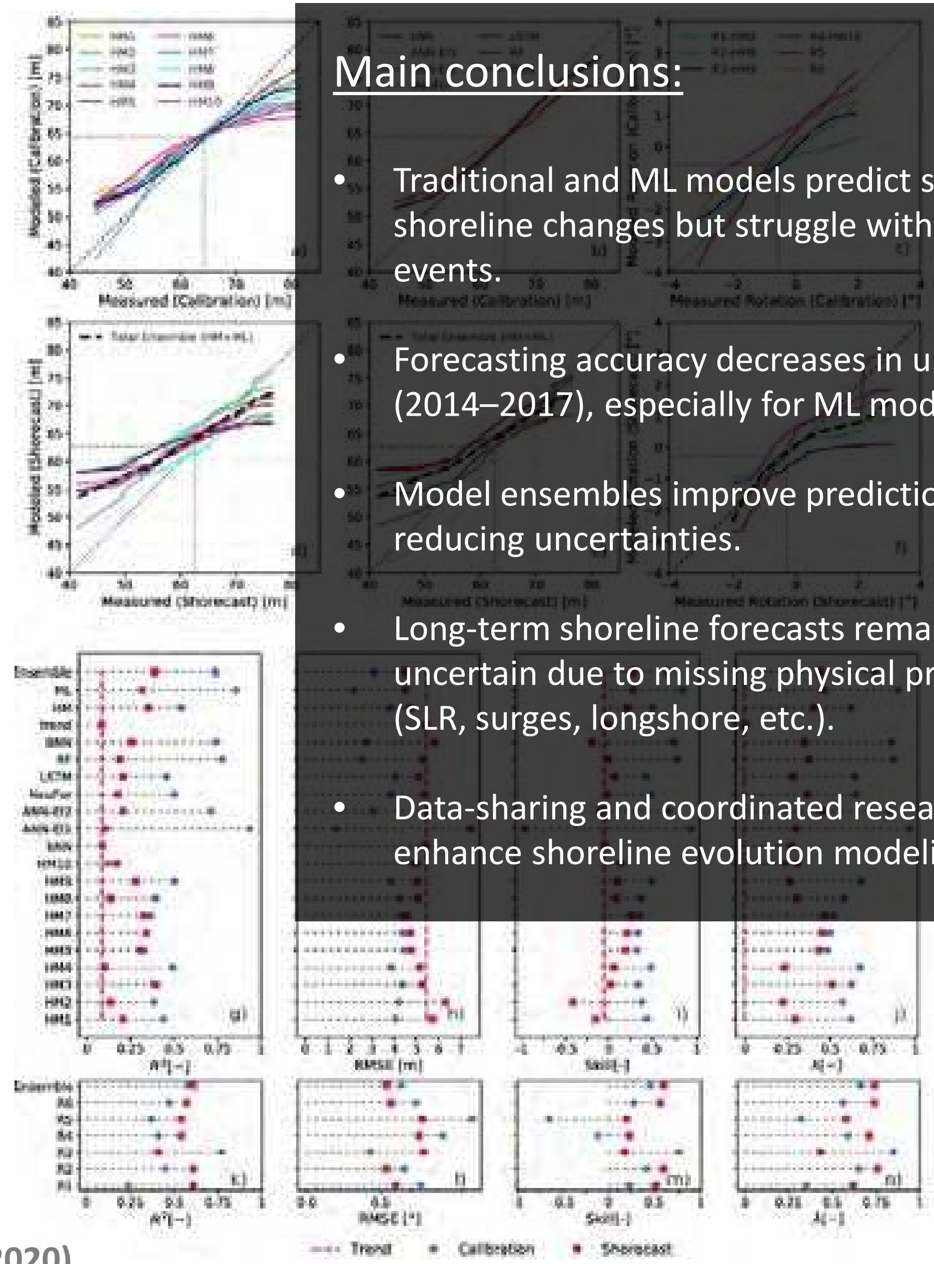
Jennifer Montaño[1*], Giovanni Coco[1], Jose A. A. Antolínez[2], Tomas Beuzen[3], Karin R. Bryan[4], Laura Cagigal[1,2], Bruno Castelle[5], Mark A. Davidson[6], Evan B. Goldstein[7], Raimundo Ibaceta[3], Déborah Idier[8], Bonnie C. Ludka[9], Sina Masoud-Ansari[1], Fernando J. Méndez[2], A. Brad Murray[10], Nathaniel G. Plant[11], Katherine M. Ratliff[10], Arthur Robinet[5,8], Ana Rueda[2], Nadia Sénéchal[5], Joshua A. Simmons[3], Kristen D. Splinter[3], Scott Stephens[12], Ian Townend[13], Sean Vitousek[14,15] & Kilian Vos[3]



Montaño et al. (2020)

Applications





Montaño et al. (2020)

Main conclusions:

- Traditional and ML models predict seasonal shoreline changes but struggle with extreme events.
- Forecasting accuracy decreases in unseen data (2014–2017), especially for ML models.
- Model ensembles improve predictions by reducing uncertainties.
- Long-term shoreline forecasts remain highly uncertain due to missing physical processes (SLR, surges, longshore, etc.).
- Data-sharing and coordinated research enhance shoreline evolution modeling.

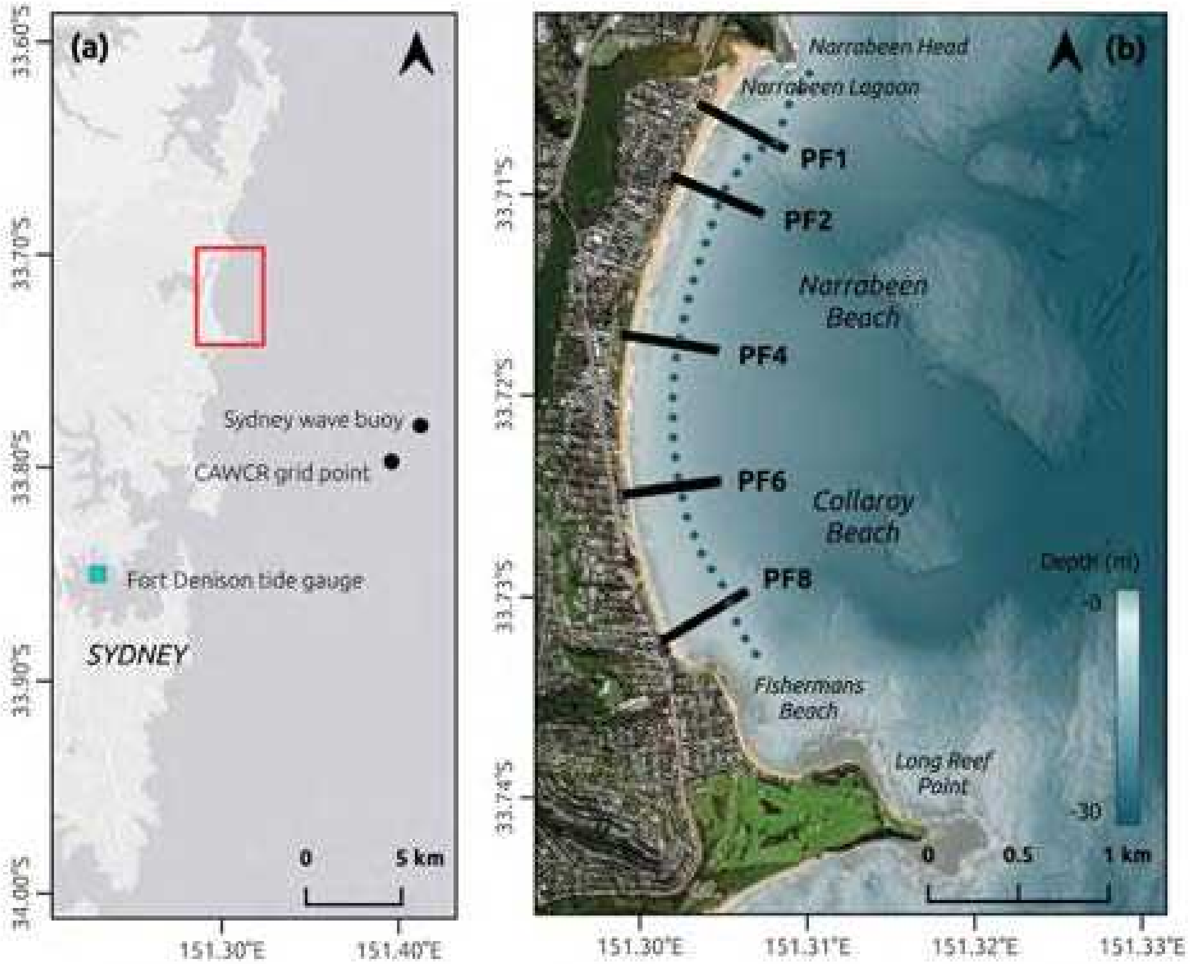
ELSEVIER

Coastal Engineering
Available online 26 February 2025, 104738
In Press, Journal Pre-proof ⓘ What's this?

Evaluating five shoreline change models against 40 years of field survey data at an embayed sandy beach

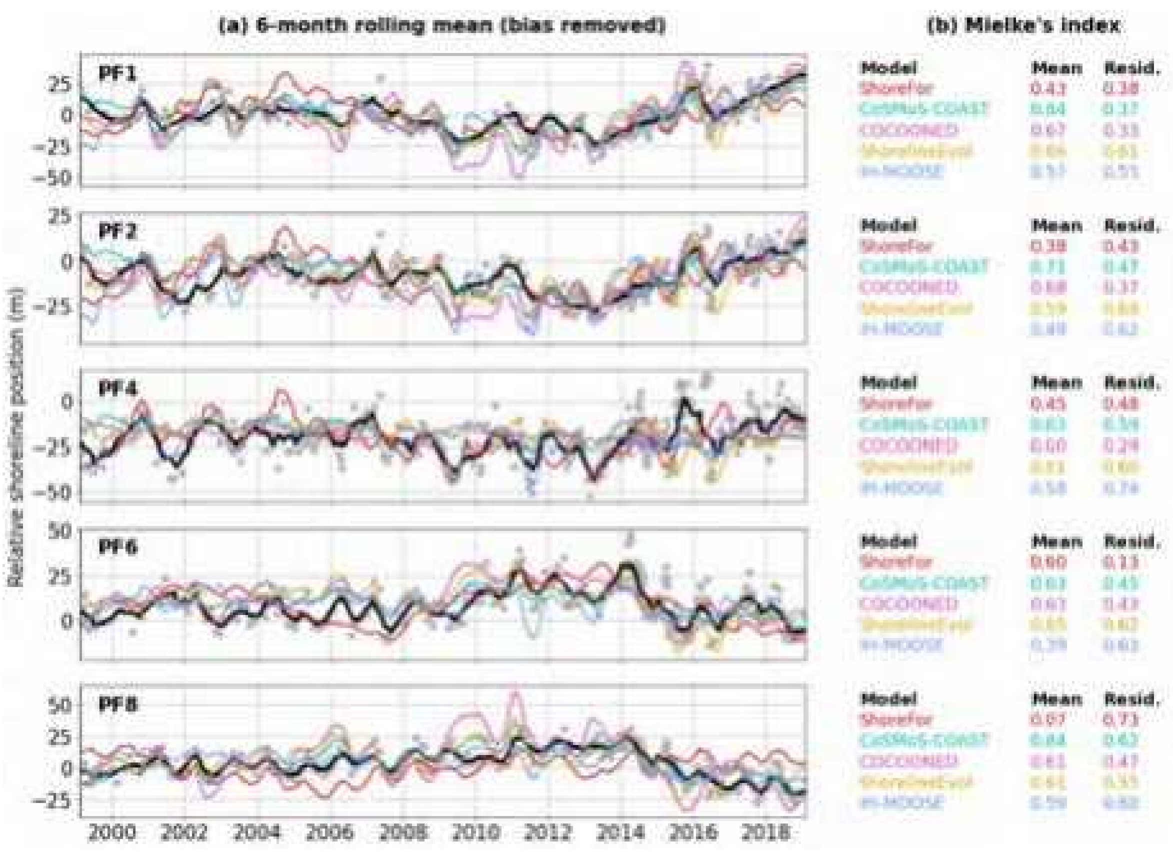
Oxana Repina, Rafael C. Carvalho, Giovanni Coco, José A.Á. Antolínez, Iñaki de Santiago, Mitchell D. Harley, Camilo Jaramillo, Kristen D. Splinter, Sean Vitousek, Colin D. Woodroffe

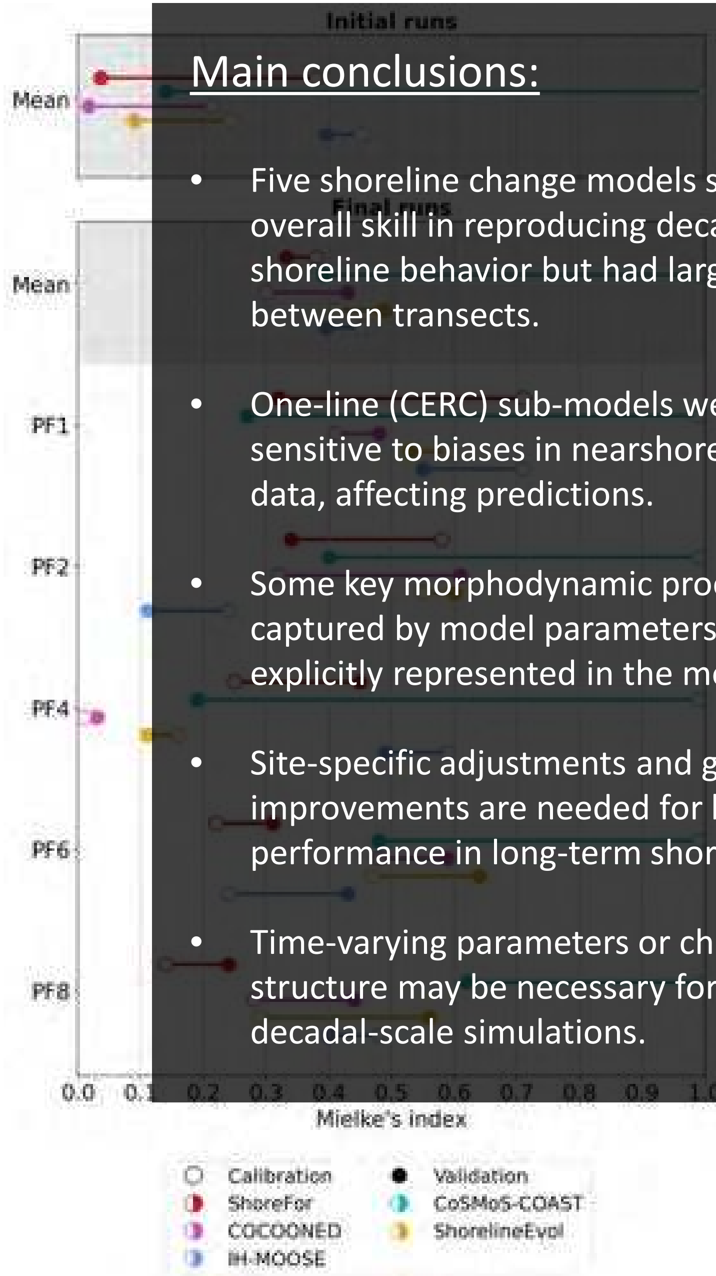
- **ShoreFor** - (Davidson et al., 2013; Splinter et al., 2014)
- **CoSMoS-COAST** - (Vitousek et al., 2017, 2023)
- **COCOONED** - (Antolínez et al., 2019)
- **ShorelineEvol** - (de Santiago et al., 2021)
- **IH-MOOSE** - (Jaramillo et al., 2021)



Repina et al. (2025)

Applications





Main conclusions:

- Five shoreline change models showed similar overall skill in reproducing decadal-scale shoreline behavior but had large variability between transects.
- One-line (CERC) sub-models were highly sensitive to biases in nearshore wave direction data, affecting predictions.
- Some key morphodynamic processes were captured by model parameters rather than explicitly represented in the models.
- Site-specific adjustments and general improvements are needed for better model performance in long-term shoreline evolution.
- Time-varying parameters or changes in model structure may be necessary for reliable decadal-scale simulations.

Repina et al. (2025)

Applications

Shoreshop 2 (2024)

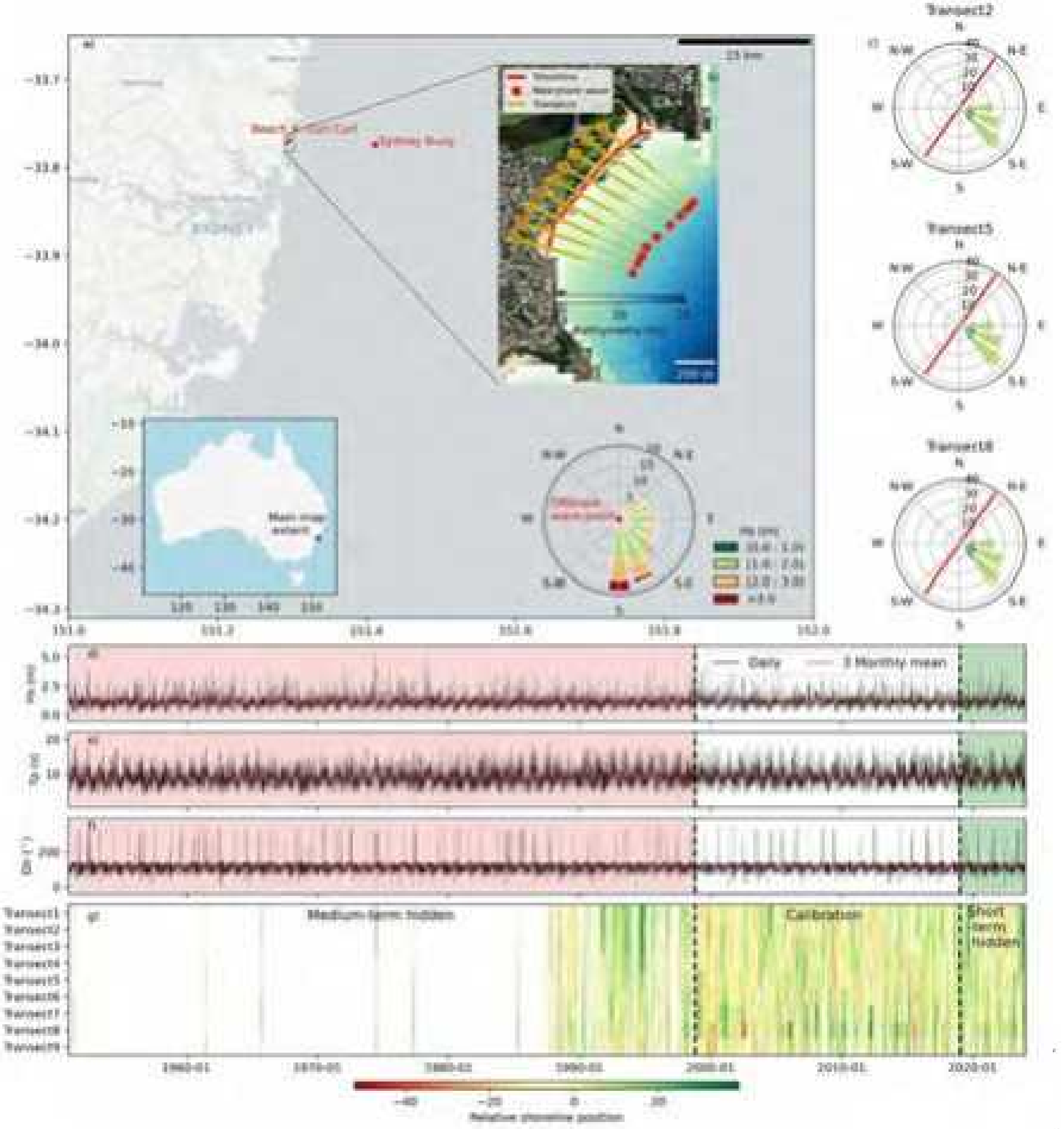
SCIENTIFIC REPORTS
natureresearch

Benchmarking shoreline prediction models over multi-decadal timescales

Yongjing Mao[1*], Kristen D. Splinter[1], Giovanni Coco[2], Sean Vitousek[3], Jose A. A. Antolinez[4], Georgios Azorakos[5], Masayuki Banno[6], Clément Bouvier[7], Karin Bryan[2], Laura Cagigal[8], Kit Calcraft[1], Bruno Castelle[5], Xinyu Chen[9], Maurizio D'Anna[2,10], Lucas de Freitas Pereira[11], Iñaki de Santiago[12], Aditya N. Deshmukh[1], Bixuan Dong[1], Ahmed Elghandour[13], Amirmahdi Gohari[2], Eduardo Gomez-de la Peña[2], Mitchell D. Harley[1], Michael Ibrahim[14], Déborah Idier[15], Camilo Jaramillo Cardona[11], Changbin Lim[11], Ivana Mingo[5], Julian O'Grady[16], Daniel Pais[17, 18], Oxana Repina[19], Arthur Robinet[7], Dano Roelvink[4, 13, 20], Joshua Simmons[21], Erdinc Sogut[22], and Katie Wilson[1]

UNSW Water Research Laboratory

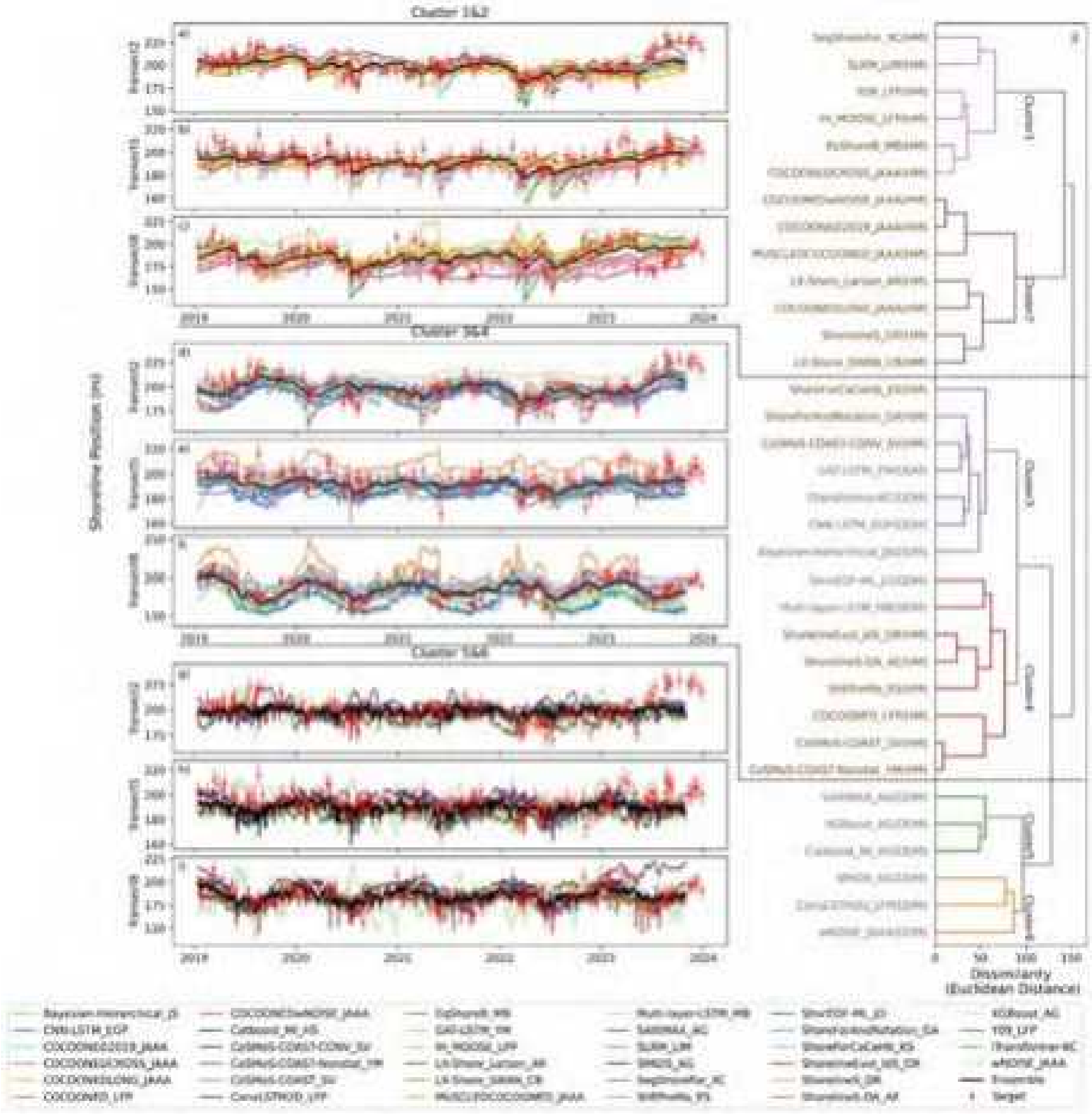
UNSW SYDNEY

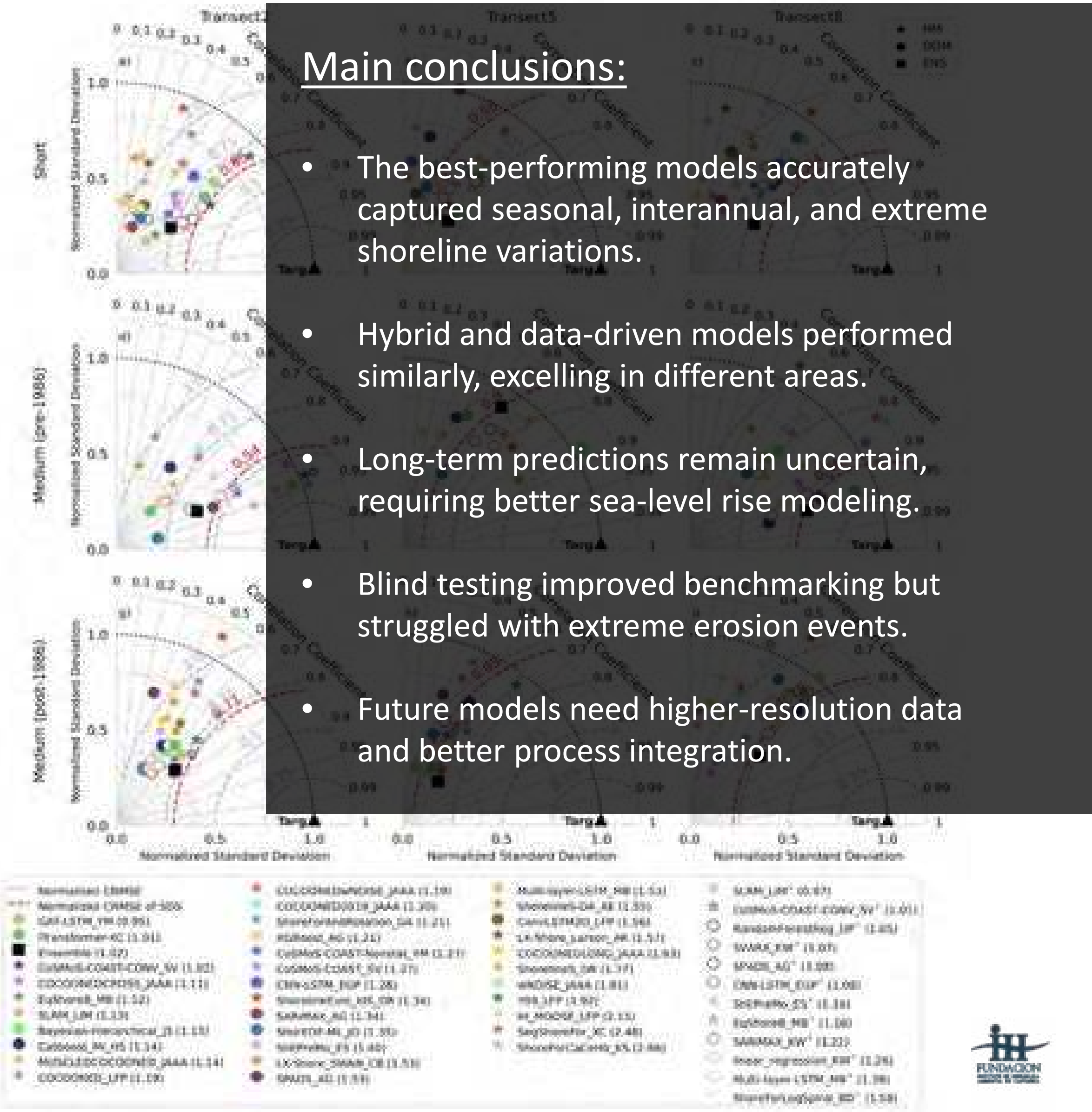


Mao et al. (2025) - submitted

IHcantabria

Applications





Main conclusions:

- The best-performing models accurately captured seasonal, interannual, and extreme shoreline variations.
- Hybrid and data-driven models performed similarly, excelling in different areas.
- Long-term predictions remain uncertain, requiring better sea-level rise modeling.
- Blind testing improved benchmarking but struggled with extreme erosion events.
- Future models need higher-resolution data and better process integration.

Mao et al. (2025) - submitted

IHSET

Shoreline Evolution Tools

IHSET
Shoreline Evolution Tools

Objective:

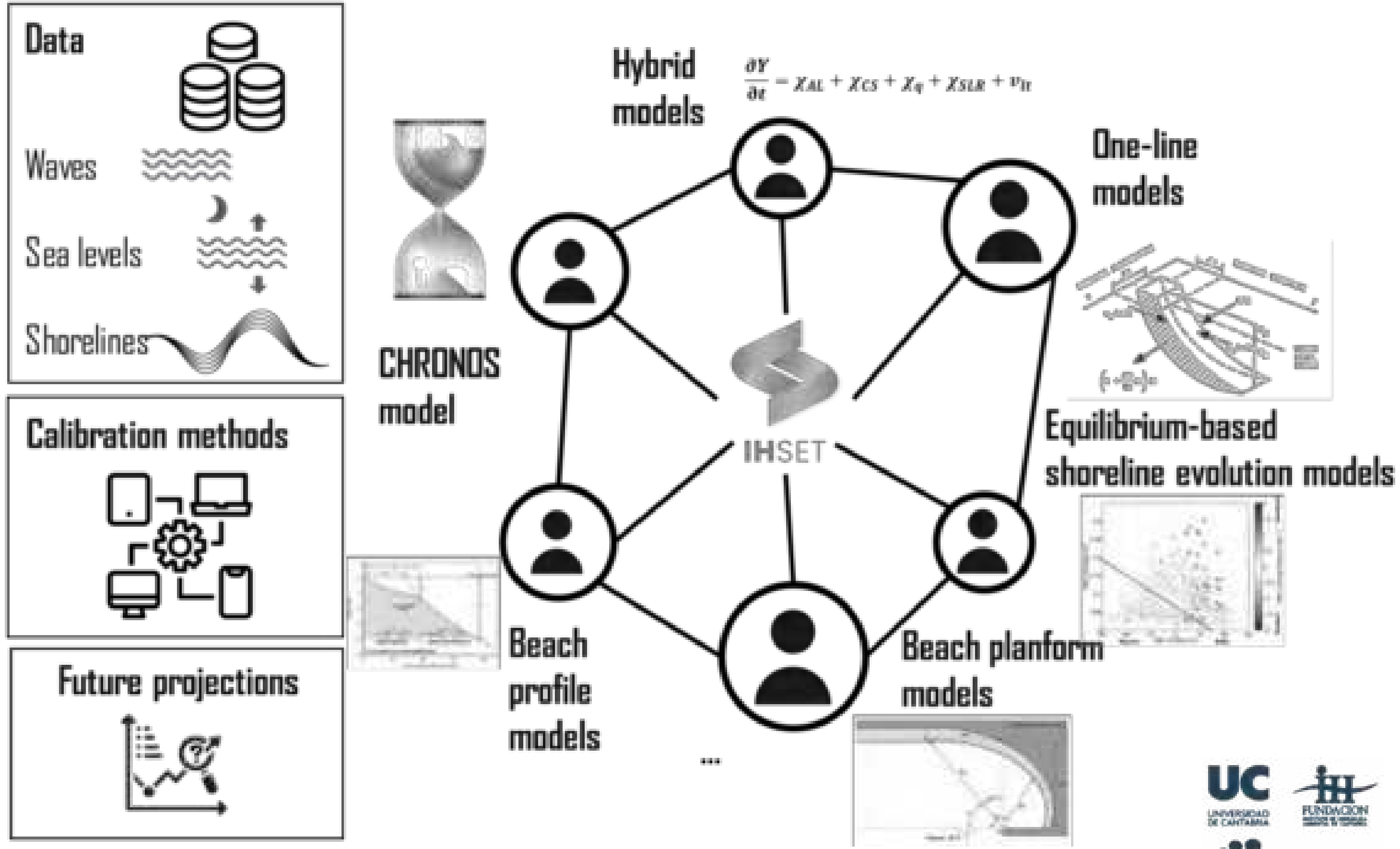
Develop the **Shoreline Evolution Tools system, IH-SET**—a versatile tool designed to enable engineers and coastal managers to conduct morphodynamic studies at varying spatial and temporal scales. This system can be applied within the context of project development or the assessment of a beach as a distinct physiographic unit.

Motivation

The Coastal Group at IHCantabria has spent years researching new proposals for morphodynamic models. Two primary needs have emerged that require attention:

1) The creation of a unified system for shoreline morphodynamic models, enabling users to select and implement the most suitable methodology quickly based on the project's scope and goals.

2) Increased research efforts to develop a shoreline evolution model that integrates cross-shore and longshore processes while ensuring sediment conservation.

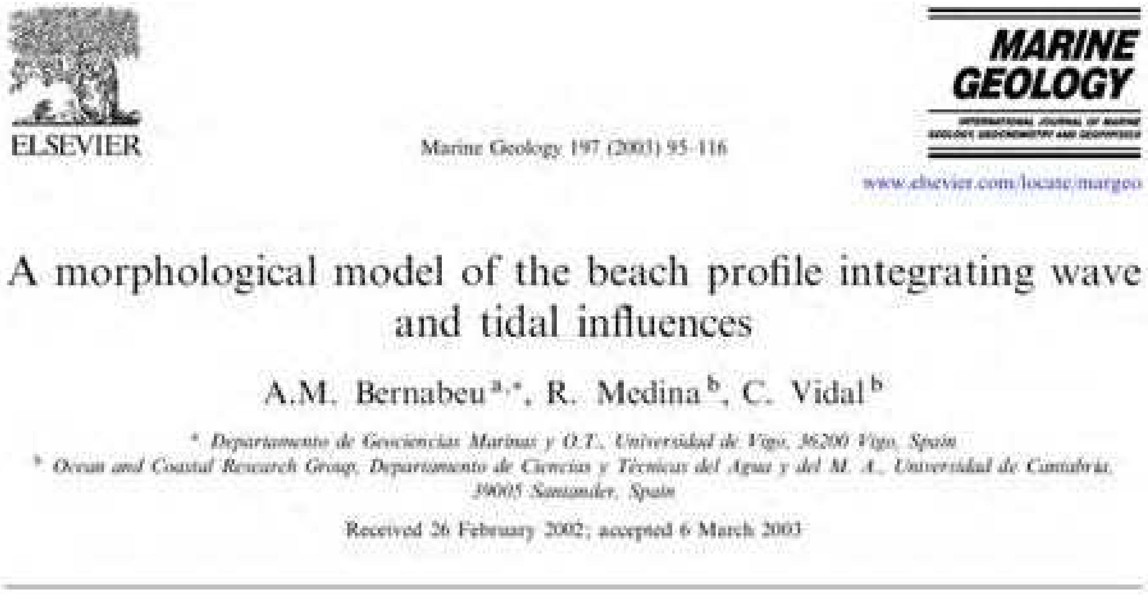


Contents - IH-SET

Models developed by the Coastal Management and Engineering Group of IHCantabria

IH-SET

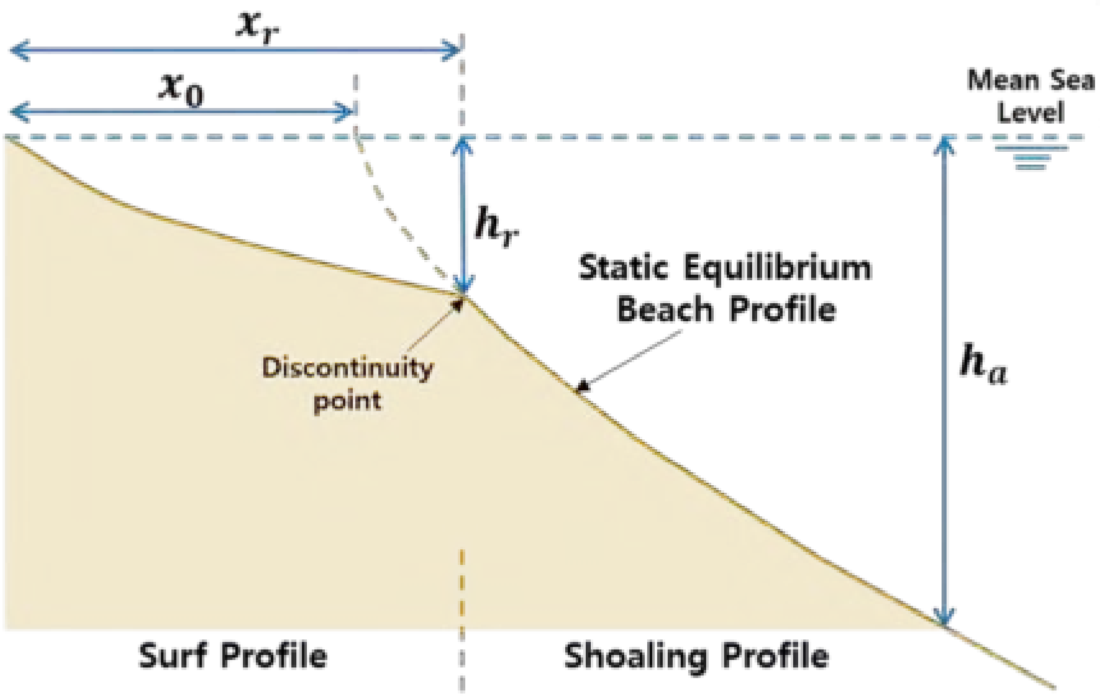
Ana M. Bernabeu Tello


ELSEVIER
Marine Geology 197 (2003) 95–116
MARINE GEOLOGY
www.elsevier.com/locate/margeo

A morphological model of the beach profile integrating wave and tidal influences

A.M. Bernabeu[a,*], R. Medina[b], C. Vidal[b]
[a] Departamento de Geociencias Marinas y O.T., Universidad de Vigo, 36200 Vigo, Spain
[b] Ocean and Coastal Research Group, Departamento de Ciencias y Técnicas del Agua y del M. A., Universidad de Cantabria, 39005 Santander, Spain

Received 26 February 2002; accepted 6 March 2003



Surf profile :

$$x = \left(\frac{h}{A}\right)^{3/2} + \frac{B}{A^{3/2}} h^3 \quad 0 \le x \le x_r$$

Shoaling profile :

$$X = x - x_0 = \left(\frac{h}{C}\right)^{3/2} + \frac{D}{C^{3/2}} h^3 \quad x_r \le x \le x_a$$

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1 2 3 4 5

IH-SET

Maria Soledad Requejo Landeira


Coastal Engineering

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

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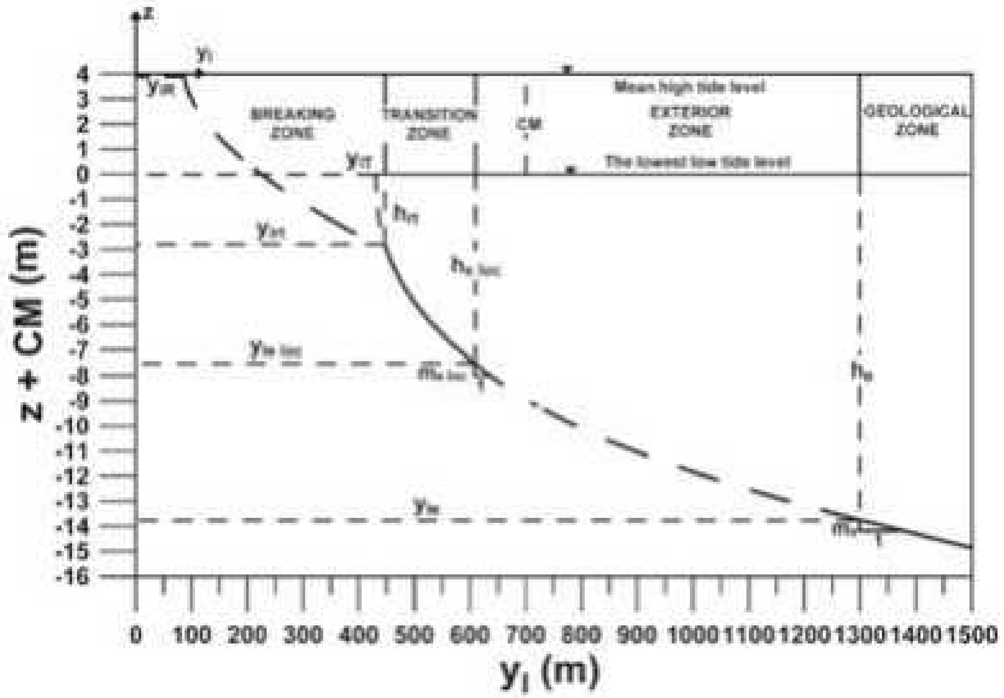
Development of a medium–long term beach evolution model

S. Requejo *, R. Medina, M. González



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IH-SET

Mauricio González Rodríguez

Raúl Medina Santamaría


ELSEVIER

Coastal Engineering 43 (2001) 209–225

Coastal Engineering

www.elsevier.com/locate/coastaleng

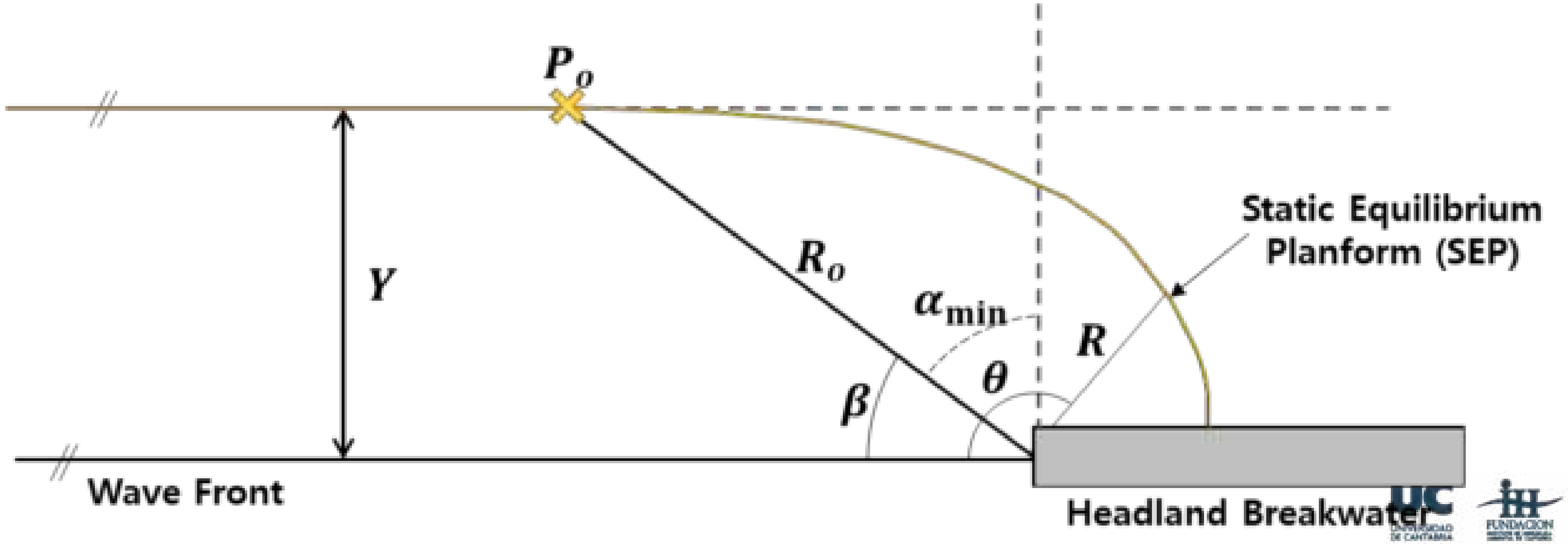
On the application of static equilibrium bay formulations to natural and man-made beaches

Mauricio González *, Raul Medina

Ocean and Coastal Research Group, Departamento Ciencias y Tecnicas del Agua y del Medio Ambiente, Universidad de Cantabria, E.T.S. Ingenieros de Caminos, C. y P., Avda. de los Castros, s/n. 39005 Santander, Spain

Received 9 August 2000; received in revised form 2 April 2001; accepted 1 May 2001

González and Medina (2001) proposed the methodology for estimating the location of the down-coast limit distance R_o from the control point as a function of α_{min}(=90°−β)



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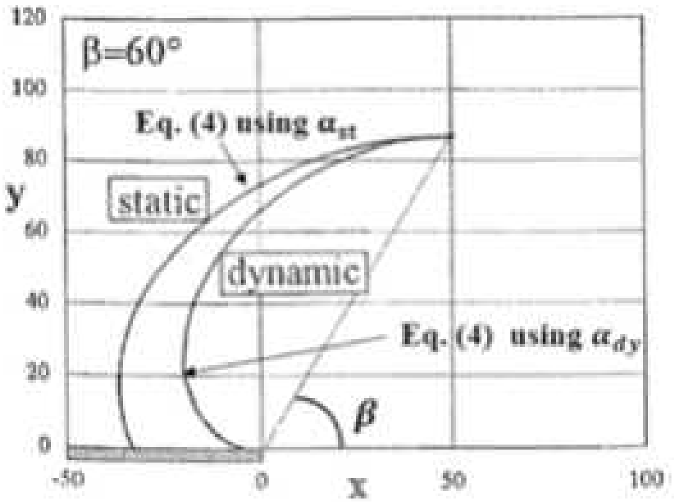
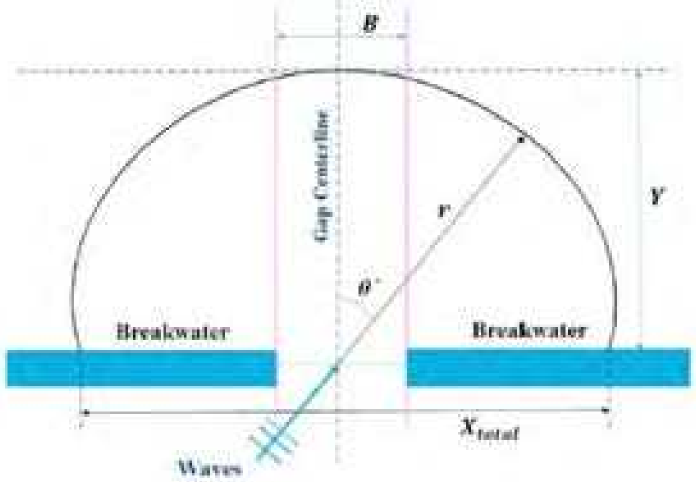
Ahmed Ibrahim Abdelmagid Elshinnaway





Contents lists available at ScienceDirect
Coastal Engineering
journal homepage: www.elsevier.com/locate/coastaleng

Dynamic equilibrium planform of embayed beaches: Part 1. A new model and its verification

Ahmed I. Elshinnawy[a,b,*], Raúl Medina[a], Mauricio González[a]

Contents lists available at ScienceDirect
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journal homepage: www.elsevier.com/locate/coastaleng

Dynamic equilibrium planform of embayed beaches: Part 2. Design procedure and engineering applications

Ahmed I. Elshinnawy[a,b,*], Raúl Medina[a], Mauricio González[a]

Contents lists available at ScienceDirect
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journal homepage: www.elsevier.com/locate/coastaleng

Equilibrium planform of pocket beaches behind breakwater gaps: On the shape of the equilibrium shoreline.

Ahmed I. Elshinnawy[a,b,*], Raúl Medina[b], Mauricio González[b]

IHcantabria

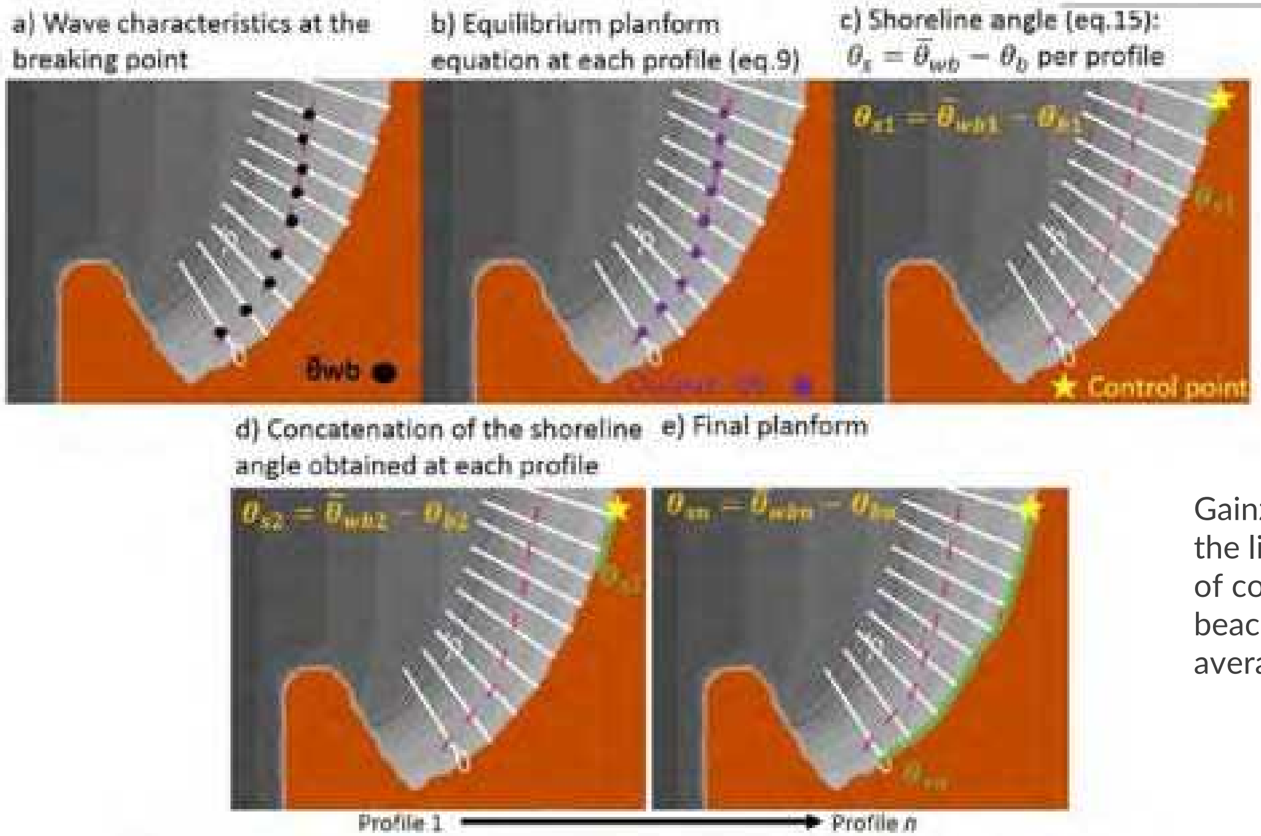
IH-SET

June Gainza Thalamas

Contents lists available at ScienceDirect
Coastal Engineering
journal homepage: www.elsevier.com/locate/coastaleng

A process based shape equation for a static equilibrium beach planform

June Gainza*, Ernesto Mauricio González, Raúl Medina
Environmental Hydraulics Institute (IHCantabria), Universidad de Cantabria, Isabel Torres 15, 39011 Santander, Spain



Gainza et al. (2018) proposed a process-based shape equation that is able to overcome the limitations that current models present and estimate the static equilibrium shoreline of complex bathymetry beaches. The equation is based on the hypothesis that a pocket beach gets its static equilibrium planform when the mean surf-zone longshore velocity averaged over a period of time is null in every point along the beach.

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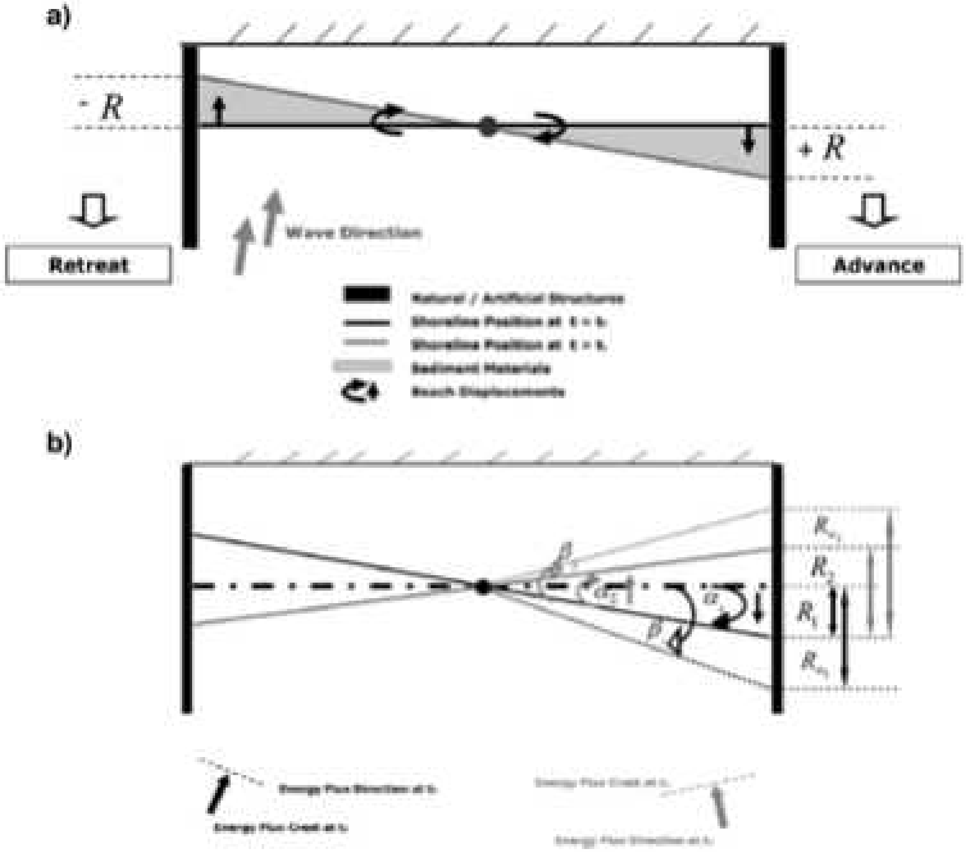
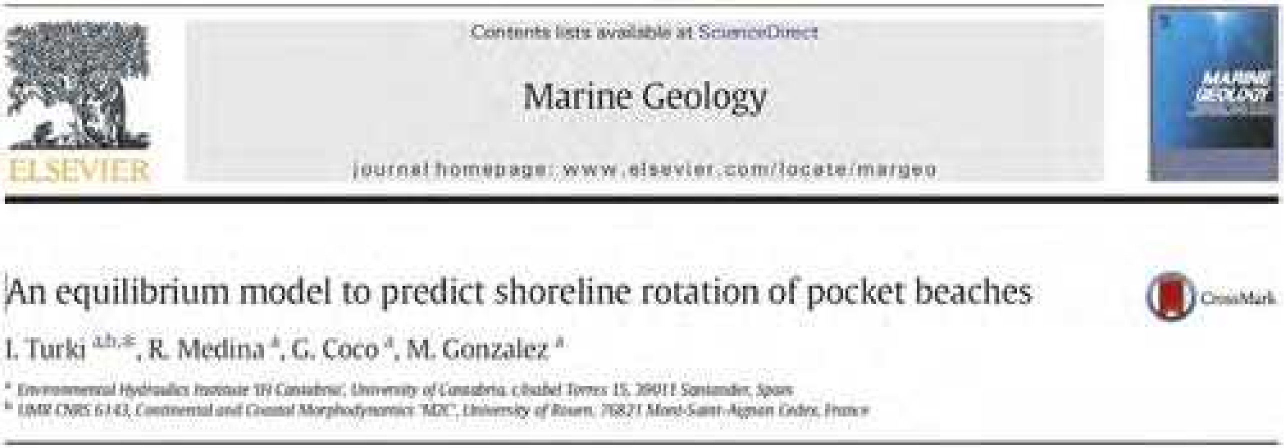
Imen Turki





Contents lists available at ScienceDirect
Marine Geology
journal homepage: www.elsevier.com/locate/margeo

An equilibrium model to predict shoreline rotation of pocket beaches

I. Turki [a,b,*], R. Medina [a], G. Coco [a], M. Gonzalez [a]
[a] Environmental Hydraulics Institute "IH Cantabria", University of Cantabria, c/Isabel Torres 15, 39011 Santander, Spain
[b] UMR CNRS 6143, Continental and Coastal Morphodynamics "M2C", University of Rouen, 76821 Mont-Saint-Aignan Cedex, France

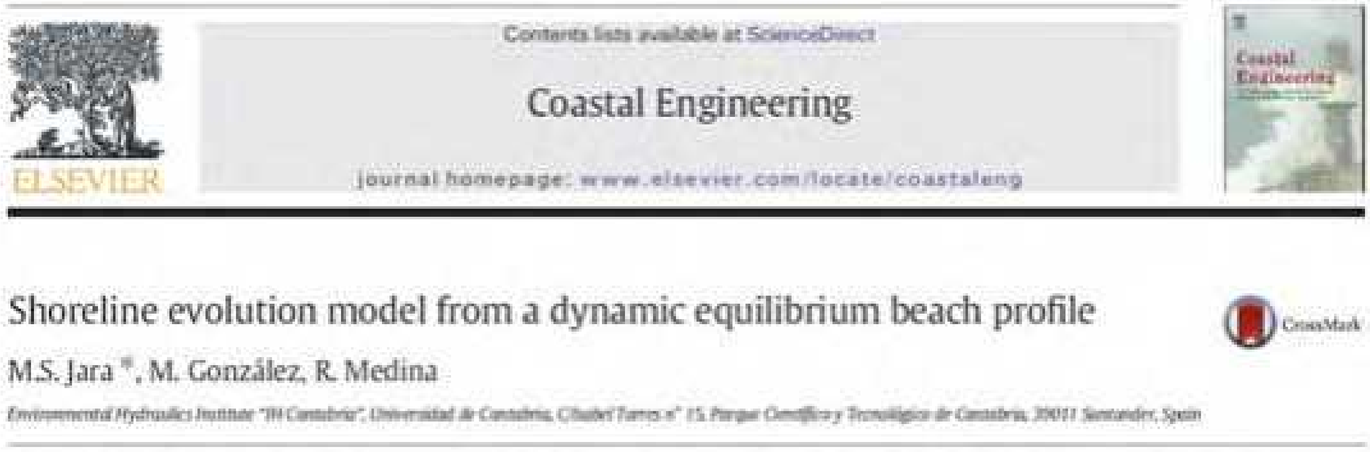
Turki et al. (2013) proposed a shoreline evolution model for predicting the shoreline rotation considering that the shoreline response rate can be expressed as proportional to the difference between the instantaneous position and the equilibrium rotation.

$$\frac{dR(t)}{dt} = \omega \cdot (R_{\infty} - R(t))$$

1 2 3 4 5

IH-SET

Jara Martínez Sánchez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journal homepage: www.elsevier.com/locate/coastaleng

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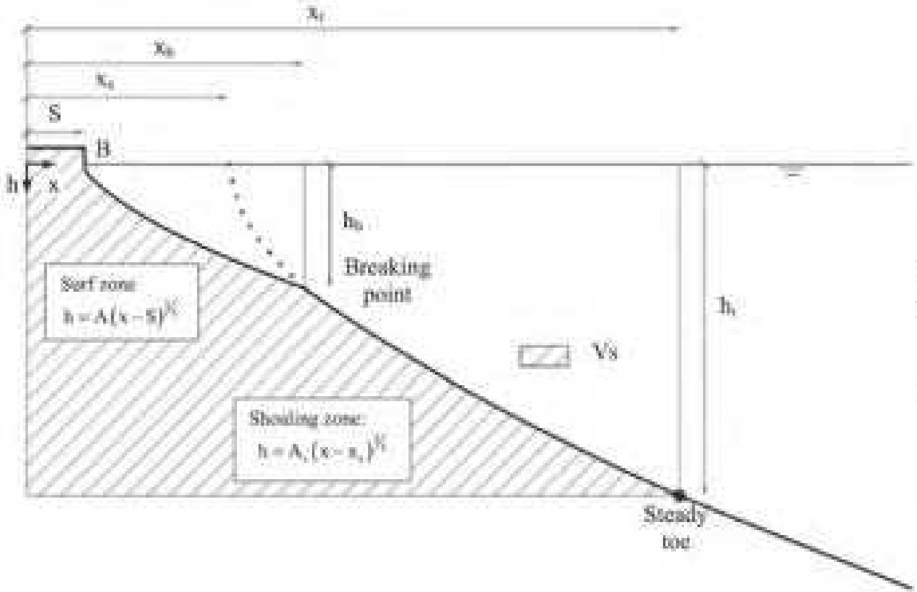
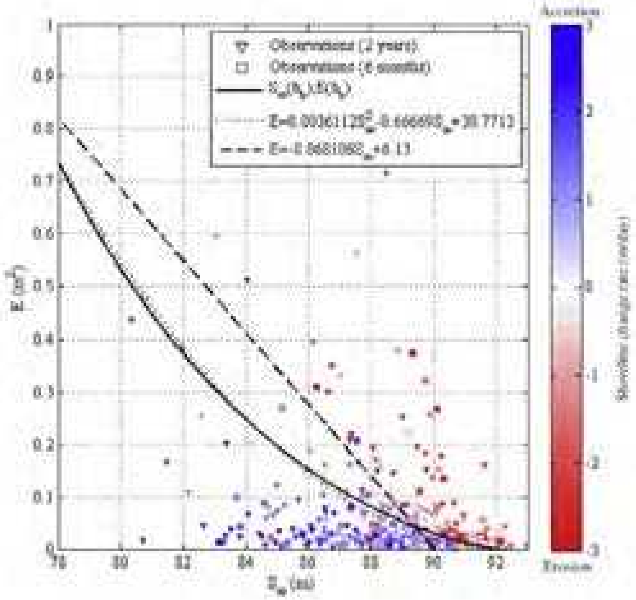
Shoreline evolution model from a dynamic equilibrium beach profile

M.S. Jara *, M. González, R. Medina

Environmental Hydraulics Institute "IH Cantabria", Universidad de Cantabria, C/Isabel Torres nº 15, Parque Científico y Tecnológico de Cantabria, 39011 Santander, Spain





$$\frac{dS(t)}{dt} = C^{\pm} \cdot (E - E_{\infty}(S))$$

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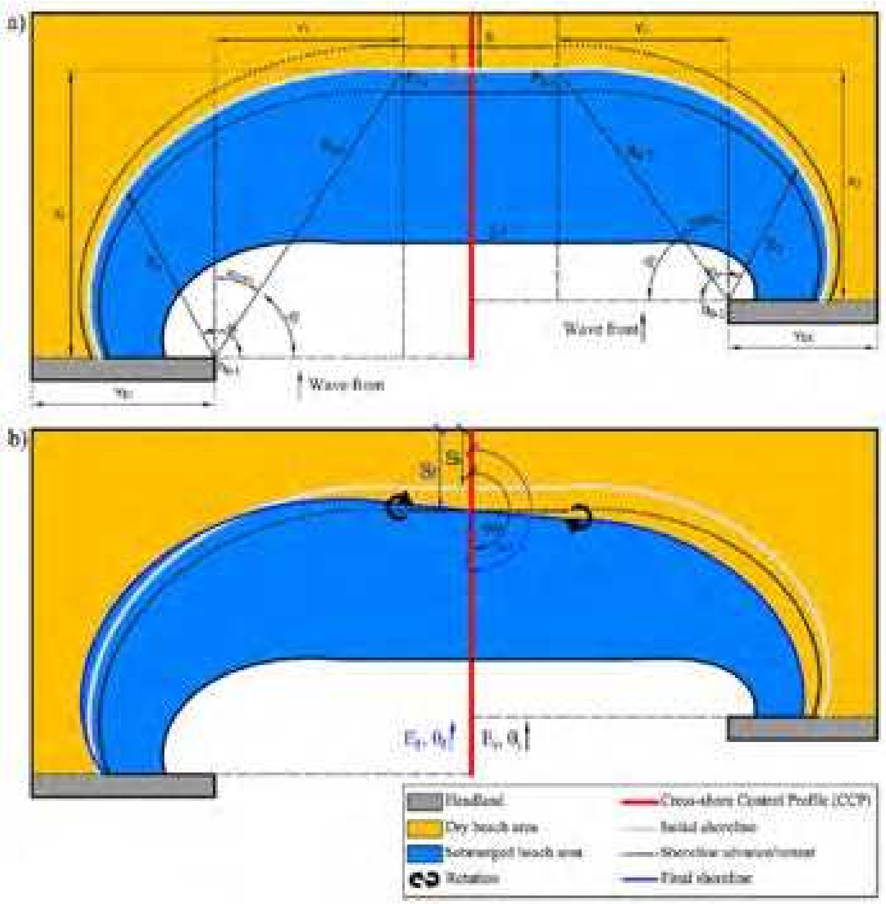
Camilo Jaramillo Cardona



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

ELSEVIER

A shoreline evolution model considering the temporal variability of the beach profile sediment volume (sediment gain / loss)

Camilo Jaramillo *, Martínez Sánchez Jara, Mauricio González, Raúl Medina

Environmental Hydraulics Institute, Universidad de Cantabria, Avda. Isabel Torres, 15, Parque Científico y Tecnológico de Cantabria, 39011, Santander, Spain

Contents lists available at ScienceDirect

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

ELSEVIER

An equilibrium-based shoreline rotation model

Camilo Jaramillo [a,*], Mauricio González [a], Raúl Medina [a], Imen Turki [b]

[a] Environmental Hydraulics Institute, Universidad de Cantabria - Avda. Isabel Torres, 15, Parque Científico y Tecnológico de Cantabria, 39011, Santander, Spain
[b] UMR CNRS 6143 Continental and Coastal Morphodynamics 'M2C', University of Rouen, 76821, Mont-Saint-Aignan Cedex, France

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Camilo Jaramillo *, Martínez Sánchez Jara, Mauricio González, Raúl Medina

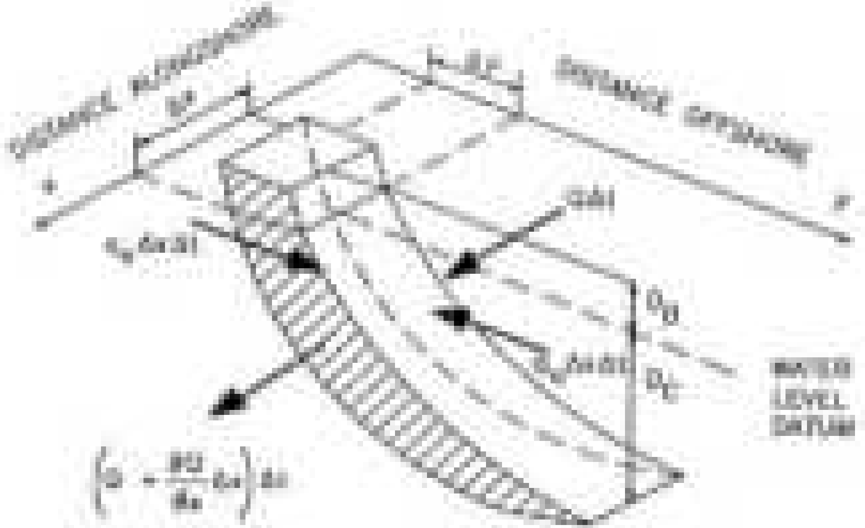
Environmental Hydraulics Institute, Universidad de Cantabria - Avda. Isabel Torres, 15, Parque Científico y Tecnológico de Cantabria, 39011, Santander, Spain

Erica Pellón de Pablo

XV Jornadas Españolas de Ingeniería de Costas y Puertos
Torremolinos, Málaga 8 y 9 de mayo de 2019

CHRONOS: Modelo de evolución costera en el medio y largo plazo

Pellón, E.[a]; Jara, M.S.[a], González-Ondina, J.[b], González, M.[a], Medina, R.[a] y Garnier, R.
[a]Instituto de Hidráulica Ambiental (IHCantabria), Universidad de Cantabria, Santander, España [b]Plymouth Ocean Forecasting Center
Email: pellone@unican.es



CHRONOS MODEL

Research under development within the project:

Lucas de Freitas Pereira

Modeling shoreline evolution on medium- to long-term scales integrating longshore and cross-shore processes

PhD: 12/2022 - 2026

Mayowa Abdusalam

Forecasting the shoreline rotation variability at different beaches around the world

MSc: 01/2024 – 08/2024

Estefanía Giraldo

Validación de modelos de evolución de costa en playas del litoral valenciano

MSc: 04/2024 – 09/2024

Carlos Muñoz Toaboaba

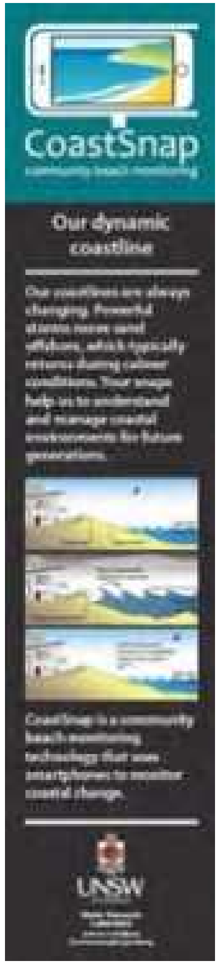
Modelo de evolución de línea de costa IH-MOOSE considerando distintos enfoques de transporte de sedimentos

MSc: 04/2024 – 09/2024

IH-SET

Research under development within the project:

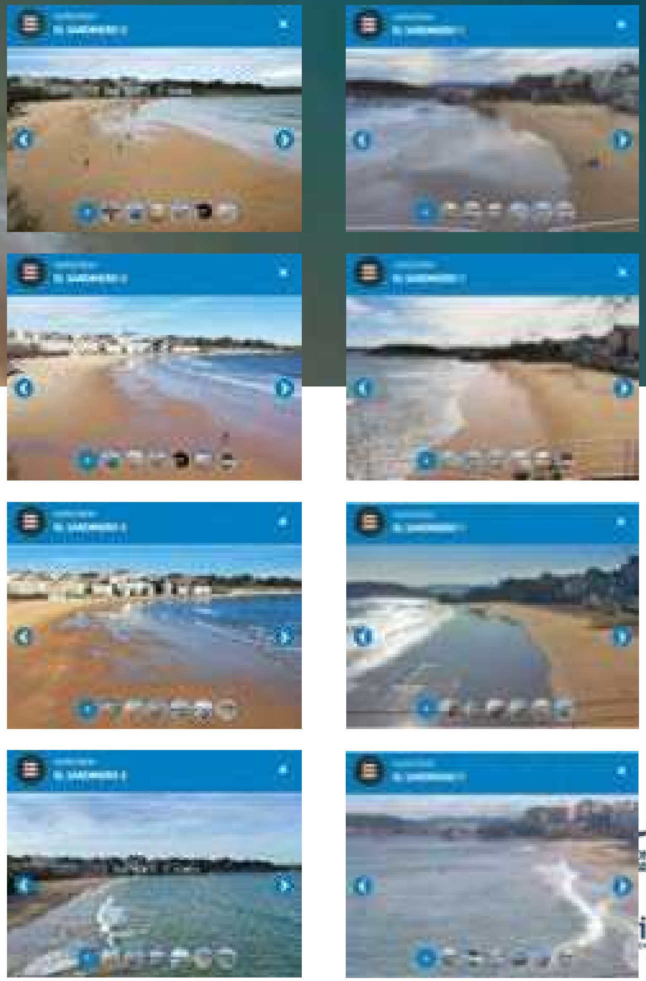
Research under development within the project:



Shoreline evolution modeling – Camilo Jaramillo Cardona

IH-SET

Research under development within the project:



IH-SET

Research under development within the project:

CoastSnap
community beach monitoring

GESEM

Global Equilibrium Shoreline Evolution Models (GESEM) network to predict medium to long-term beach change

info@gesemnetwork.com

Who? What?

17 October 2022

Initial call to join the GESEM network

A Global Equilibrium Shoreline Evolution Models (GESEM) network to predict medium to long-term beach change

The GESEM (Global Equilibrium Shoreline Evolution Models) network

Who? Brings together coastal engineers and scientists with expertise in beach morphodynamics to research shoreline evolution models

What?

- **GESEM** aims at improving the predictability of shoreline evolution models and will focus on investigating key physical processes governing beach evolution across a range of spatial and temporal scales.
- **GESEM** will employ diverse datasets, as well as numerical, statistical, and machine-learning approaches to address the challenge of predicting past and future shoreline evolution.

ICCE 2022

December 8, 2022

30 Researchers
13 Countries
21 Institutions

GESEM - towards integrating, standardizing, and harmonizing work on shoreline evolution modeling

Why GESEM?

Bring a new generation of shoreline evolution models

Promote standards and validated tools for shoreline evolution modeling

Enhance capacity of practitioners and stakeholders through targeted training

Understand the diverse forcing conditions that shape the beach change

Foster global coastal engineering community for improved beach understanding.

GESEM objectives

Develop robust methods and models

Integrate cross-shore and longshore processes, preserving the sediment budget and considering climate change impacts

Share standardized, open-source tools, guidelines, and practices

Mutualize efforts testing and improving the ability of models to predict shoreline changes

Predict future shoreline evolution integrating different spatial scales from local to regional scales

Provide effective tools of coastal evolution, useful for different applications (e.g., beach nourishment, coastal adaptation plans) accessible to engineers and stakeholders

Disseminate results

GESEM CORE GROUP

Camilo Jaramillo Cardona
IHCantabria

Lucas de Freitas Pereira
IHCantabria

Marissa Yates
Ecole des Ponts / Saint-Venant Hydraulics Laboratory

Imen Turki
University of Rouen

Nicolas Le Dantec
Université de Bretagne Occidentale

José A. Álvarez Antolínez
Delft University of Technology

Mauricio González Rodríguez
IHCantabria

Raúl Medina Santamaría
IHCantabria

Giovanni Coco
University of Auckland

Sean Vitousek
Pacific Coastal and Marine Science Center, USGS

Kristen Splinter
University of New South Wales, UNSW

Mitchell Dean Harley
University of New South Wales, UNSW

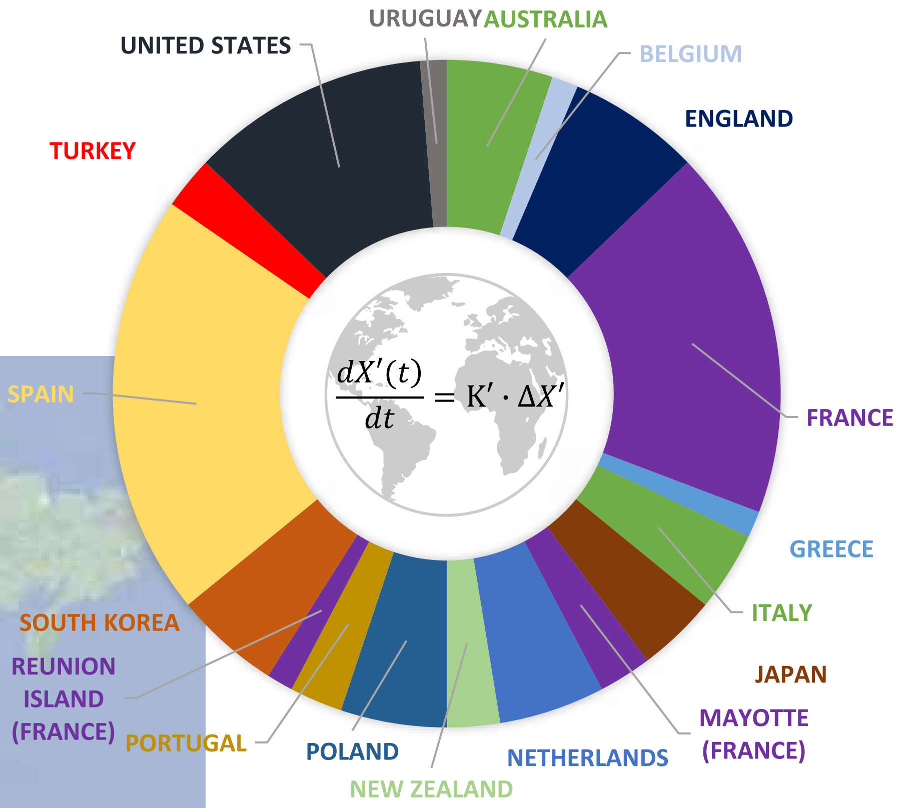
GESEM status

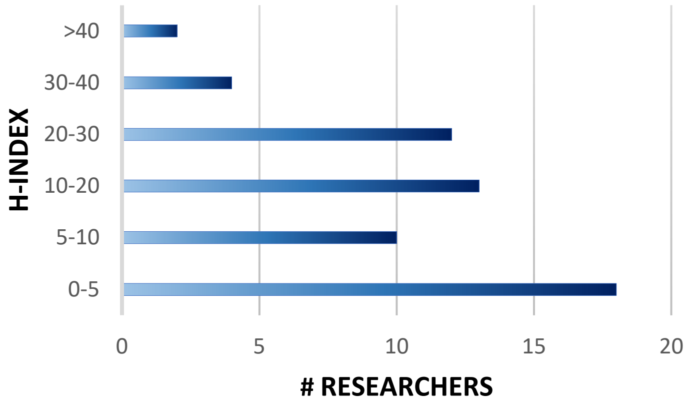
80 Researchers

16 Countries

56 Institutions

89% 11%





Activities

Journal of *Marine Science and Engineering*

Special issue: **Assessment of Multi-scale Coastal Evolution in a Changing Climate: from Observation to Modelling**

A special issue of Journal of Marine Science and Engineering (ISSN 2077-1312). This special issue belongs to the section "Coastal Engineering".

Deadline for manuscript submissions: 31 December 2024

Special Issue Editors:
Dr. E. Imen Turki
Dr. Marissa Yates
Dr. Camilo Jaramillo Cardona
Dr. Nicolas Le Dantec

COASTAL DYNAMICS 2025
AVEIRO, PORTUGAL

Special session: '**Shoreline Evolution Modeling**'

Session Details:

Conveners: Camilo Jaramillo Cardona, E. Imen Turki, Jose A. Á. Antolínez, Marissa Yates, Nicolas Le Dantec

Abstract Submission Dates: From 01/03/2024 to 30/06/2024

10th Coastal Dynamics Conference Dates: 7th – 11th April 2025

Location: Aveiro, Portugal

- **18 oral presentations (divided into 3 sessions)**
- **7 posters**

“COMMONCOAST: A common coast to cherish – capping climate change”
(Invited Speaker Jara Martínez, IHCantabria)

“COMMONCOAST: A common coast to cherish – capping climate change in MALTA”

Let’s close the risk information gap!

Dr. Jara Martínez

11th March 2025

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DRR and CCA

[Thought Leadership Course - Synergizing Disaster Risk Reduction and Climate Change Adaptation | UNSSC | United Nations System Staff College]

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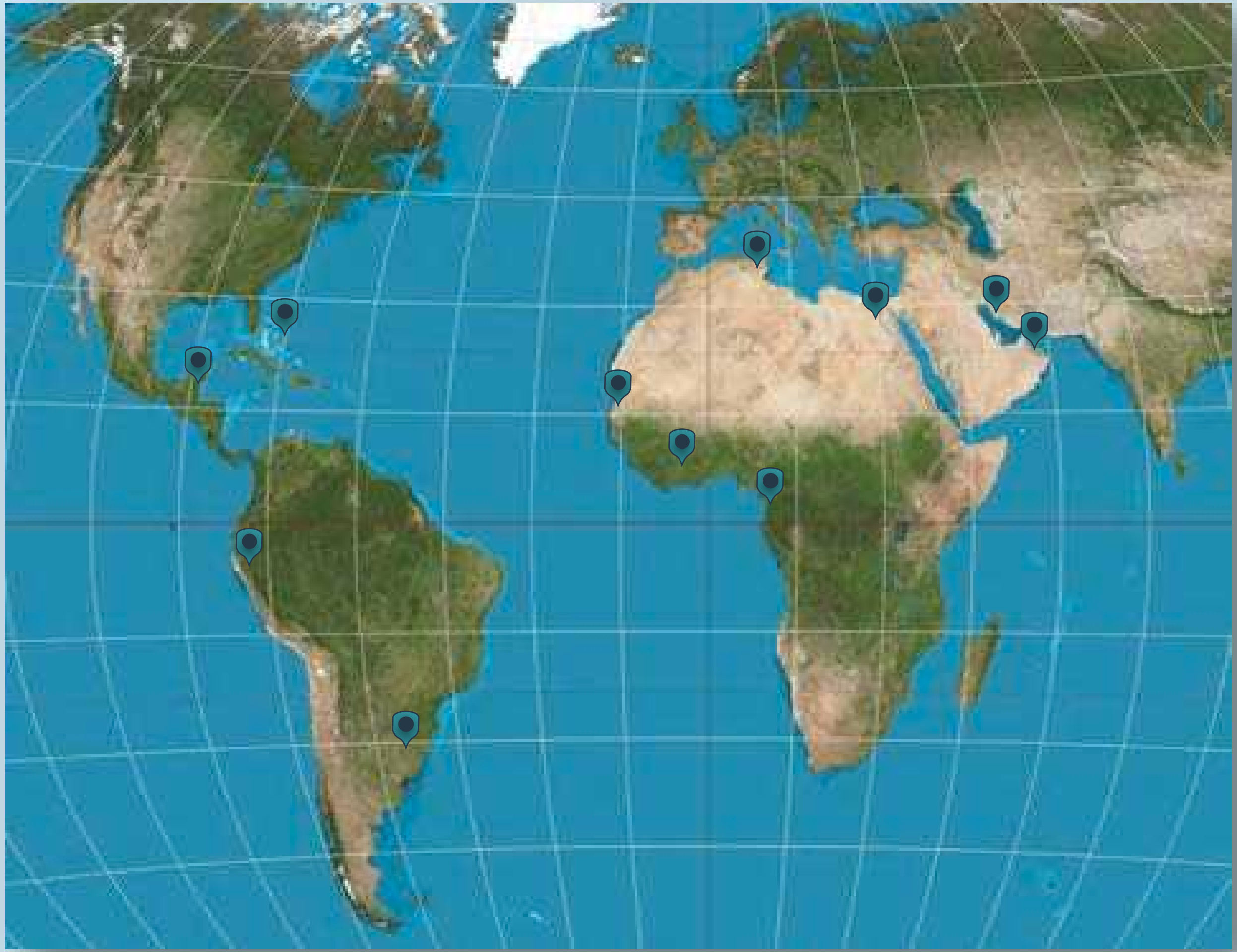
DRR and CCA in Coastal Areas

- International works since 2007: Oman, Qatar, Egypt, Tunisia, Gabon, Belize, Bahamas, Peru, Uruguay…



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DRR and CCA in Coastal Areas

- International works since 2007: Oman, Qatar, Egypt, Tunisia, Gabon, Belize, Bahamas, Peru, Uruguay…
- Request from European countries since 2019: 4 regional and 2 national strategies – Spain and Malta

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IHcantabria
INSTITUTO DE HIDRÁULICA AMBIENTAL
UNIVERSIDAD DE CANTABRIA

The Maltese Islands

The world's 10th-smallest country and the 9th most densely populated

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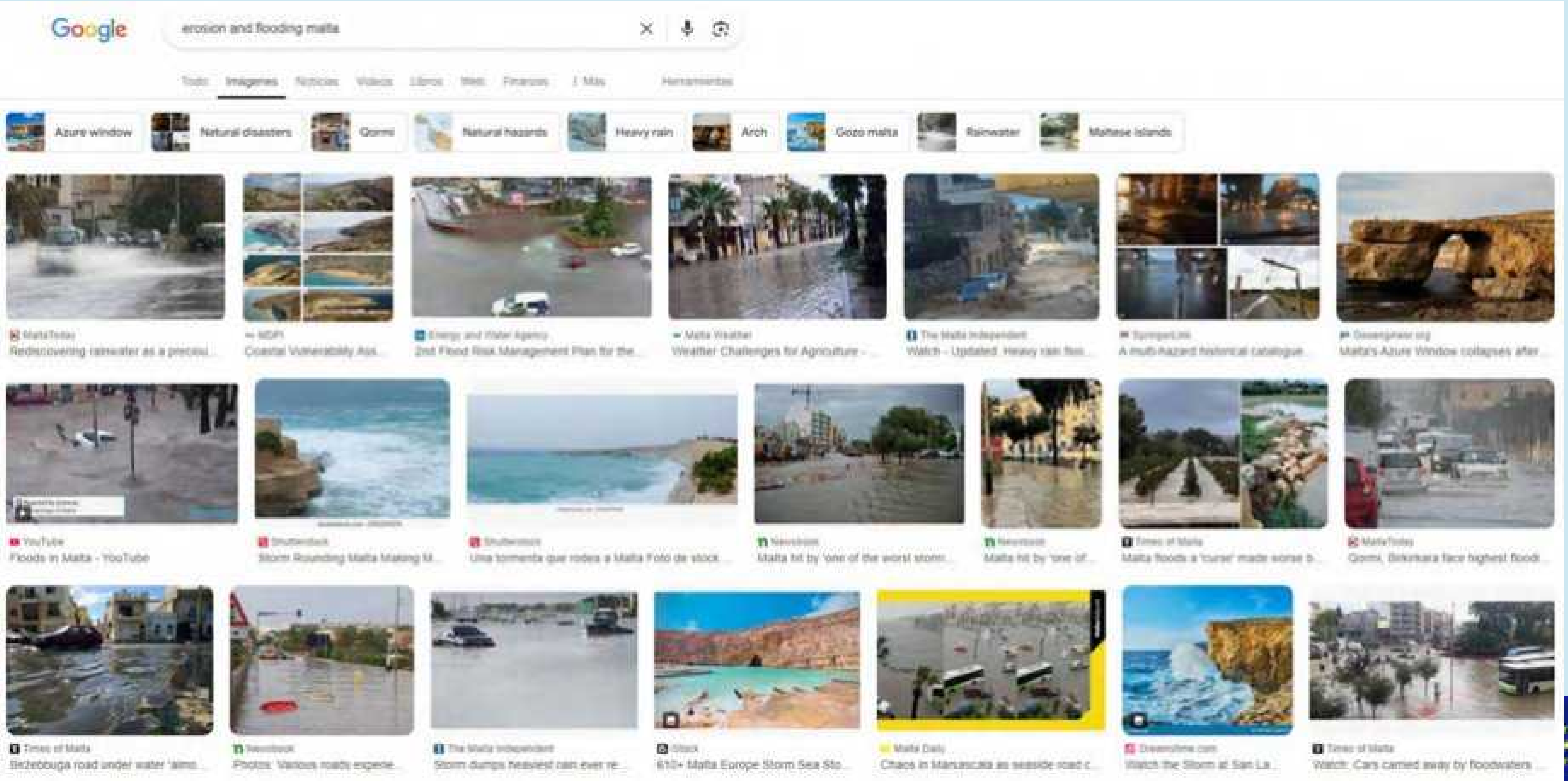
UNIVERSIDAD DE CANTABRIA

Coastal erosion and flooding hazards in Malta



“COMMONCOAST:
A common coast to cherish – capping climate change in MALTA”

From Coastal-COVER (2022-2023)

- ***Coastal-Climate Overall Vulnerability and Exposure Risk***

to Climate-MATCH (2024-2025)

- ***Mainstreaming of Climate Adaptation for Horizontal Coordination***

PUBLIC CLEANLINESS

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Project 1. Coastal-COVER (2022-2023)

YEAR 1 - Diagnosis

YEAR 2 - Development of the strategy

- Governance Analysis
- Physical Assessment & Integrative coastal erosion and flooding risk assessment
  - Baseline data & information
  - Perception of risks, key issues & hotspots
- EU practical experiences in coastal protection & beach management plans
- Proposals of suitable coastal protection measures
- Methodology for the selection of the courses of action
- Design & development of the National Coastal Protection Strategy

Strategy for coastal protection and adaptation to climate change in the Maltese Islands

Stakeholder Engagement & Communication

Plan | CONSULTATION | CONSULTATION | Factsheets

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Coastal & Marine

IHcantabria
INSTITUTO DE HIDRÁULICA AMBIENTAL
UNIVERSIDAD DE CANTABRIA

Aktis Hydraulics

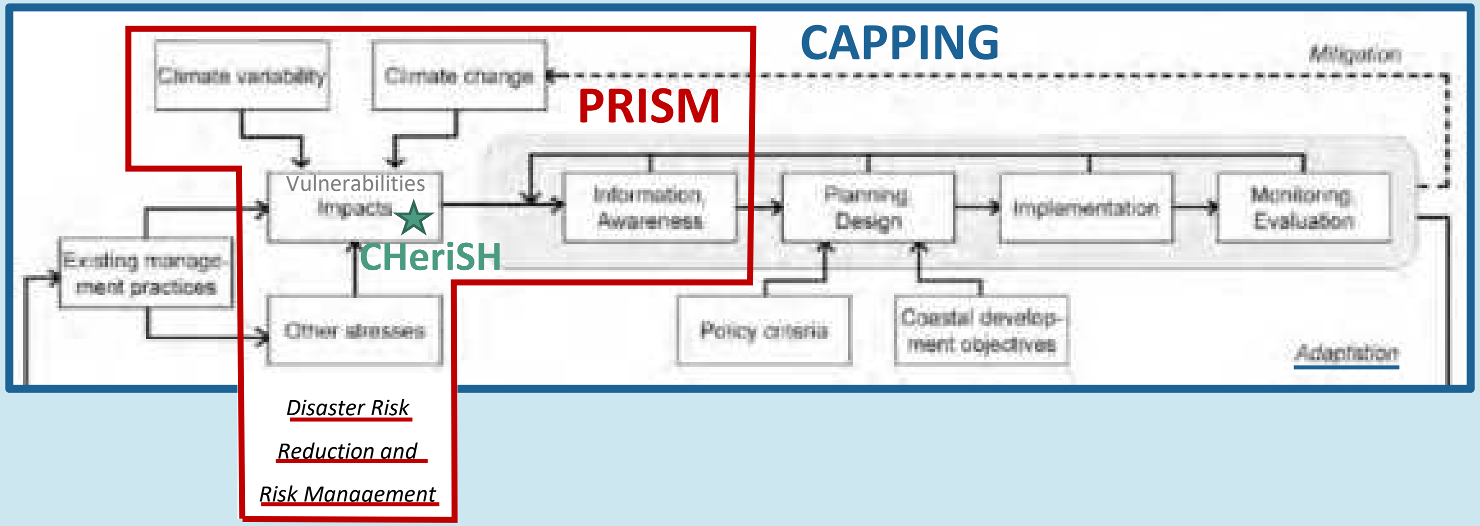
L-Università ta' Malta

Project 2. Climate-MATCH (2024-2025)

Risk information > Risk managment through a model for multi-layered data integration into a central hub for interinstitutional data sharing

PRISM

~ Preparation towards Risk Interdisciplinary Surveillance and Management in Coastal areas ~



CAPPING

~Climate Adaptation in Policy and Planning with integrated governance and knowledge~

CHERISH

~Coastal Heritage and Safeguards against Hazards~

Public Works Department

GOVERNMENT OF MALTA
MINISTRY FOR THE ENVIRONMENT, ENERGY AND PUBLIC CLEANLINESS

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Contents

1. Background Analysis
   - Data gathering process and baseline data
   - Coastal Hydro-morphodynamics
2. Coastal Risk Assessment
3. Integrative Risk Assessment
4. Risk Information Hub

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1. Background Analysis

- **Baseline information**

Pre-existing segmentation of the coastal area

Physical geography

NEW Marine climate

- Sea wind
- Waves
- Astronomical tide
- Storm surge
- Climate change projections

Hydrology

Geology

Geomorphology

NEW Erosion evidence

Protected natural areas

Land cover

Uses of coastal areas

- Urban areas and buildings
- Tourism sector
- Cultural, ethnographic and heritage
- Critical infrastructures

Permanent population

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1. Background Analysis

- **Data gathering process**
  - ✓ 16 Local Data Contributors

Participants were provided with a data collection form, which divided categorised expected inputs into four broad categories

- Public Works Department
- Malta Tourism Authority
- Continental Shelf Department
- Ministry for Gozo
- Superintendence of Cultural Heritage
- Transport Malta
- Planning Authority
- Ministry for the Environment, Energy and Enterprise
- National Statistics Office
- ADI Associates
- Ministry for the National Heritage, the Arts and Local Government
- Project Green
- University of Malta
- Infrastructure Malta
- National Statistics Office
- Environment and Resources Agency
- Participants in Consultation

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1. Background Analysis

- **Data gathering process**
  - ✓ 16 Local Data Contributors
  - ✓ Challenges

Local data gathering was fruitful but posed many challenges including

- ❑ Data errors or outdated software suites
- ❑ Identical data sets from different entities, sometimes with differing parameters
- ❑ Lack of standardization
- ❑ Paperwork delays (information management, NDAs)
- ❑ Unclear or missing metadata
- ❑ Uncertain ownership of data


Public Work Department

Preamble

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1. Background Analysis

- **Data gathering process**
  - ✓ 16 Local Data Contributors
  - ✓ Challenges
  - ✓ Compilation of data

    - ❑ The data gathering process took **six months** to complete (excluding quality control)
    - ❑ Uncertainties arose during technical appraisal and necessitated **further inquiry** concerning certain data sets
    - ❑ Datasets were inspected and **quality control** flags were assigned

Entity	Data type index	Data Name	Format
PA (SintegraM)	BN, APE	Base Map (coastal buffer)	GIS (vector)
PA (SintegraM)	BN, APE	Base Map (portal link)	GIS service
PA (SintegraM)	BN	DTM (Mosaic)	GIS (raster)
PA (SintegraM)	BN	DSM (Mosaic & Tiles)	GIS (raster)
PA (SintegraM)	BN6	Orthophotos (Mosaic)	GIS (raster image)
PA (SintegraM)	BN6	Orthophotos (Portal link) (BN_PA_SintegraM_Portal_Links.txt)	GIS service (WMS)
PA	BN	PA MapServer (BN_PA_SintegraM_Portal_Links.txt)	Weblinks (mhtml) / WebGIS
PA (MSDI)	APE9.2	msdi.data.gov.mt (APE9.2_PA_MSDI.txt)	Weblinks (mhtml) / WebGIS
PA	BN2	Bathymetric data from ERDF156 Project	GIS (raster image)
PA	BN4	1998, 2004, 2008, 2016 & 2018 Orthophotos	GIS (File Geodatabase Raster
PA	BN4	2018 Orthophoto	GIS (raster image)
PA	BN1, BN5	Urban and Rural Coastal Regions	GIS (vector)
PA (ERDF156)	BN2	DTM (Mosaic)	GIS (raster)
CSD	BN3	Malta Water Line	GIS (vector)
CSD	NPE2	Geological Map Of Malta	GIS (vector)
CSD	NPE8	EMODnet Coastal Migration	GIS (vector)
PARKS	NPE3	Water Catchments	GIS (vector)
PARKS	NPE3	Stream Network Malta	GIS (vector)
PARKS	NPE3	Stream Network Gozo	GIS (vector)
PARKS	NPE3	Flow Observation Names	GIS (vector)

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1. Background Analysis

- **Data gathering process**
  - ✓ 16 Local Data Contributors
  - ✓ Challenges
  - ✓ Compilation of data
  - ✓ Local knowledge gaps

Examples of missing/incomplete local knowledge

- ❑ **Caves**: No formal dataset denoting all cave systems in Malta.
- ❑ **Coastline**: No agreed upon local definition for what constitutes coastline/shoreline. As such, there is no national physical shoreline.
- ❑ **Coastal heritage**: Available heritage data sets often only demark location of coastal heritage sites and lack other details.
- ❑ **2018 DTM**: Recent digital terrain model (2018) has insufficient vertical resolution to be used for wave modelling. The interface between land and sea was done using 2012 data.
- ❑ **Coastal structures**: Structural typology and design parameters of the built-up waterfront to characterise their sensitivity under wave loads.

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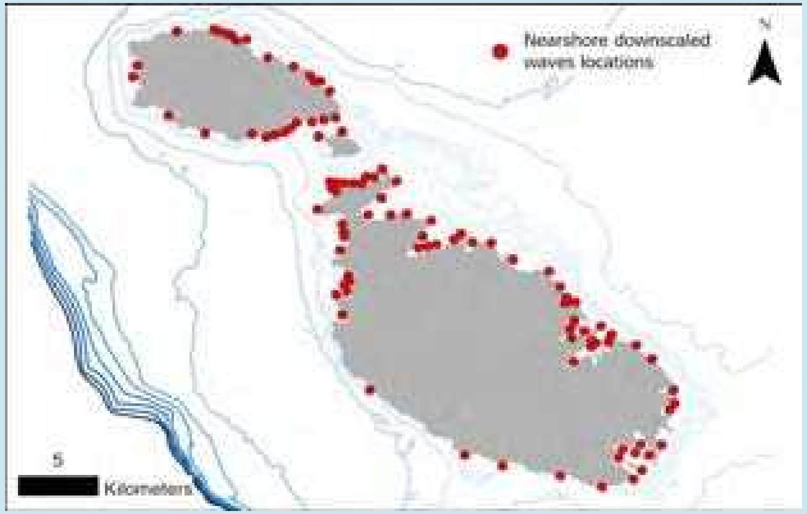
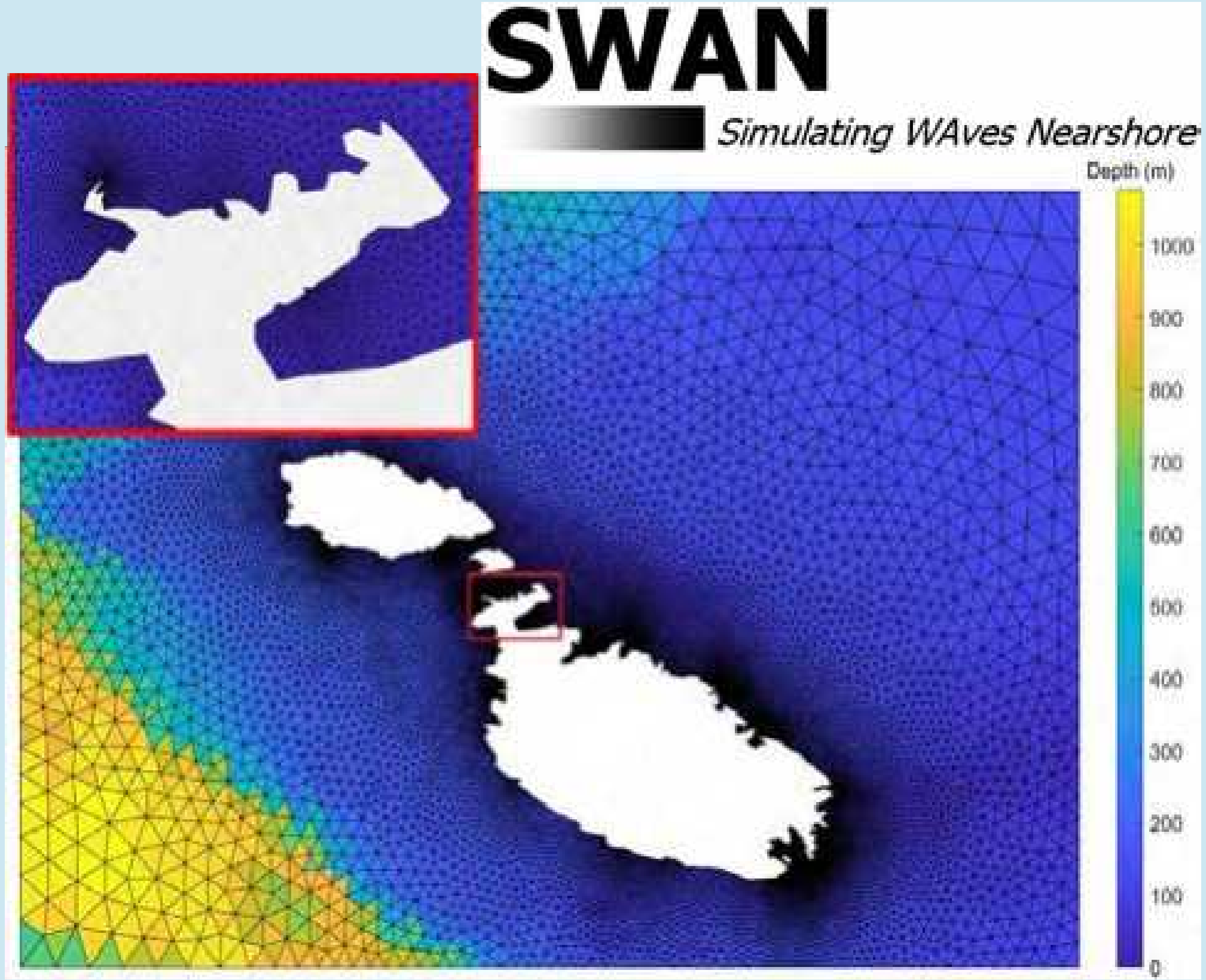
1. Background Analysis

- **Coastal hydro-morphodynamics**
  - ✓ Nearshore wave regime





- ❑ Total water level (tide+surge+run-up)
- ❑ Wave overtopping discharge
- ❑ Wave force

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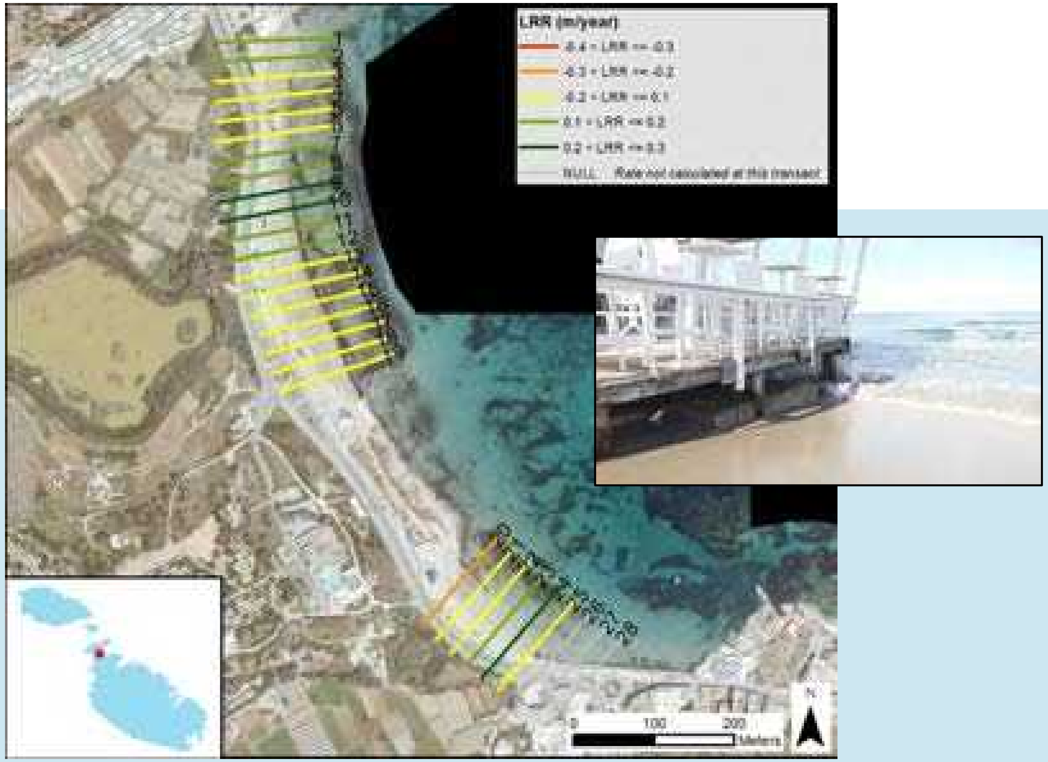
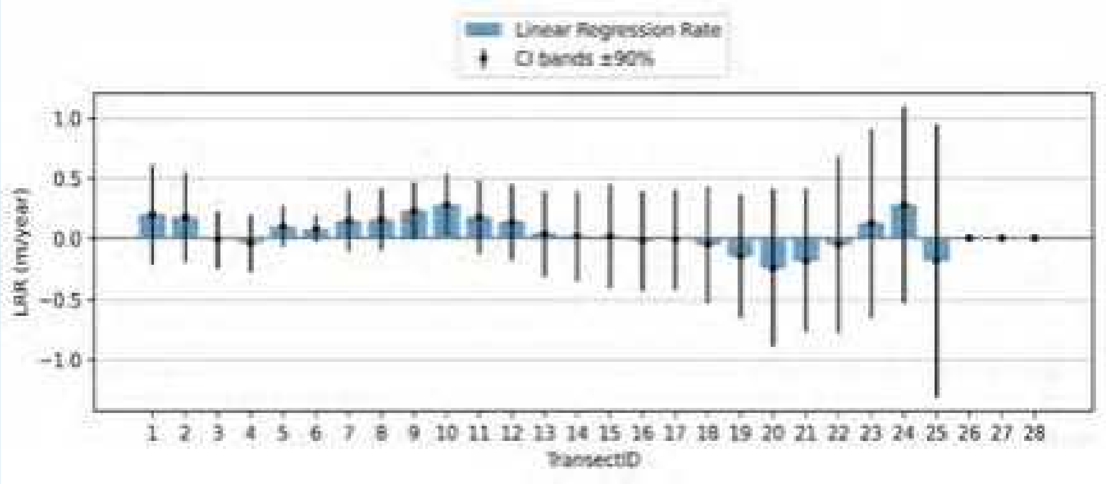
1. Background Analysis

- **Coastal hydro-morphodynamics**
  - ✓ Nearshore wave regime
  - ✓ Morphological changes in 14 beaches
    - ❑ Not significant observed change rates (past 20 years) in most beaches
    - ❑ Erosion in Armier Bay and Ġnejna Bay
    - ❑ Accretion in St. George’s Bay – Saint Julian’s (replenishment since 2004)





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Contents

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2. Coastal Risk Assessment

HAZARD x **VULNERABILITY** = **RISK**

- ✓ **Beach erosion**
- ✓ **Rocky coast erosion**
- ✓ **Coastal flooding**

- ✓ **Population**
- ✓ **Tourism sector**
- ✓ **Cultural, ethnographic and heritage**
- ✓ **Critical infrastructures**
- ✓ **Other buildings**
- ✓ **Vehicles**
- ✓ **Coastal structures**
- ✓ **(built-up waterfront)**

H, V & R Level
None (0)
Very low (>0 and ≤1)
Low (>1 and ≤2)
Medium (>2 and ≤3)
High (>3 and ≤4)
Very high (>4 and ≤5)

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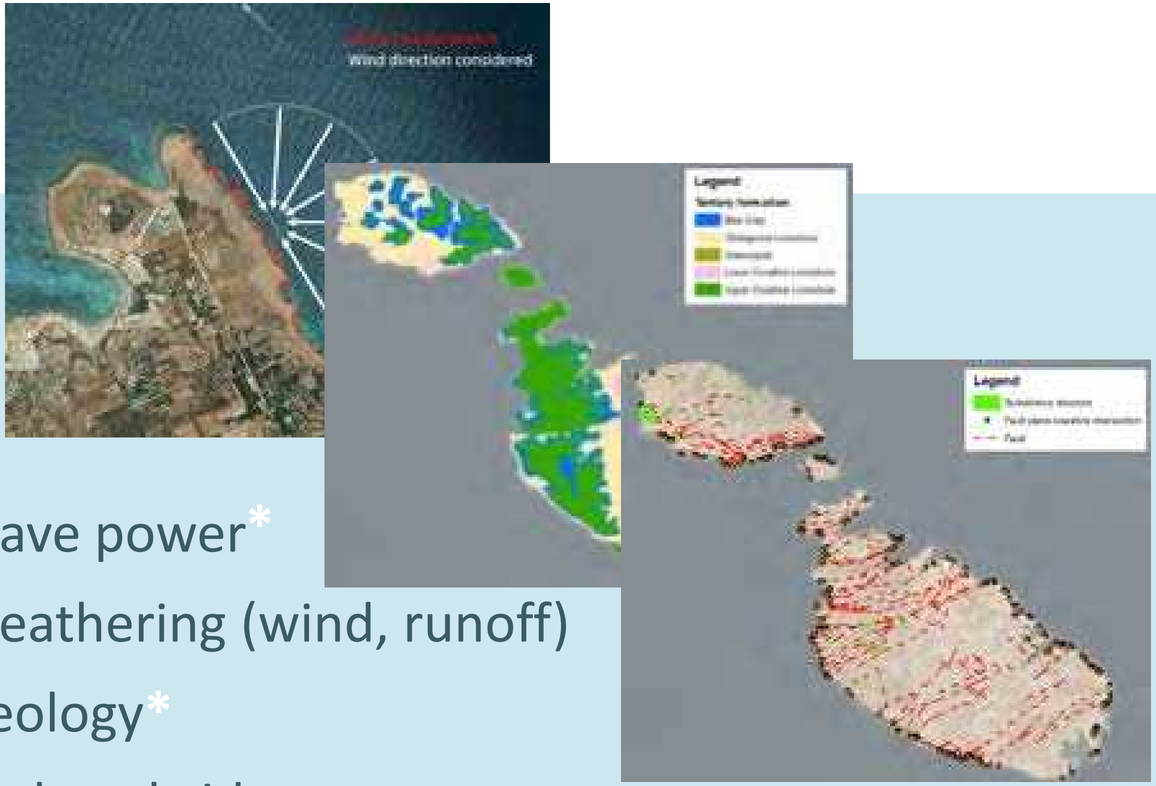
2. Coastal Risk Assessment

HAZARD x **VULNERABILITY** = **RISK**

✓ **Beach erosion**, potential for the loss of dry beach area

- ❑ Observed erosion trend
- ❑ Wave power
- ❑ Sediment grain size
- ❑ Sediment confinement
- ❑ Dry beach area
- ❑ Beach backshore
- ❑ Runoff

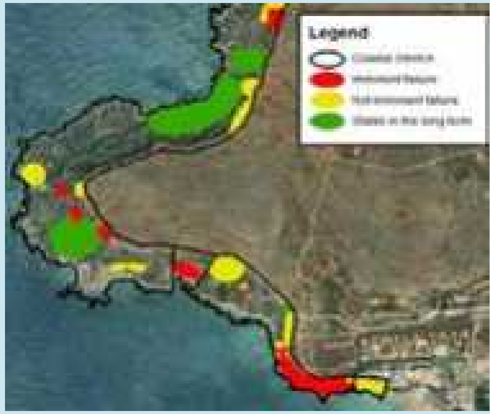
2. Coastal Risk Assessment



HAZARD x **VULNERABILITY** = **RISK**

- ✓ **Beach erosion**, potential for the loss of dry beach area
- ✓ **Rocky coast erosion**, rockfalls, landslides and rock mass collapses

- ❑ Wave power*
- ❑ Weathering (wind, runoff)
- ❑ Geology*
- ❑ Fault, subsidence, caves, arcs
- ❑ Erosion evidences
- ❑ Geometry*
- ❑ Bare soil
- ❑ Coastal* typologies



***Different values in the frontshore and backshore**

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2. Coastal Risk Assessment

HAZARD x **VULNERABILITY** = **RISK**

- ✓ **Beach erosion**, potential for the loss of dry beach area
- ✓ **Rocky coast erosion**, rockfalls, landslides and rock mass collapses

1. Shore platform.

2. Sloping coast.

3. Scree.

4. Cliff with exposed toe.

5. Plunging cliff.

6. Backshore cliff (landward of a beach).

- ❑ Coastal typologies

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2. Coastal Risk Assessment

HAZARD x **VULNERABILITY** = **RISK**

- ✓ **Beach erosion**, potential for the loss of dry beach area
- ✓ **Rocky coast erosion**, rockfalls, landslides and rock mass collapses
- ✓ **Coastal flooding**, addressing the total water level rise during storms resulting in a quasi-steady inundation, the **wave overtopping** in terms of the sea water discharge, and the **wave force**, which refers to the hydrodynamic loads of sea waves

Xlendi (Gozo) 2019
Flood height

Xemxija 2019
Drag force

St Julians 2016(Sliema)
Wave loads

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2. Coastal Risk Assessment

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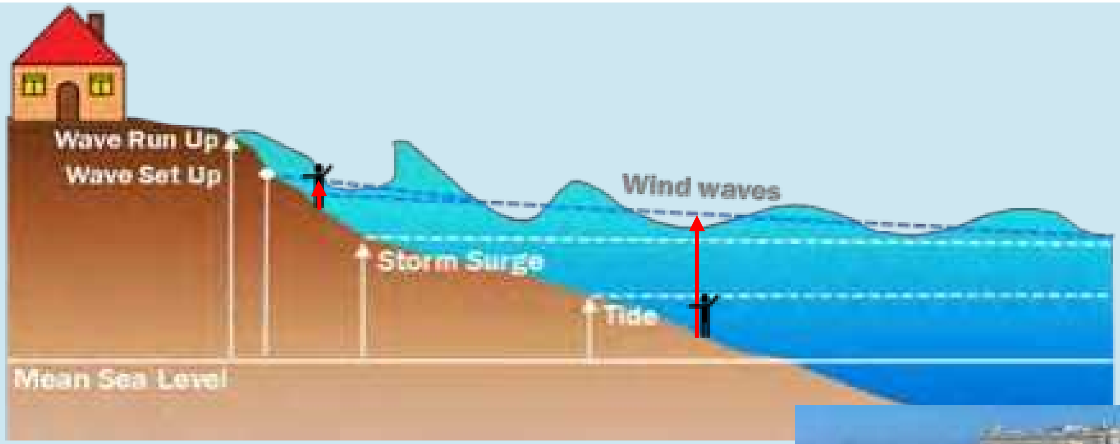
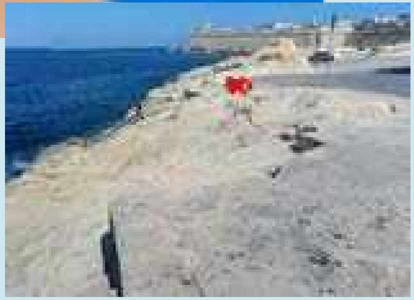
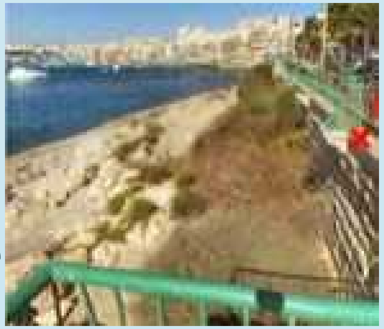


- ❑ Total Water Level – Flood height
- ❑ Frequency of overtopping events exceeding the safety values for pedestrians and vehicles
- ❑ Wave power at the front-shore. Water excursion at the back-shore





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2. Coastal Risk Assessment

- **Horizon and scenario**

  - ✓ **Current situation (2022)**
  - ✓ **Future horizon year: 2050 + SSP5-8.5 (0.25 m sea level rise)**

Hazard indexes $\mathbf{H_{BE}}$ $\mathbf{H_{RE}}$ $\mathbf{H_{TWL}}$ $\mathbf{H_{WO}}$ $\mathbf{H_{WF}}$

- ❑ $\mathbf{H_{BE}}$: Reduction of the dry beach area (1 of 7 indicators)
- ❑ $\mathbf{H_{RE}}$: Waves reaching backshore cliffs more often (1 of 11 indicators and only in backshore cliffs)
- ❑ $\mathbf{H_{TWL}}$: Increased flood height
- ❑ $\mathbf{H_{WO}}$: Reduced freeboard, thus increased water discharge
- ❑ $\mathbf{H_{WF}}$: Waves reaching backshore structures more often

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2. Coastal Risk Assessment

- **Target impacts**

HAZARD x **VULNERABILITY** = **RISK**

Impacts		**Coastal hazard**				
		Beach erosion	Rocky coast erosion	Coastal flooding		
				Quasi-steady	Wave overtopping	Wave force
Receptors at risk	Population	Indirect	Direct	Indirect	Direct	
	Tourism sector	Indirect	Direct	Direct		
	Cultural, ethnographic and heritage		Direct	Direct		
	Critical infrastructures		Direct	Direct		
	Other buildings		Direct	Direct		
	Vehicles				Direct	
	Coastal structures (built-up waterfront)					Direct

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2. Coastal Risk Assessment

- **Geographical scope**
  - ✓ **61 Coastal Units**
  - ✓ **417 Coastal Stretches**

❑ **Indirect impacts of beach erosion**: walking distance from the beaches, topography, roads, urban fabric

❑ Special locations: Comino and Cominotto, Fort Ricasoli, main ports

❑ Coastal typology

❑ Locality boundaries

❑ Flood prone area

❑ Erosion evidences

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2. Coastal Risk Assessment

- **Beach erosion impacts**

HAZARD x **VULNERABILITY** = RISK

✓ $V_{BE\text{-}POP}$, indirect impacts to the population (use and enjoyment of coastal areas)

- ❑ Exposed population: The highest exposure in Malta and lowest in Cominotto
- ❑ Social value of the beach: Managed by the MTA; services, equipment and facilities; type of sediment
- ❑ Natural value of the beach: Protected Beaches managed by the ERA

✓ $V_{BE\text{-}TS}$, indirect impacts to the tourism sector (tourism economic activity)

- ❑ Accommodation stock in the Costal Unit: Nº of beds
- ❑ Tourism infrastructures and services in the Coastal Unit: Nº of tourism facilities

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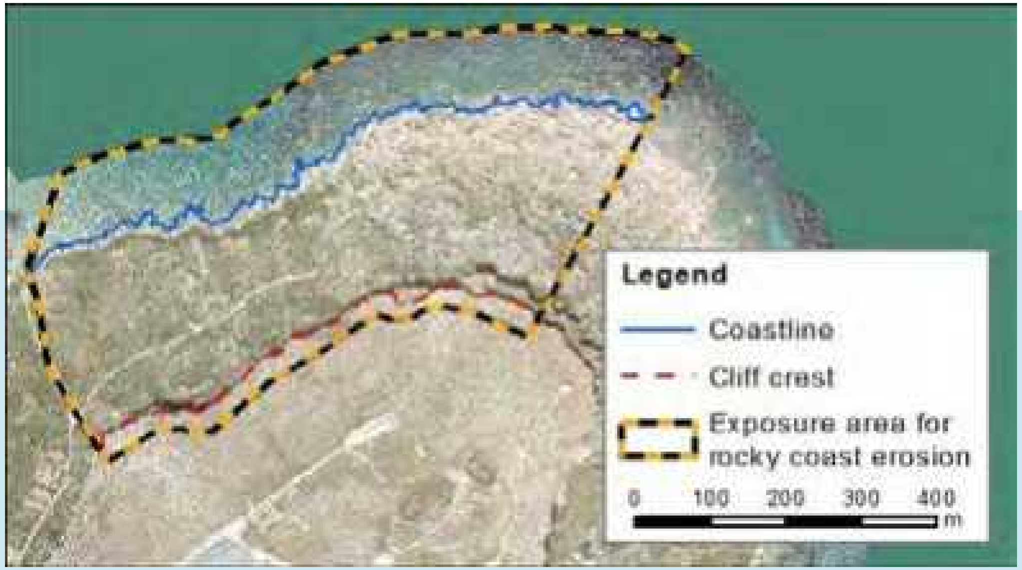
2. Coastal Risk Assessment



- **Rocky coast erosion impacts**

HAZARD x **VULNERABILITY** = **RISK**

✓ $V_{RE\text{-}POP}$, direct impacts to the population (injuries or death)

❑ Exposed population: Probability to find an attraction (beaches, swimming, diving, climbing, mooring zones, view points, paths, CEH assets) in any given standard section (100 m long) of the Coastal Stretch

✓ $V_{BE\text{-}TS}$, $V_{BE\text{-}CEH}$, $V_{BE\text{-}CI}$, $V_{BE\text{-}OB}$, direct impacts to coastal assets (damages)

❑ Exposed assets: Probability to find some coastal asset in any given standard section (100 m long)

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2. Coastal Risk Assessment

- **Coastal flooding impacts**

HAZARD x **VULNERABILITY** = **RISK**

✓ $V_{CF\text{-}POP}$, indirect impacts to the population due to the quasi-steady coastal flooding (disruption of the use of the public space)

✓ $V_{CF\text{-}TS}$, $V_{CF\text{-}CEH}$, $V_{CF\text{-}CI}$, $V_{CF\text{-}OB}$, direct impacts to coastal assets (damages)

✓ V_{WO}, direct impacts to the population (safety)

✓ $V_{WF\text{-}Str}$, direct impacts to coastal structures (damages)

❑ Exposed population: Nº of inhabitants of the Coastal Unit

❑ Rel … an fabric, inc … and acc … return pe…

❑ Exp … rea

❑ Exp … ass along the … an fabric, inc…

❑ Exposed vehicles: parking or roads along the crest

❑ Exposure: Length of structures in the Coastal Stretch

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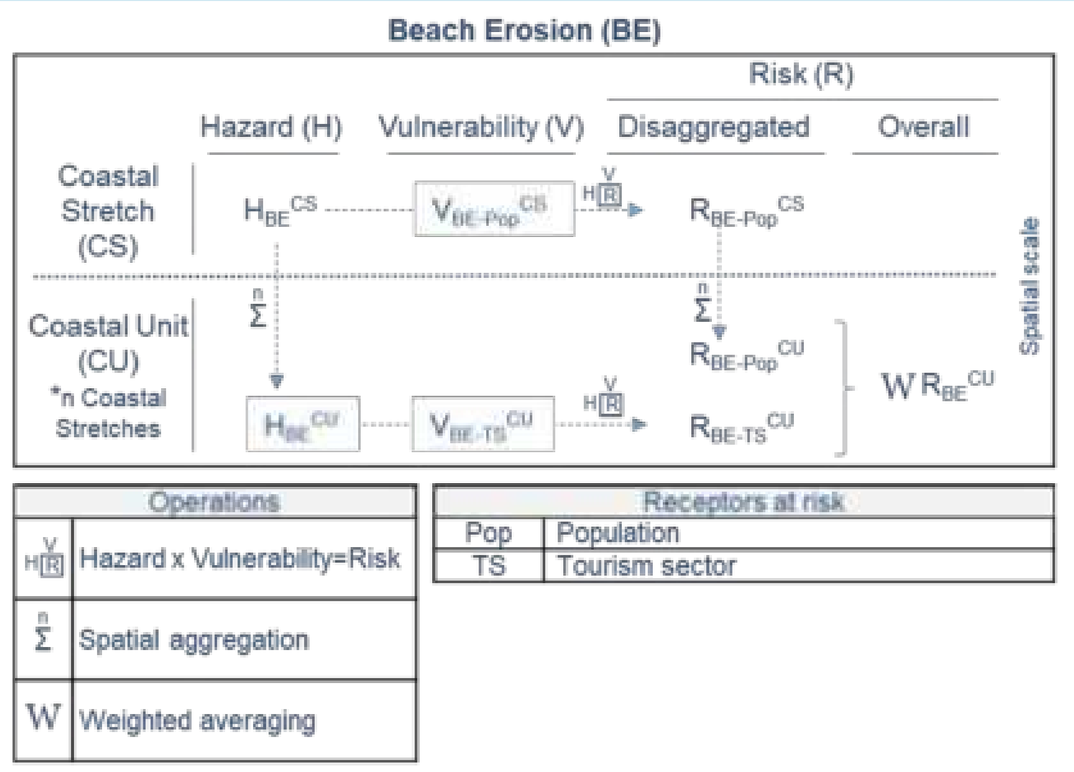
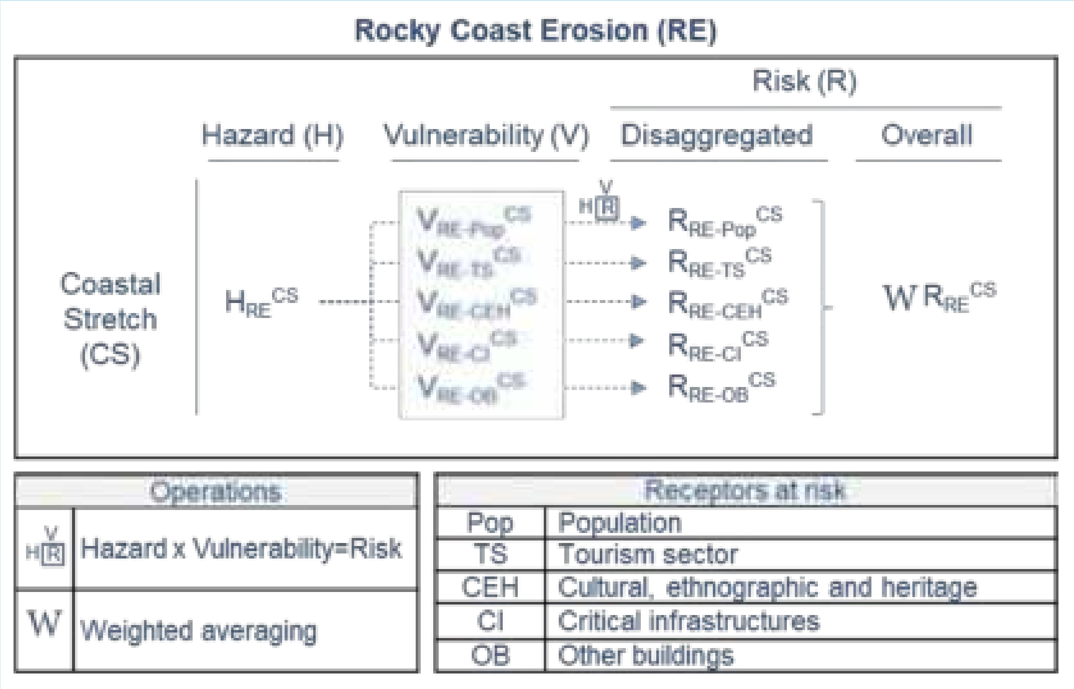
2. Coastal Risk Assessment

- ## Coastal flooding impacts

HAZARD x **VULNERABILITY** = **RISK**





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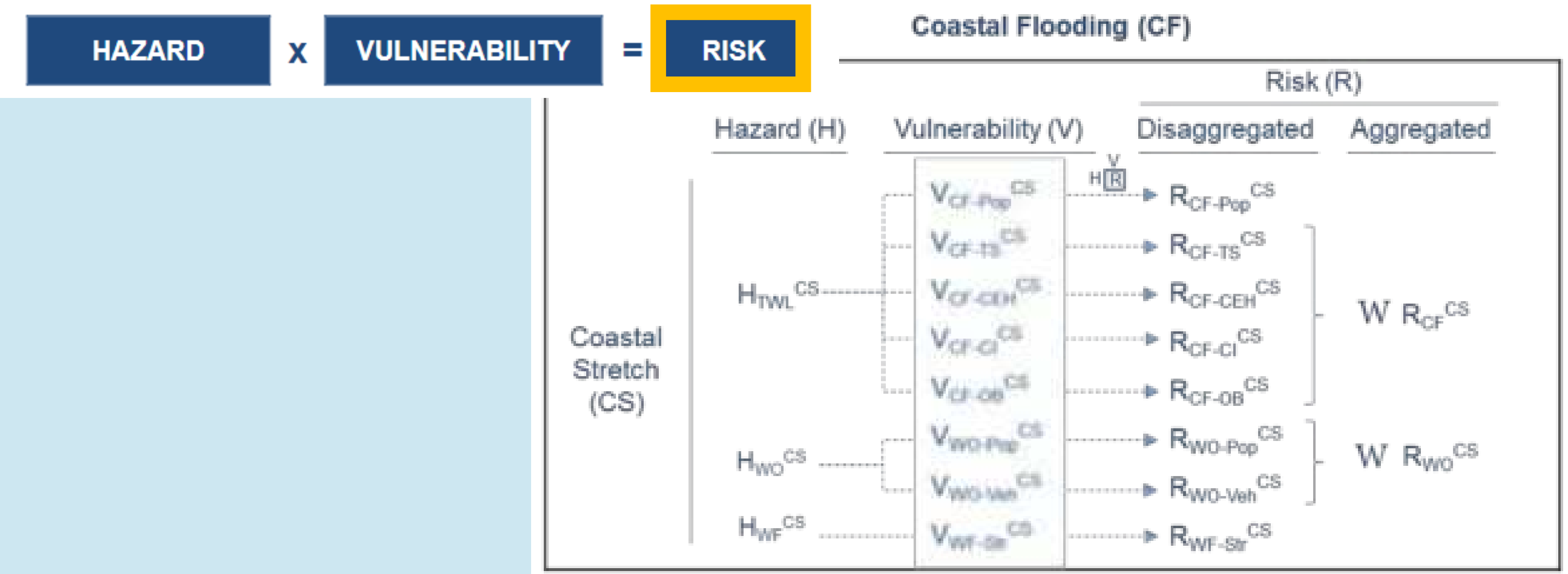
2. Coastal Risk Assessment

- **Coastal flooding impacts**



Threats	
TWL	Total water level
WO	Wave overtopping
WF	Wave force

Operations	
H[R]V	Hazard x Vulnerability=Risk
W	Weighted averaging

Receptors at risk	
Pop	Population
TS	Tourism sector
CI	Critical infrastructures
CEH	Cultural, ethnographic and heritage
OB	Other buildings
Veh	Vehicles
Str	Coastal structures

H, V & R Level
None (0)
Very low (>0 and ≤1)
Low (>1 and ≤2)
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High (>3 and ≤4)
Very high (>4 and ≤5)

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Contents

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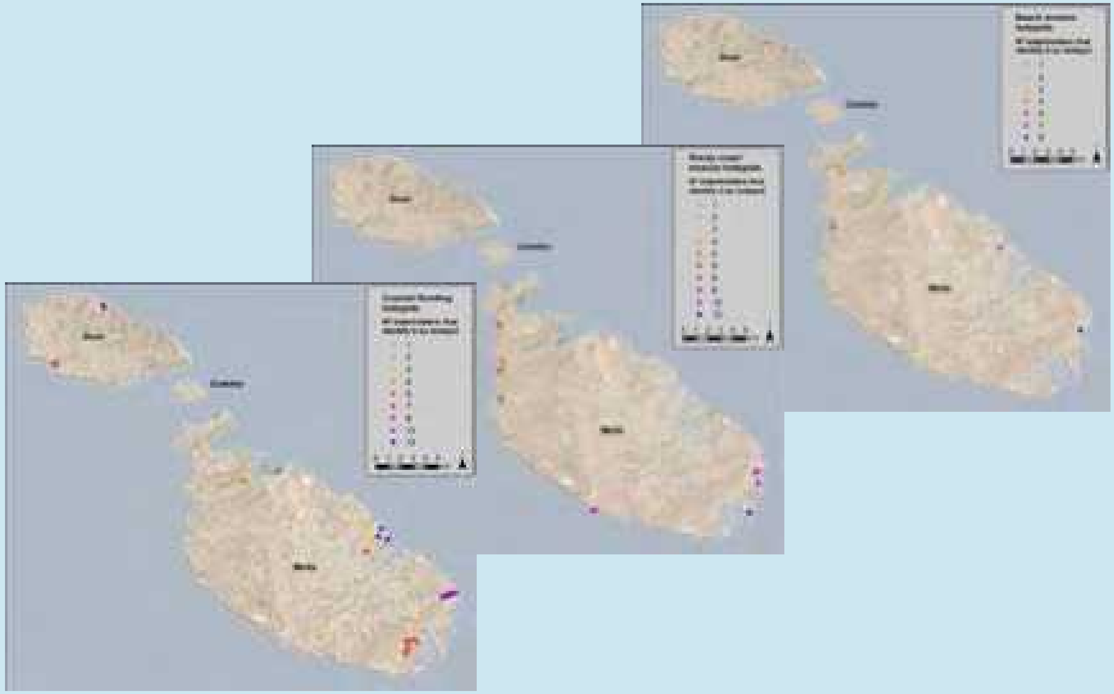
3. Integrative Risk Assessment

- **Perceptions of risk**
  - 2nd Consultation -
  - ✓ **Classes of severity and extension of perceived hazards o impacts**
  - ✓ **Identification of perceived hotspots**
  - ✓ **Relative value of receptors at risk**

Perception levels
Not relevant
Moderate at a few locations
Critical / Severe at very few locations
Moderate everywhere
Critical / Severe at some locations and moderate elsewhere
Critical / Severe everywhere

Weights (%)		**Coastal hazard**				
		Beach erosion	Rocky coast erosion	Coastal flooding		
				Quasi-steady	Wave overtopping	Wave force
Receptors at risk	Population	60	35	-	60	
	Tourism sector	40	15	20		
	Cultural, ethnographic and heritage		20	30		
	Critical infrastructures		20	30		
	Other buildings		10	20		
	Vehicles				40	
	Coastal structures (built-up waterfront)					-



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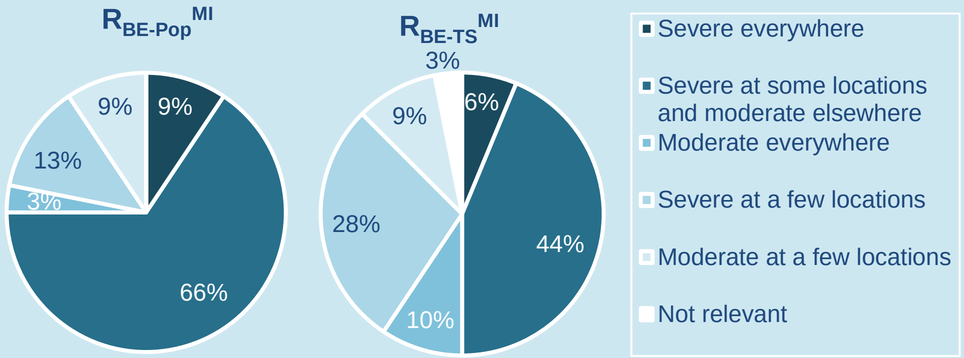
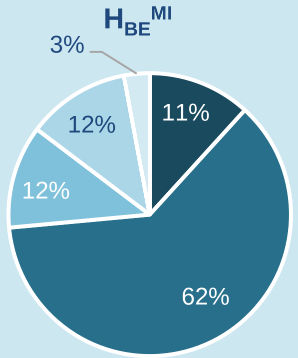
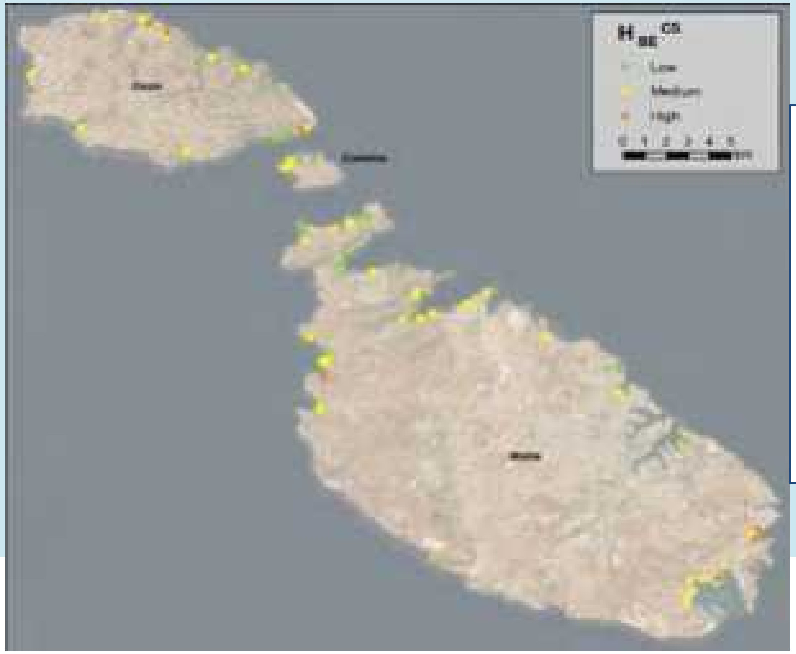
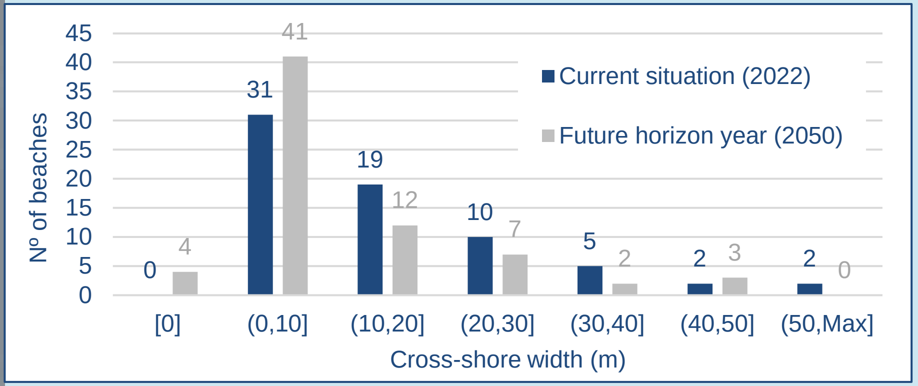
3. Integrative Risk Assessment

- **Beach erosion key issues**









- ❑ The **impacts of beach erosion on the socioeconomic environment**, with focus on the population but also on the tourism sector.
- ❑ The beach erosion in terms of the **reduction of the dry beach area** due to the loss of beach sediments.
- ❑ The **effects of climate change** on beach erosion, which exacerbates the reduction of the dry beach area **in the long term**.

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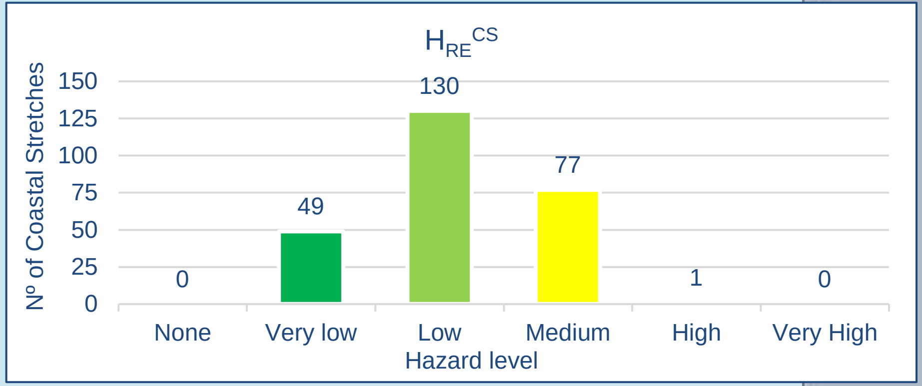
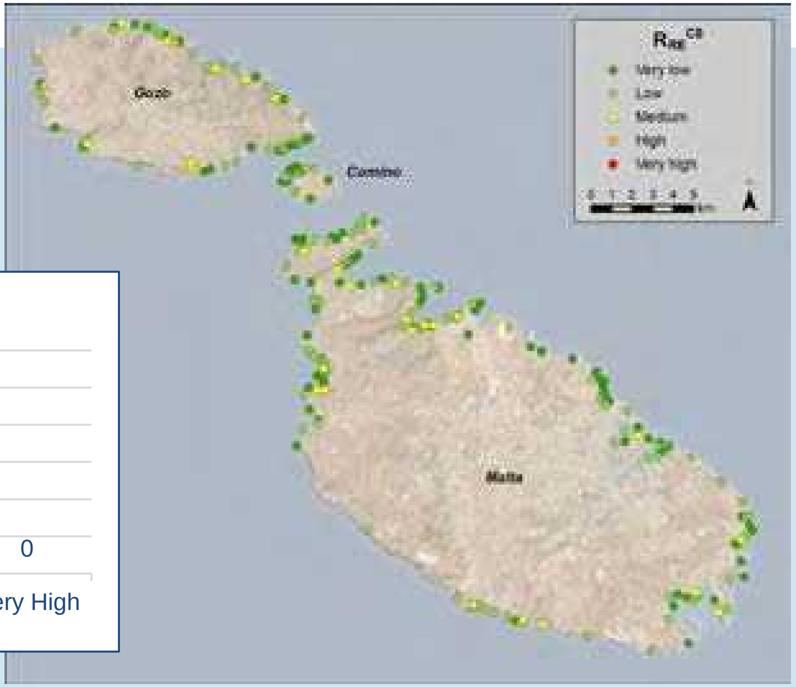
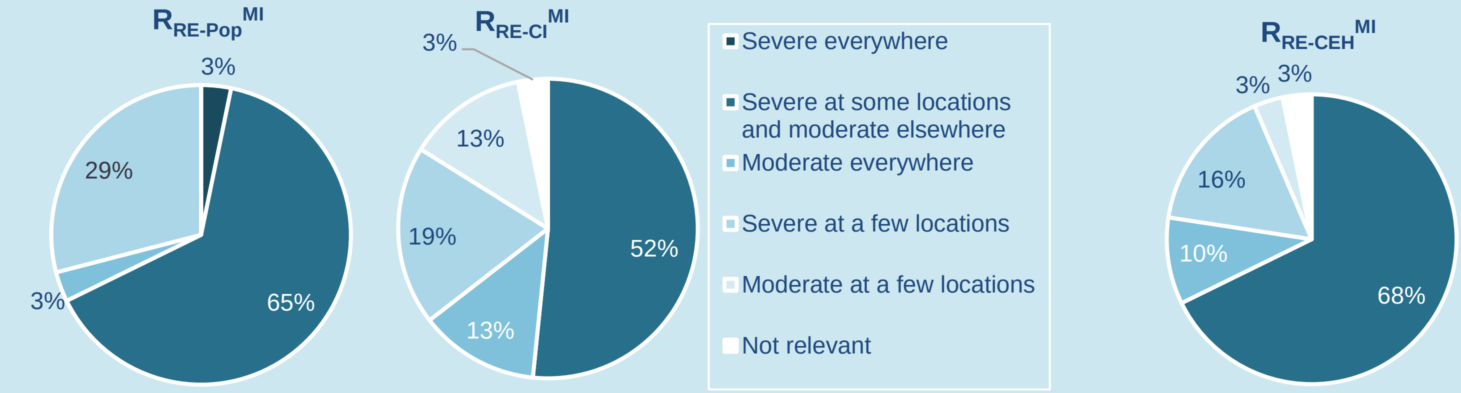
3. Integrative Risk Assessment

- **Rocky coast erosion Key issues**





- The **prediction of rocky coast erosion events** is still a challenge not resolved.
- The **impacts of rocky coast erosion on the population and coastal assets**, in terms of injuries / death or damages.
- The **public safety**, with focus on the population but also on the critical infrastructures.
- The **damages to irreplaceable cultural, ethnographic and heritage assets**, which are critical losses for the Maltese society but also at a global scale.



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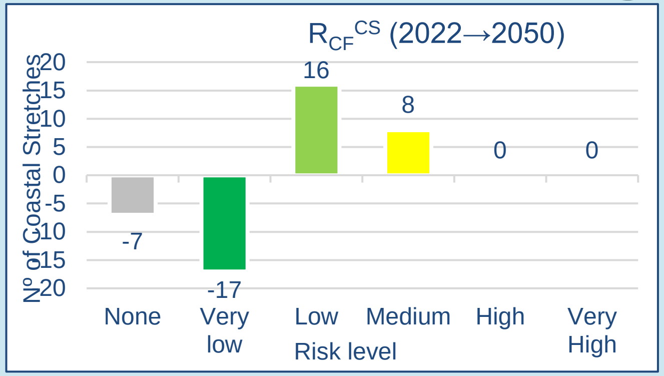
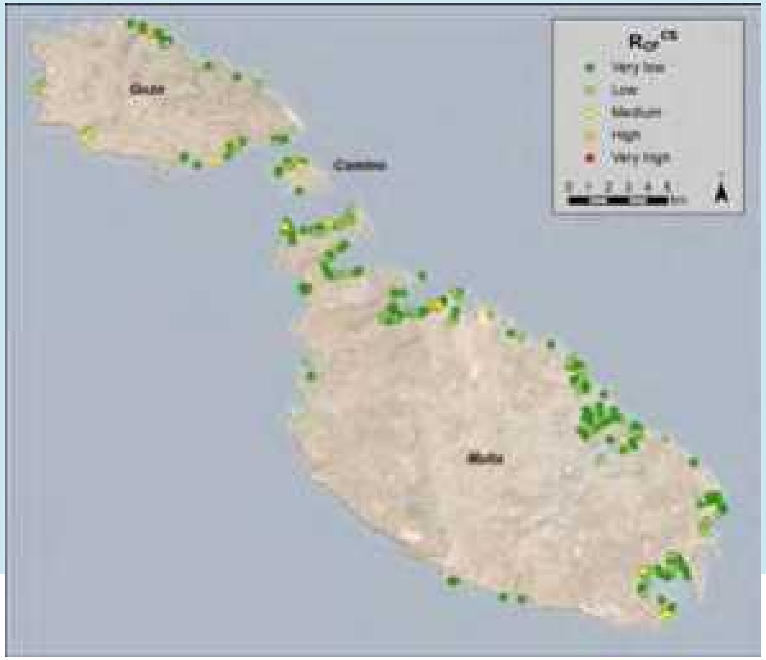
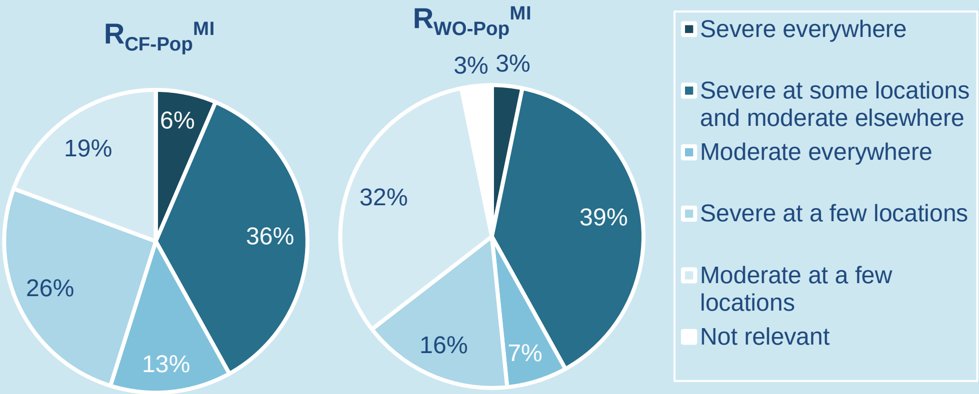
3. Integrative Risk Assessment

• Coastal flooding key issues







- ❑ The **knowledge gap with regards to relevant physical processes** such as local rainfall or the *milghuba* seiche waves.
- ❑ The indirect and direct **impacts of coastal flooding on the population**.
- ❑ The direct **impacts of coastal flooding on coastal assets**.
- ❑ The **knowledge gap with regards to the sensitivity of coastal structures** to wave force.

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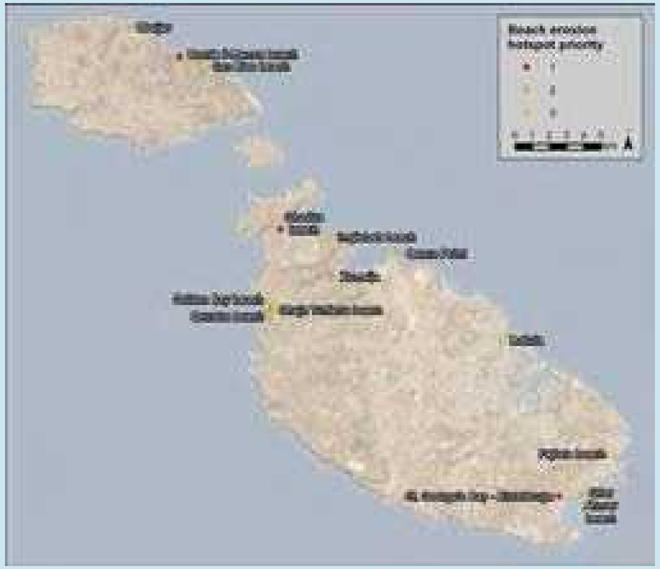
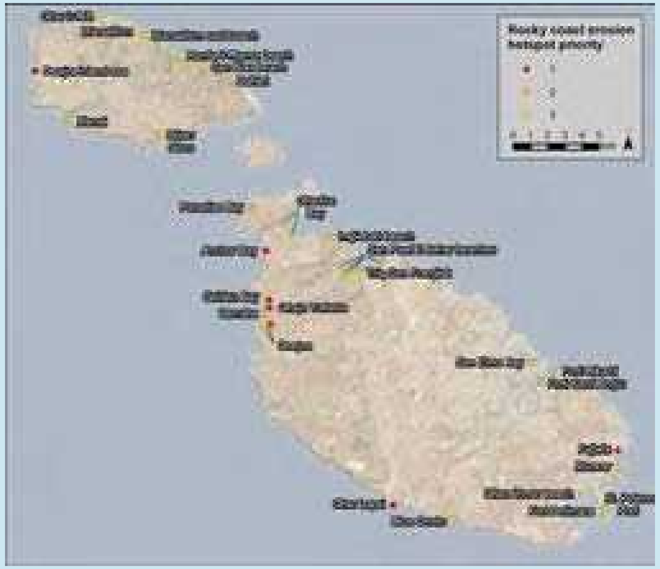
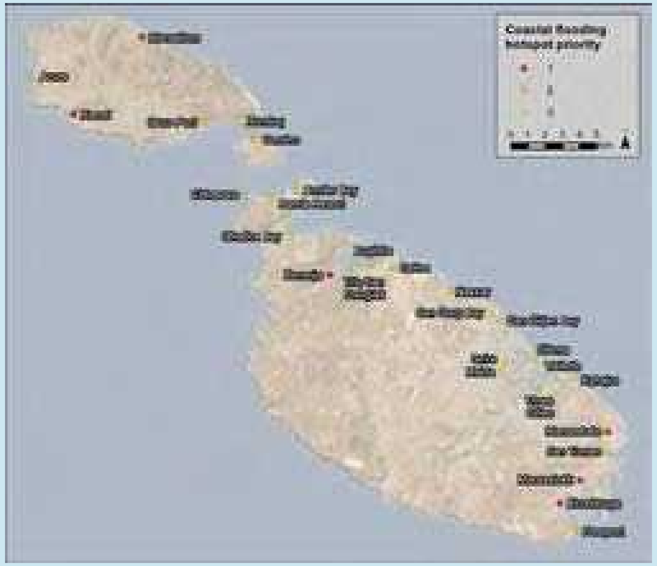
3. Integrative Risk Assessment

- **Selection and prioritisation of hotspots**
  - ✓ **Relevant hazard and risk results**
  - ✓ **Perceived hotspots**
  - ✓ **Relevant baseline information**

Beach erosion	**Rocky shore erosion**	**Coastal flooding**
Fajtata		Sliema
Balluta	St Peters Pool	Marsaskala
Ghajn Tuffieha	Munxa	Marsalforn
Ghadira	Ghar Lapsi	Msida
Golden Bay	-	Xlendi







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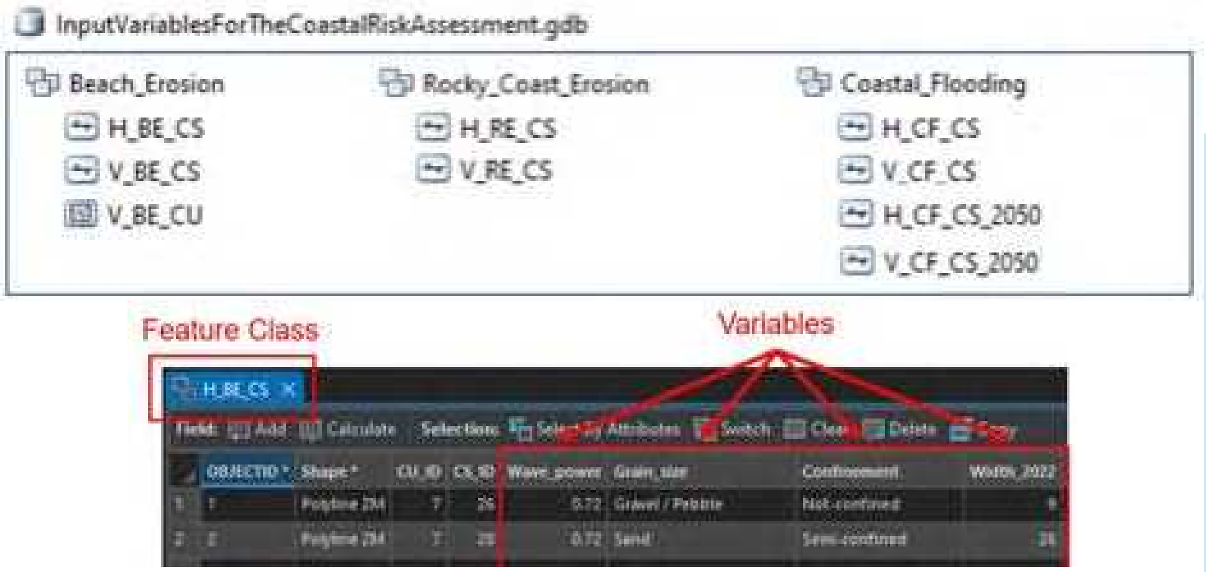
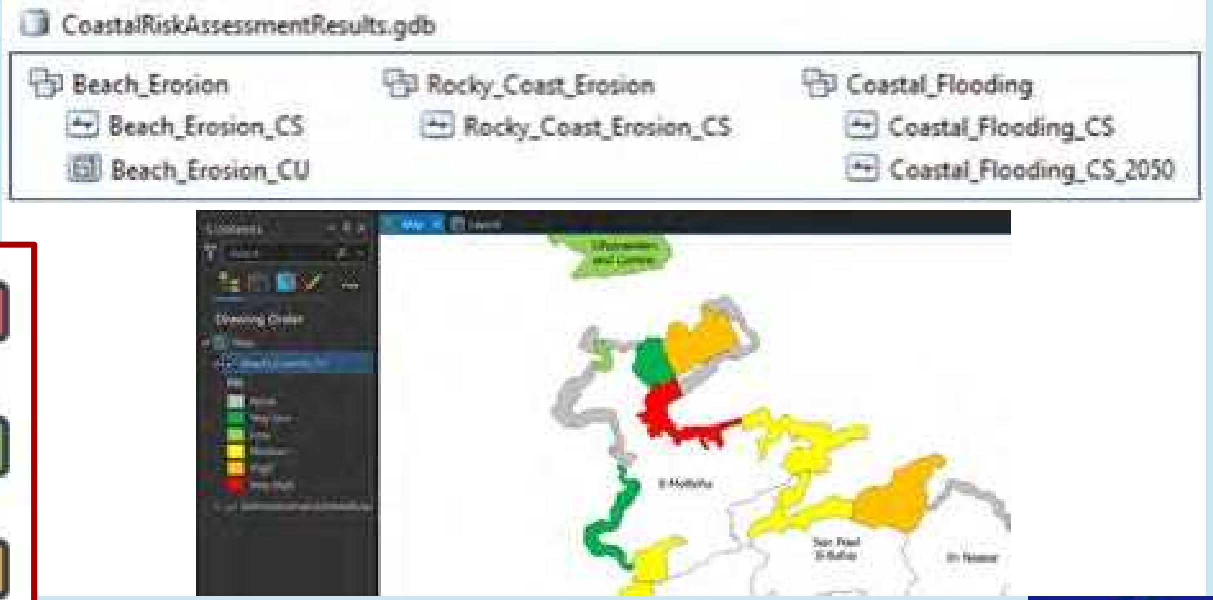
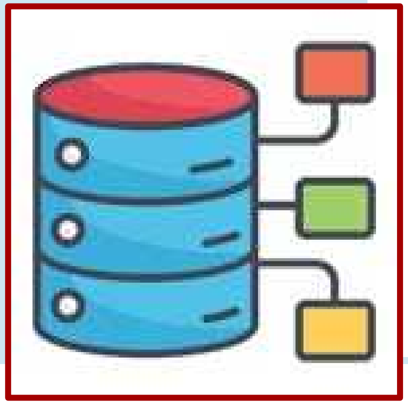
Contents

1. Background Analysis ⇦ Geodatabase
   - Data gathering process and
   - Coastal Hydro-morphodynamics
2. Coastal Risk Assessment
   - Framework and scope
   - Interpretation of results
3. Integrative Risk Assessment
   - Perceptions of risks
   - Key issues and hotspots
4. Risk Information Hub
   - C-COVER
   - PRISM





C-COVER
Integrative Coastal
Geodatabase
(2.5 Gb)



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4. Risk Information Hub

Beach erosion hazard index, potential for the loss of dry beach area in one Coastal Unit

Hazard classes
None (0)
Very low (>0 and ≤1)
Low (>1 and ≤2)
Medium (>2 and ≤3)
High (>3 and ≤4)
Very high (>4 and ≤5)

Combination of
beach erosion indicators
(expressed in classes)

- ❑ Sediment grain size
- ❑ Wave power
- ❑ Observed erosion trend
- ❑ Sediment confinement
- ❑ Dry beach area
- ❑ Beach backshore
- ❑ Runoff

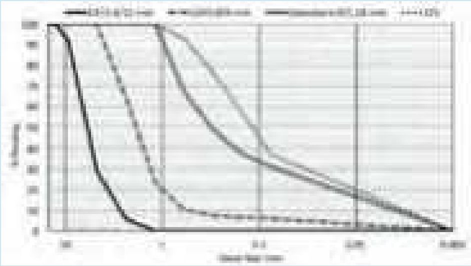
Input variables

D50 (mm)

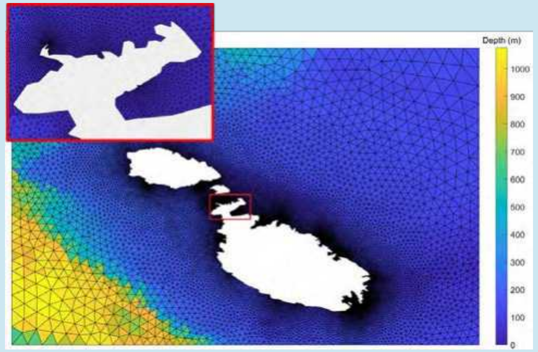
Difference between the 50% and 95% percentile of the wave power

Raw data

Sand samples granulometry



Time series of wave parameters from the waves onshore



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4. Risk Information Hub

Project 1. Coastal-COVER (2022-2023)

Project 2. Climate-MATCH (2024-2025)

PRISM outputs

- Inception report: methods and results
- **Content:** Risk Assessment Technical Guidelines (Output 1)
- **Technology:** Risk Information Hub Blueprint (Output 2)
- **Governance:** Information Management Framework (Output 3)
- **Skills:** Capacity Building Program (Output 4)

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4. Risk Information Hub

PRISM Inception

1. Background Assessment:

- Data needs across different entities
- Local, national and international sources of information (EO, citizen science, previous/ongoing projects)
- Data gaps and overlaps
- Key issues and challenges for a cooperative approach

2. Outline of PRISM outputs:

- Clear definition of specific objectives
- Rough outline of final deliverables

Working methods:

- National PRISM Consultation
  1. Online
  2. Workshop
  3. Interviews
- Synergies between components and other on-going projects

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4. Risk Information Hub

July-August 2024

- 35 questions in 4 blocks
- 34 public agencies, 11 NGOs/associations, 9 University departments/faculties: 98 persons invited.
- 37 participated, from 26 different entities

24th October 2024

✓ Refinement of answers from online survey

✓ New questions that require previous explanation

slido

November 2024

Assessment of current capabilities:

- Technology
- Skills
- Governance

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4. Risk Information Hub

Conceptual framework for Hazard, Exposure, Vulnerability and Risk Assessment

- in C-COVER: coastal erosion and flooding hazards and socioeconomic impacts
- in PRISM: additional coastal hazards and environmental / intangible impacts

Critical factors for success: Shared understanding of the proposed risk assessment approach (across 3 project components and Risk Information Hub users)

Scope:

✓ **Development of methods (Risk Assessment Technical Guidelines)**

x **Calculations and mapping**

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4. Risk Information Hub

Relevant coastal hazards (examples for impact chain development)

- **Marine hazards (forcing hazards) :** sea waves overtopping, sea waves forces, storm surge (TWL), meteo-tsunamis (*milghuba*), sea level rise
- **Marine hazards (non-forcing):** water temperature, water acidity, saline intrusion
- **Geo-hazards:** earthquake, tsunami, beaches erosion, landfall, rockfalls, ground movement, subsidence, marine sedimentation shifts, volcanoes
- **Atmospheric hazards:** meteorological, climatological, air quality
- **Biological hazards:** invasive species, vegetation cover, aquatic bloom, loss of habitat
- **Human stressors:** trampling, anchoring, water pollution, storm water discharge, construction

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4. Risk Information Hub

Cross-sectoral at-risk receptors

- **Health, safety and wellbeing:** local population, visitors, vehicles, vulnerable groups
- **Infrastructure and transport:** Water supply, sewage. Roads, vehicles, energy, telecommunications, industrial harbours, public service infrastructures (hospitals, schools, police stations, fire stations), maritime transport
- **Urban areas and economic activities:** Coastal structures (built-up waterfront), other buildings, urban fabric, industrial and commercial areas, parks and recreation, accommodation stock, tourism services and infrastructure, fishery capacities, livestock activities
- **Natural heritage:** Beaches, sand dunes, coastal wetlands (saltmarshes), coastal reefs, Posidonia meadows, coastal cliffs, natural streams and aquifers, aquatic and terrestrial biodiversity, caves, coastal garrigue. Intangible impacts
- **Historical, cultural and ethnographic heritage:** Paths and tracks, buildings and assets, climbing zones, viewpoints, cultural landscapes, diving sites, bathing waters, recreational activities, archaeological sites. Intangible impacts
- **Public services:** Local councils, ecosystem monitoring. Intangible impact

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4. Risk Information Hub

The Risk Information Hub Blueprint will include the conceptual development of methods and tools for:

1. Data acquisition (local and global sources)
2. Data integration (processing and analysis)
3. Data update (and continuous upgrade)
4. Information management: specific task

And a roadmap for the implementation of recommended developments including technical specifications

Objectives

- Data centralization and standardization
- Data sharing to promote science-based decision-making

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4. Risk Information Hub

Development of the Information Mangement Framework

1. **Roles and responsibilities:**
   - Maintenance of the Risk Information Hub
   - Data acquisition, integration, update
2. **Data access:**
   - Ownership of data
   - Utilization

Critical factors for success:

- Engagement with all relevant stakeholders from early stages
- Agreement on working methods and project specific objectives

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4. Risk Information Hub

Design of a Capacity Building Program for the uptake of the Risk Conceptual Framework:

- Identification of potential trainees and needs
- Assessment of current capabilities
- Description of training and capacity building activities:
  - Contents
  - Methods and Timeline
  - Quality control and certification
  - Cost estimates
- Alumni action plan

Critical factors for success.

- Robust commitment by participant institutions (after project finalisation)

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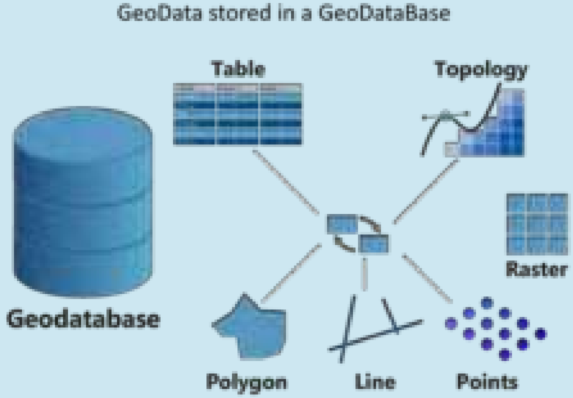
CONCLUSIONS

Impacts		Coastal hazard				
		Beach erosion	Rocky coast erosion	Coastal flooding		
				Quasi-steady	Wave overtopping	Wave force
Receptors at risk	Population	Indirect	Direct	Indirect	Direct	
	Tourism sector	Indirect	Direct	Direct		
	Cultural, ethnographic and heritage		Direct	Direct		
	Critical infrastructures		Direct	Direct		
	Other buildings		Direct	Direct		
	Vehicles				Direct	
	Coastal structures (built-up waterfront)					Direct



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Coastal-COVER

A Coastal Protection Strategy for Malta - European Commission

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THANK YOU FOR YOUR ATTENTION

Dr. Jara Martínez
jara.martinez@unican.es

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“Sediment transport in vegetated ecosystems”

(María Maza, IHCantabria)

Sediment transport in vegetated ecosystems

Maria Maza

Instituto de Hidráulica Ambiental de la Universidad de Cantabria (IHCantabria)

mazame@unican.es

- **Motivation**
- **HyWedges**
- **SHACC**
- **Conclusions**

Motivation

- The World Economic Forum's (**WEF**) Global Risks 2023 report identifies the **failure of climate-change adaptation** as one of the main global risks in 10 years.

- **Adaptation** to climate change is a key priority for our society. An example is the Agenda 2030 of **AIVP** (International Association of Cities and Ports)

10 years

1	Failure to mitigate climate change
2	Failure of climate-change adaptation
3	Natural disasters and extreme weather events
4	Biodiversity loss and ecosystem collapse
5	Large-scale involuntary migration
6	Natural resource crises
7	Erosion of social cohesion and societal polarization
8	Widespread cybercrime and cyber insecurity
9	Geoeconomic confrontation
10	Large-scale environmental damage incidents

Motivation

- In the last fifty years, human action has transformed ecosystems more rapidly and extensively than in any other period. This has resulted in a considerable, and largely irreversible, **biodiversity loss**. This loss has consequences for human well-being (Millennium Assessment Report).

- The **climate crisis and the biodiversity crisis are intimately linked**; while ecosystems play an important role in climate regulation and can help sequester and store carbon, their loss has contributed significantly to climate change.

Motivation

- Adaptation to climate change requires **multifunctional solutions**: solutions that maximize benefits for both society and the natural system.

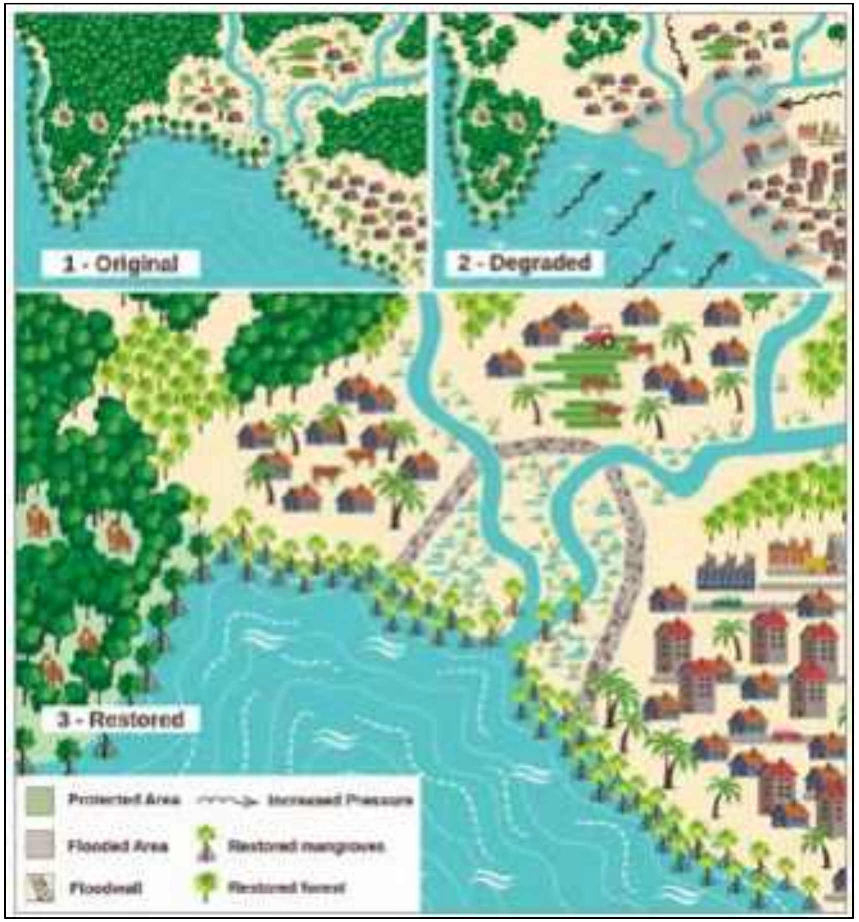
- During the United Nations Climate Change Conference COP25 and COP26 there was a common view that **Nature-based Solutions** (NBS) are an invaluable part of the solution

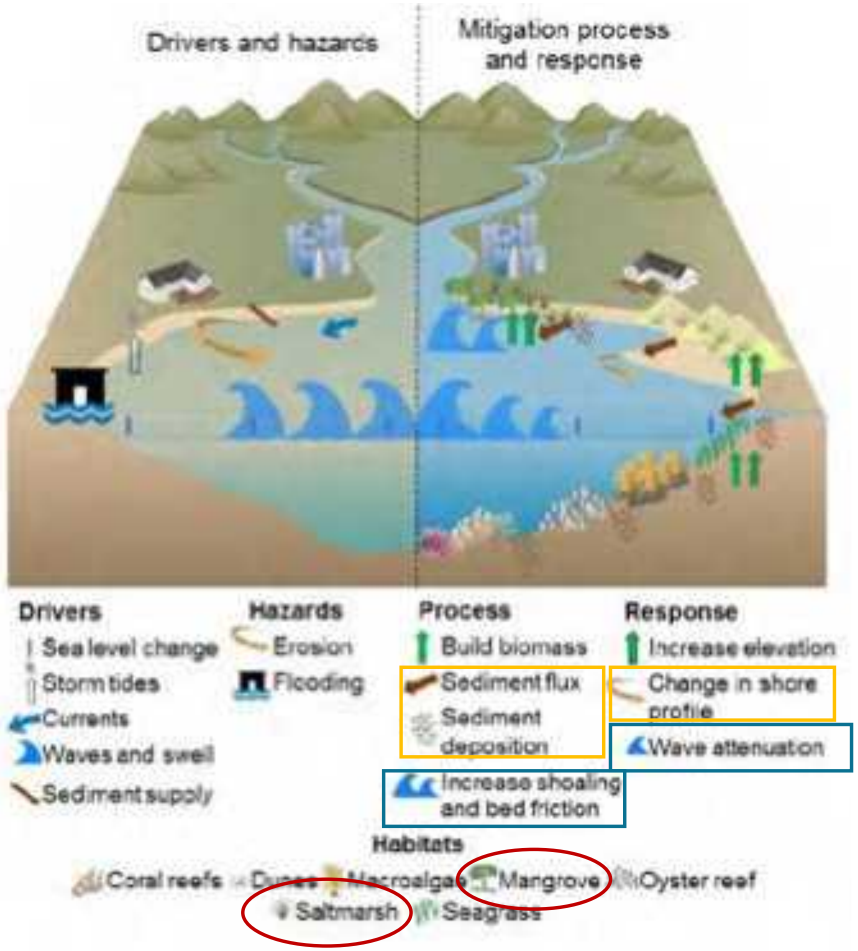
Motivation

- Coastal areas are experiencing an incresing risk and **NbS based on coastal ecosystems** are specially important to for disaster risk reduction in these areas.
- These solutions provide with several ecosystem services, among them we find the **coastal protection service.**

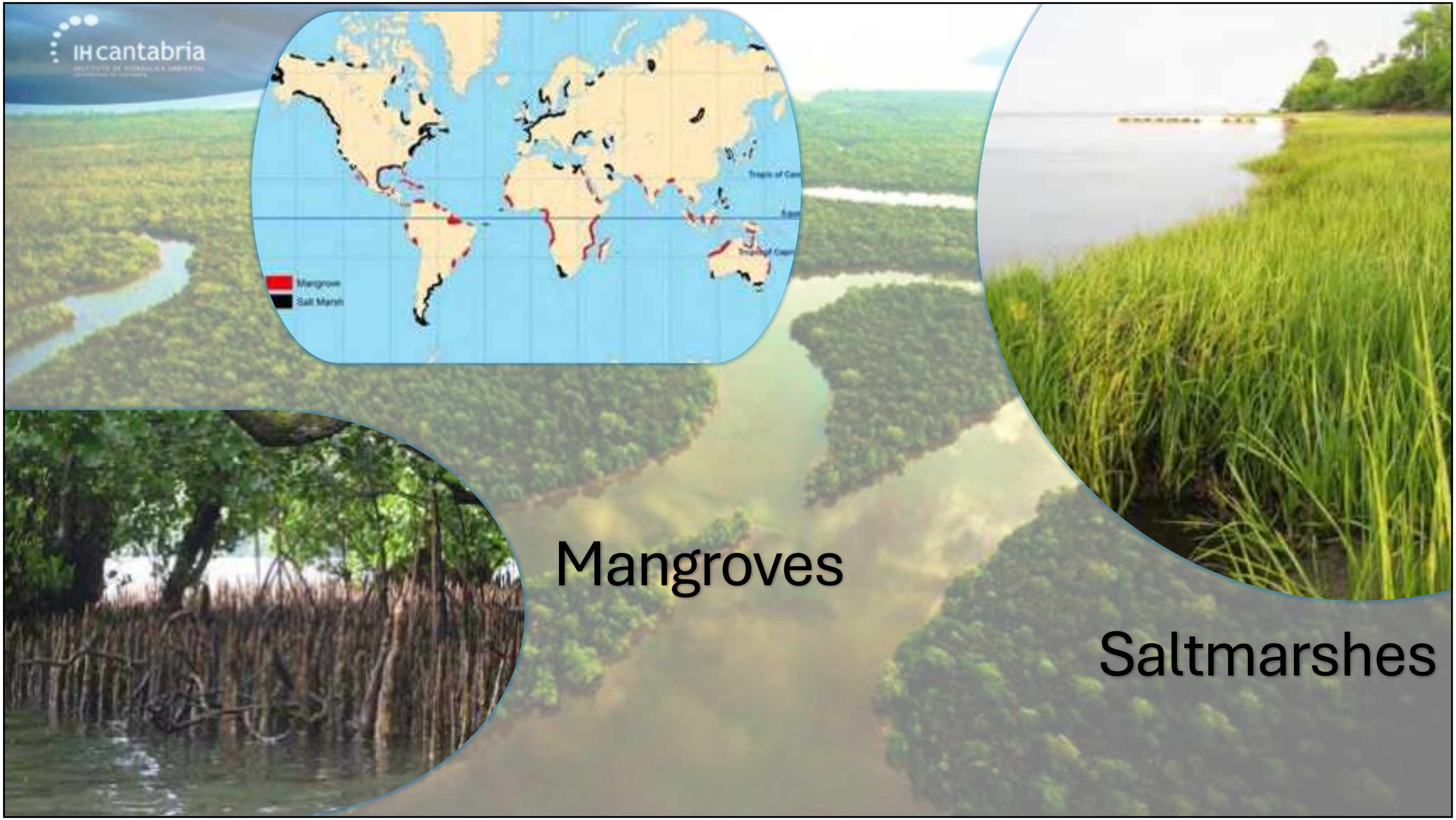
International Guidelines on Natural and Nature-Based Features for Flood Risk Management, 2021

Motivation



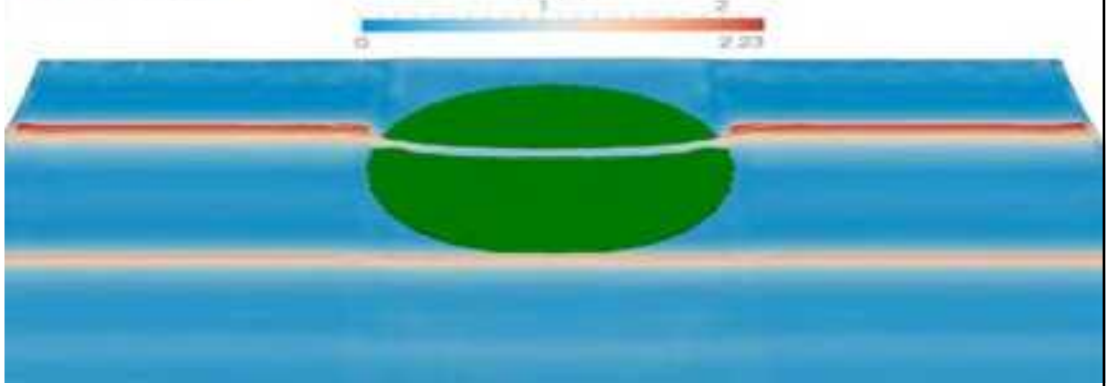


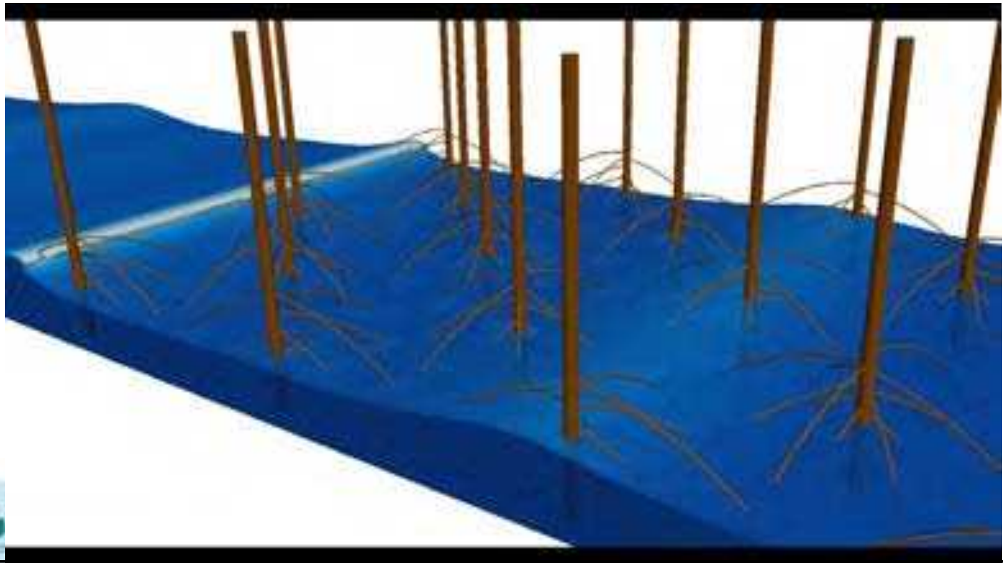
Morris et al. (2018)

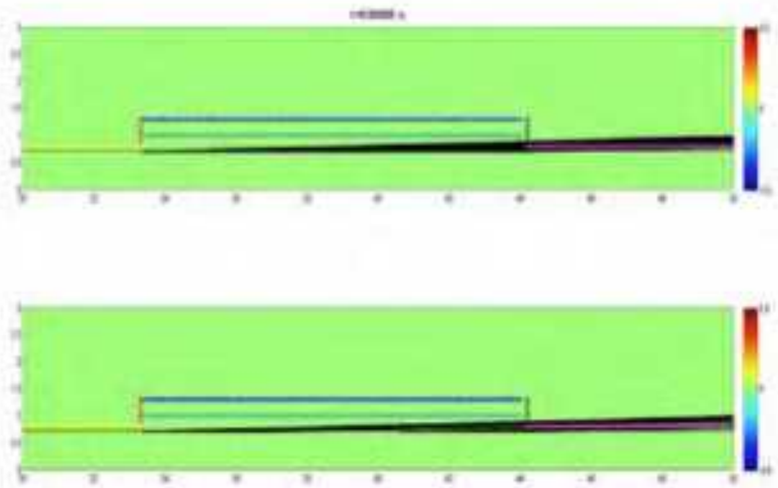

IHcantabria
Mangrove
Salt Marsh
Mangroves
Saltmarshes

Motivation

- Coastal protection service:
  - Flow energy attenuation
  - Erosion reduction







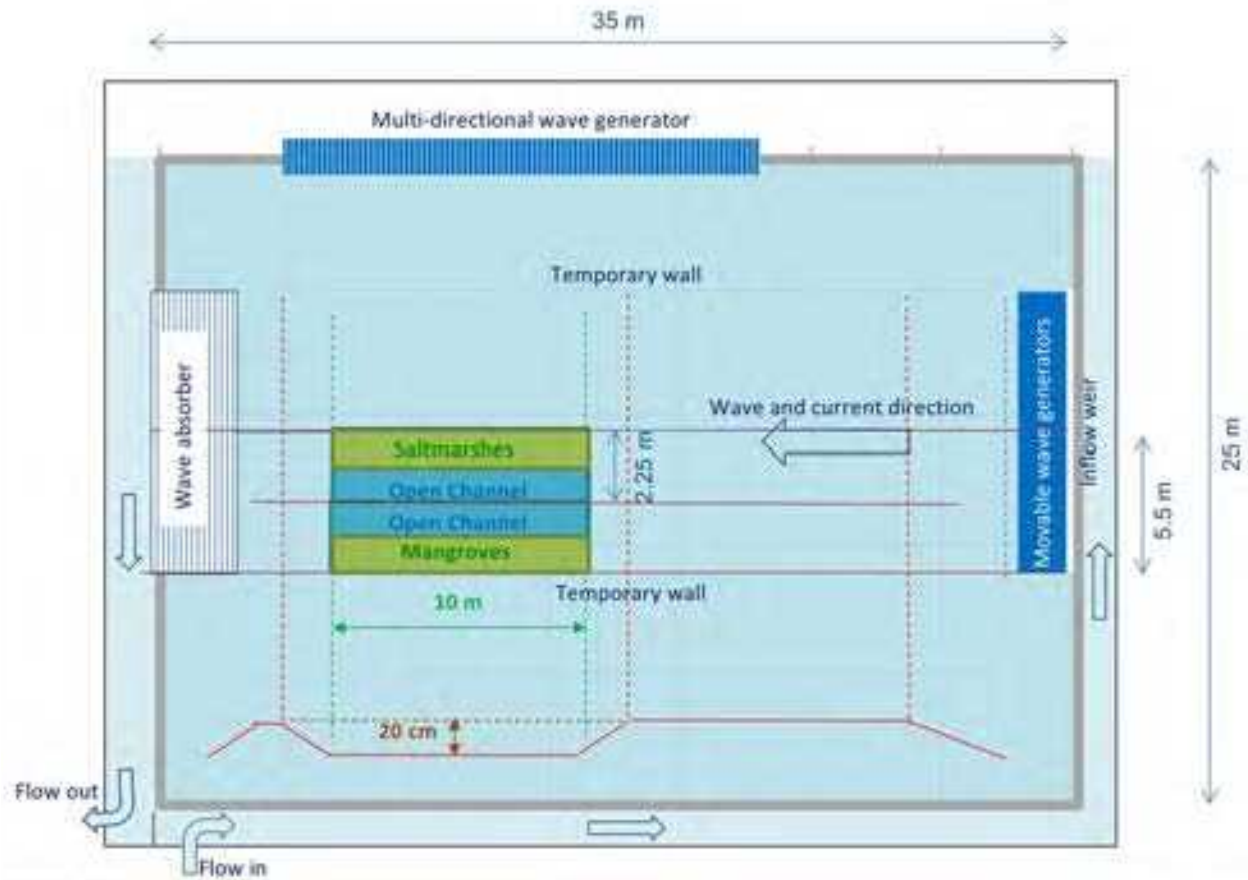
Motivation

- It is still necessary to know in depth and characterize the **sediment transport** in these ecosystems.
- **HyWEdges** (hydrodynamics at coastal wetland edges) and **SHACC** (Hybrid Solutions for Coastal Adaptation to Climate Change Climate Change) projects aimed to evaluate sediment transport patterns in vegetation fields.

- Motivation
- **HyWedges**
- SHACC
- Conclusions

Experimental set-up

- Tests were carried out in the wave tank at the Denmark Hydraulics Institute (DHI) in Denmark:
  - Maximum discharge: 1 m^3/s
  - Water depth: 0.30 m
  - Velocity: 0.30 m/s
  - Test section width: 5.5 m
  - Two channels: 2.75 m
  - Vegetation fields: 1.25 m
  - Open channels: 1.5 m



Experimental set-up

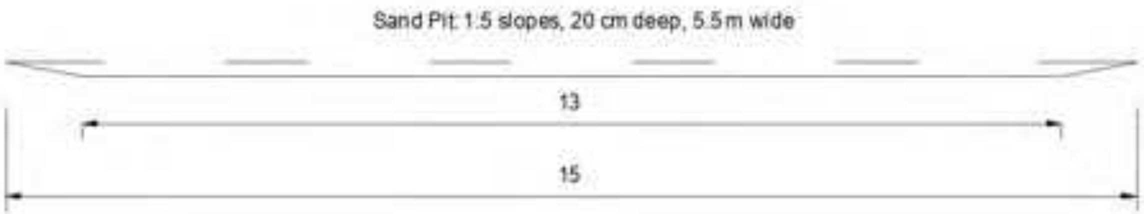
- Vegetation mimics:
  - Field 10 m long x 1.25 m wide ➞ 12.5 m^2
  - Saltmarshes: plastic tubes
    - 420 stems/m^2 ➞ 5250 stems
    - Simplified geometry: flexible cylinders
    - Diameter: 0.005 m
    - Length: 0.30 m
    - E = 14 MPa
  - Mangroves: wood cylinders
    - 84 stems/m^2 ➞ 1050 stems
    - Simplified geometry: rigid cylinders
    - Diameter: 0.03 m
    - Length: 1 m
    - Rigid

Experimental set-up

- Hydrodynamic conditions:
  - Water depth: 0.30 m
  - Unidirectional current: 0.30 m/s

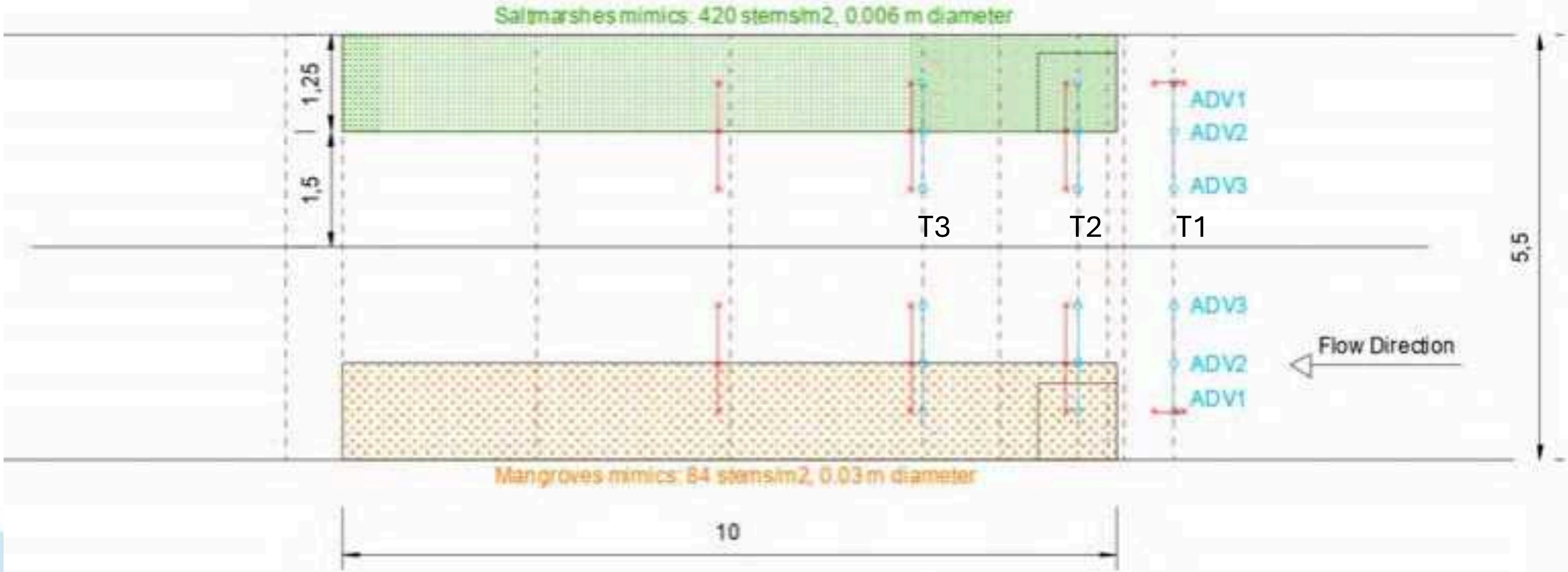
Experimental set-up

- Sediment area:
  - 0.20 m of depth
  - Smooth slopes 1:5
  - Total volume: 15.4 m^3
- Sediment:
  - Nominal diameter equal to 0.18 mm
  - Availability/characteristics/movement iniciation based on Van Rijn 1989 and Soulsby 1997 formualtions

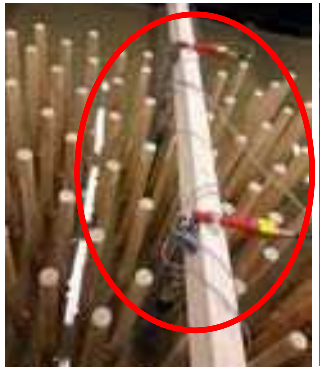


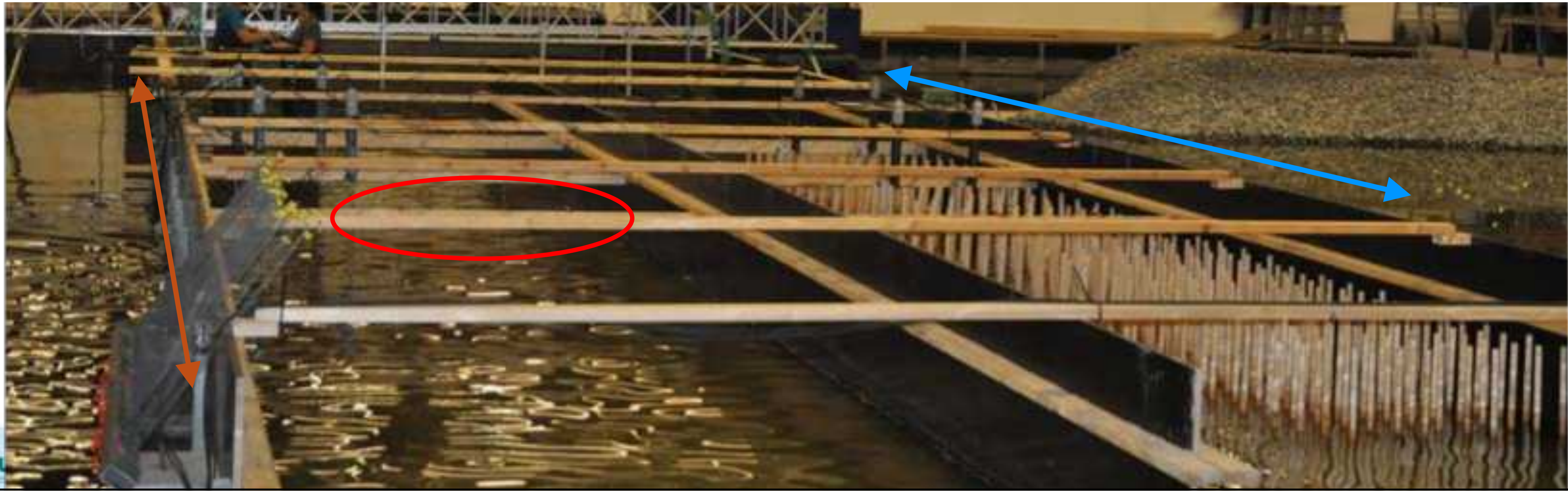
Experimental set-up

- 24 free surface sensors at 4 longitudinal positions
- 6 ADVs: profiles at 3 lateral positions and 3 longitudinal ones
- Sediment elevation using 60 sediment bars at 10 longitudinal positions

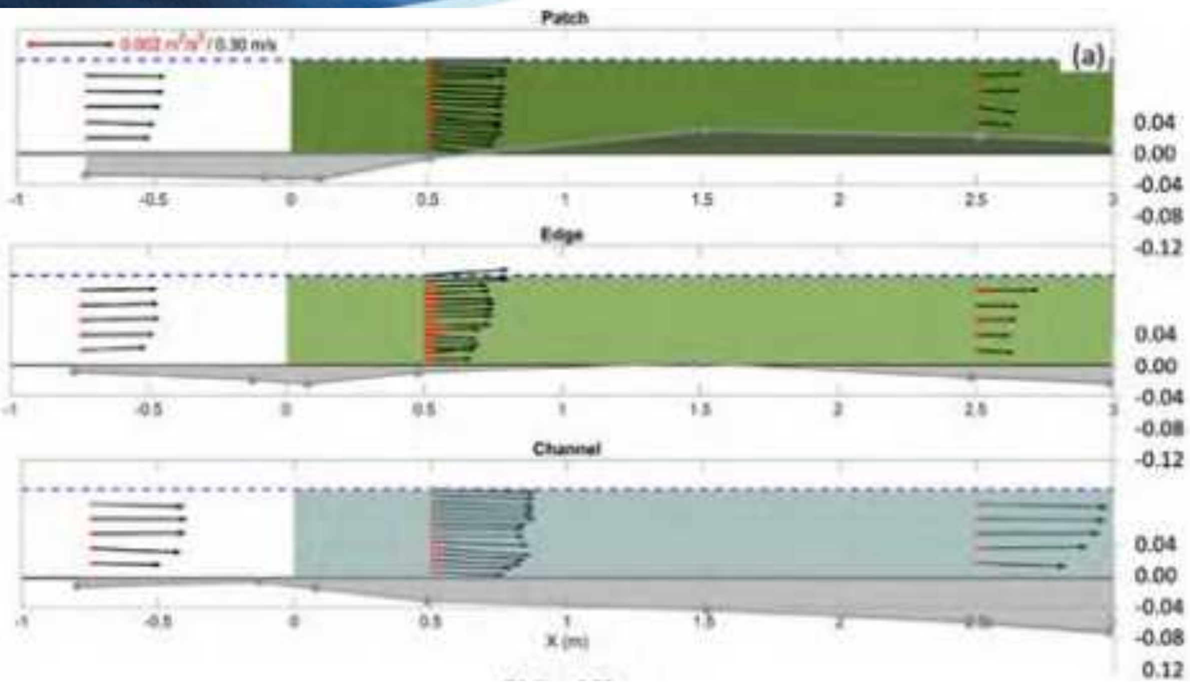


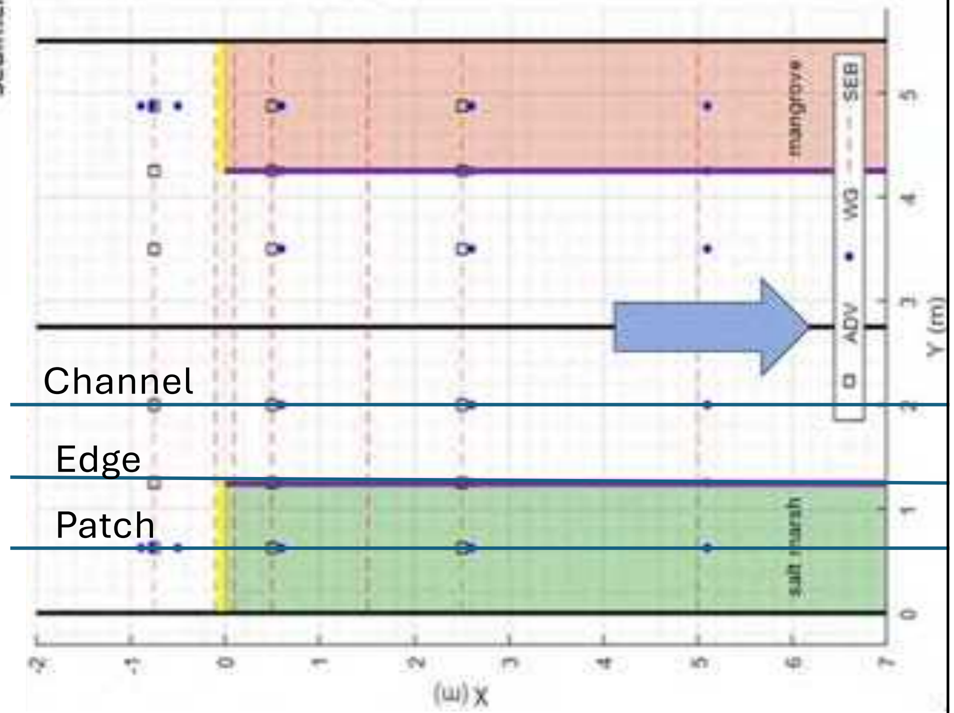
Experimental set-up





Results

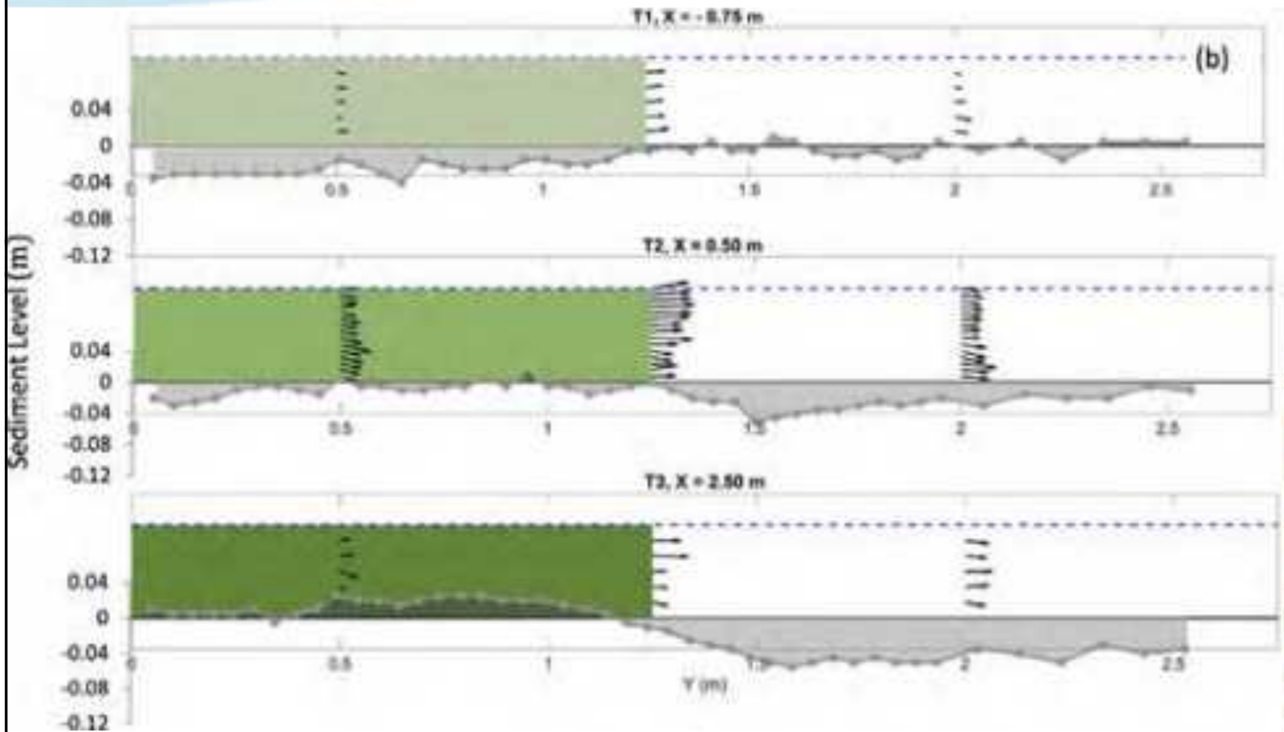


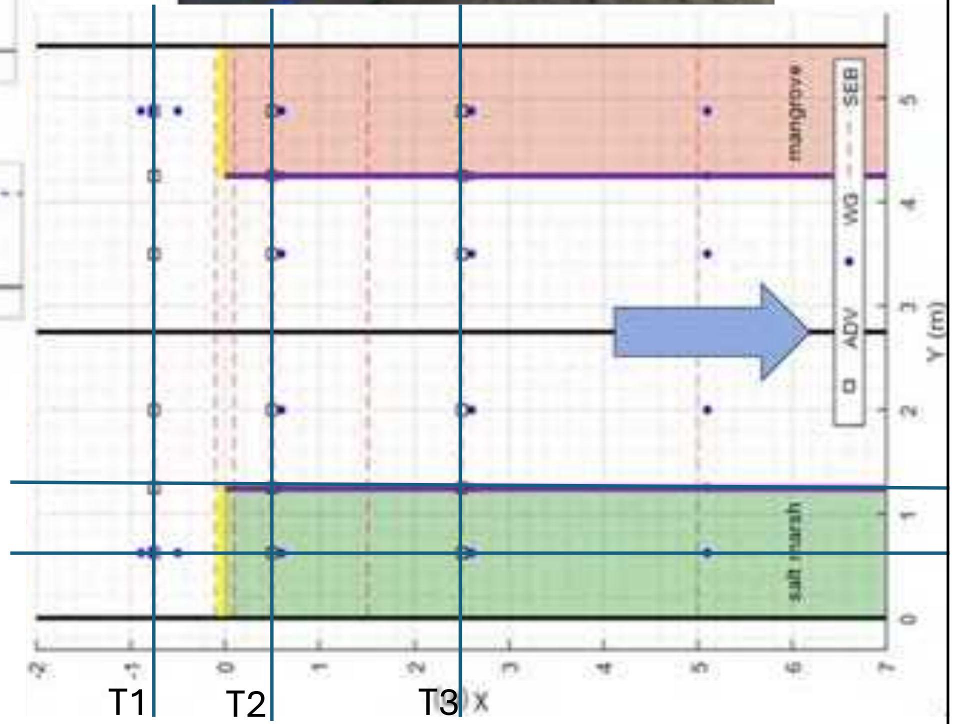


Longitudinal sections (inside the patch *Y* = 0.625 m, dark green, at the lateral edge *Y* = 1.25 m, light green, and at the channel *Y* = 2.00 m, blue). Velocity profiles obtained using X and Z components.

- Flow velocity (black arrows)
- TKE magnitude (red lines)
- Sediment elevation (gray lines)

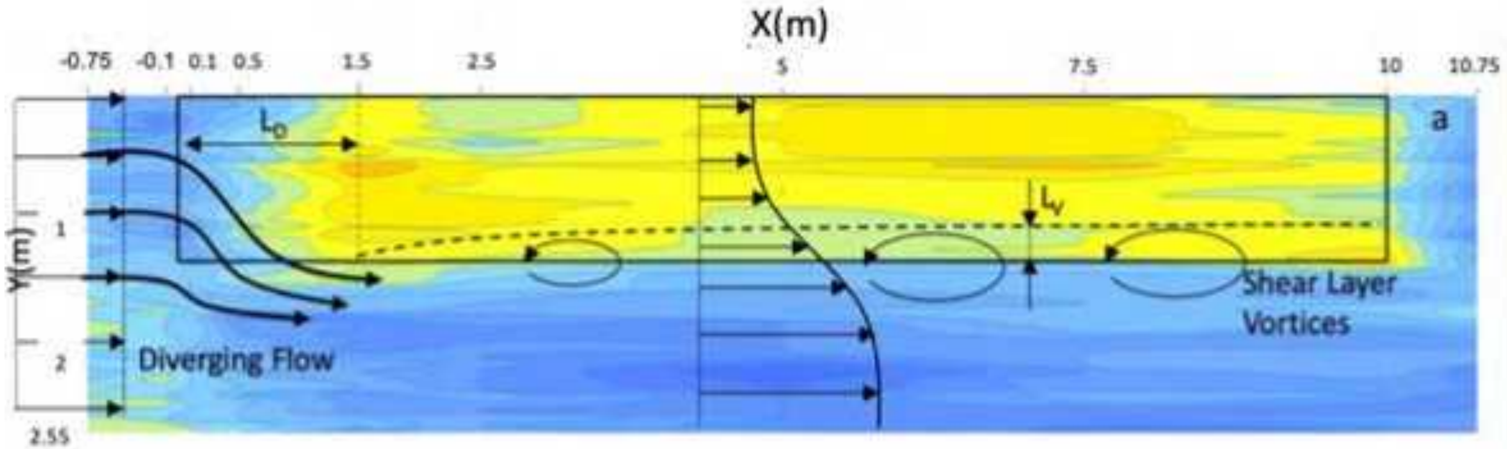
Results



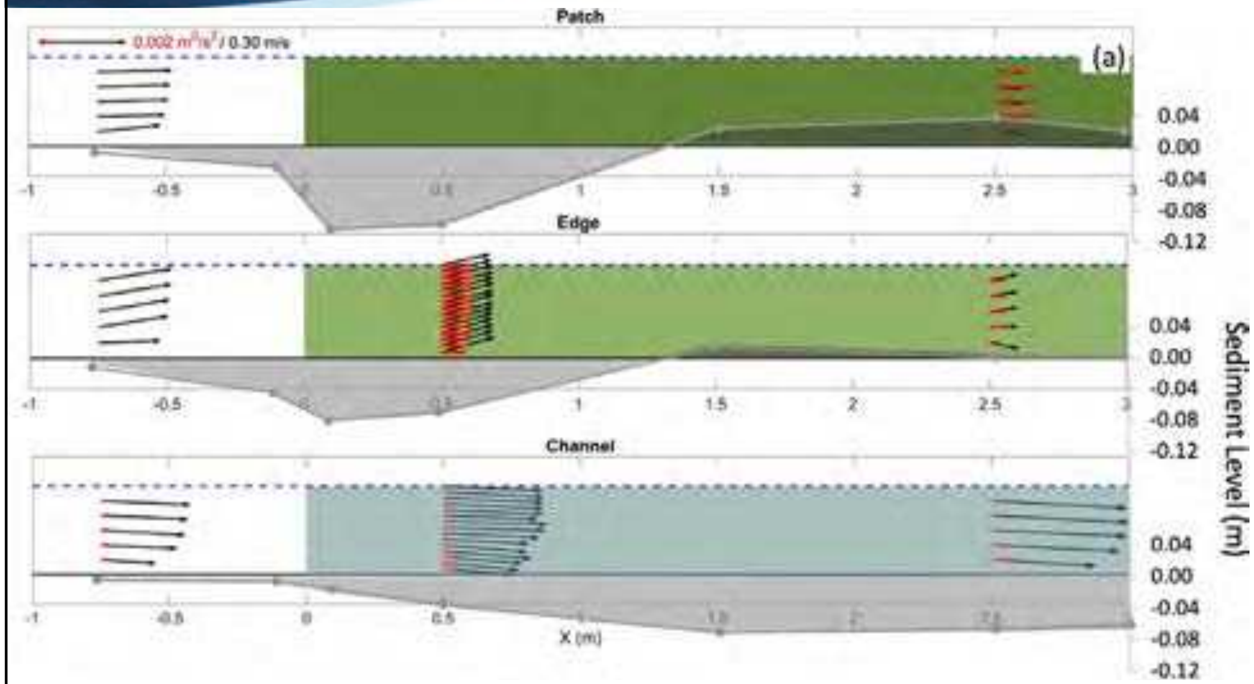


Cross sections (at T1 X = - 0.75 m, T2 X = 0.50 m, and T3 X = 2.50 m). Velocity profiles obtained using Y and Z components.

Results

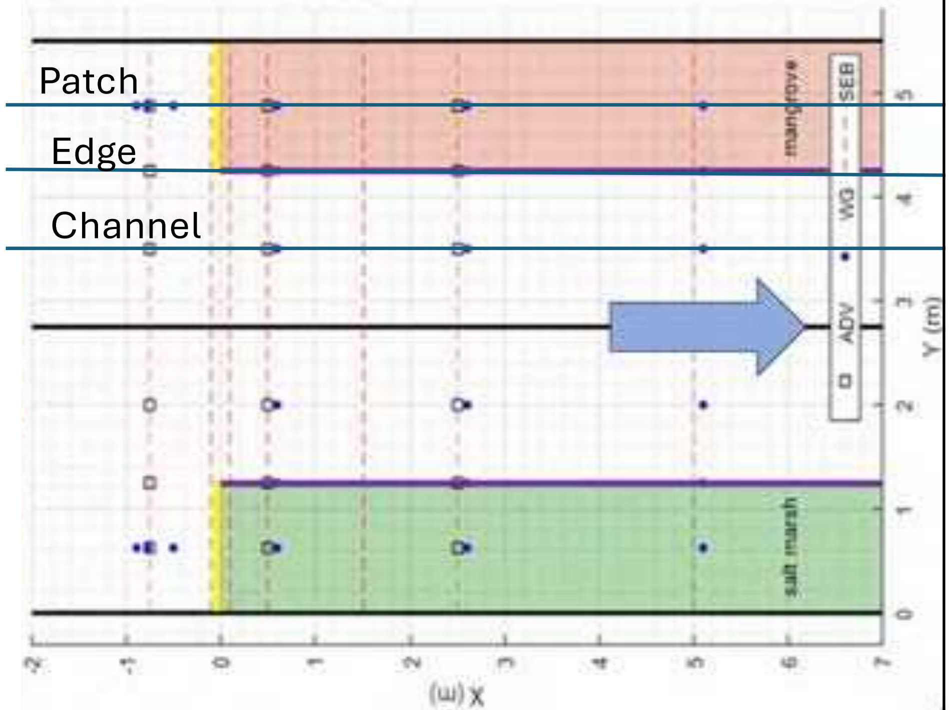

X(m)
-0.75
-0.1
0.1
0.5
1.5
2.5
5
7.5
10
10.75
Y(m)
1
2
2.55
a
Diverging Flow
Shear Layer
Vortices

Results

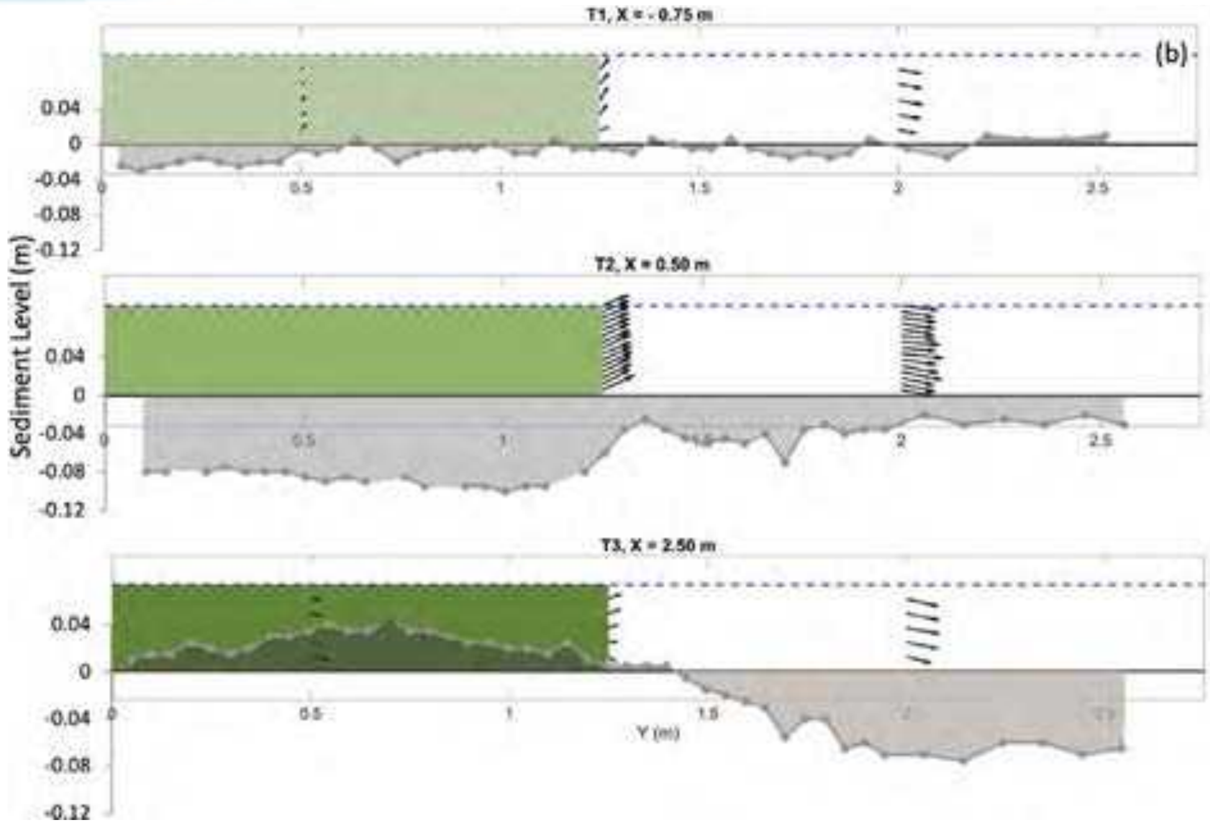


Longitudinal sections (inside the patch Y = 0.625 m, dark green, at the lateral edge Y = 1.25 m, light green, and at the channel Y = 2.00 m, blue). Velocity profiles obtained using X and Z components.

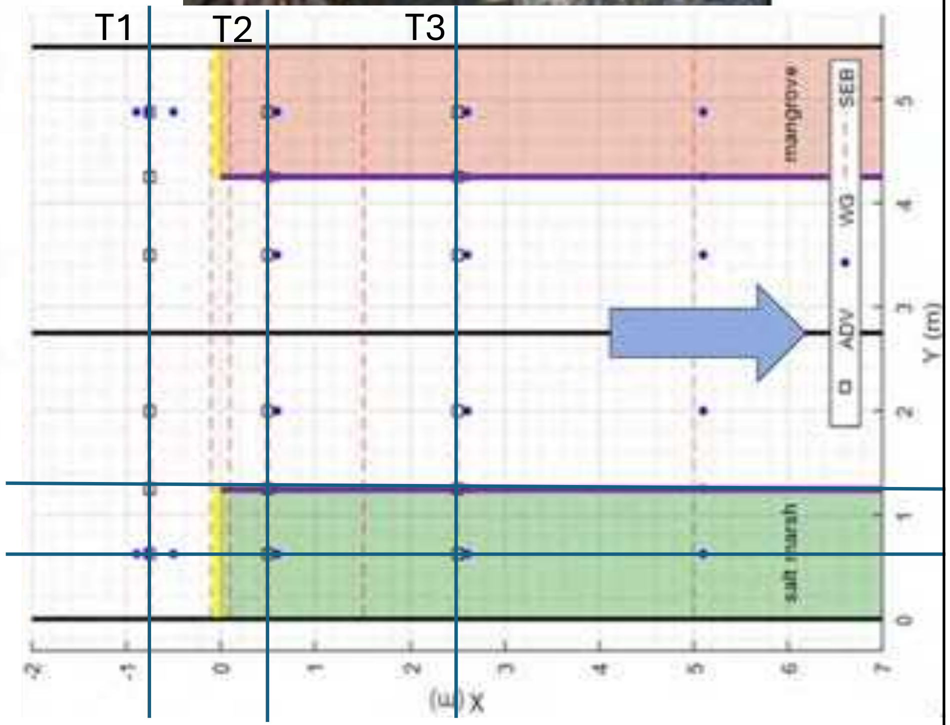
- Flow velocity (black arrows)
- TKE magnitude (red lines)
- Sediment elevation (gray lines)



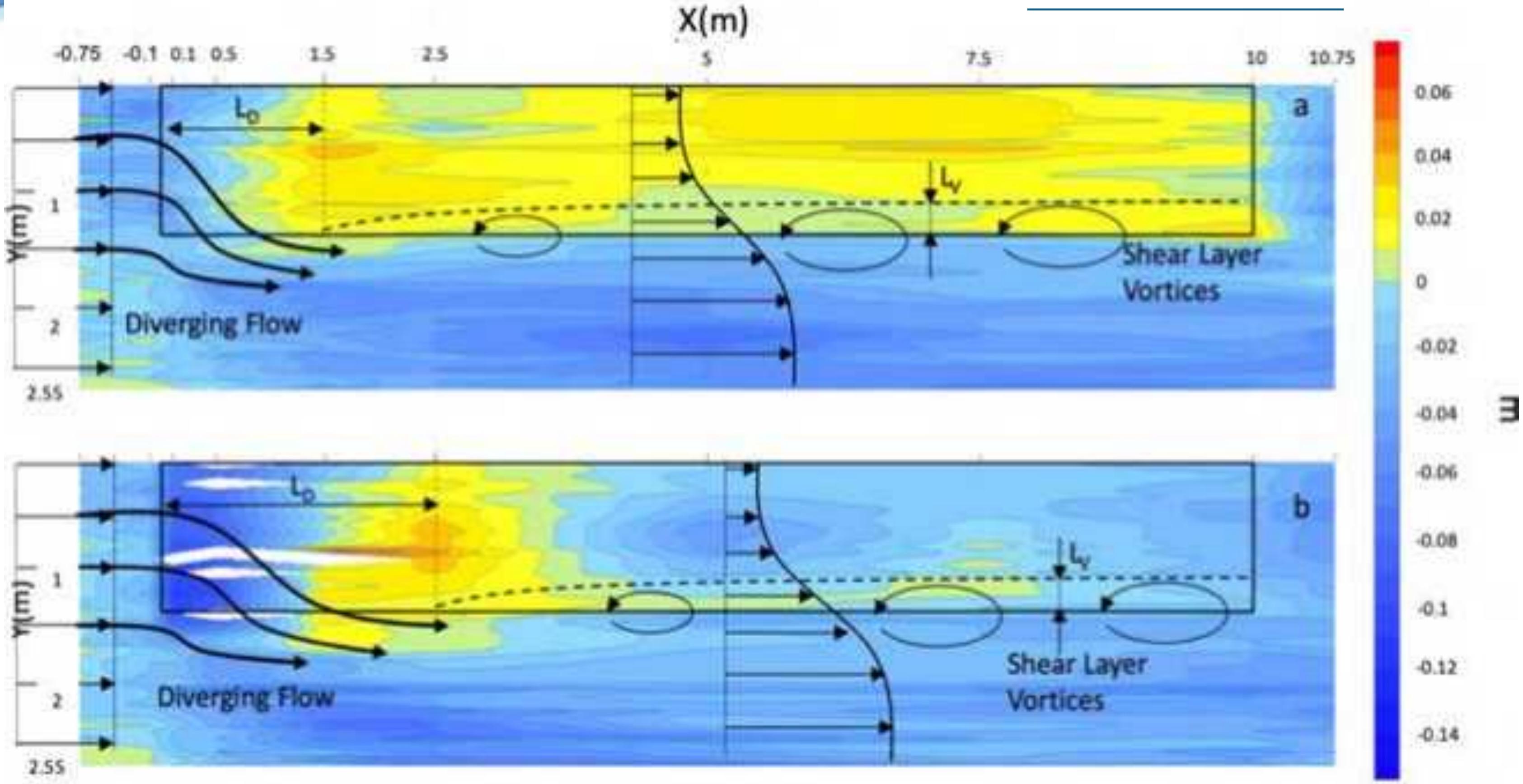
Results



Cross sections (at T1 X = - 0.75 m, T2 X = 0.50 m, and T3 X = 2.50 m). Velocity profiles obtained using Y and Z components.



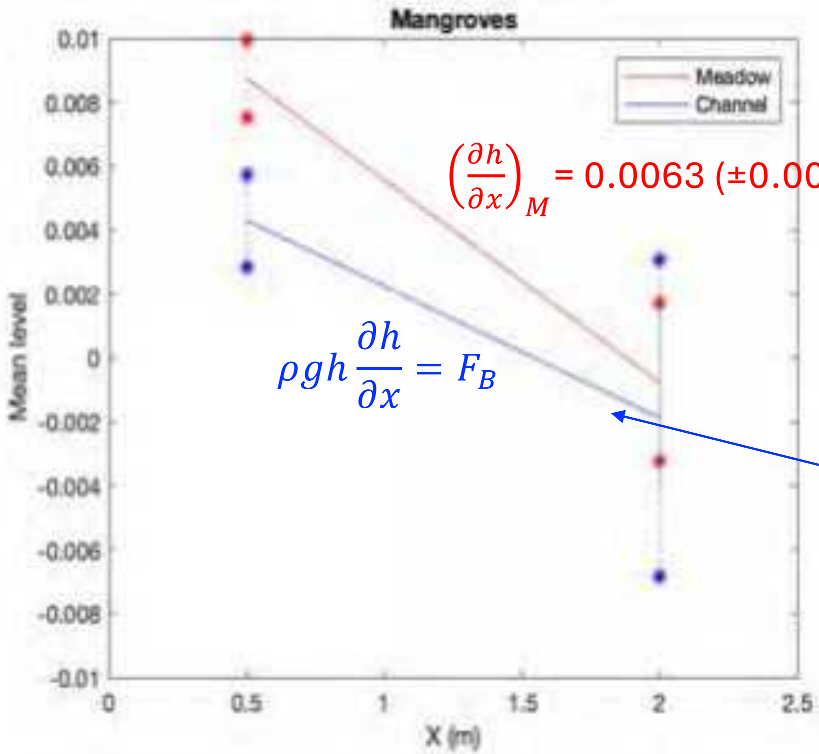
Results



Diverging region, L_D:

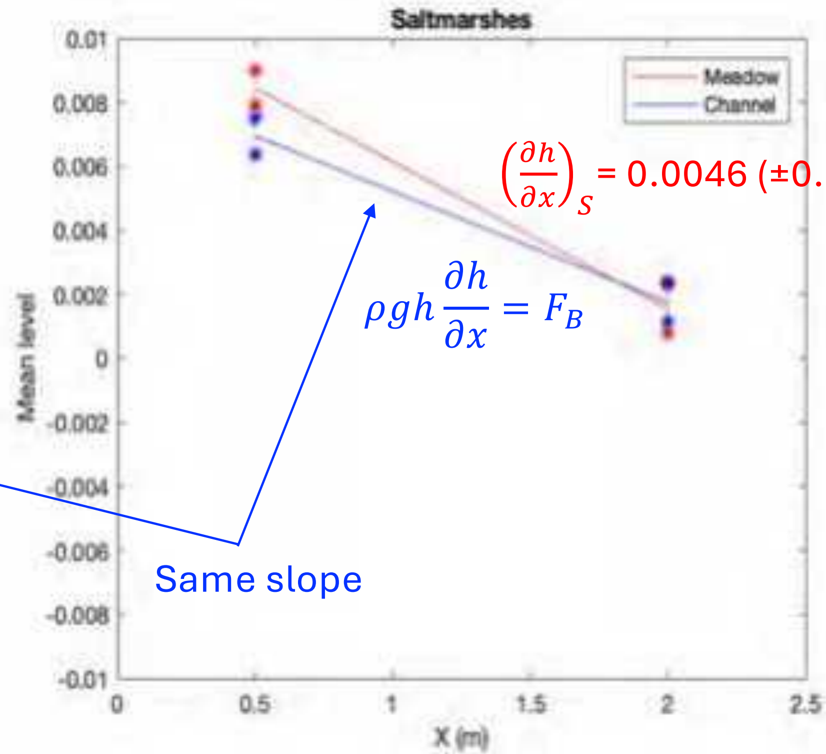
Downstream of **L_D** the flow field evolves into a flow field where the velocity within the vegetation is smaller than the velocity in the open channel. L_D = 1.5 m for saltmarshes and L_D = 2.5 for mangroves.

Results



$\left(\frac{\partial h}{\partial x}\right)_M$ = 0.0063 (±0.0008)

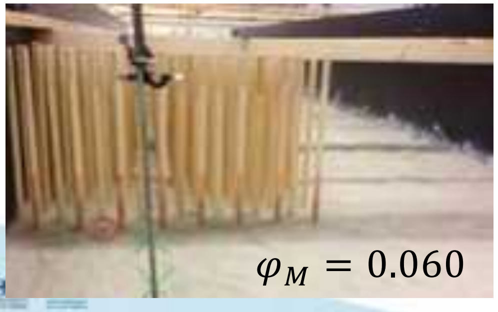
$$\rho g h \frac{\partial h}{\partial x} = F_B$$



$\left(\frac{\partial h}{\partial x}\right)_S$ = 0.0046 (±0.0001)

$$\rho g h \frac{\partial h}{\partial x} = F_B$$

Same slope



$$\rho g h \frac{\partial h}{\partial x} = F_D + F_B$$

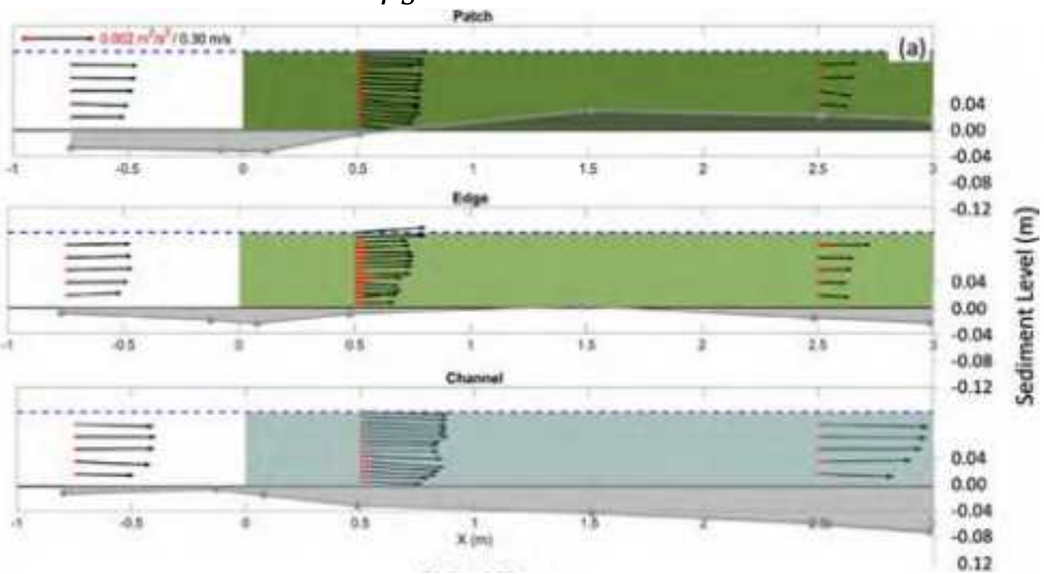
$$\left(\frac{\partial h}{\partial x}\right)_M > \left(\frac{\partial h}{\partial x}\right)_S$$

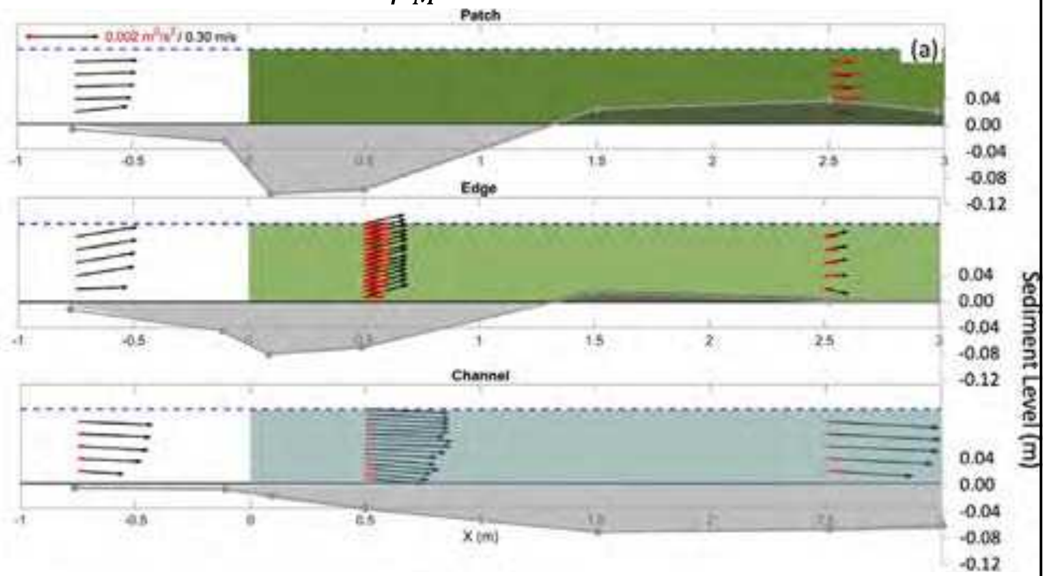
$$(F_D)_M > (F_D)_S$$

Results

$\varphi_S = 0.012$

$\varphi_M = 0.060$

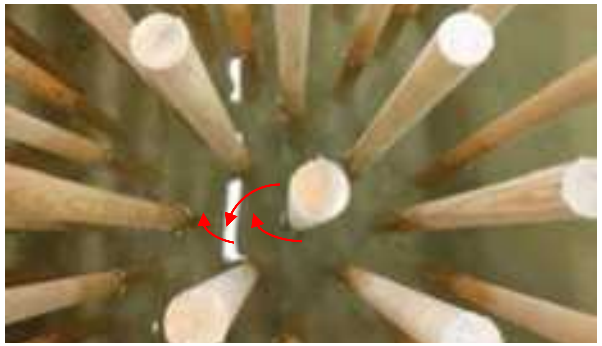




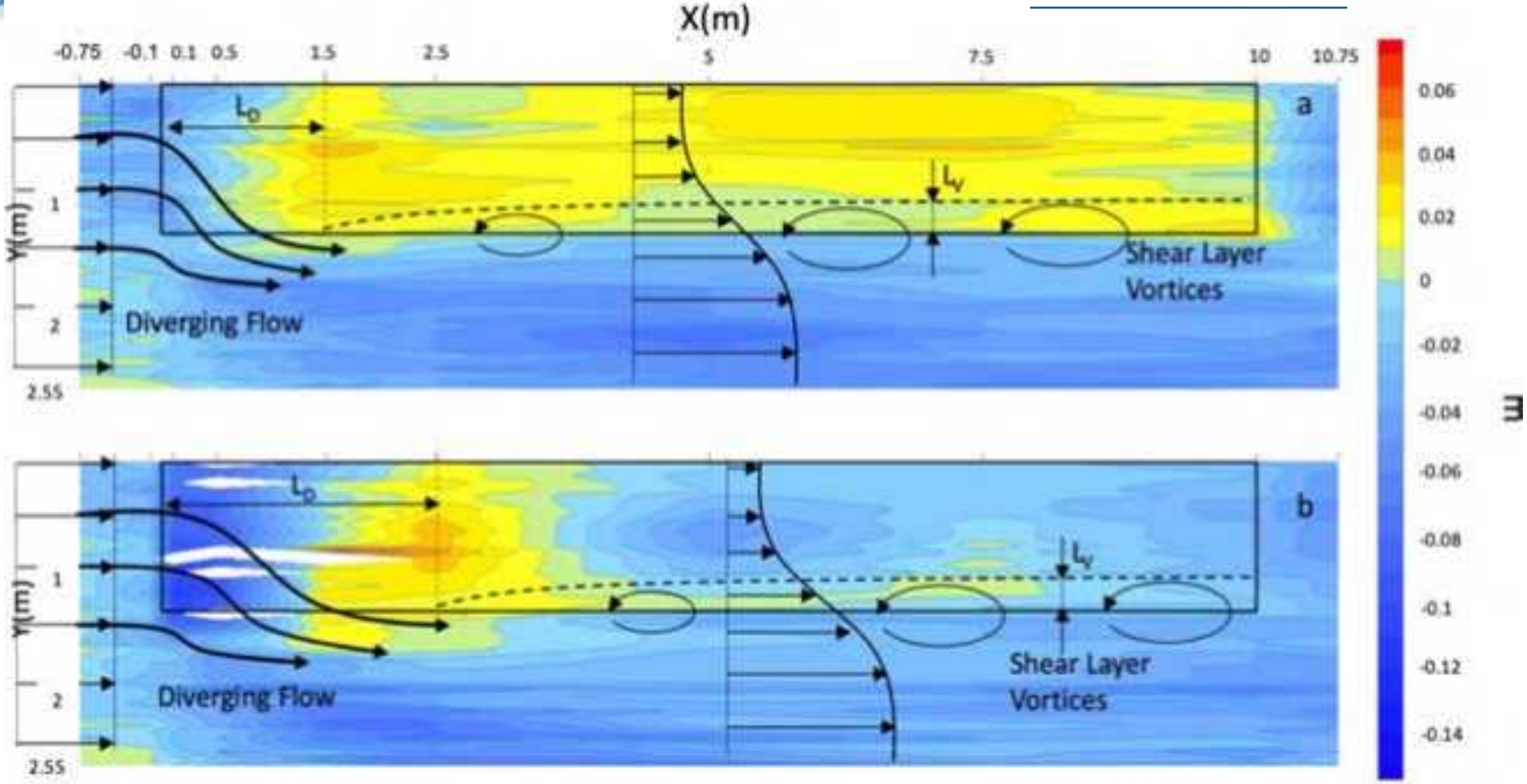
$$\frac{\sqrt{TKE}}{U} = 1.1\left[C_D \frac{\varphi}{(1-\varphi)\,{}^{\pi}/_{2}}\right]^{1/3}$$

Saltmarsh $TKE = 0.001\ \mathrm{m^2/s^2}$

Mangrove $TKE = 0.006\ \mathrm{m^2/s^2}$



Results

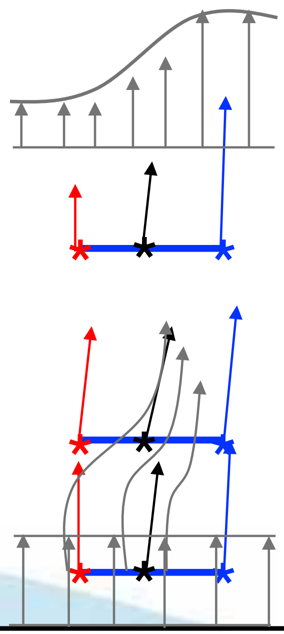


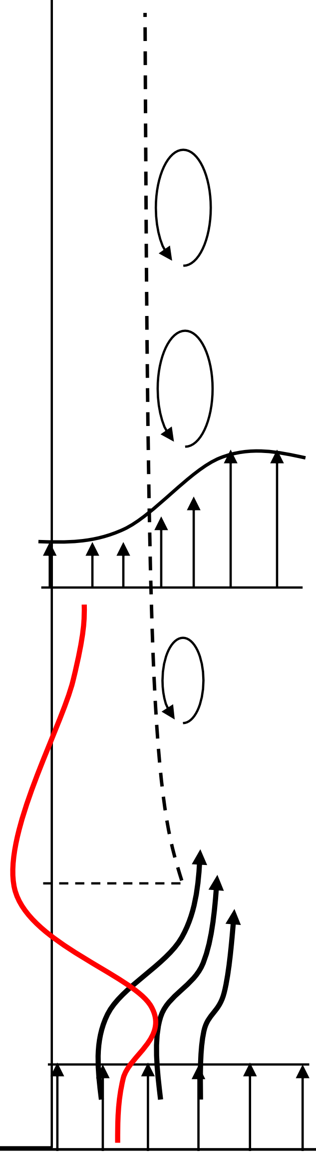
Length-scale of vortex penetration, Lv:

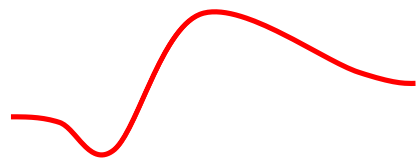
A shear layer forms at the interface between the patch and the lateral channel, where shear layer vortices develop. Since both patches present the same frontal area per volume, L_V is expected to be similar for both cases, being slightly bigger for the rigid vegetation due to its larger C_D value. Taking C_D = 1: $L_V = 0.5(C_D a)^{-1} \approx 0.2\ m$

Results

400 sticks/m2
6 - 8 mm diameter



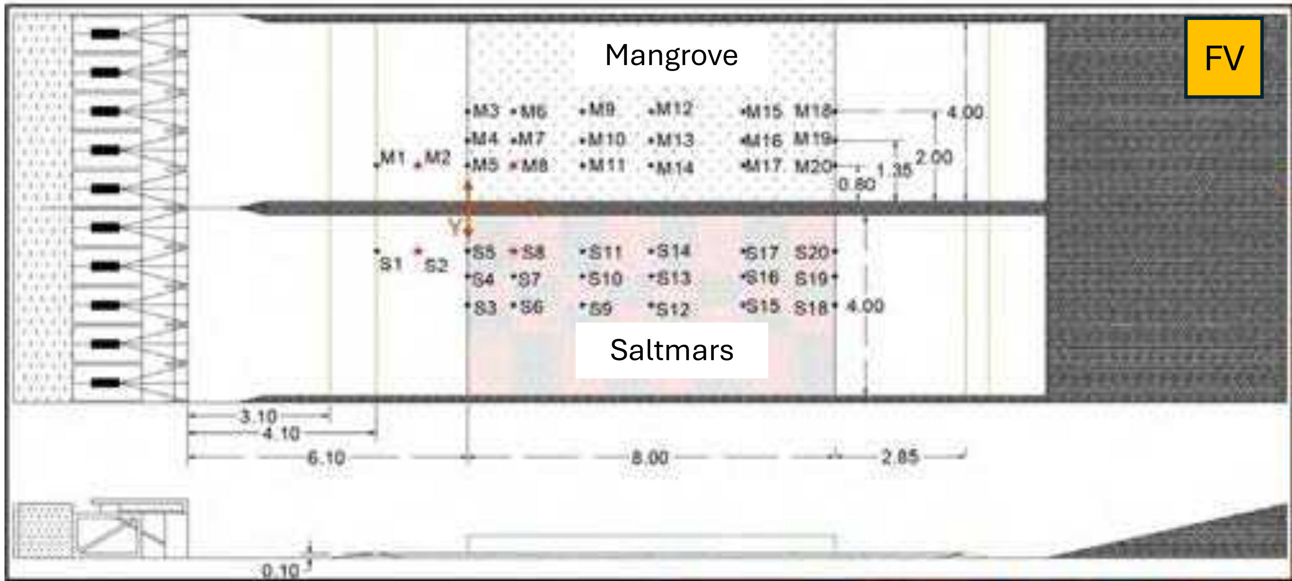


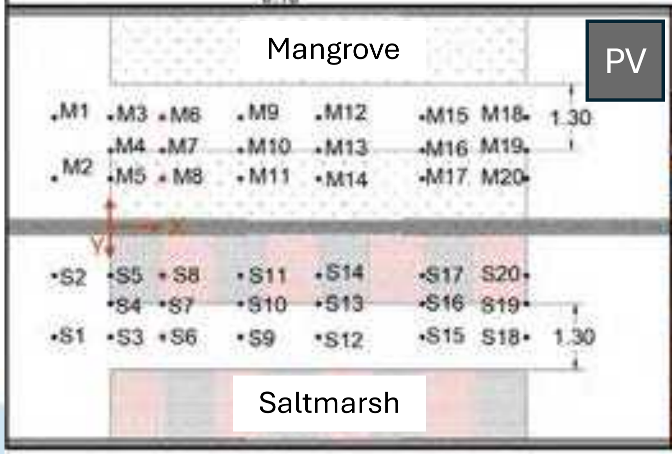


Bouma et al. (2005)

- Motivation
- HyWedges
- **SHACC**
- Conclusions

Experimental set-up





Experimental set-up

Saltmarsh characteristics

$$b_v = 0.6\ cm$$

$$h_v = 40\ cm$$

$$N = 312.5\ stems/m^2$$

$$\Delta X = \Delta Y = 0.04\ m$$

Maza et al. (2016), Norris et al. (2019)

Mangroves characteristics

$$b_v = 3\ cm$$

$$h_v = 40\ cm$$

$$N = 12.5\ stems/m^2$$

$$\Delta X = \Delta Y = 0.2\ m$$

Schulze et al. (2019), Vuik et al. (2018); Zhu et al. (2020)

Sediment

$$d_{50} = 0{,}168\ mm$$

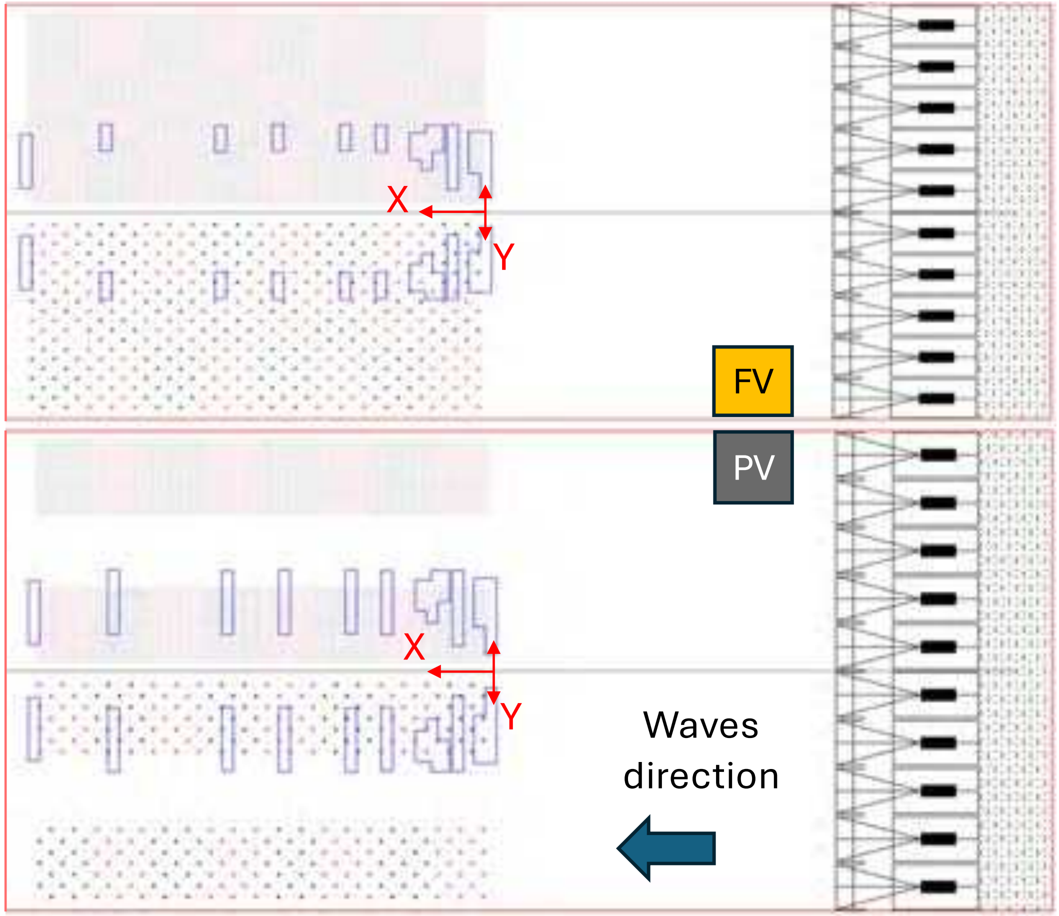
(Horstman et al., 2014; Hu et al., 2021)

Experimental set-up

Regular waves

Test	h (m)	H (m)	T (s)	L (m)	H/h	H/L
C13	0.4	0.1	1.5	2.61	0.25	0.04
C24	0.4	0.1	2.5	4.74	0.25	0.02
C35	0.6	0.2	1.5	2.99	0.33	0.07
C46	0.2	0.1	1.5	1.97	0.50	0.05
C57	0.2	0.1	2.5	3.43	0.50	0.03
C68	0.4	0.2	1.5	2.61	0.50	0.08
C79	0.6	0.3	1.5	2.99	0.50	0.10

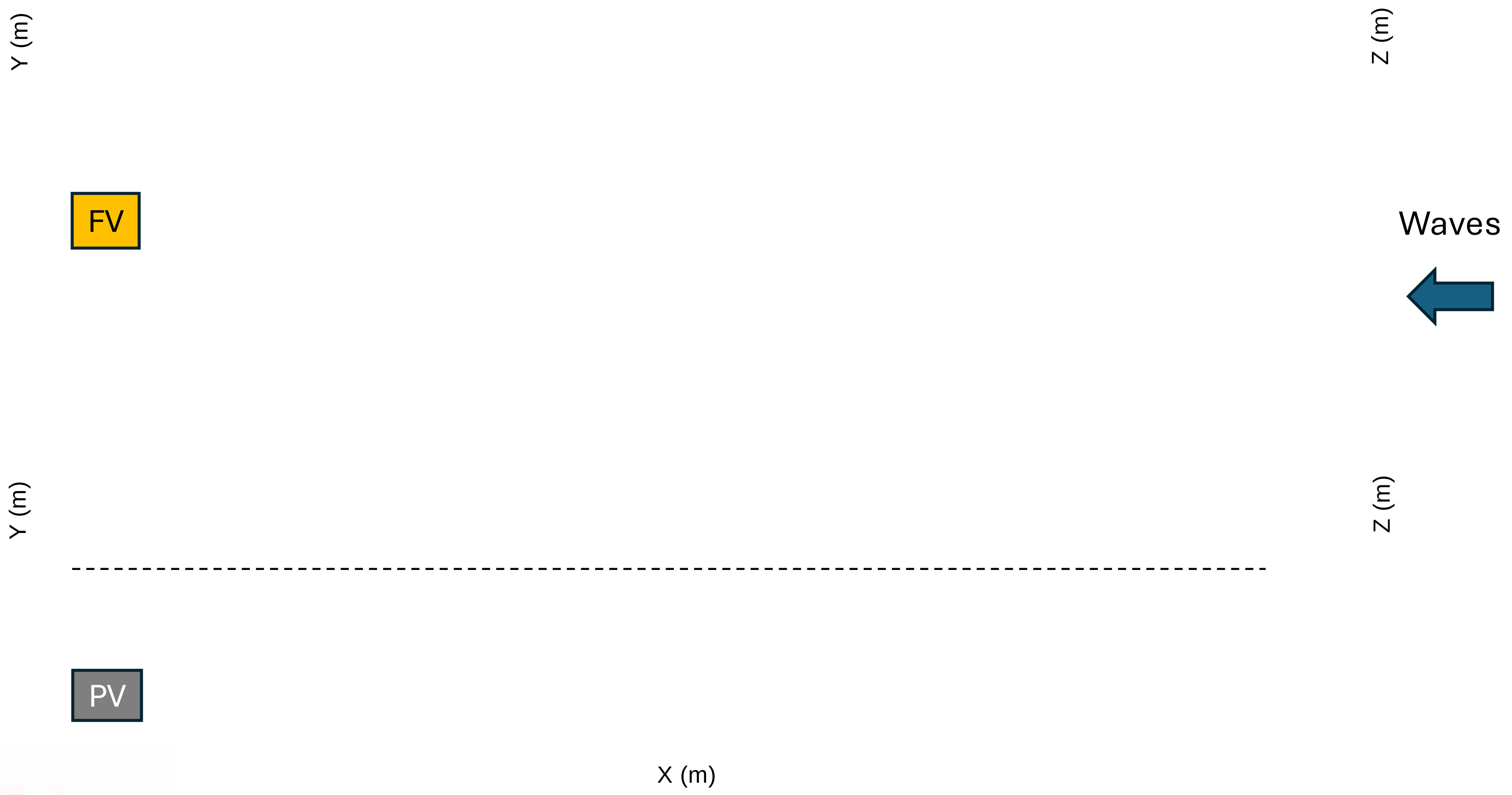
Experimental set-up



Laser scanner

- Minimum resolution: 0.4 mm
- Full Vegetation: 20 areas ≈ 20x40 cm
- Partial Vegetation: 25 areas≈ 20x40 cm

Mangroves initial bed elevation



Saltmarsh initial bed elevation

Mangroves – bed elevation evolution

FV

PV

Test	h (m)	H (m)	T (s)
C57	0.2	0.1	2.5
C68	0.4	0.2	1.5
C79	0.6	0.3	1.5

No significant erosion/accretion patterns

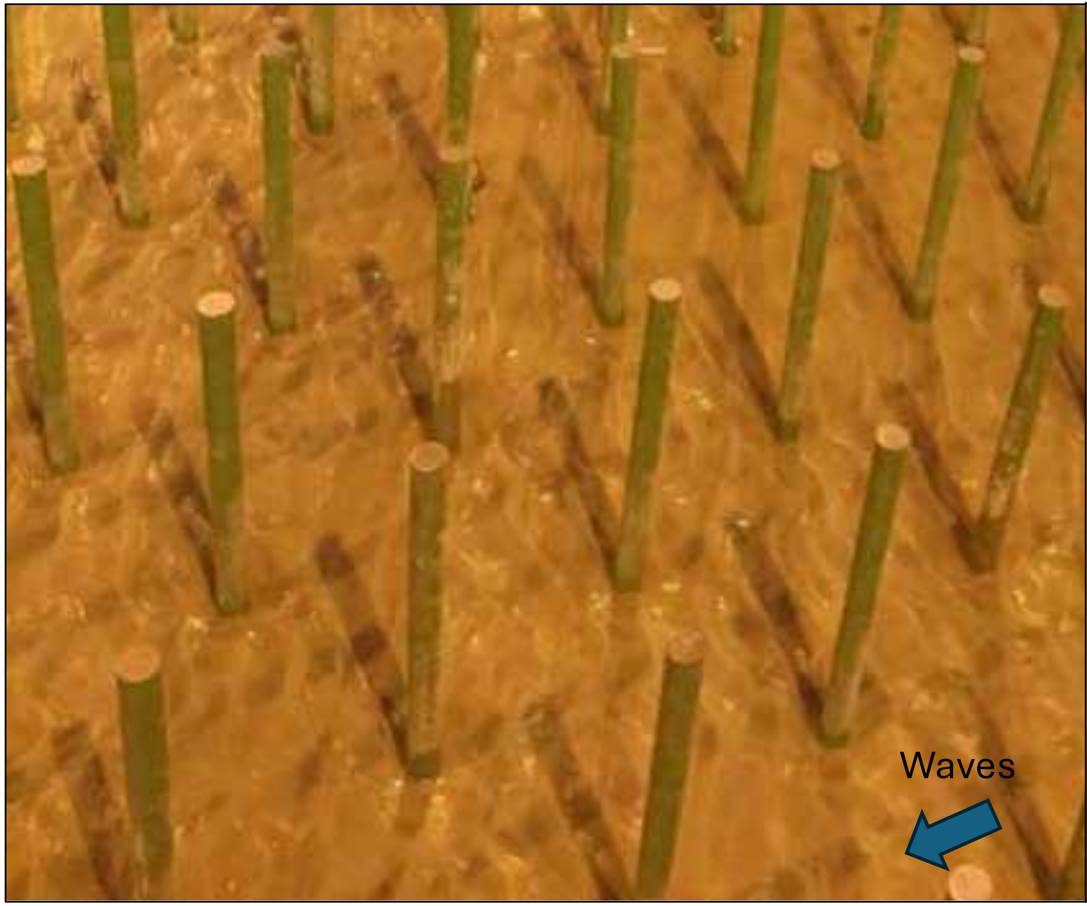
Saltmarshes – bed elevation evolution

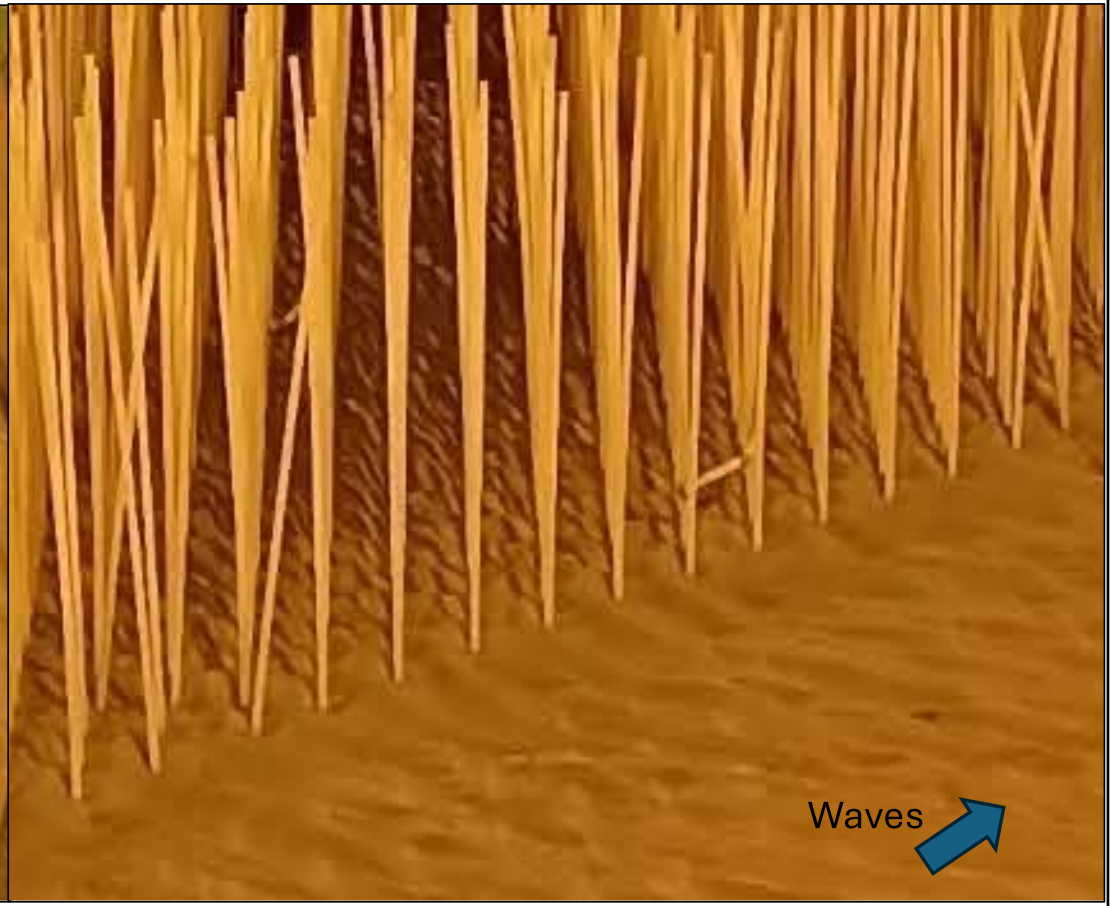
FV

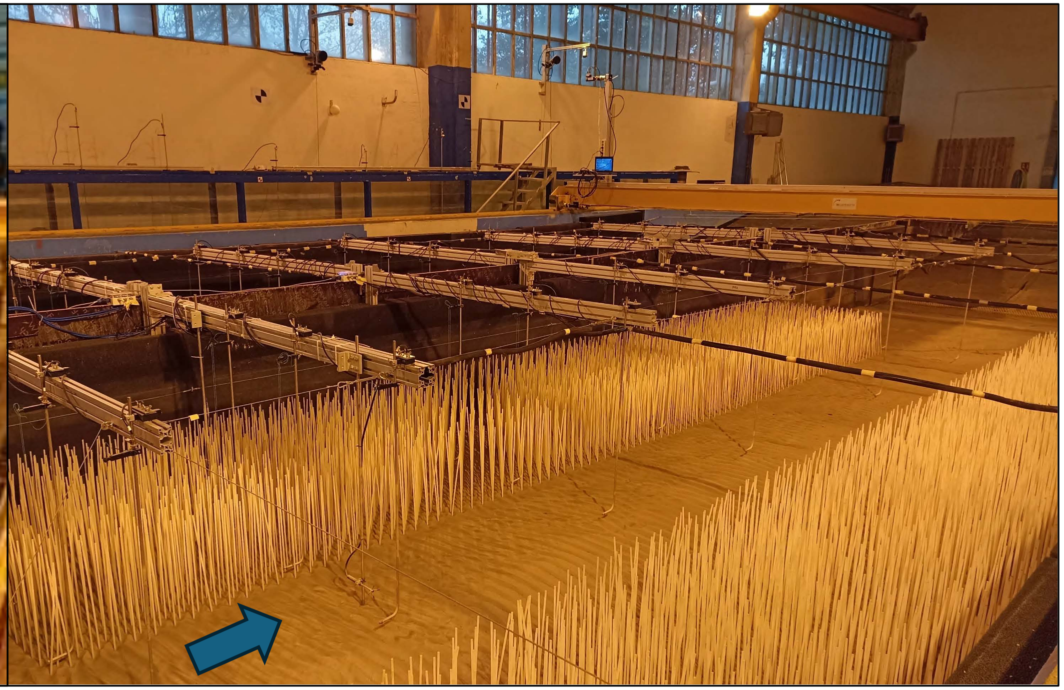
PV

Test	h (m)	H (m)	T (s)
C57	0.2	0.1	2.5
C68	0.4	0.2	1.5
C79	0.6	0.3	1.5

No significant erosion/accretion patterns


Waves

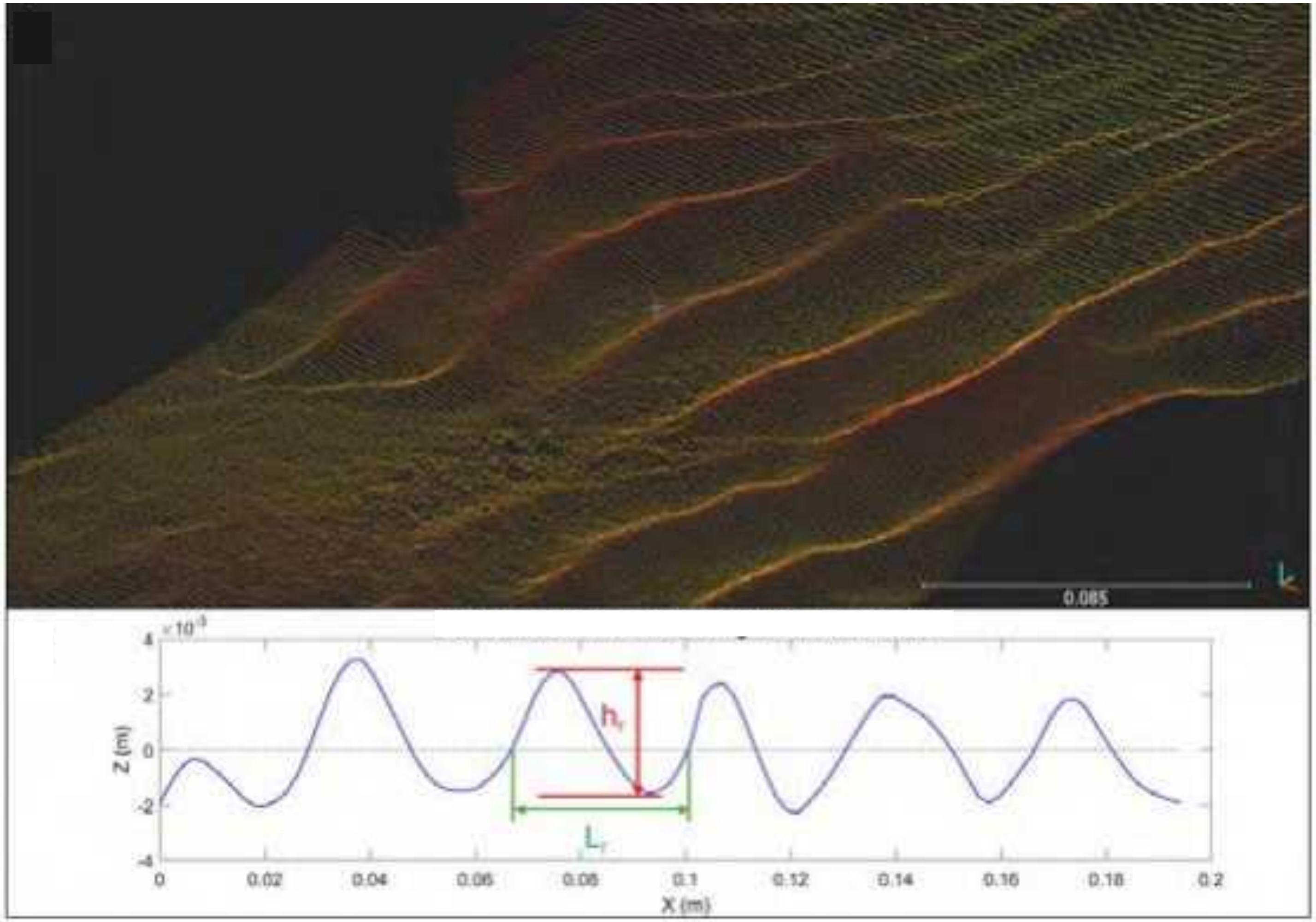

Waves

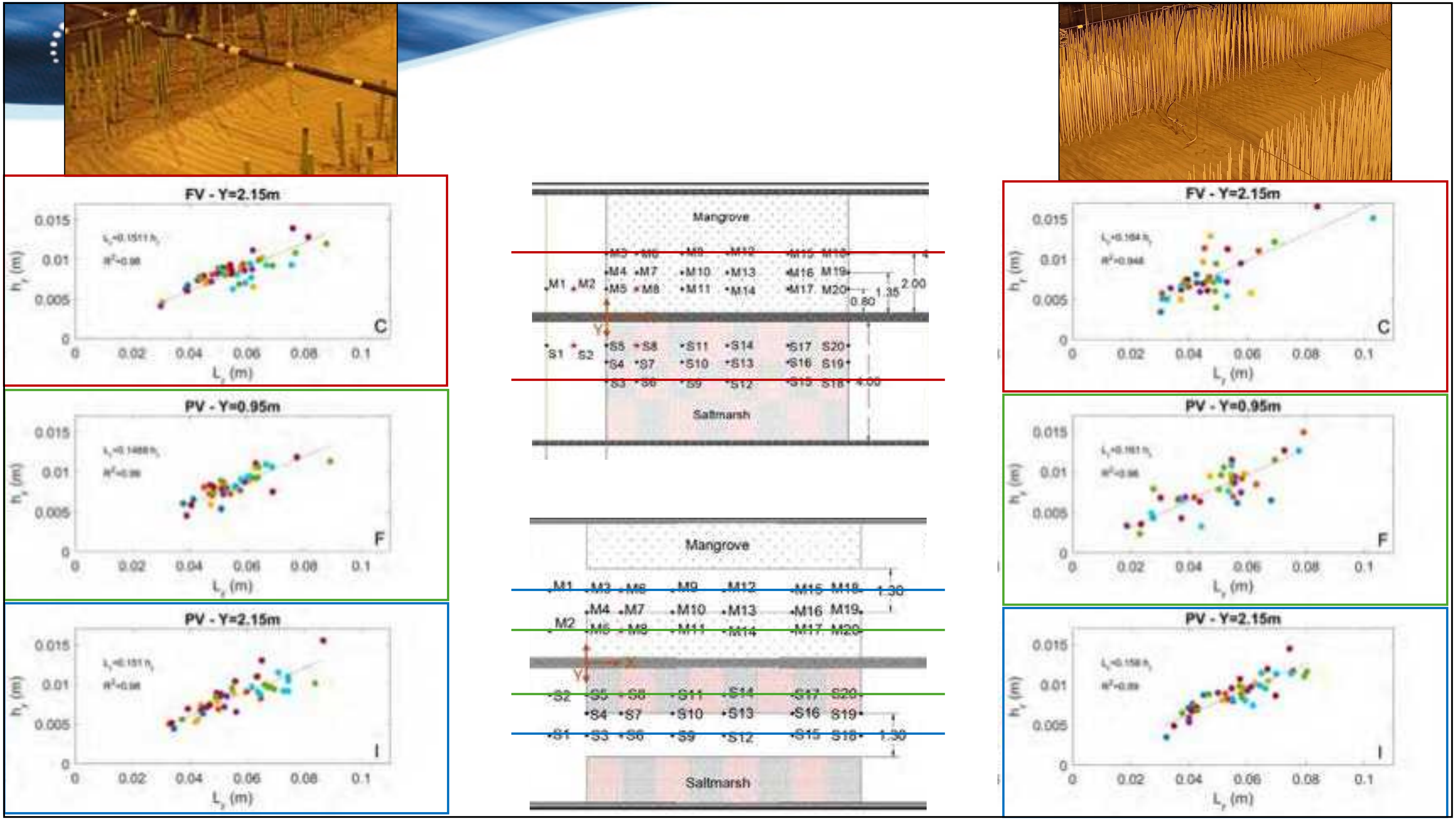


Ripples characterization

- h_r: ripples height
- L_r: ripples length

- X ≈ 0, 0.48, 1.7, 2.33, 3.5, 4.5, 6.5 y 8 m
- Measured at the center of the channel (Y≈2.15 m) and within the vegetation fields (Y≈0.95 m)

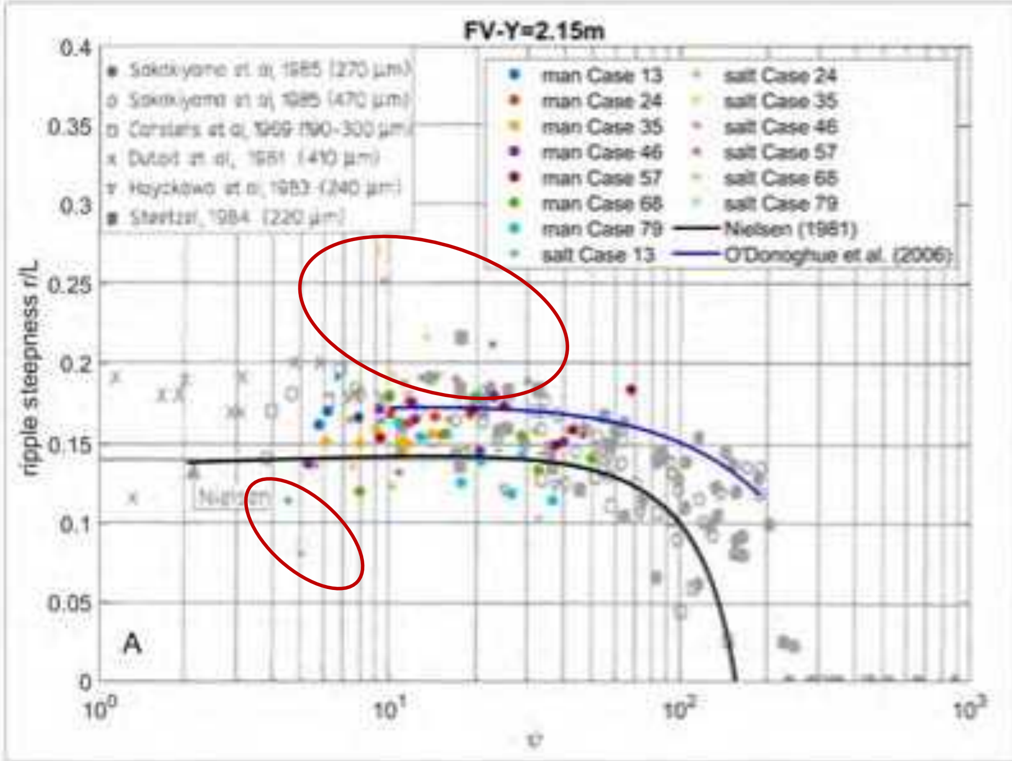




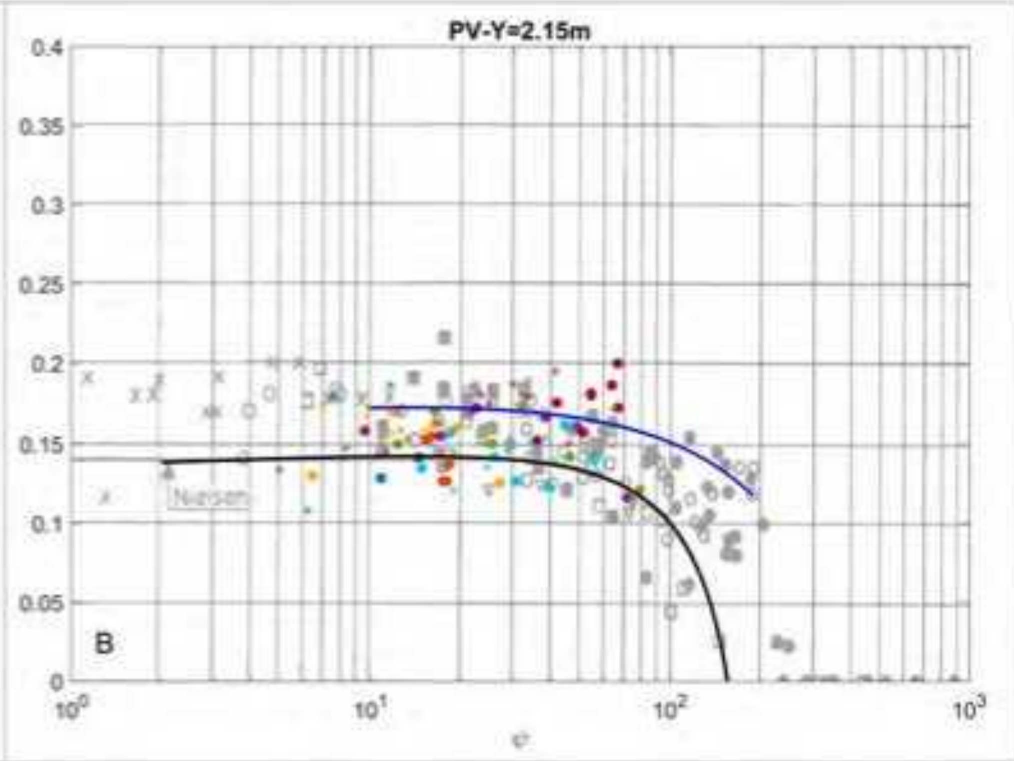
FV - Y=2.15m
PV - Y=0.95m
PV - Y=2.15m
Mangrove
Saltmarsh
C
F
I
FV - Y=2.15m
PV - Y=0.95m
PV - Y=2.15m
C
F
I

Ripples steepness

Measured bedforms geometry in the laboratory is compared to van Rijn (1993)



Vegetation



Bare bottom

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Ripples steepness

Can we estimate their geometry within vegetation fields?

Vegetation type	Formula	RMSE within vegetation	RMSE at the channel
Saltmarsh	Nielsen (1981)	0.047	0.026
	O'Donoghue et al. (2006)	0.039	0.023
	Nelson et al. (2013)	0.063	0.043
Mangrove	Nielsen (1981)	0.023	0.026
	O'Donoghue et al. (2006)	0.023	0.027
	Nelson et al. (2013)	0.041	0.037

Nielsen (1981)

$$\frac{h_r}{L_r} = \frac{0.275 - 0.022\,\psi^{0.5}}{2.2 - 0.345\psi^{0.34}}$$

O' Donoghue et al. (2006)

$$\frac{h_r}{L_r} = \frac{0.275 - 0.022\,\psi^{0.42}}{1.97 - 0.44\psi^{0.21}}$$

Nelson et al. (2013)

$$\frac{L_r}{A_{w,b}} = \left\{0.72 + 2.0\times10^{-3}\frac{A_{w,b}}{d_{50}}\left[1 - exp\left(-\left(1.57\times10^{-4}\frac{A_{w,b}}{d_{50}}\right)^{1.15}\right)\right]\right\}^{-1}$$

$$\frac{h_r}{L_r} = 0.120\,L_r^{-0.056}$$

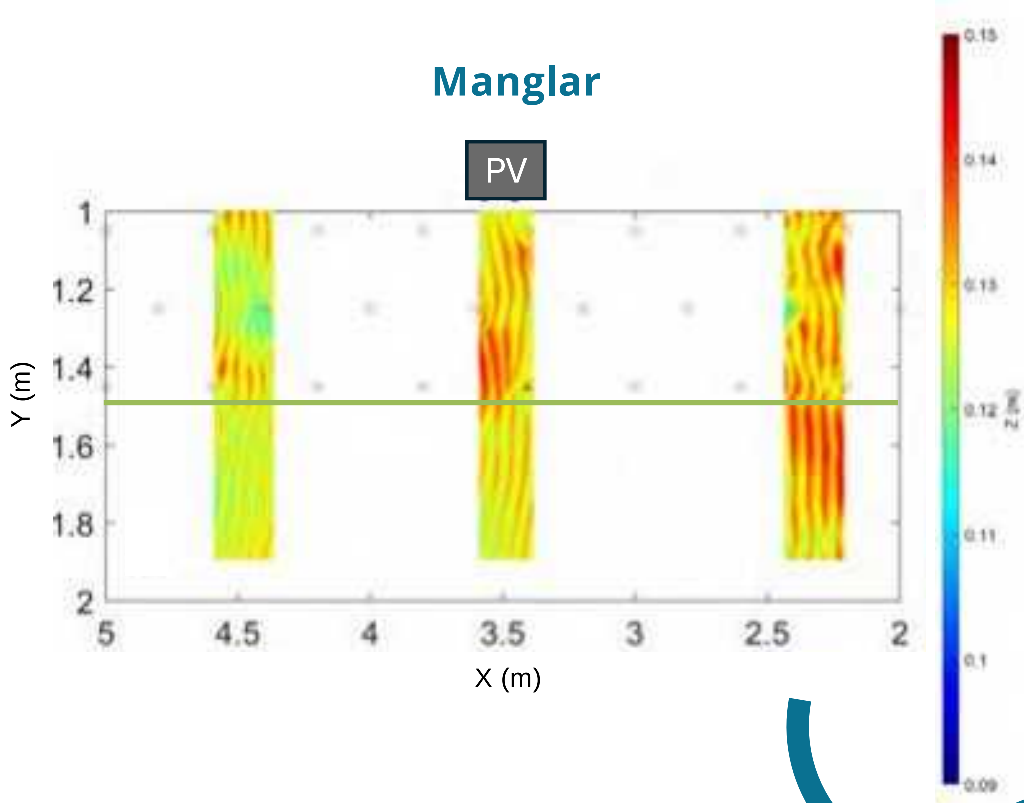
ψ: mobility parameter

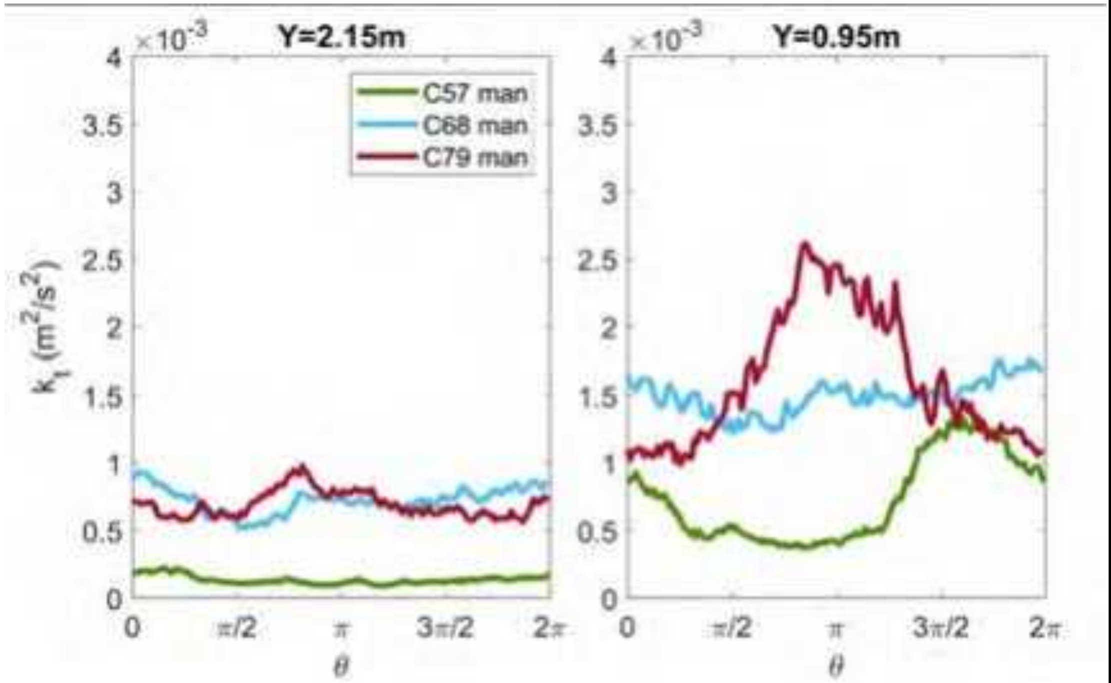
$A_{w,b}$: orbital excursion at the bottom

IH UC

Ripples pattern

Manglar

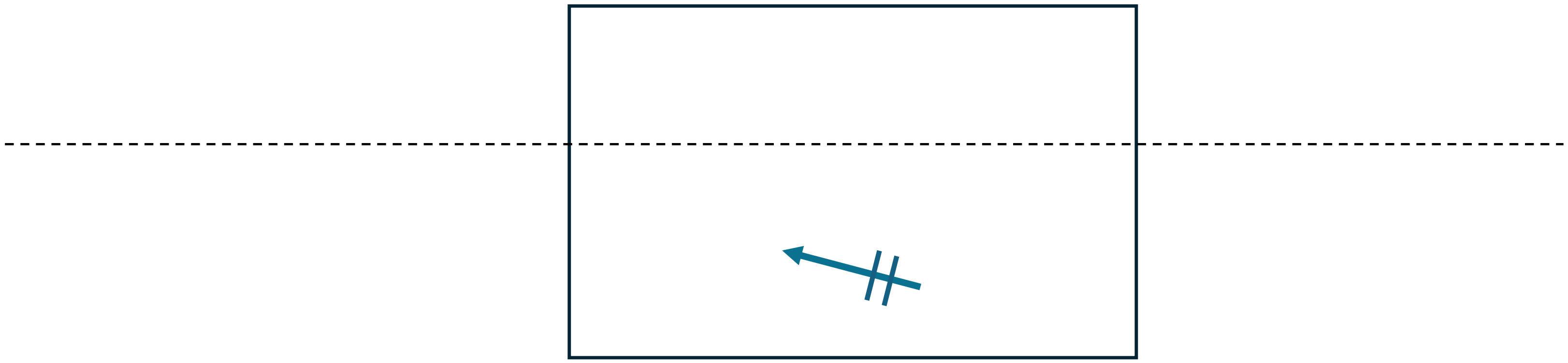




Ripples and wave energy dissipation

Ripples and wave energy dissipation

Ripples orientation



Ripples orientation

- Motivation
- HyWedges
- SHACC
- **Conclusions**

Conclusions

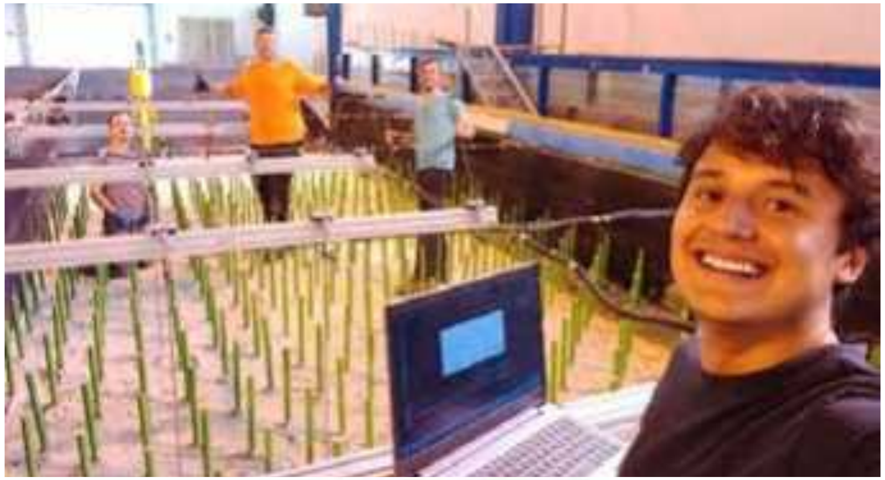
- The flow and sediment transport patterns observed under **currents** show the expected divergence region, which is influenced by the vegetation field properties.
- Vegetation fields allow trapping sediment and creating soil while preventing erosion but **edge effects** that may result in local ecosystem loss must be considered.
- Under the tested **wave conditions** significant erosion and accretion areas were not observed.
- **Ripples** size within the vegetation area in the mangrove mimics can be estimated using existing formulations. That is not the case for saltmarshes mimics. For both the pattern is not regular due to the turbulence produced by the stems and the orientation of the ripples is affected by the transformation processes produced by the vegetation in the waves.
- More studies are still needed to well characterized flow-sediment-ecosystem interactions.

IHcantabria

Acknowledgments

European Commission

GOBIERNO DE ESPAÑA | MINISTERIO DE CIENCIA E INNOVACIÓN




Advances in Water Resources

ELSEVIER

Living on the edge: How traits of ecosystem engineers drive bio-physical interactions at coastal wetland edges

Gillis LG, M Maza, J Garcia-Maribona, JL Lara, T Suzuki, M Argemi Cierco, M Paul, AM Folkard, T Balke

Thank you for your attention!

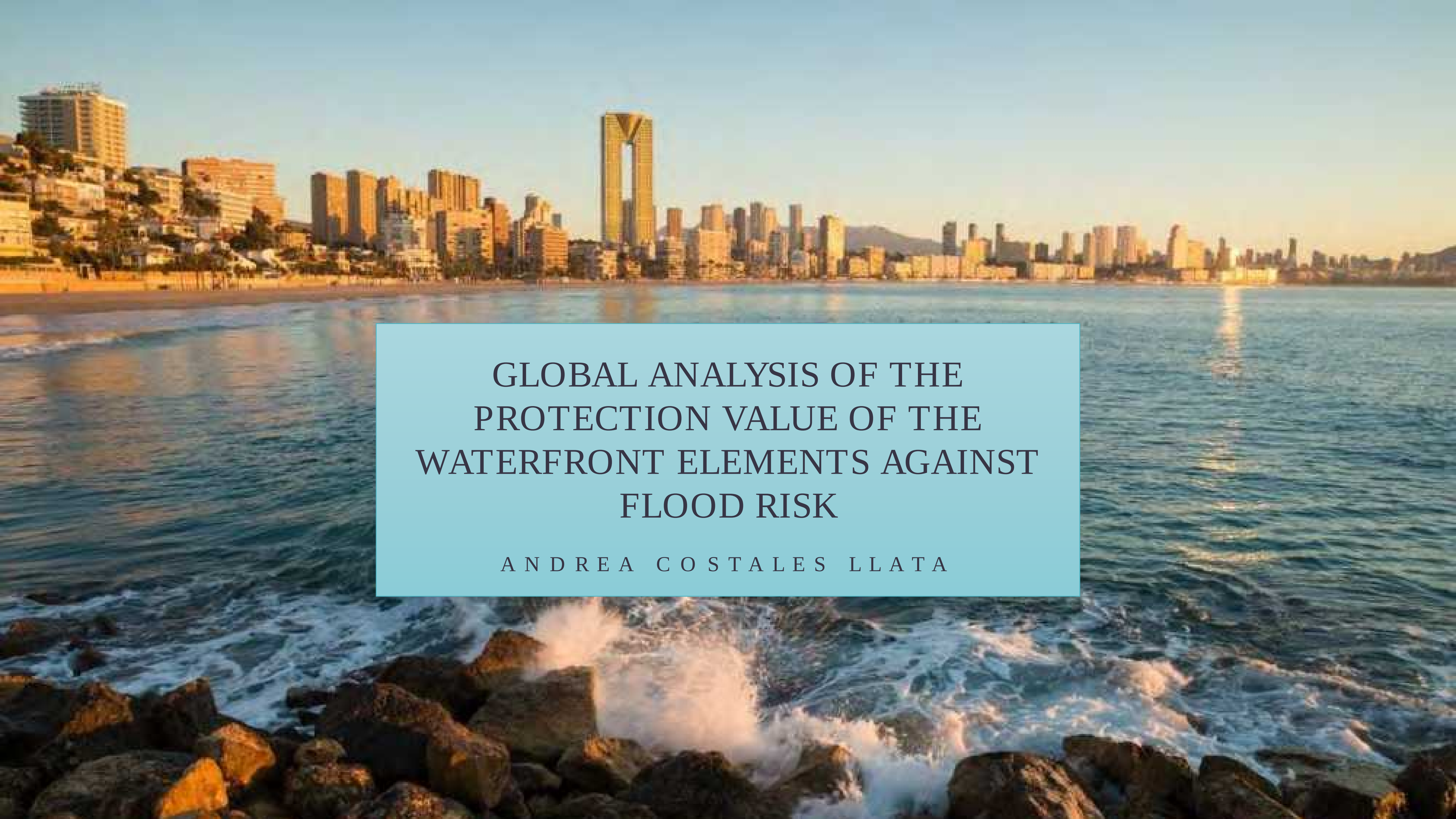
mazame@unican.es

@MariaE_Maza

Maria Maza

UC

Interactive session with FIHAC PhD students by Andrea Costales, Lucas de Freitas and Arnau García (IHCantabria)



GLOBAL ANALYSIS OF THE PROTECTION VALUE OF THE WATERFRONT ELEMENTS AGAINST FLOOD RISK

ANDREA COSTALES LLATA

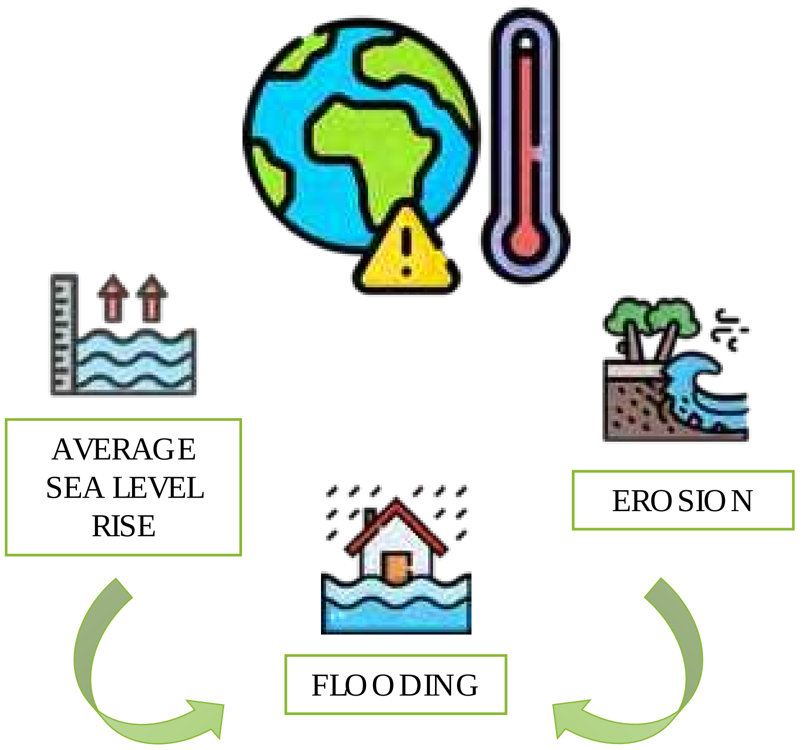
Author: Andrea Costales Llata

Supervisors: Íñigo J. Losada Rodríguez
Alexandra Toimil Silva

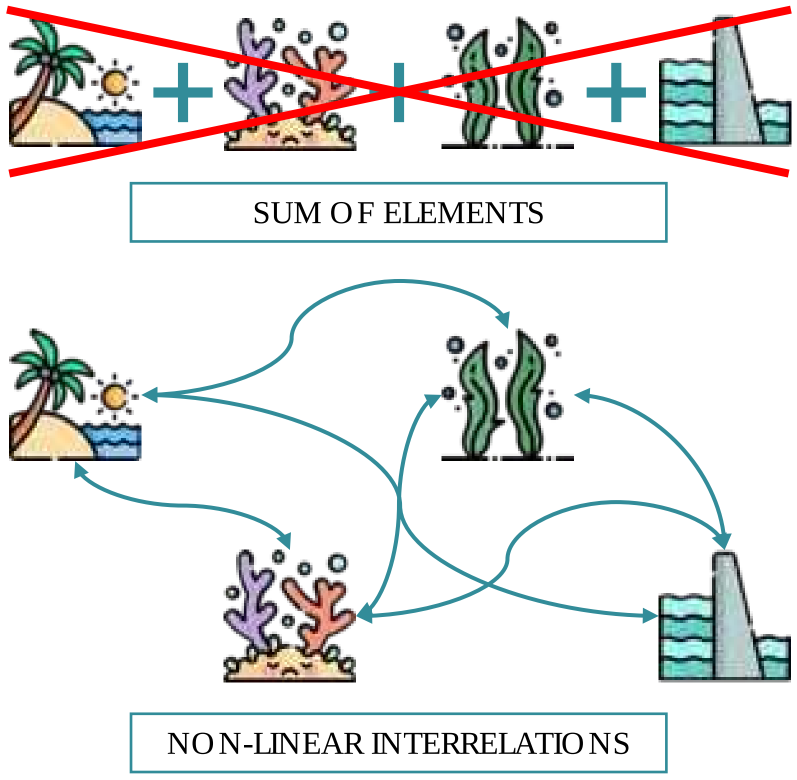
PhD programme: Coastal Engineering, Hydrobiology and Management of Aquatic Systems

BACKGROUND AND OBJETIVES

COASTAL RISK ASSOCIATED WITH CLIMATE CHANGE



WATERFRONT PROTECTION SERVICE



MAIN GOAL

Development of a methodology to economically assess the protection against flooding (and implicitly erosion) offered by the different elements of the waterfront both in isolation and as a whole by identifying the non-linearities derivate from their combination

OBJETIVES

- IMPROVING THE FLOOD MODELLING
- APPLICATION AT LOCAL SCALE
- IMPROVING THE ANALYSIS OF ASSOCIATED RISK
- APPLICATION AT REGIONAL SCALE
- IMPROVING THE ECONOMIC QUANTIFICATION
- ADAPTATION AND CLIMATE CHANGE

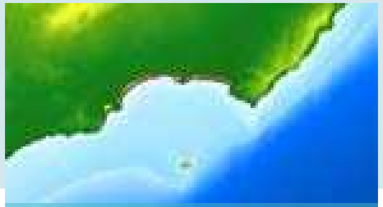
THE CASE OF BENIDORM

Poniente's beach

Levante's beach

HR TOPOBATHYMETRY

- MDT02-ETRS-HU30 (*IGN, 2016*).
- Ecocartografía de Alicante (*MITECO, 2006-2007*).
- EMODnet (*2020*).



DEM resolution = 5m

WAVE DATA

- GOW2 ERA 5 (*IHData*).
- GOS (*IHData*).
- GOT (*IHData*).

WATERFRONT ELEMENTS

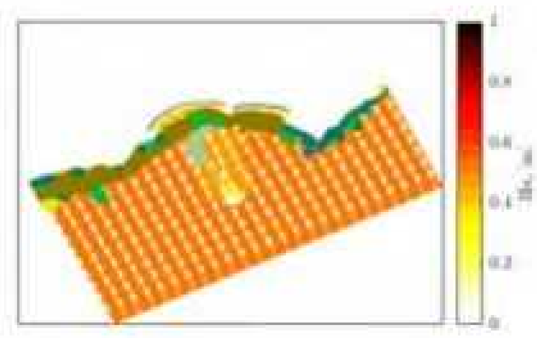
SEAGRASS	Variable	Source
Posidonia oceanica	Height (m), Diameter (m)	Ondiviela et al. (2014); Klein et al., 2008
Cymodecea nodosa	Density (p/m2)	Instituto de Ecología Litoral
Caulerpa racemosa	Drag coefficient	Infantes et al. (2012)

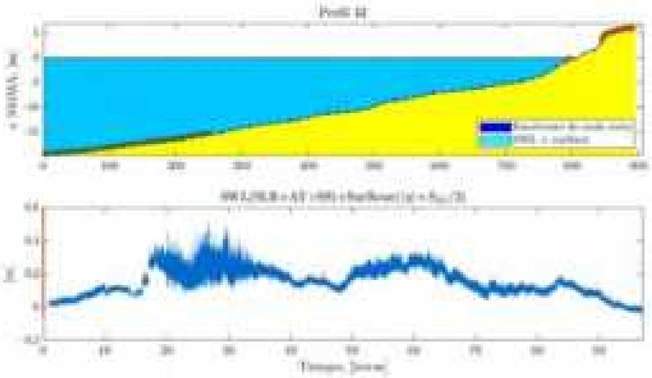
BEACHES
- Poniente
- Levante

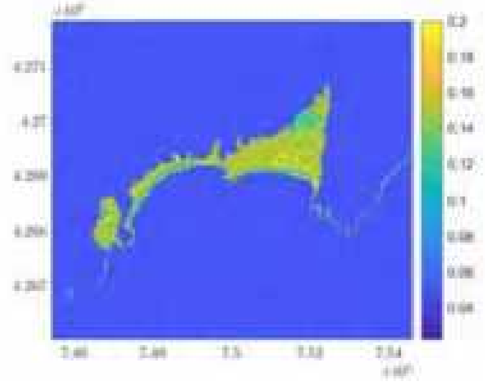
STRUCTURES
- Promenade
- Breakwater

METHODOLOGY

PROTECTION VALUE OF THE WATERFRONT ELEMENTS → LONG TERM MODELLING → SHORT TERM MODELLING → FLOOD MODELLING → ECONOMIC ASSESSMENT







PROTECTION VALUE OF THE WATERFRONT ELEMENTS → LONG TERM MODELLING → SHORT TERM MODELLING → FLOOD MODELLING → ECONOMIC ASSESSMENT

HYBRID DOWNSCALING

Hourly propagated time series.

HIGHT COMPUTATIONAL COST

SWAN *Booig* et al. (1999)

Simulating WAves Nearshore

\+

Statistical models

\+

IHLANSloc *Álvarez-Cuesta* et al. (2023)

- Regionalisation of coastal dynamics.
- Generation of updated topo-bathymetries for every time step.
- It considers both long-shore and cross-shore sediment transport.

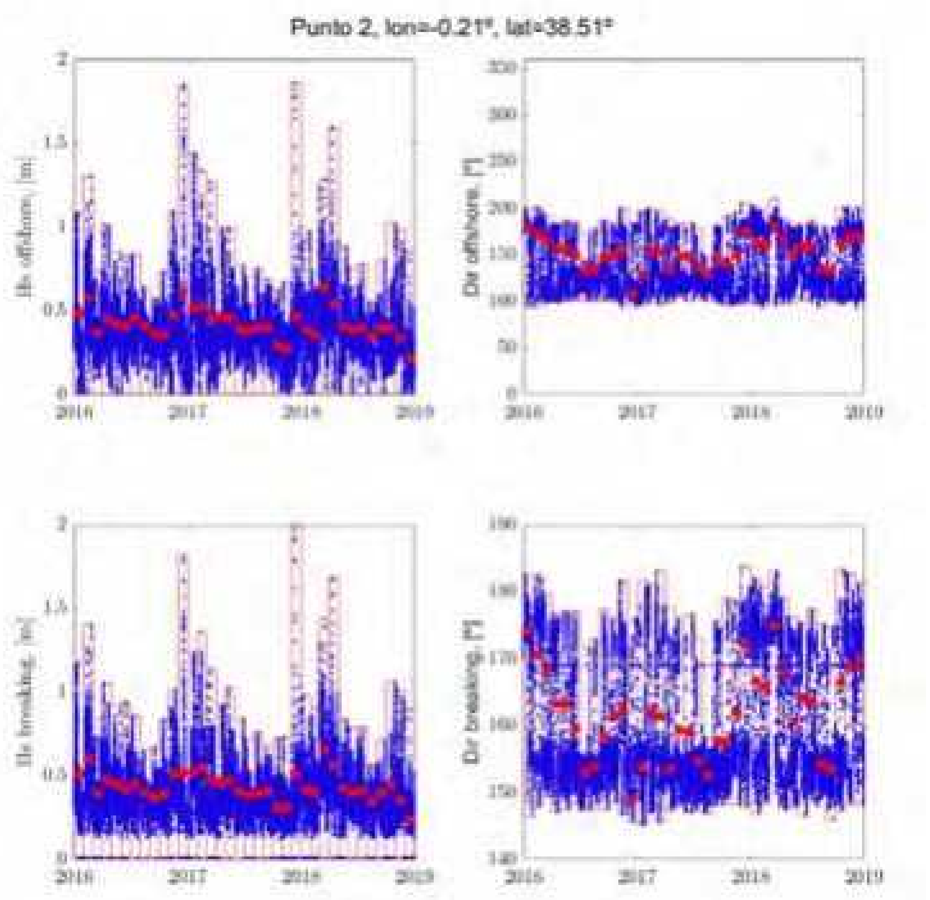
IHLANS	ShoreTrans	SWAN
Álvarez-Cuesta et al. (2021)	*McCarroll* et al. (2021)	*Booig* et al. (1999)
- Shoreline evolution	- Profile translation	- Wave propagation

\+ Waterfront elements

\+ Data assimilation

Input Reduction

Scipione et al. (2024)



PROPAGATION UP TO THE BREAKING POINT

$x_{e,j}$ $X_{w,j}$ $X_{wb,j} \equiv x_{eb,j}$

BACK-PROPAGATION OF THE REDUCED SERIES

X_w x_e Same longshore sediment transport.

Assumption

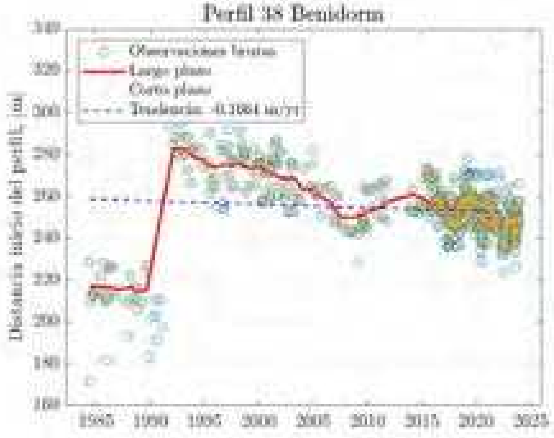
Shore line evolution induced only by the longshore sediment transport.

Cross-shore sediment transport is neglected.

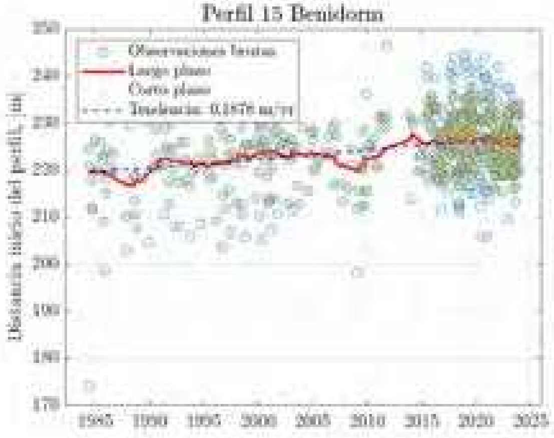
DATA ASSIMILATION

CoastSat

Vos et al. (2019)



It allows us to introduce sand nourishments

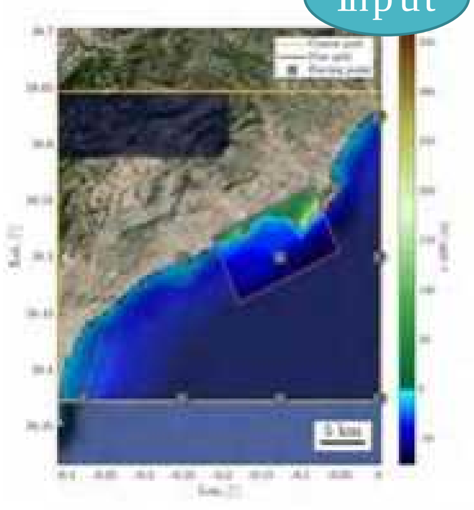


DOWNSCALING HÍBRIDO

+

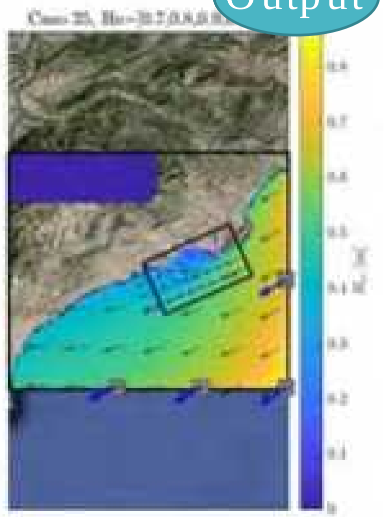
IHLANSloc

Input



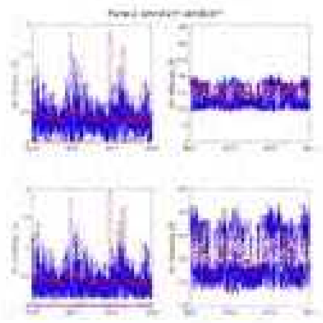
HR topobathymetry
Wave data

Output



Hourly propagated time series

372525 time steps



Monthly propagated time series

510 time steps

Running time:
From 8:42 to 15:28

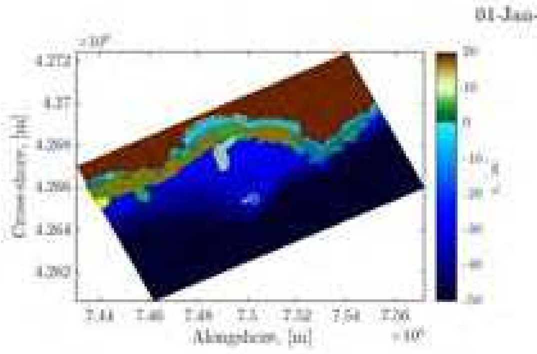
Input

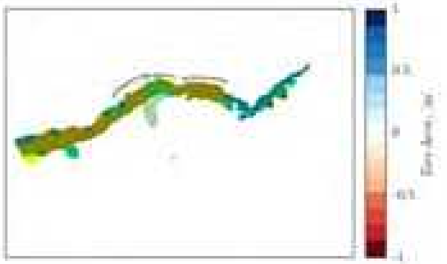
HR topobathymetry
Propagated series
Data assimilation
Waterfront elements

Output

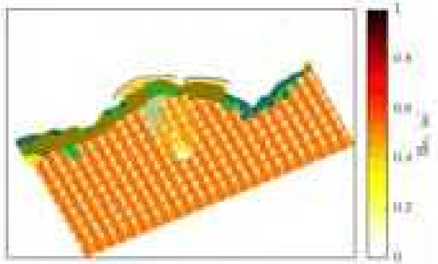
HR topobathymetry for every time step

Monthly HR topobathimetries generated in a very short space of time.

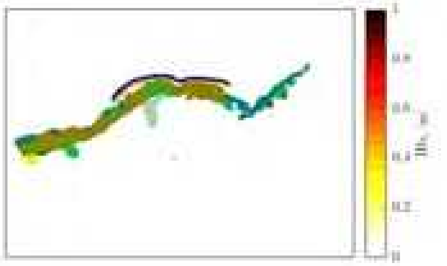




Erotion/Acretion



Propagated dynamics



Shoreline/Break

PROTECTION VALUE OF THE WATERFRONT ELEMENTS → LONG TERM MODELLING → SHORT TERM MODELLING → FLOOD MODELLING → ECONOMIC ASSESSMENT

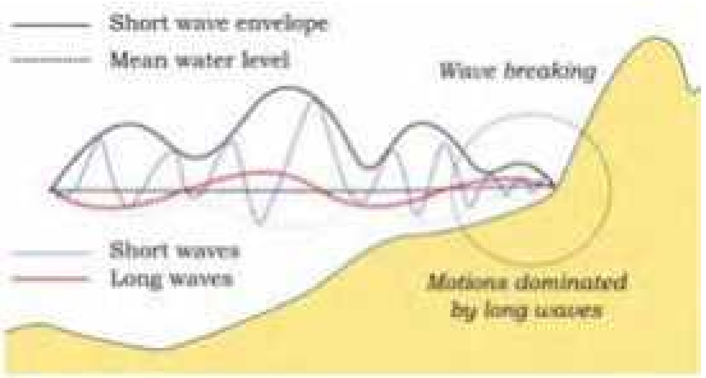
XBeach → **Surfbeat mode (instationary)**

Roelvink et al. (2009)

Hydrodynamics + **Morphodynamics**

- Waves
- Currents

- Sediment transport
- Seabed changes



Principle sketch of the relevant wave profile (XBeach manual)

- Resolves the short-wave envelope of the wave group and the associated long-wave envelope.
- In 1D cross-shore mode it solves the transversal sediment transport.
- This mode doesn't allow capturing fine details of sediment transport on very small scales (grain by grain). This is done by Non-hydrostatic mode.

Allows us to introduce different types of elements in the model.

Structure

Promenade → Non-erodible layer

struct = 1

Assumption

Non-erodible layers are infinitely deep.

Input

- File with the same format as bathymetry with the width (m) of the erodible layer [0-10].

Seagrass

Posidonia oceanica
Cymodecea nodosa → Vegetation module

vegetation = 1

Assumption

Mendez and Losada (2004); Suzuki et al.,(2012)

Vertically uniform vegetation.

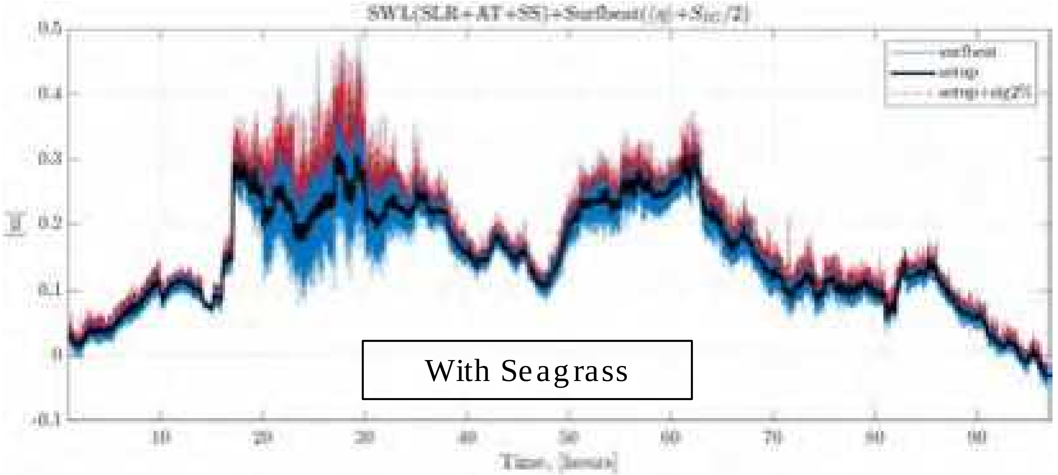
$$D_{veg,s} = \frac{1}{2\sqrt{\pi}} \rho \tilde{C}_{D} b_v N \left(\frac{kg}{2\sigma}\right)^3 \frac{\left(\sinh^3 k\alpha_s h - \sinh^3 k\alpha_{s-1} h\right) + 3\left(\sinh k\alpha_s h - \sinh k\alpha_{s-1} h\right)}{3k \cosh^3 kh} H_{rms}^3$$

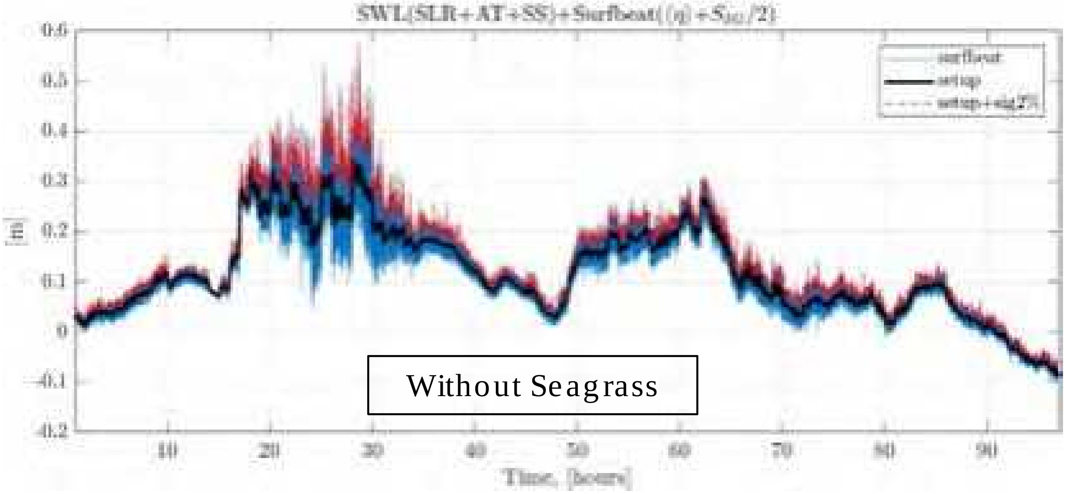
Van Rooijen et al. (2015)

Input

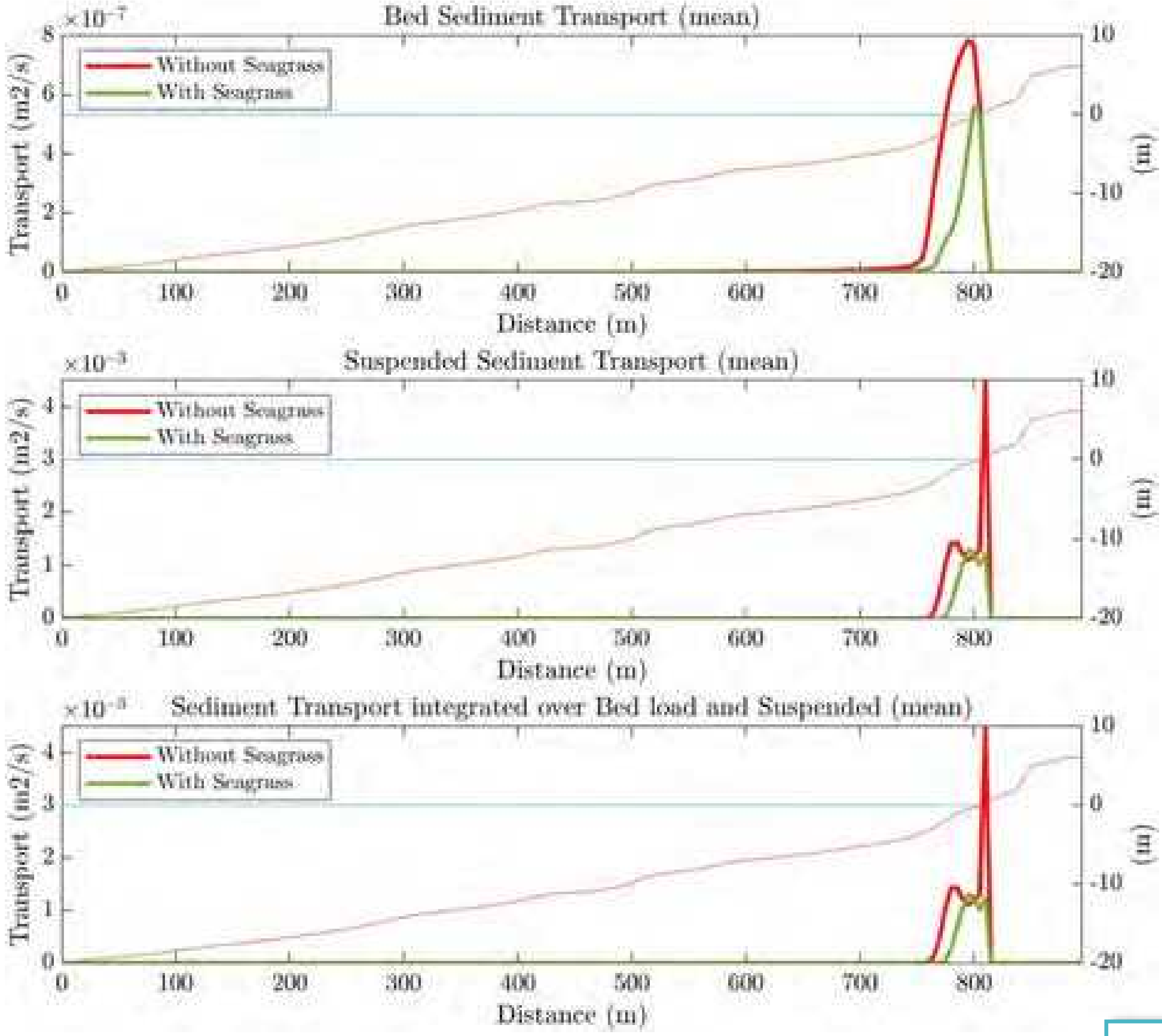
- File with the same format as bathymetry with the location.
- ah: height (m).
- Cd: drag coefficient (-).
- bv: stem diameter (m).
- N: density (shoots/m2).

Hydrodynamics





Morphodynamics



Profile 42

Input

HR long-term topobathymetry (storm month, IHLANSloc)

Wave data

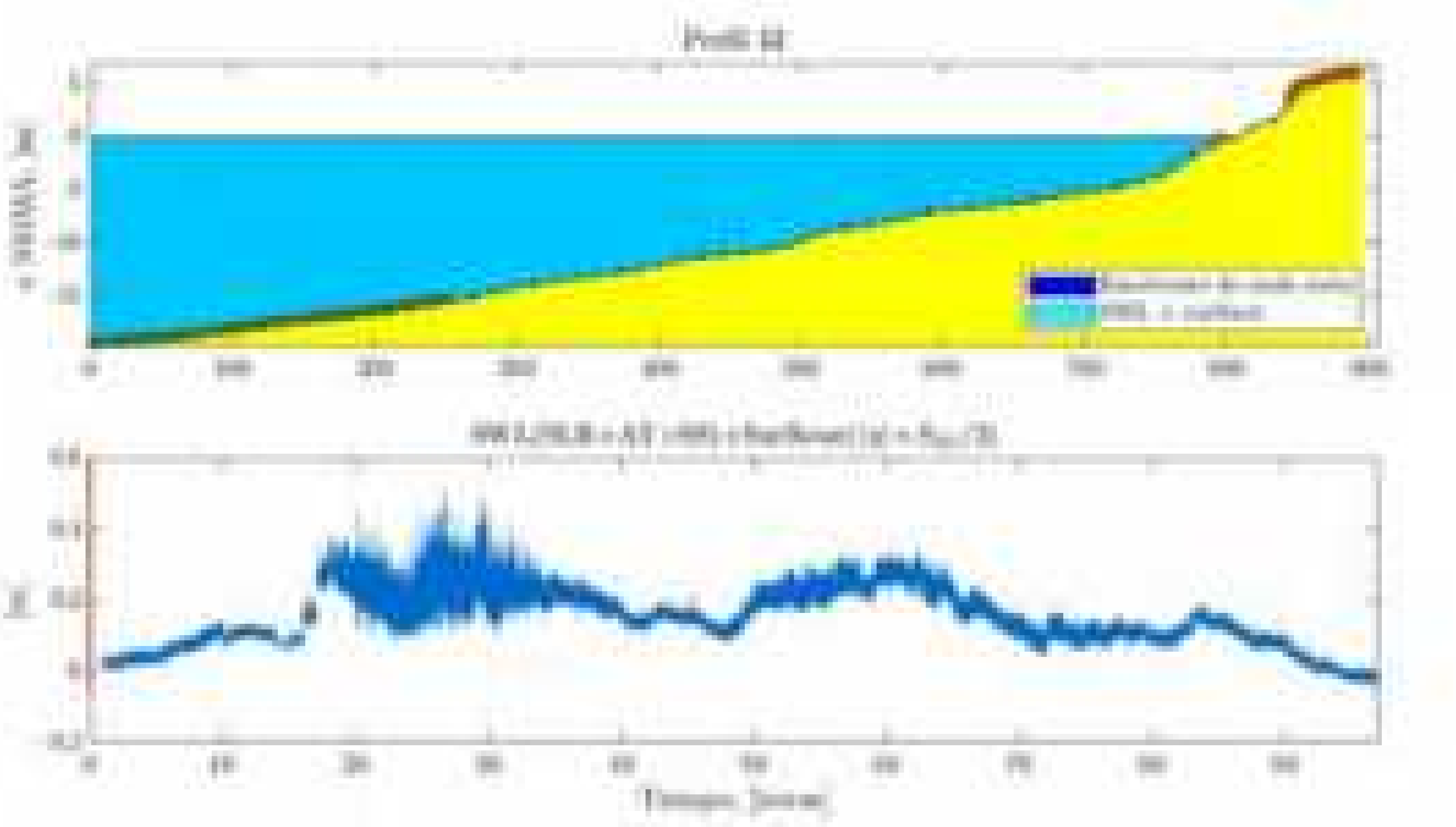
Waterfront elements

Output

HR topobathymetry (post storm)

Set-up series

IG wave series



- Seagrass meadows have a clear effect on morphology (sediment transport and seabed changes).
- Reduced effect on hydrodynamics (reduction of the IG waves).

PROTECTION VALUE OF THE WATERFRONT ELEMENTS → LONG TERM MODELLING → SHORT TERM MODELLING → FLOOD MODELLING → ECONOMIC ASSESSMENT

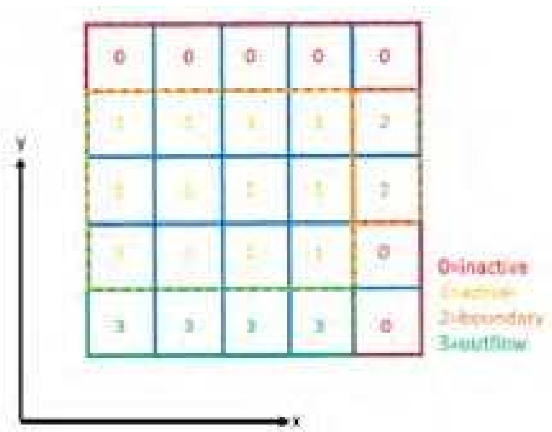
SFINCS

Leijnse et al. (2021)

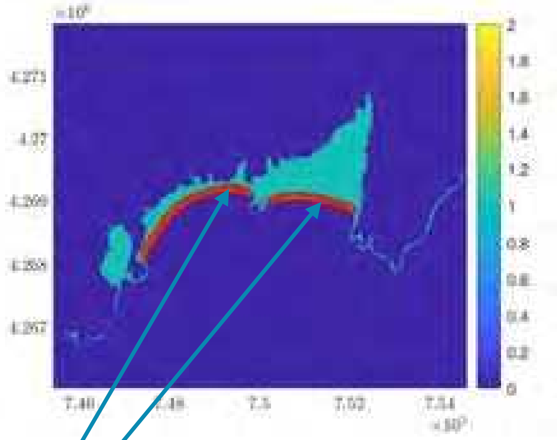
Reduced complexity model designed to rapidly modelling compound flooding

FORCINGS

- Fluvial
- Tide
- Rainfall
- Waves
- Wind



Example of the different mask values on a grid (SFINCS manual)

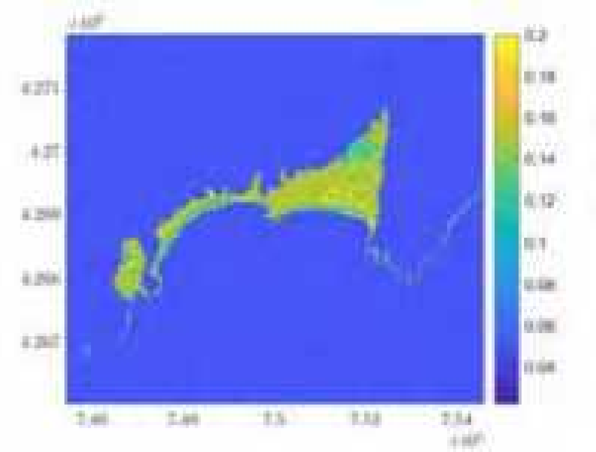


- Generally winds, tides and waves are forced at -2.
    - In this case, we will force after maximum dissipation.

Input

HR topobathymetry (post storm, XBeach)

Manning roughness map



Slowly varying water level

at + ss + set up (XBeach) + ref

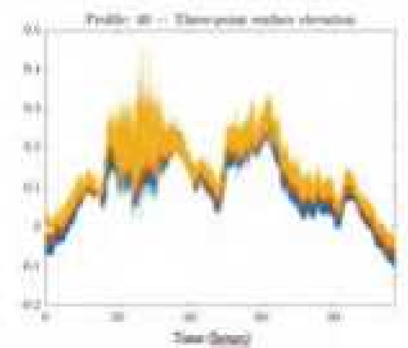
Quickly varying water level

Infragravity wave (XBeach)

- Unseparated incident and reflected component.
- Random phase .

Deltares Wave Toolbox

de Ridder et al. (2023)

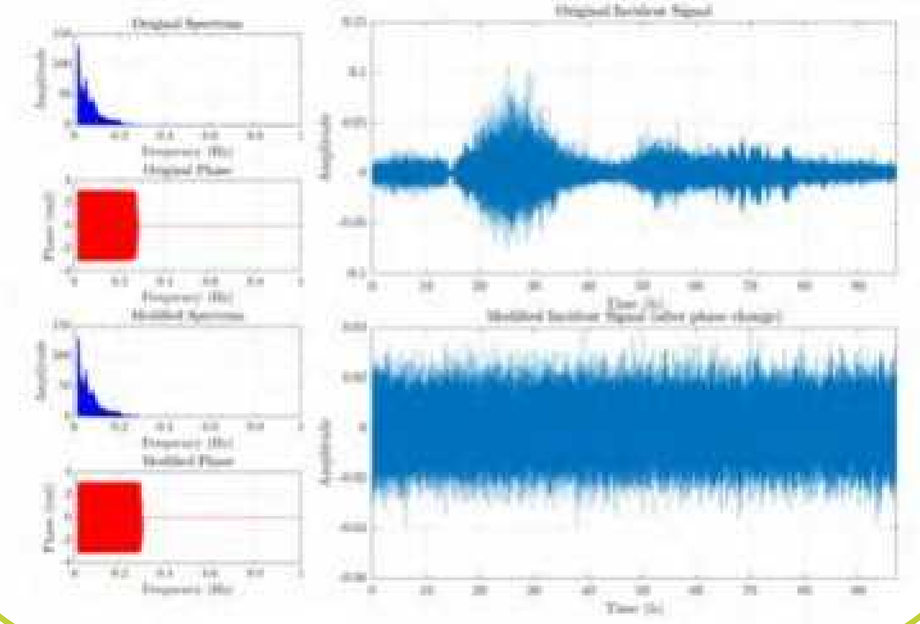


2 signals

Goda and Suzuki (1976)

3 signals

Mansard and Funke (1980)



- The incident component of the IG wave series has been separated.
- The same phase (randomly chosen) has been applied.

- Create the flood map for Gloria event.
- Maybe add the rainfall component?

PROTECTION VALUE OF THE WATERFRONT ELEMENTS → LONG TERM MODELLING → SHORT TERM MODELLING → FLOOD MODELLING → ECONOMIC ASSESSMENT

SCENARIOS

Erosion

- Beaches.

Degradation

- Decrease of seagrass density
- Reduction of coral cover.
- More possible scenarios.

DAMAGE COST AVOIDED

Damage quantification (€/day)

NEXT STEPS

ADAPTATION AND CLIMATE CHANGE

Simulation of climate change scenarios

SSP1 - 2.6 | SSP2 - 4.5 | SSP5 - 8.5

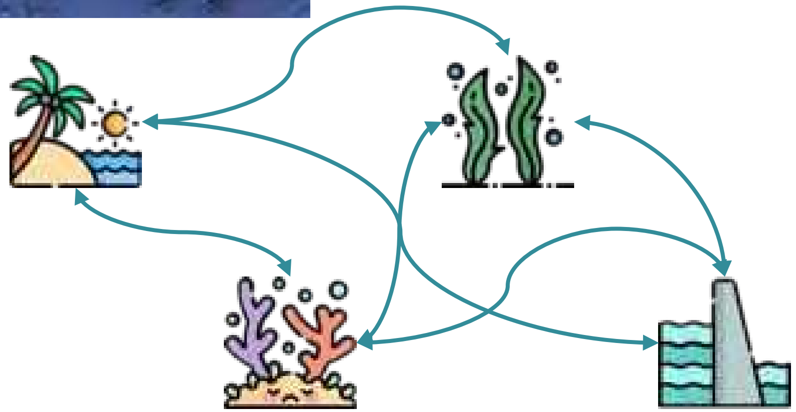
Implementation of adaptation actions through dynamics pathways

Cost-Benefict analysis of dynamic pathways

APPLICATION AT REGIONAL SCALE

O'ahu, Hawaii (USA)

- Different levesl of development of beaches.
- Coral reefs.
- Seagrass.



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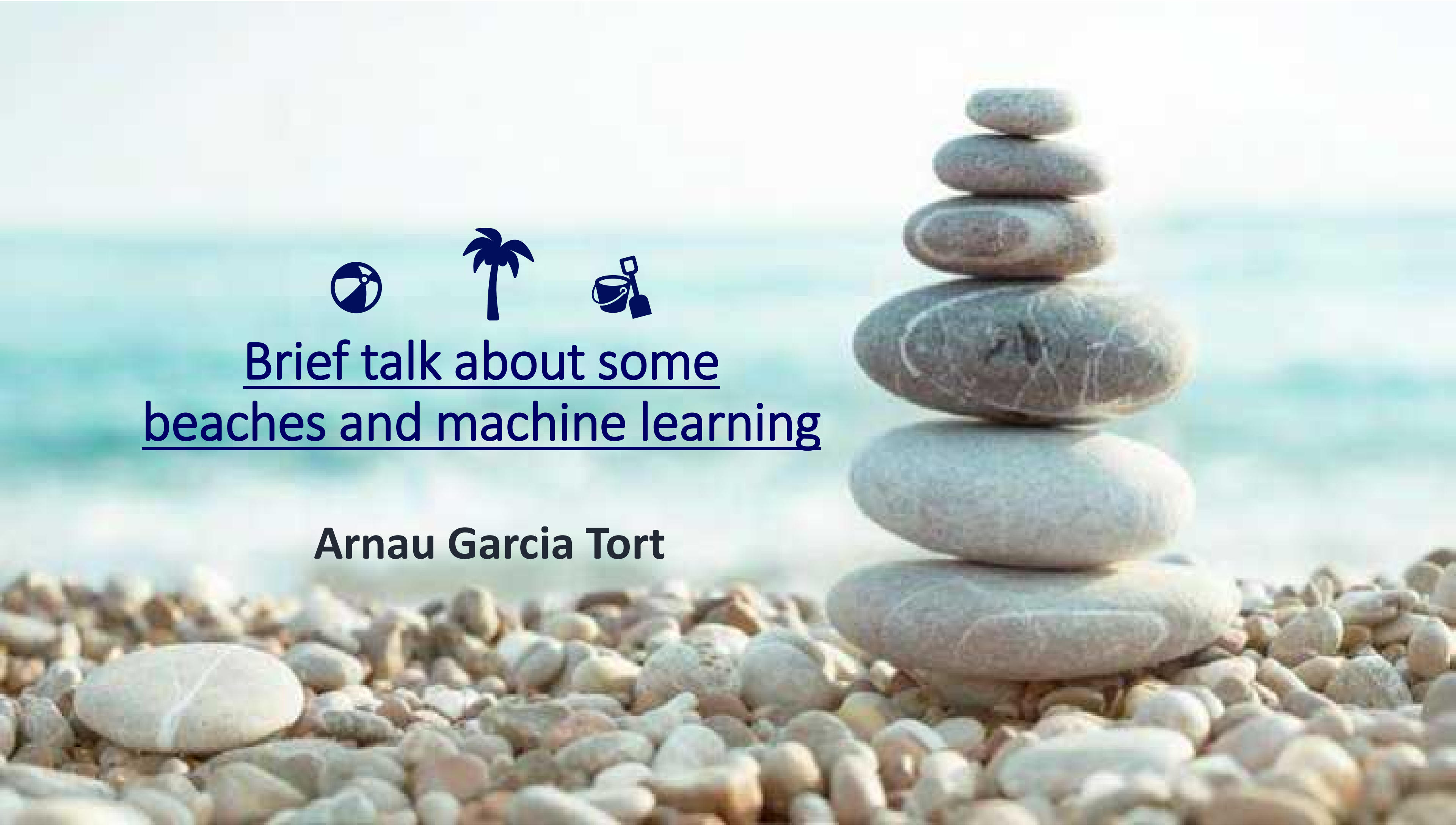
Thanks for your attention!

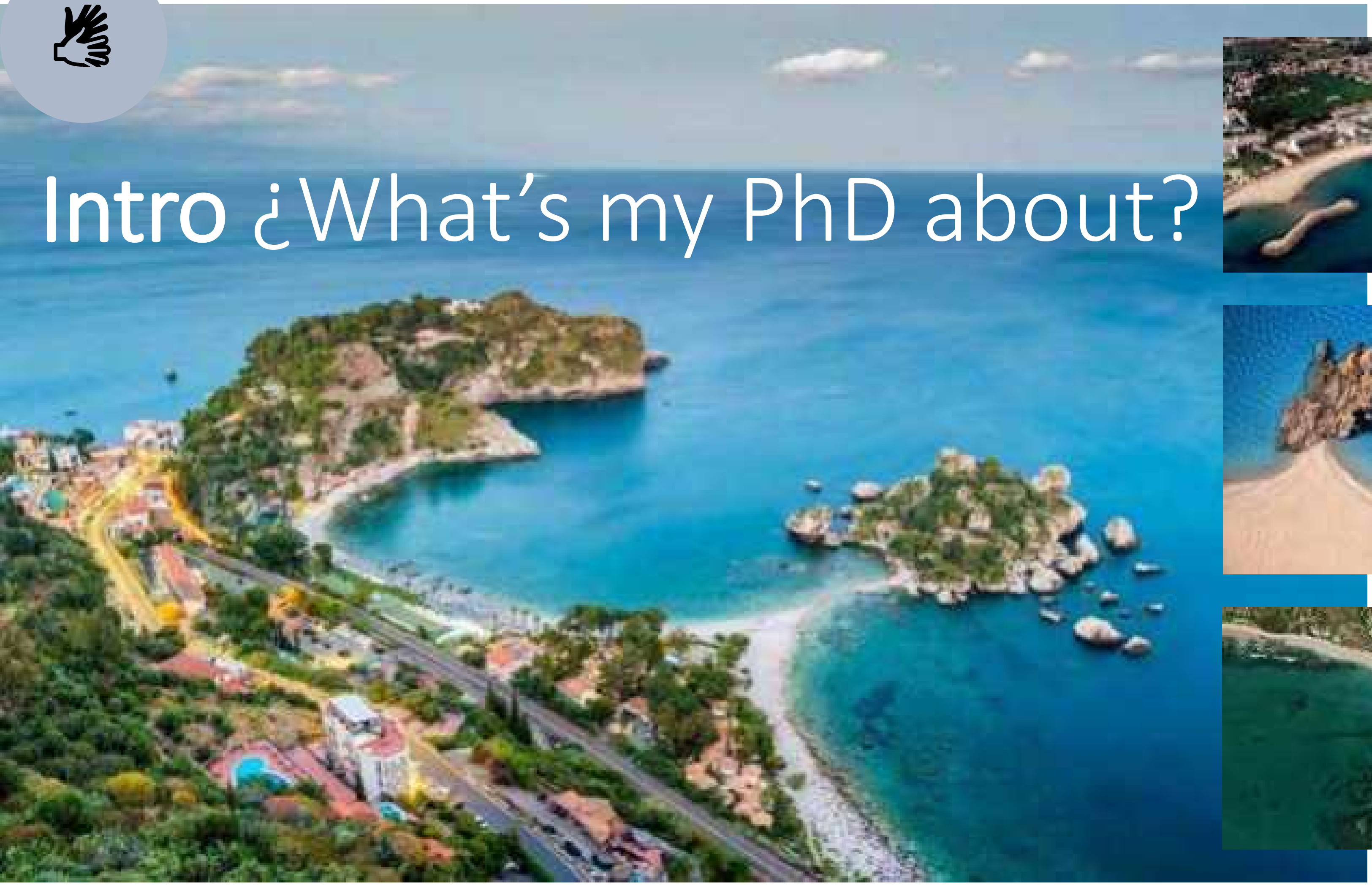
ANDREA COSTALES LLATA
costalesa@unican.es

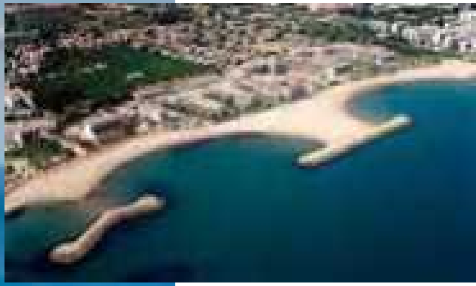


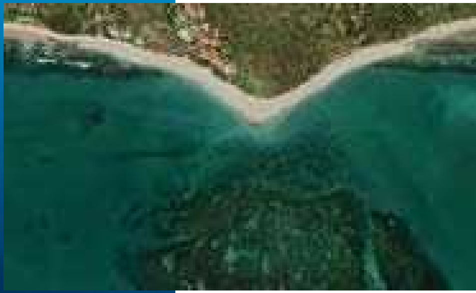
Brief talk about some beaches and machine learning

Arnau Garcia Tort

Intro ¿What's my PhD about?





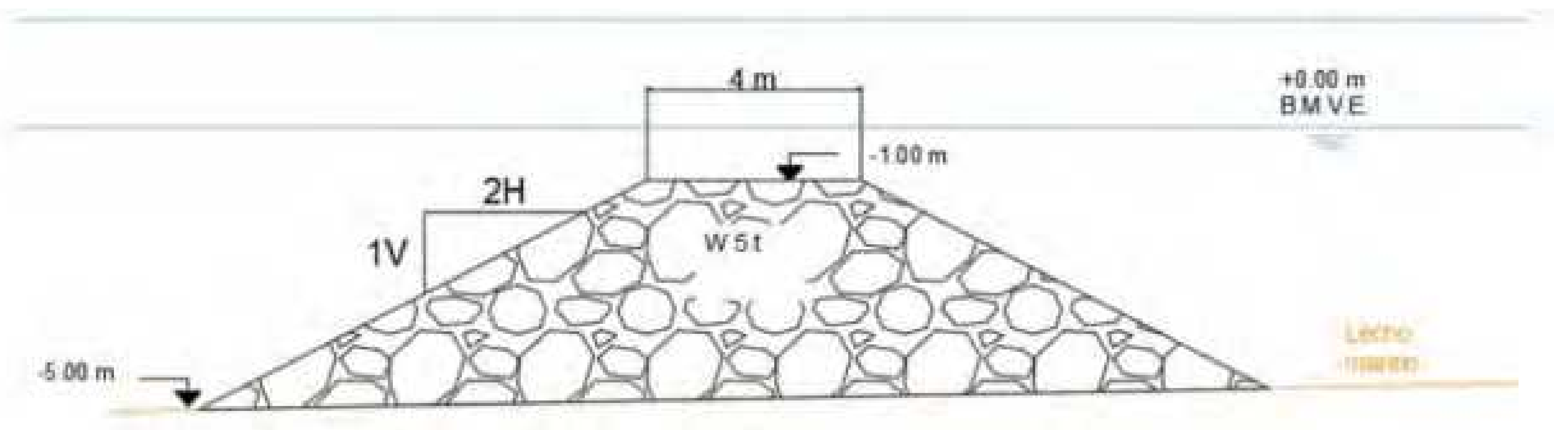


Morphology of equilibrium beaches protected by submerged detached structures

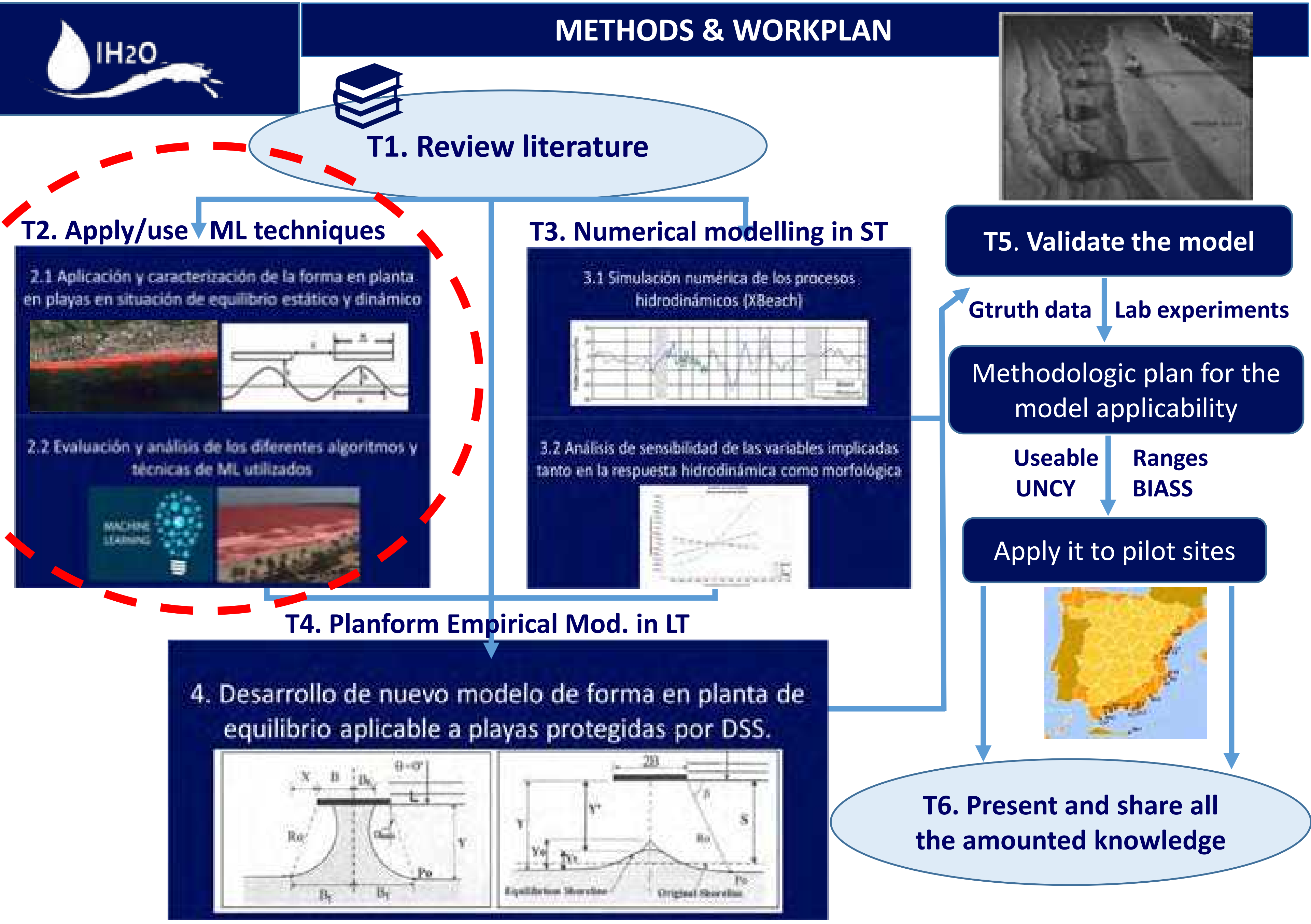
PhD Student: **Arnau Garcia Tort**

Tutor: **Dra. Erica Pellón**

Director: **Dr. Ernesto Mauricio González**




SAFE EMERGENT ZONE
DANGER SUBMERGED ZONE



METHODS & WORKPLAN
T1. Review literature
T2. Apply/use ML techniques
2.1 Aplicación y caracterización de la forma en planta en playas en situación de equilibrio estático y dinámico
2.2 Evaluación y análisis de los diferentes algoritmos y técnicas de ML utilizados
MACHINE LEARNING
T3. Numerical modelling in ST
3.1 Simulación numérica de los procesos hidrodinámicos (XBeach)
3.2 Análisis de sensibilidad de las variables implicadas tanto en la respuesta hidrodinámica como morfológica
T4. Planform Empirical Mod. in LT
4. Desarrollo de nuevo modelo de forma en planta de equilibrio aplicable a playas protegidas por DSS.
Equilibrium Shoreline
Original Shoreline
T5. Validate the model
Gtruth data
Lab experiments
Methodologic plan for the model applicability
Useable UNCY
Ranges BIASS
Apply it to pilot sites
T6. Present and share all the amounted knowledge

Can ML algorithms help us to reduce the uncertainty in these detached beaches?

First paper: Classification

Second paper: Regression

Inputs

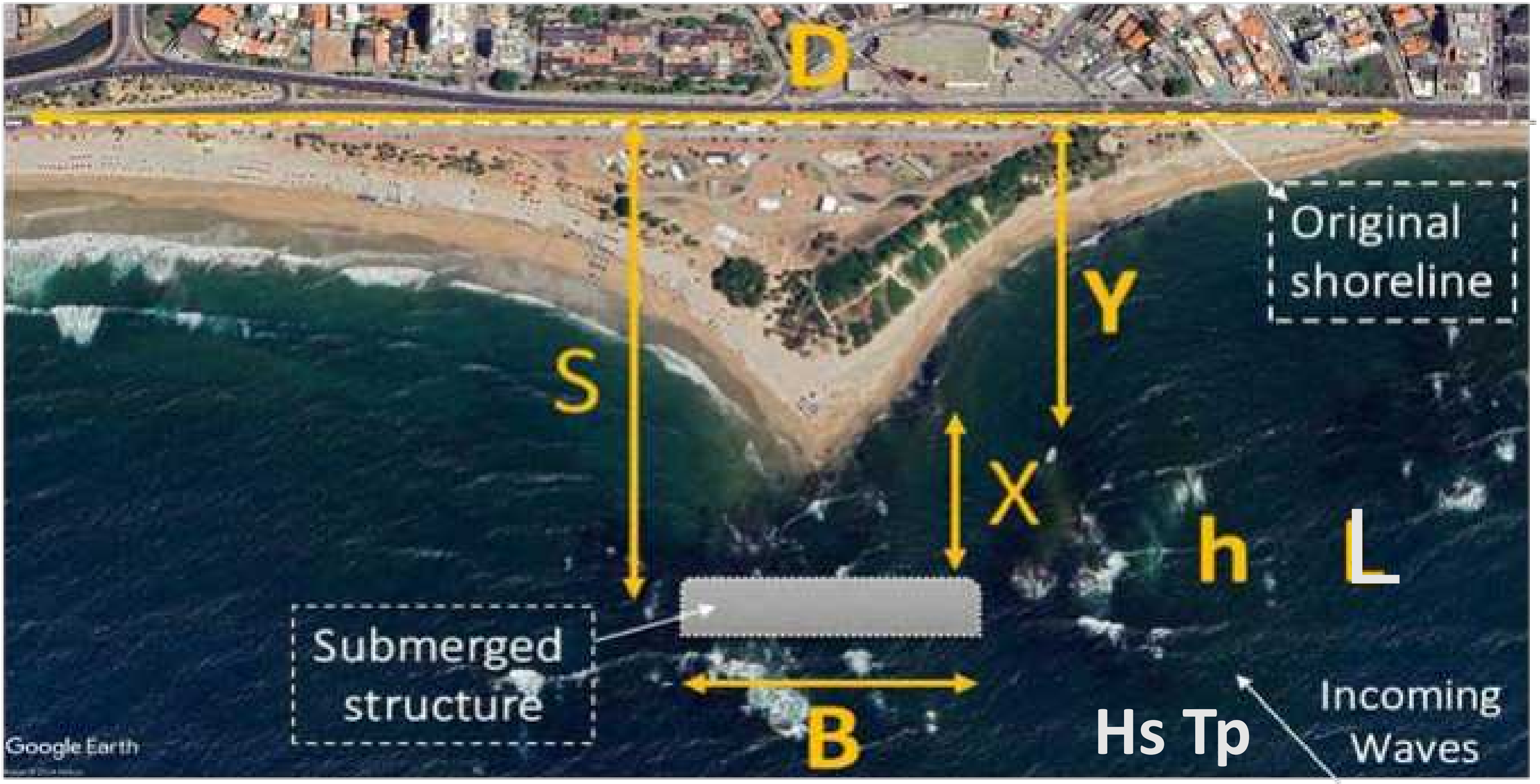
The idea here is to benchmark some previous empirical models versus our ML results to see if helps to improve

PAPERS #1 + #2

Parameters considered

Params geomorphological

Params hydrodynamical

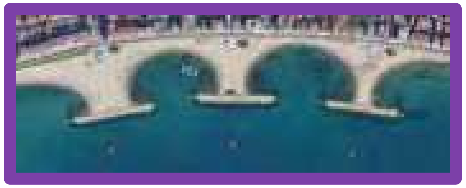


PAPERS #1 + #2

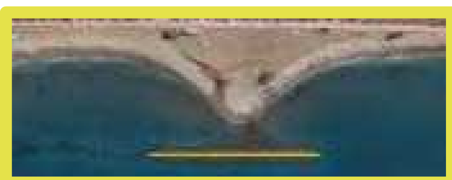
The > 370 beaches of our DATABASE were grouped by:

Their level of submergence :

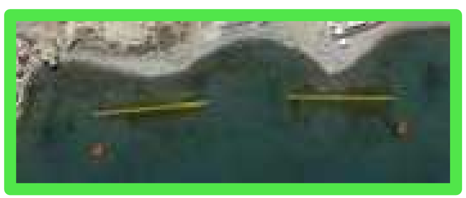
Estructuras emergidas (ED)



Estructuras low-crested (LC)



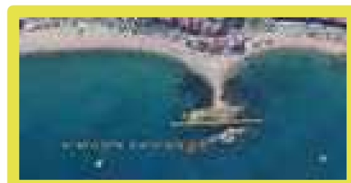
Estructuras sumergidas (SD)



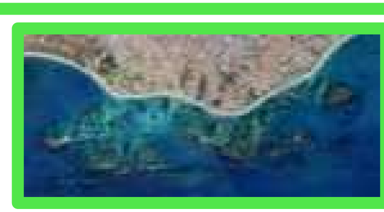
Their formation origin process :

Human-made Breakwaters (BW)

Natural emerged (Island)



Natural submerged (Reef)



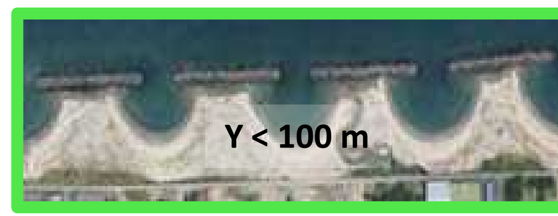
The size of their response :

Mega (XL)

Large (L)

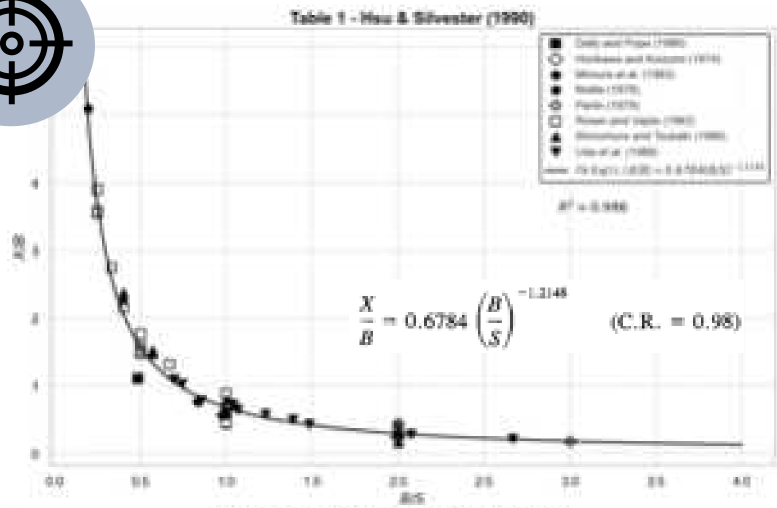
Medium (M)

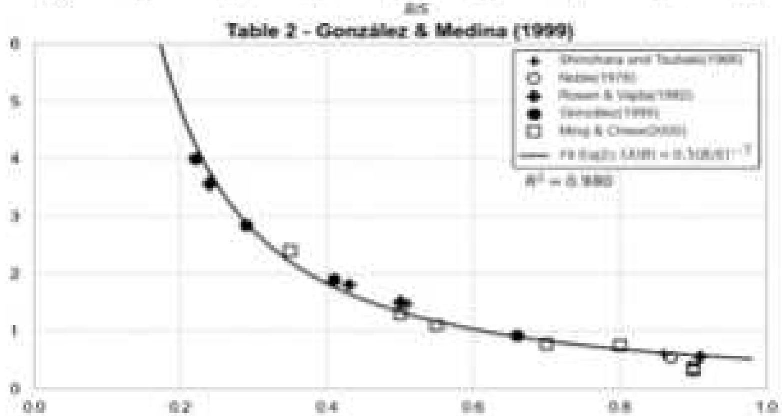
Small (S)

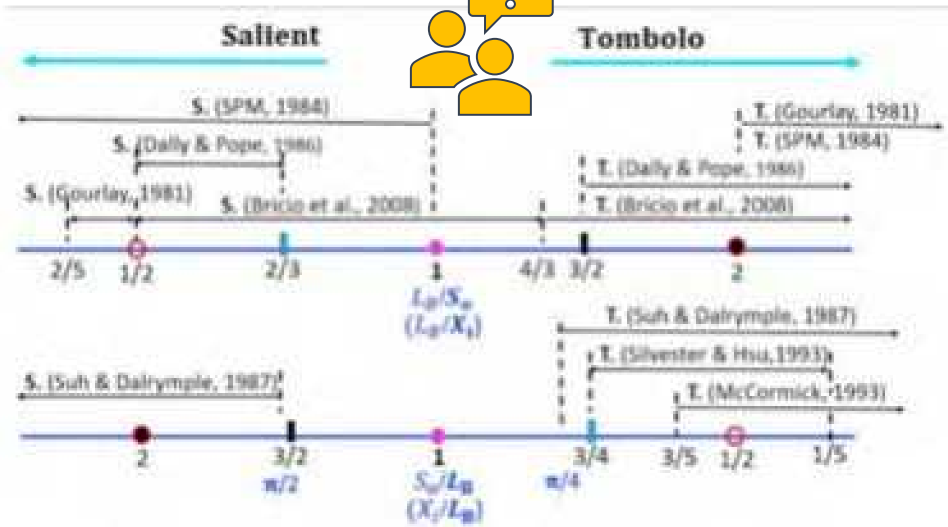


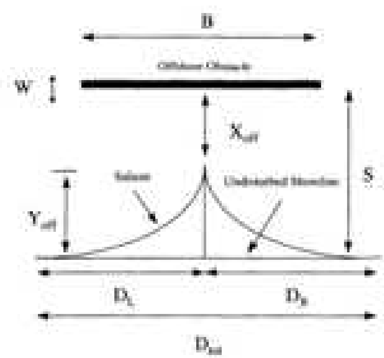
PAPER #1 + #2

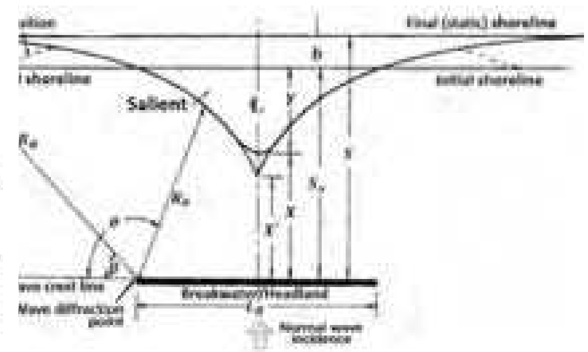
Salient and Tombolo insights











Previous literature equations, fits and knowledge …

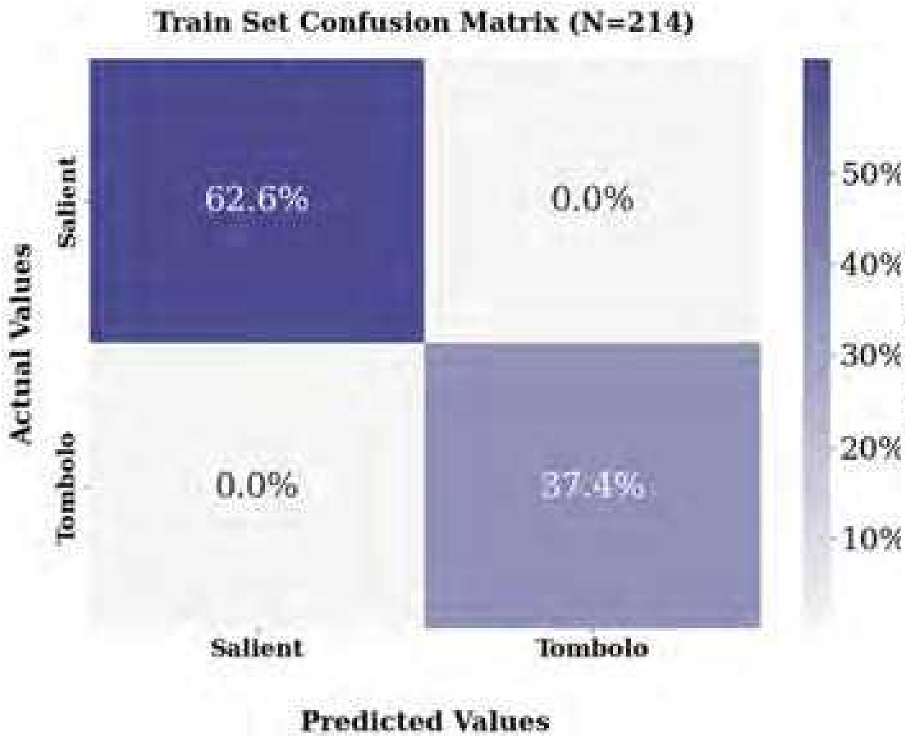
¿What about the ML results?

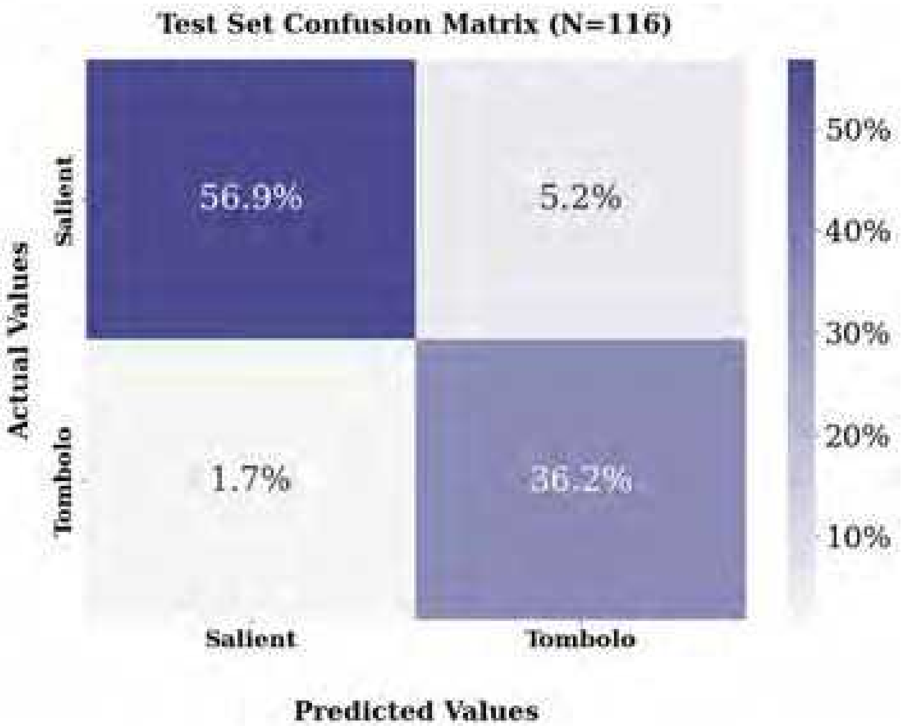
¿They are better tan previous models?

PAPER #1

Salient and Tombolo classification

The model must predict from the given inputs if is more likely to form T or S





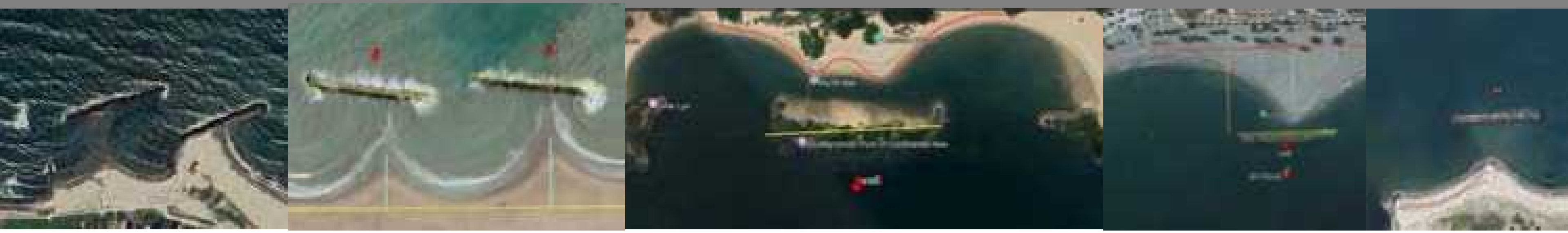
From all predicted events the model only misclassify eight!

What can we extract from the misclassified events?

¿How many beaches misclassified?

Only 8 data misclassified! < (2,45%)
2 Tombolo y 6 Salients

¿Are they logical errors?

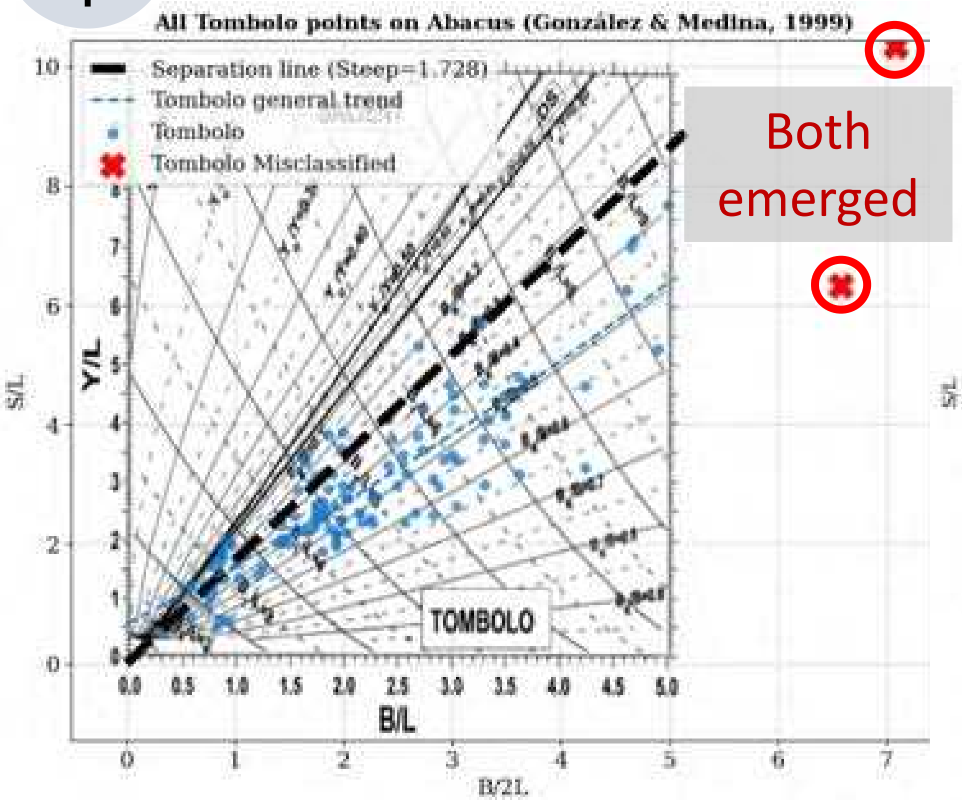


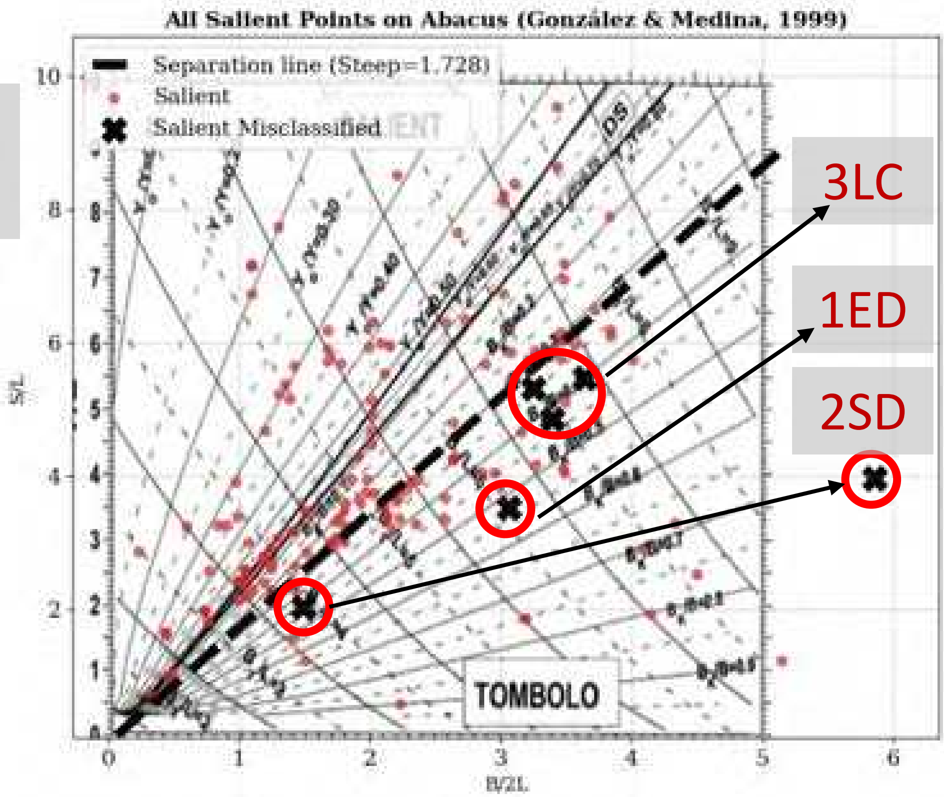
What can we extract from the misclassified events?

Tombolos well-predicted

Salients
Tombolos

Salients well-predicted



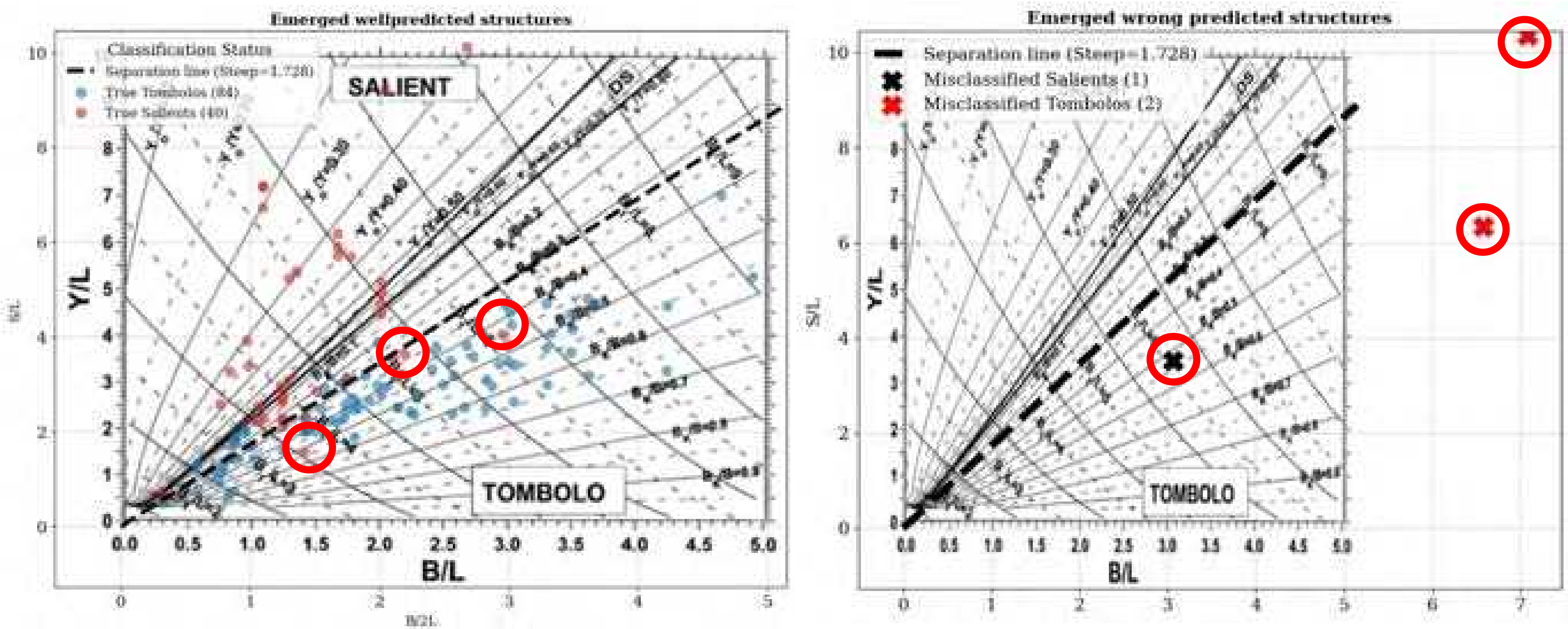


The major part of the events are correctly classified and the missed ones are logic and consistent, always the same

What can we extract from the results?

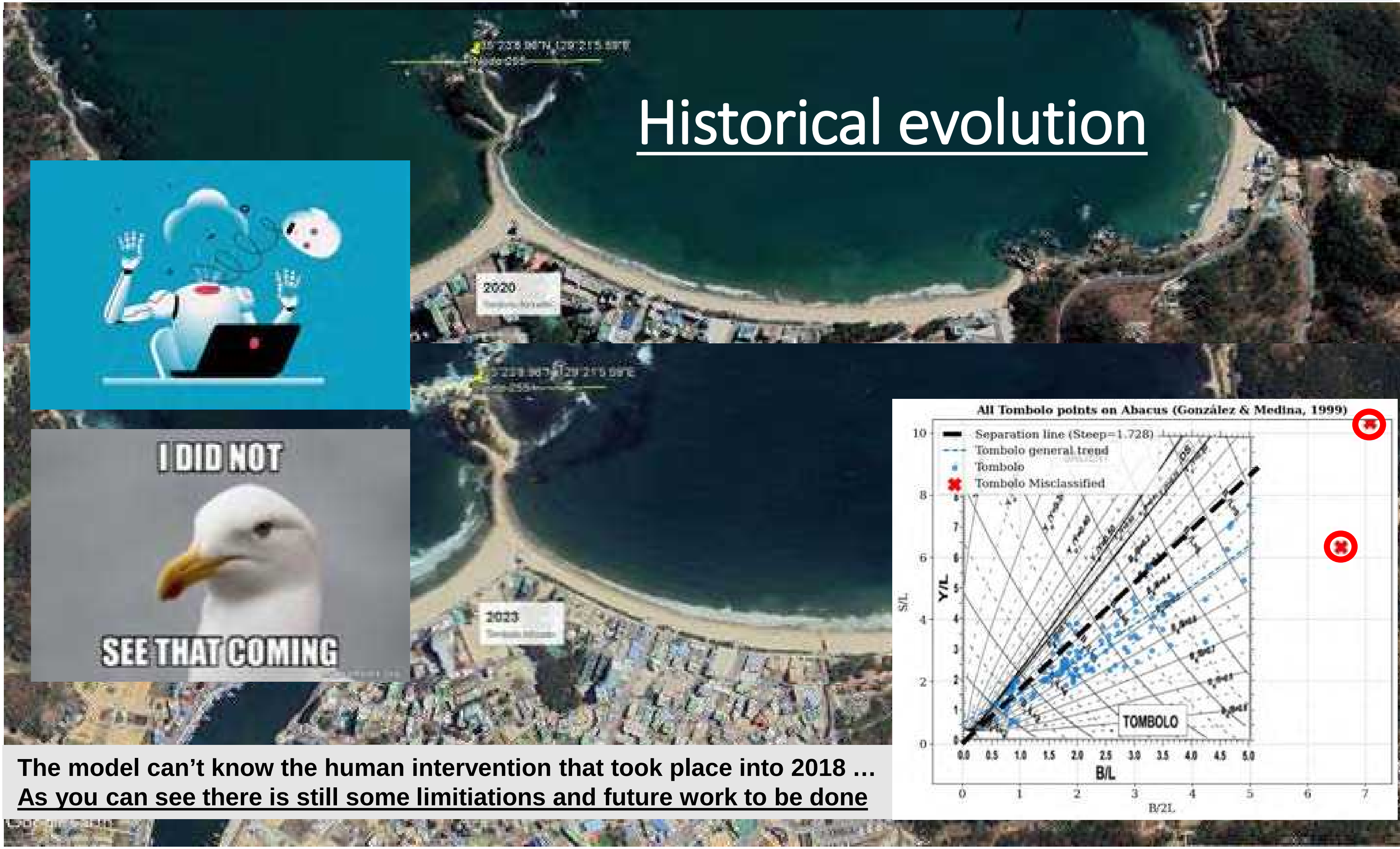
From 127 Emerged structures
2 tombolos and only 1 salient misclassified

Salients
Tombolos



The model was able to correctly classify some complex events that exceeds the previous literature ranges & limits capabilities

Some inherent problems …



The model can't know the human intervention that took place into 2018 …

<u>As you can see there is still some limitiations and future work to be done</u>

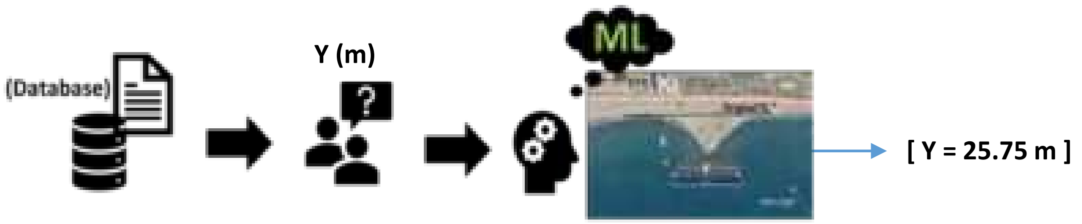
PAPER #2

Salient and Tombolo extension prediction

Same inputs and training methodology

Before: Classification problem

Now: Regression problem



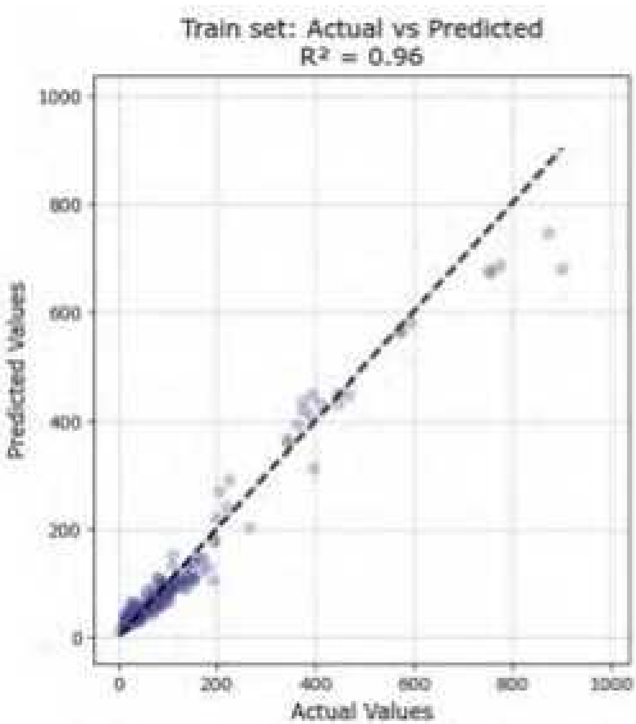
The target here is to predict the cross-shore extension that the Tombolo/Salient will have

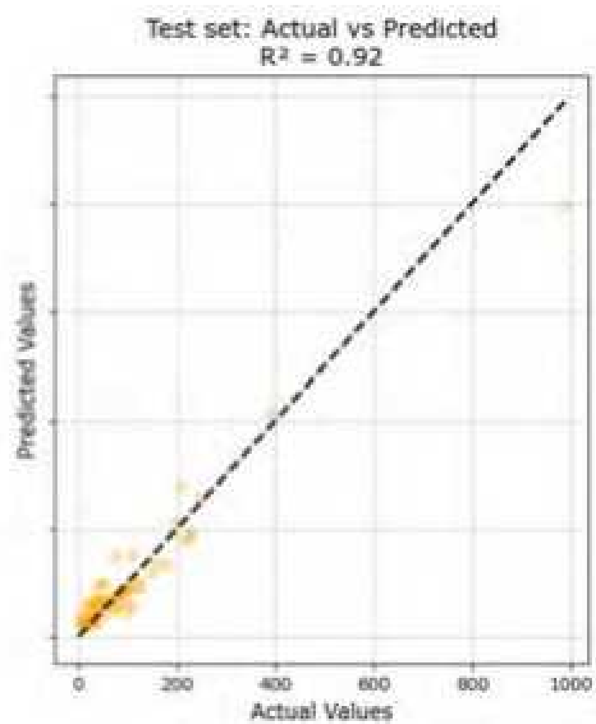
What can we extract from the misclassified events?

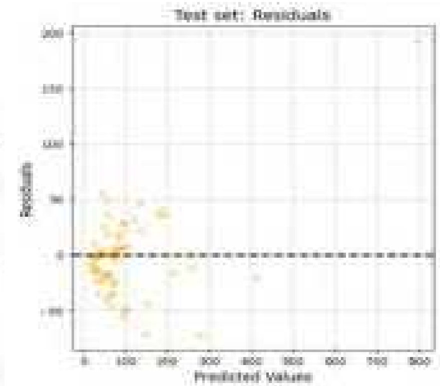
Given to data distribution, the model struggles with large Y values

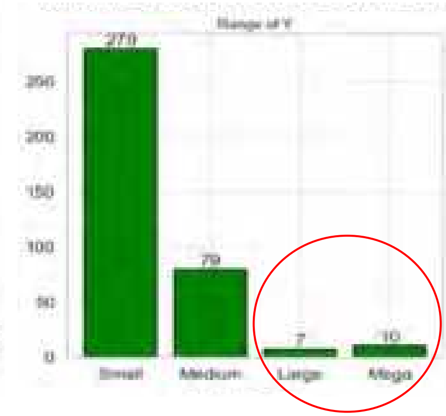
ML models to predict: Y (m) →

Small data well-predicted but model has bigger errors on larger salient events



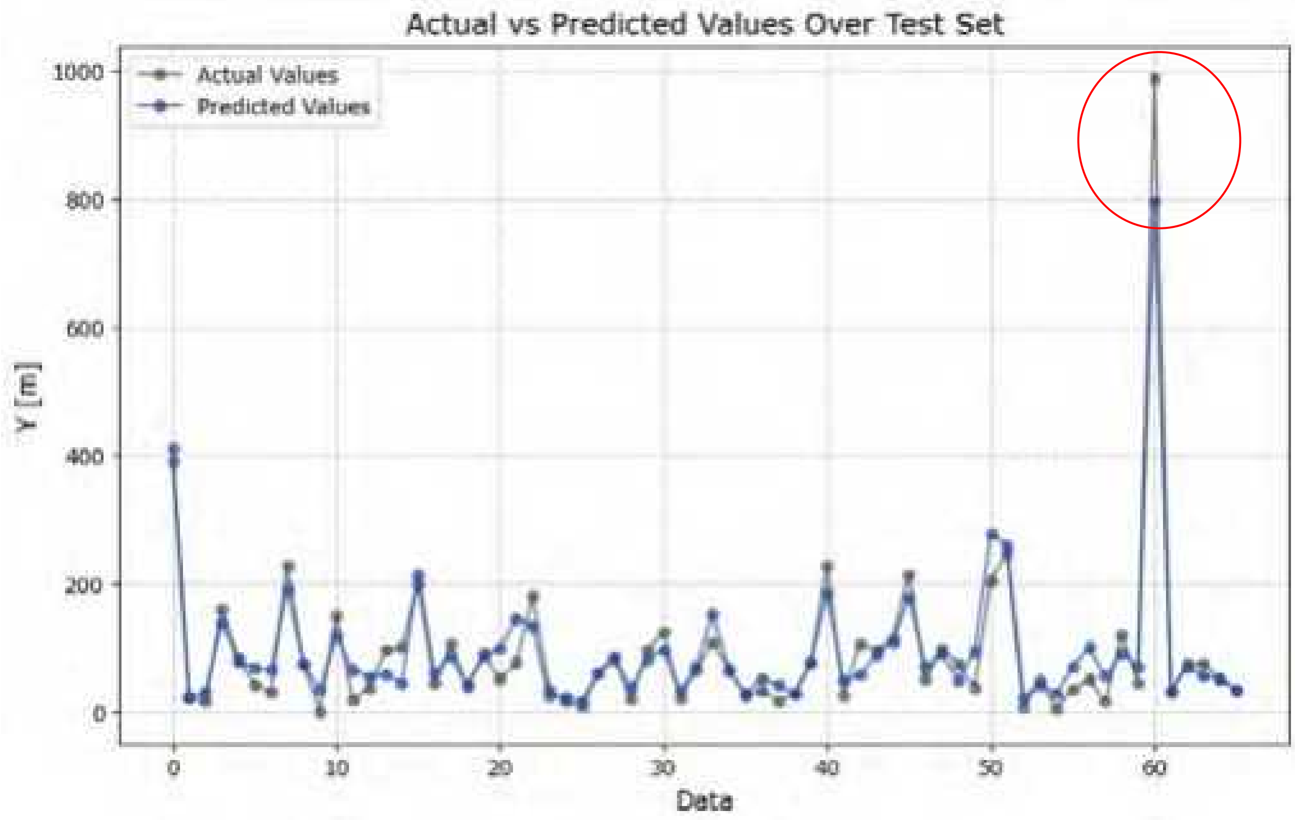


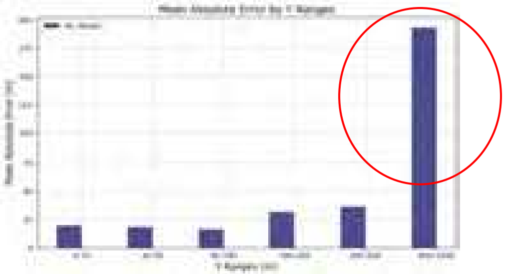


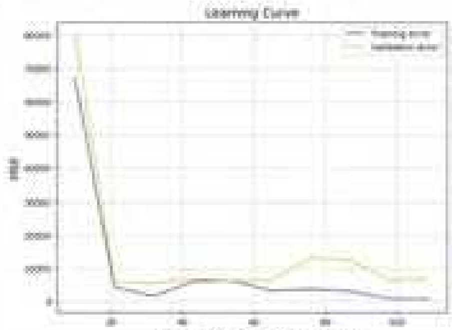


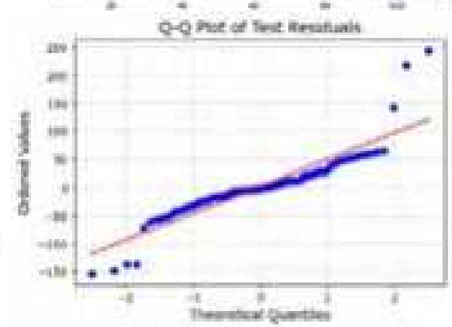
What can we extract from the misclassified events?

Given to data distribution, the model struggles with the large Y values



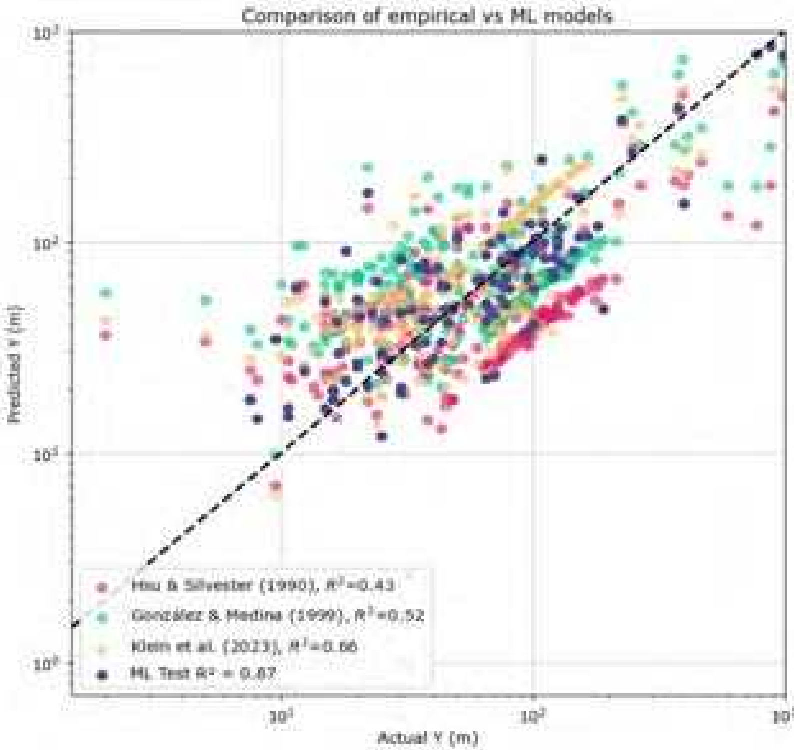


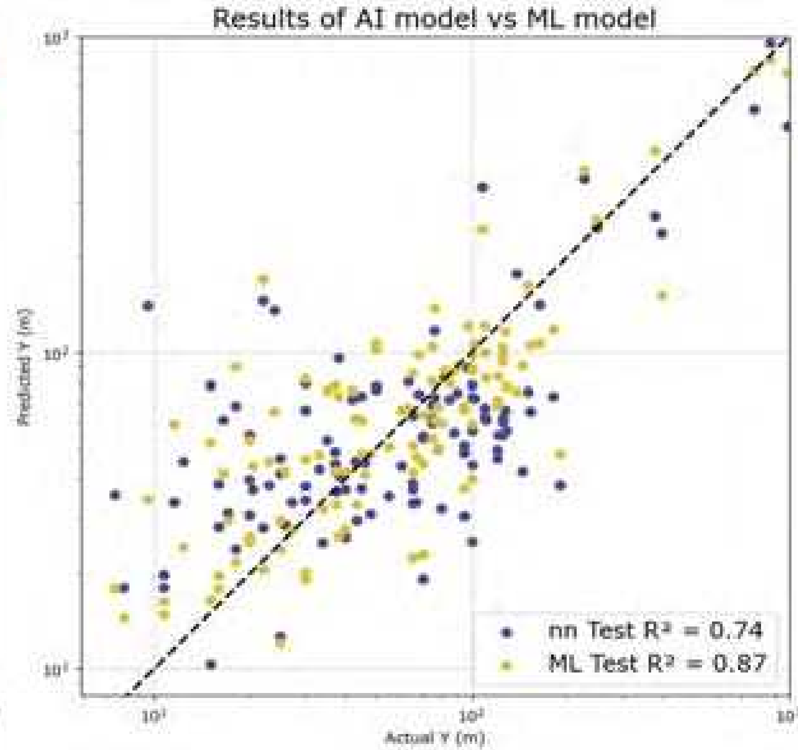




What can we extract from the benchmarks?

3. Benchmarking vs other previous models





ML beats some empirical models but still need some refinements to overcome all the limitations

What are the ML strengths or potential benefits?

Generality and suitability

Is more general, can be globally applied and it's not restricted to a limitted set of data and conditions

Training and Model Optimization

ML procedure it's simple and effective, allowing interpretability and explainable learning

Robust and powerful

Potential host and manage large amounts of data

→ Scalability (The more data, the better)

¿How would you classify if you were a ML model?

¿How would you handle this intermittent events?

References

For deeper understanding

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[2]M. A. Chasten, J. D. Rosati, J. W. McCormick, and R. E. Randall, ‘Engineering Design Guidance for Detached Breakwaters as Shoreline Stabilization Structures’, US Army Corps of Engineers, Dec. 1993.

[3]V. Negro, J. J. Diez Gonzalez, L. Bricio Garberí, and J. S. López Gutiérrez, ‘Coastal erosion. Geometric detached breakwaters indicators for preventing the shoreline erosion. Fringe session’, Proceedings of the Coasts, Marine Structures and Breakwaters 2009.

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[5]R. Ranasinghe and I. Turner, ‘Shoreline response to submerged structures: A review’, Coastal Engineering, vol. 53, pp. 65–79, Jan. 2006, https://doi.org/10.1016/j.coastaleng.2005.08.003.

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[7] A. H. da F. Klein, L. B. Filho, and D. H. Schumacher, ‘Short-Term Beach Rotation Processes in Distinct Headland Bay Beach Systems’, Journal of Coastal Research, vol. 18, no. 3, pp. 442–458, 2002.

Insights into long-term shoreline modelling and my Phd

Lucas de Freitas Pereira

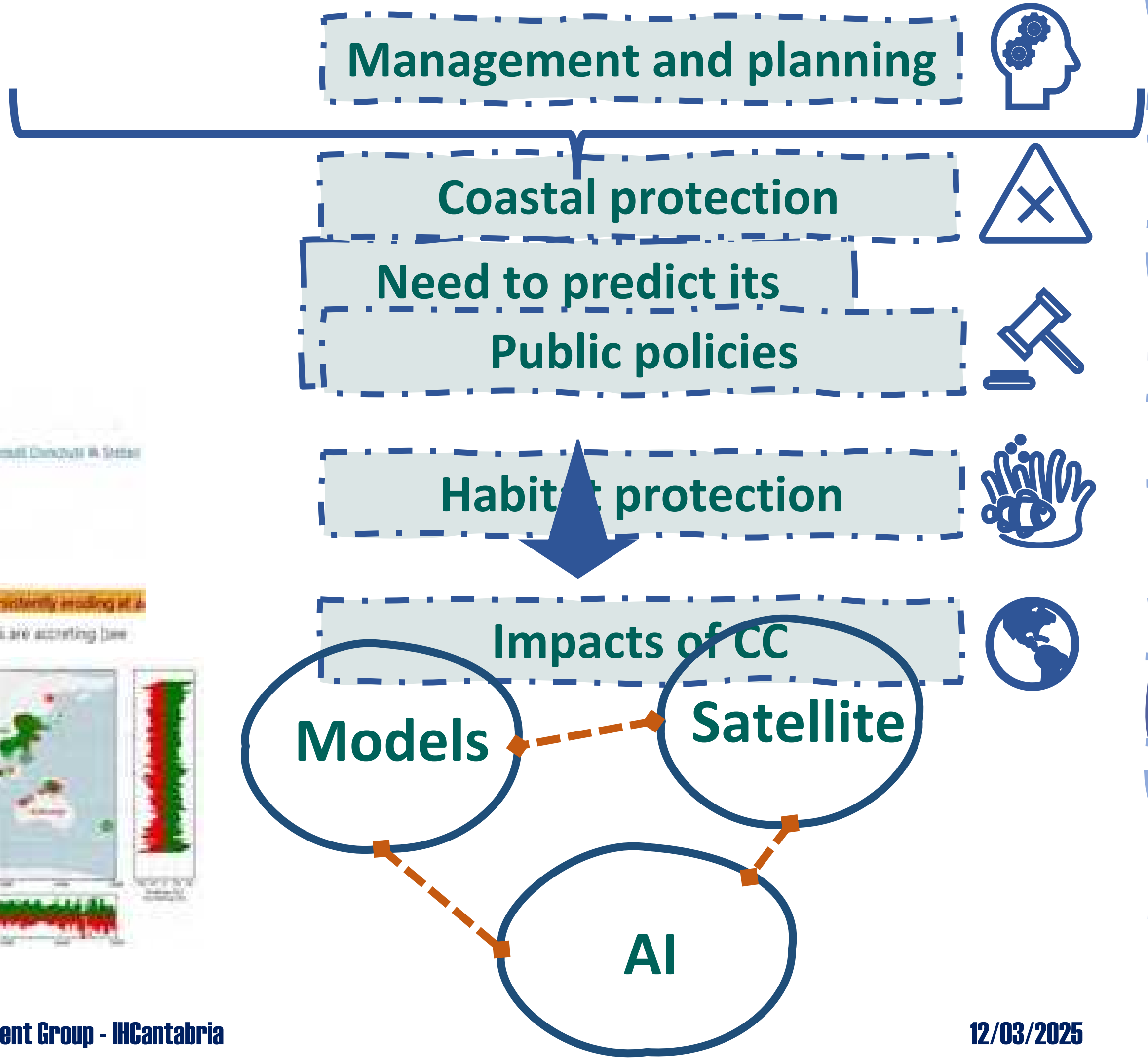
Supervisors:
Mauricio González and Camilo Jaramillo

IH cantabria
INSTITUTO DE HIDRÁULICA AMBIENTAL
UNIVERSIDAD DE CANTABRIA

Coastal engineering and management Group

UC
UNIVERSIDAD DE CANTABRIA

Introduction



Shoreline Modeling

✓ Short- to mid-term

Processes based

✓ Short- to long-term

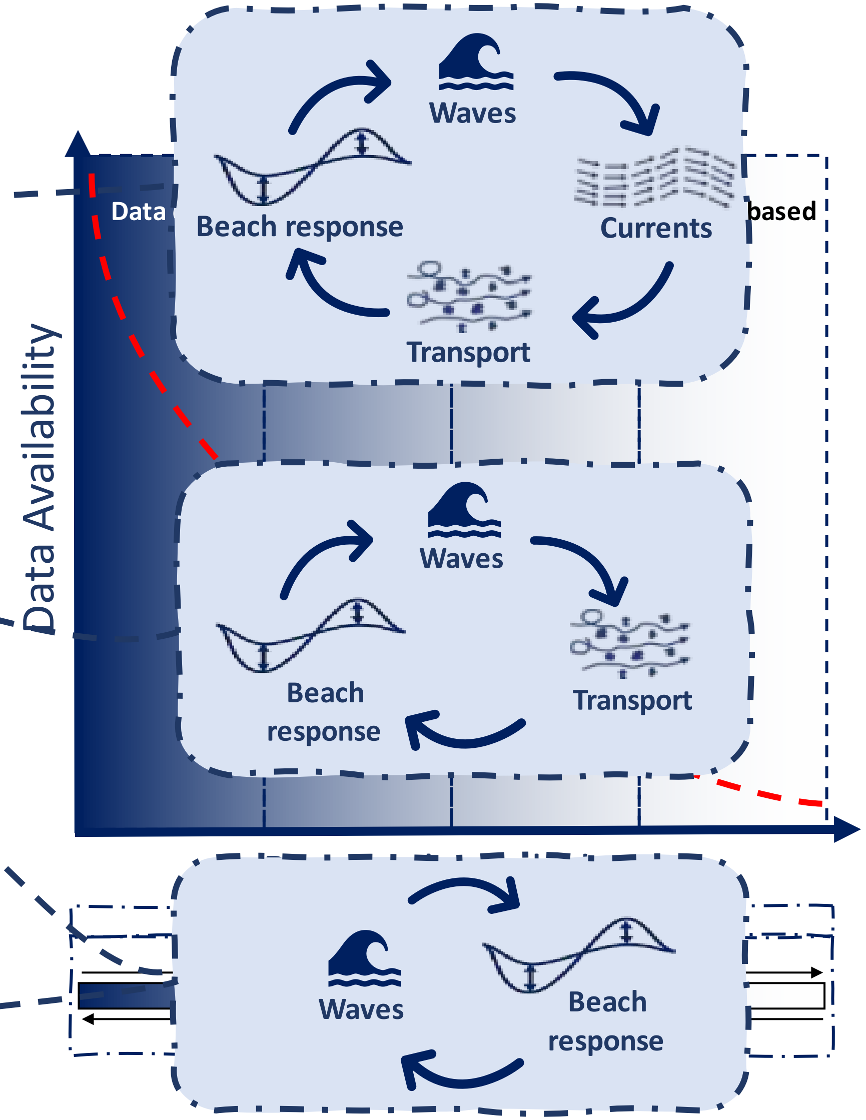
Reduced complexity

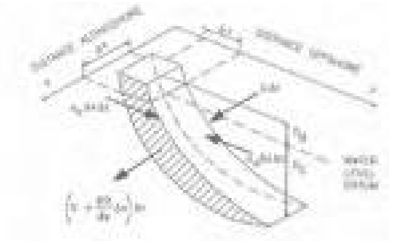
✓ Short- to long-term

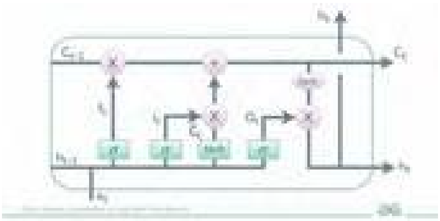
Semi-empirical (data-driven)

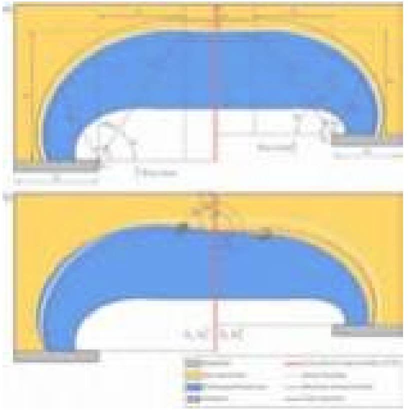
✓ Short- to long-term

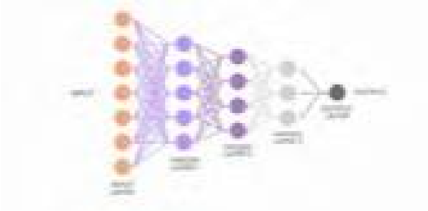
Data-driven.





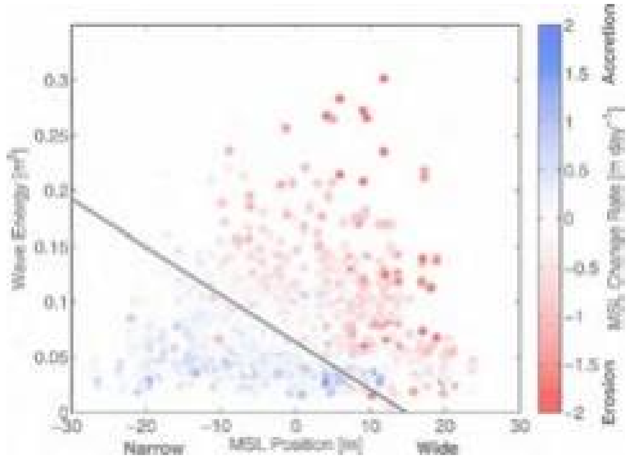


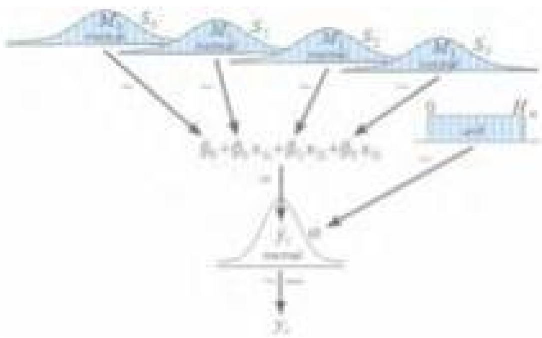


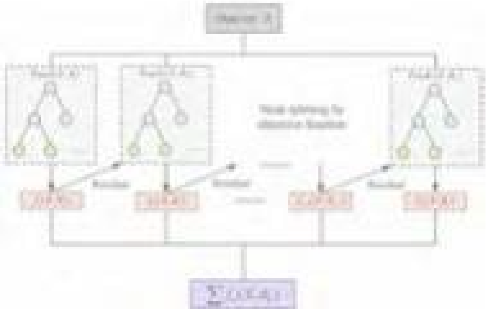


For long-term forecasts, which models are best?

$$\frac{\partial y_s}{\partial t} = -\frac{1}{(h_* + h_b)}\left(\frac{\partial Q_L}{\partial x} - q\right) + q_{FS}$$







ShoreShop (2019)

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Blind testing of shoreline evolution models

Jennifer Montaño, Giovanni Coco, Jose A. A. Antolínez, Tomas Beuzen, Karin R. Bryan, Laura Cagigal, Bruno Castelle, Mark A. Davidson, Evan B. Goldstein, Raimundo Ibaceta, Déborah Idier, Bonnie C. Ludka, Sina Masoud-Ansari, Fernando J. Méndez, A. Brad Murray, Nathaniel G. Plant, Katherine M. Ratliff, Arthur Robinet, Ana Rueda, Nadia Sénéchal, Joshua A. Simmons, Kristen D. Splinter, Scott Stephens, Ian Townend, Sean Vitousek & Kilian Vos — Show fewer authors

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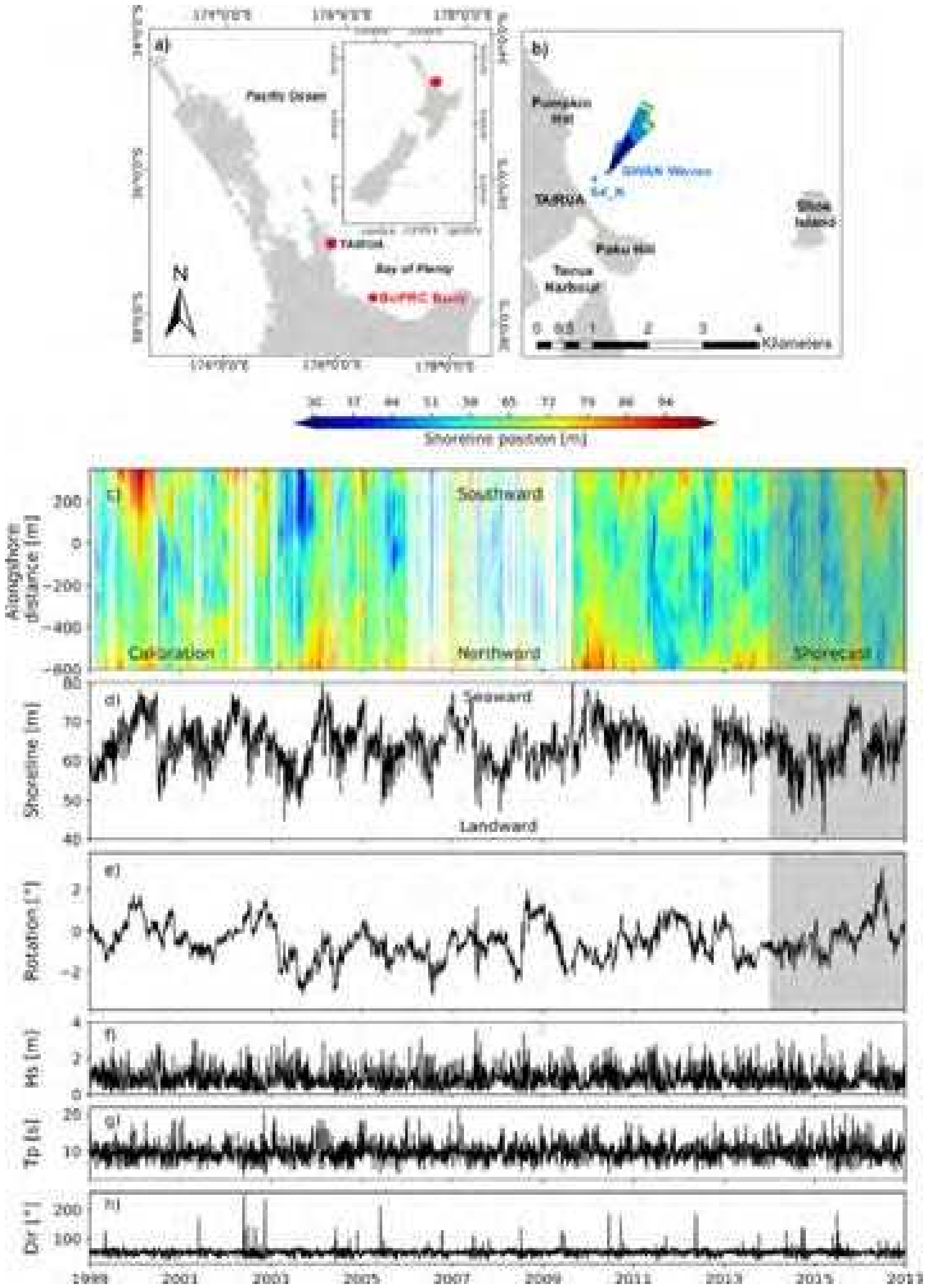
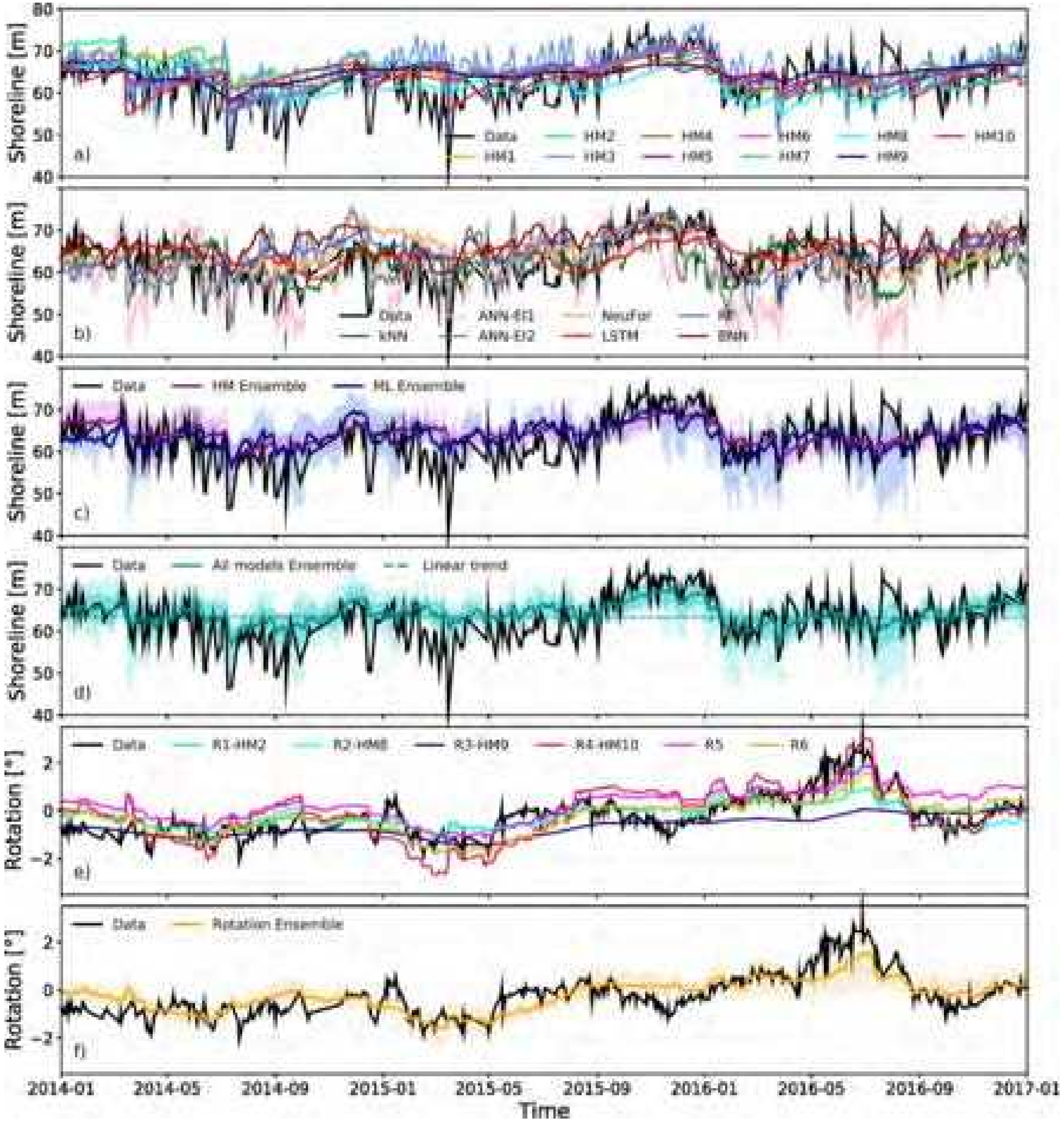
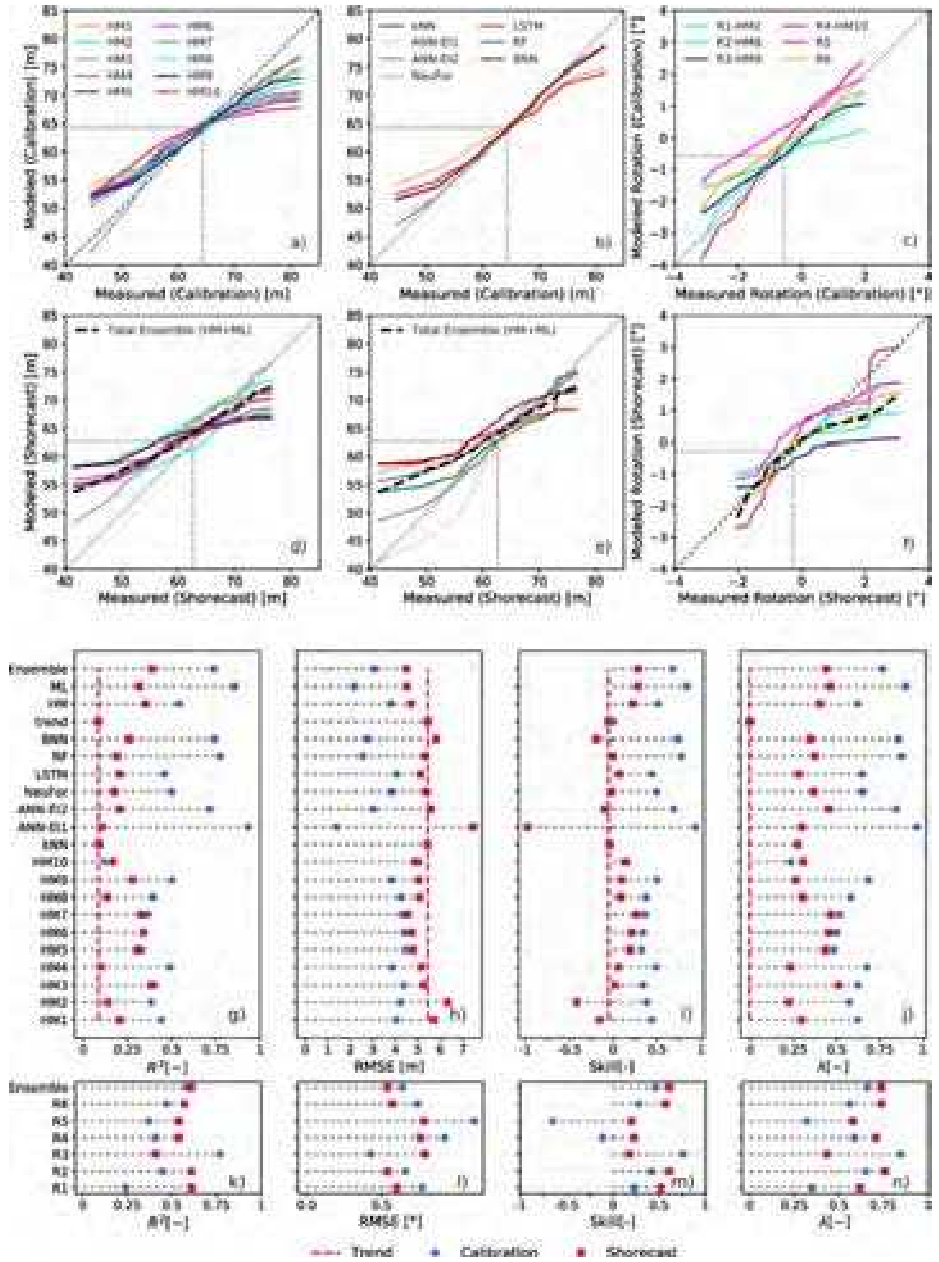
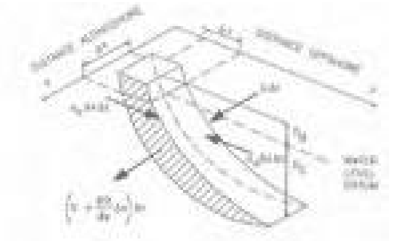
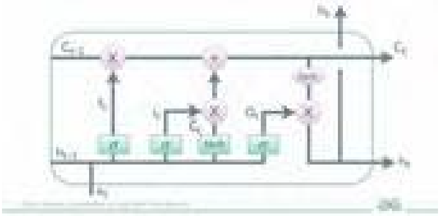
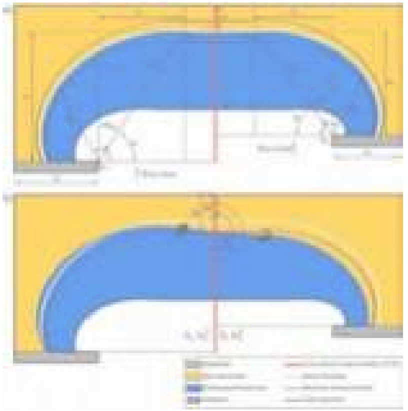



Shoreline [m]
a)
Data HM1 HM2 HM3 HM4 HM5 HM6 HM7 HM8 HM9 HM10
b)
Data kNN ANN-EI1 ANN-EI2 NeuFor LSTM RF BNN
c)
Data HM Ensemble ML Ensemble
d)
Data All models Ensemble Linear trend
Rotation [°]
e)
Data R1-HM2 R2-HM8 R3-HM9 R4-HM10 R5 R6
f)
Data Rotation Ensemble
2014-01 2014-05 2014-09 2015-01 2015-05 2015-09 2016-01 2016-05 2016-09 2017-01
Time

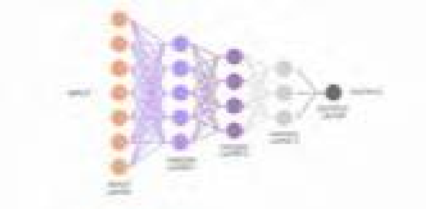

Modeled (Calibration) [m]
Measured (Calibration) [m]
Modeled Rotation (Calibration) [°]
Measured Rotation (Calibration) [°]
Modeled (Shorecast) [m]
Measured (Shorecast) [m]
Modeled Rotation (Shorecast) [°]
Measured Rotation (Shorecast) [°]
Total Ensemble (HM+ML)
Ensemble
ML
HM
Trend
BNN
RF
LSTM
NeuFor
ANN-EI2
ANN-EI1
kNN
HM10
HM9
HM8
HM7
HM6
HM5
HM4
HM3
HM2
HM1
R6
R5
R4
R3
R2
R1
RMSE [m]
RMSE [°]
Trend Calibration Shorecast



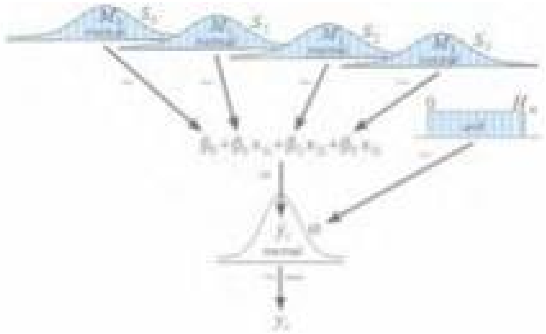


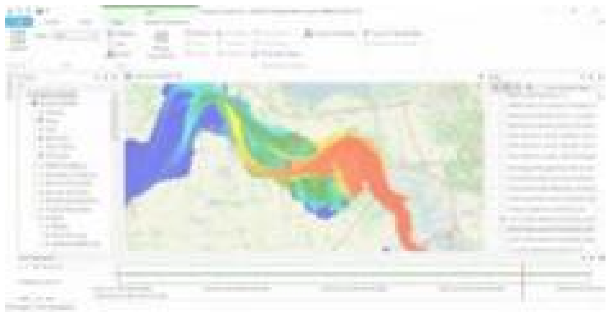


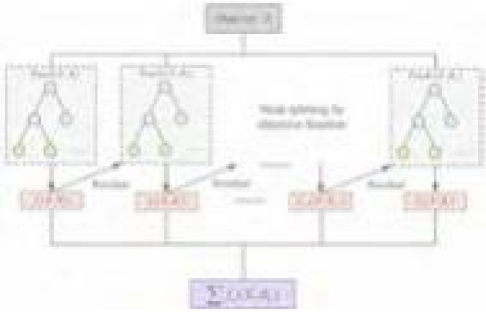
5 years latter…

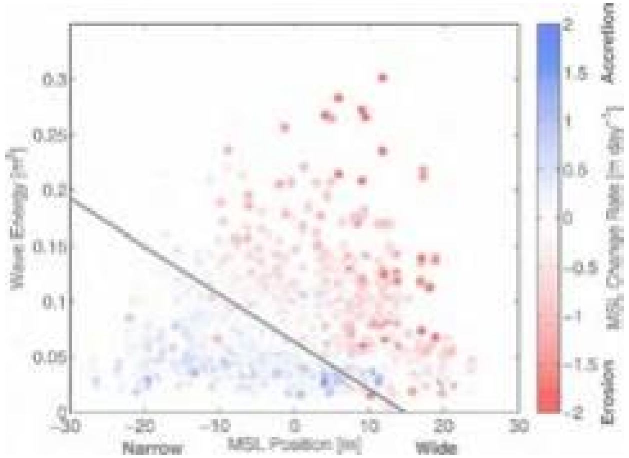


$$\frac{\partial y_s}{\partial t} = -\frac{1}{(h_* + h_b)}\left(\frac{\partial Q_L}{\partial x} - q\right) + q_{FS}$$

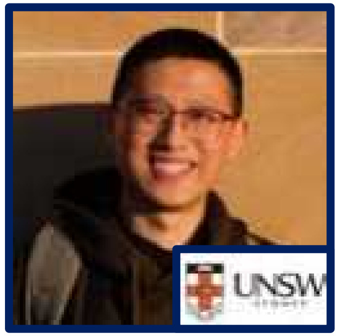






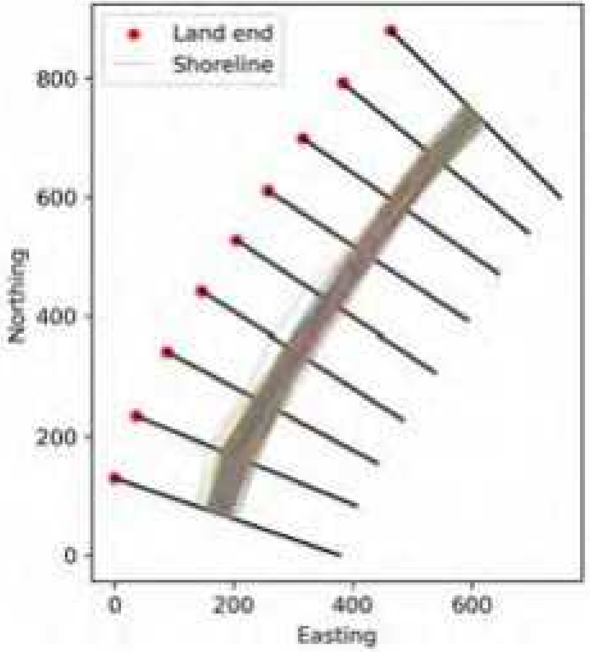


ShoreShop 2.0 (2024)



Yongjing Mao

BEACH X:



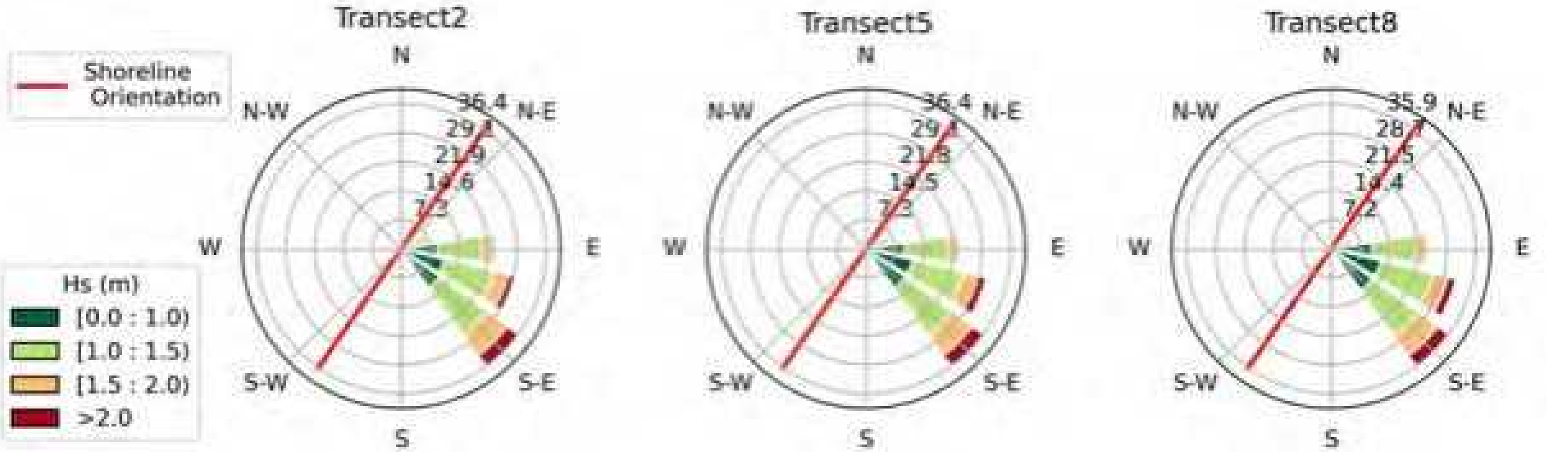
ShoreShop 2.0: Advancements in Shoreline Change Prediction Models

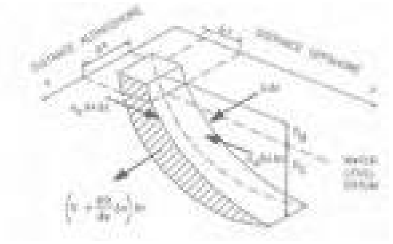
This repository is a testbed for shoreline modelling algorithms. It contains all benchmark datasets, input files, codes, and results.

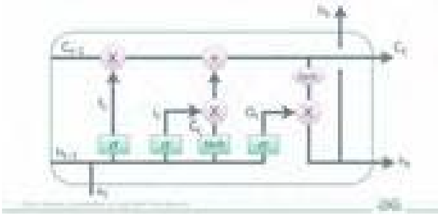
Tasks

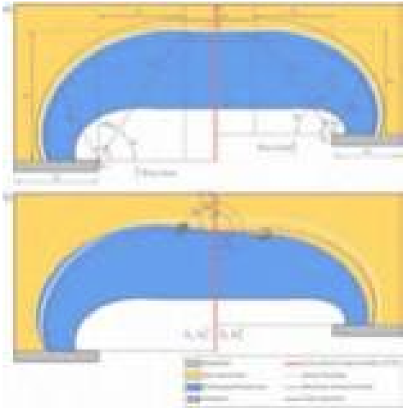
Given 20 years shoreline position data in the 1999-2018 period, along with the shoreline position in 1951-05-01 as well as wave and sea level data spanning from 1940 to 2100, participants are tasked with:

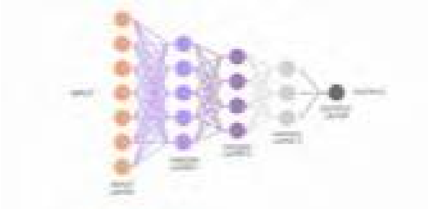
- *Task1.Short-term prediction*: Predict the shoreline position between **2019-01-01 and 2023-12-31 with daily** timestep.
- *Task2.Medium-term prediction*: Predict the shoreline position between **1951-05-01 and 1998-12-31 with daily** timestep.
- *Task3.Long-term prediction*: Predict the shoreline position between **2019-01-01 and 2100-12-31 with daily** timestep (no evaluation).





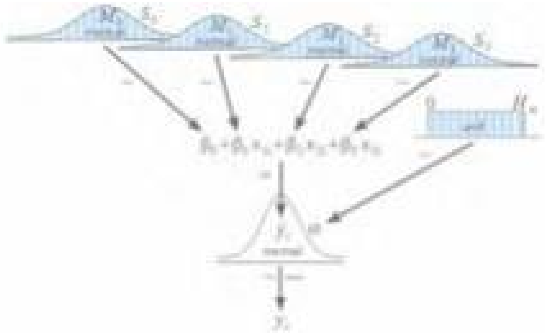


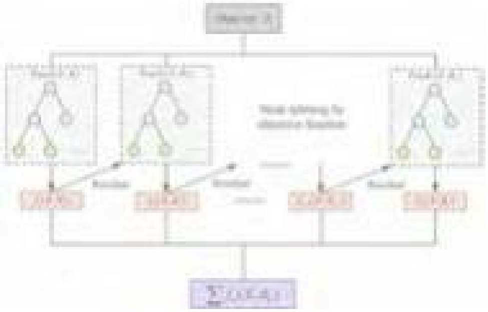


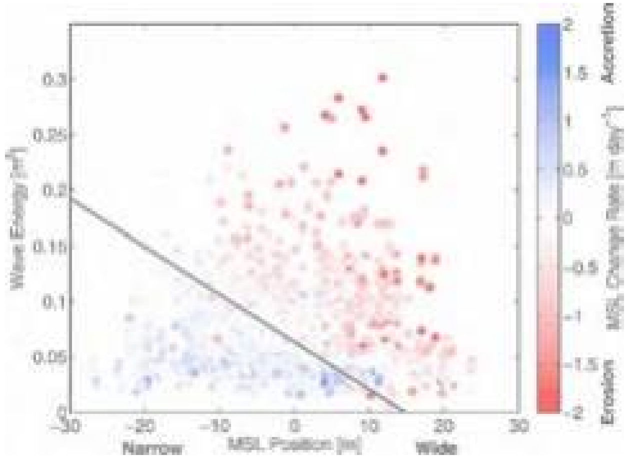


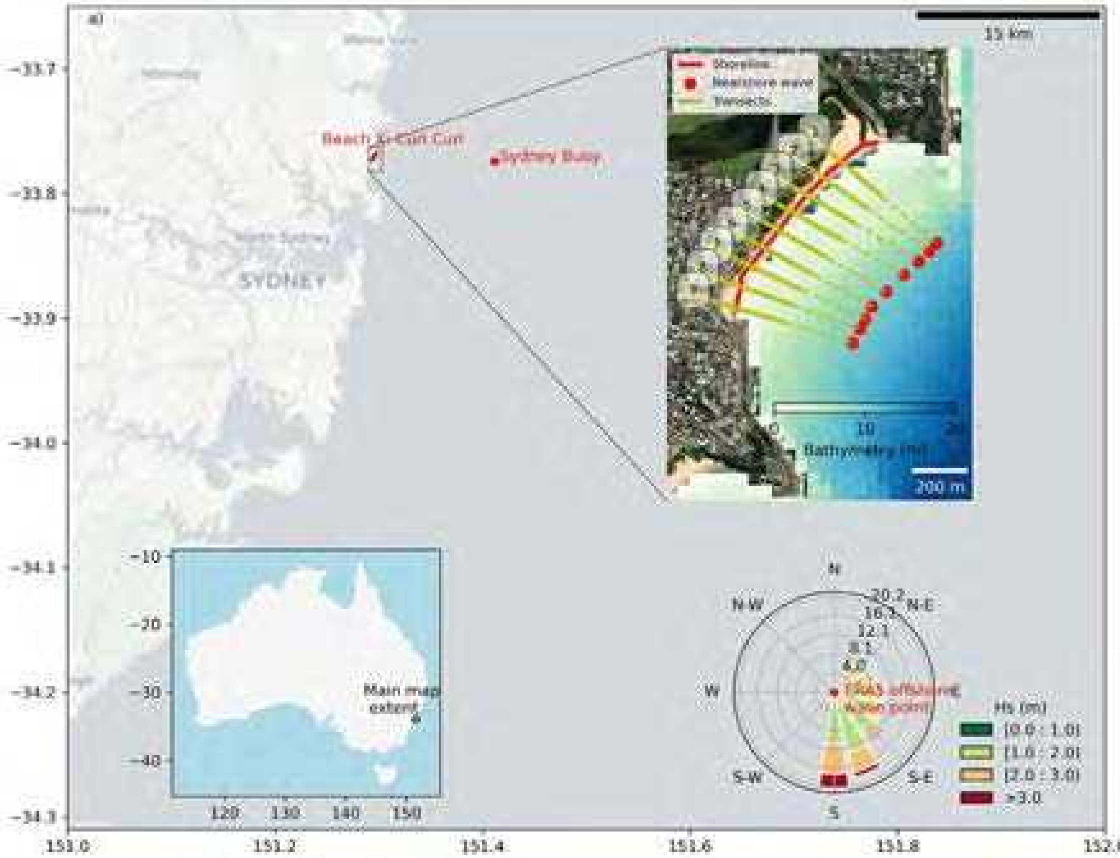
Can AI beat traditional models?

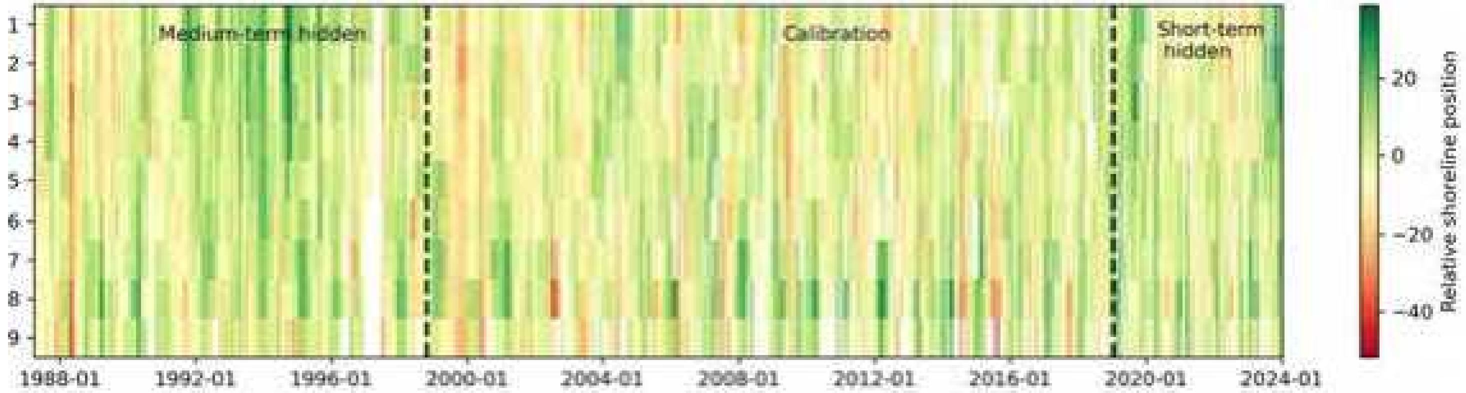
$$\frac{\partial y_s}{\partial t} = -\frac{1}{(h_* + h_b)}\left(\frac{\partial Q_L}{\partial x} - q\right) + q_{FS}$$

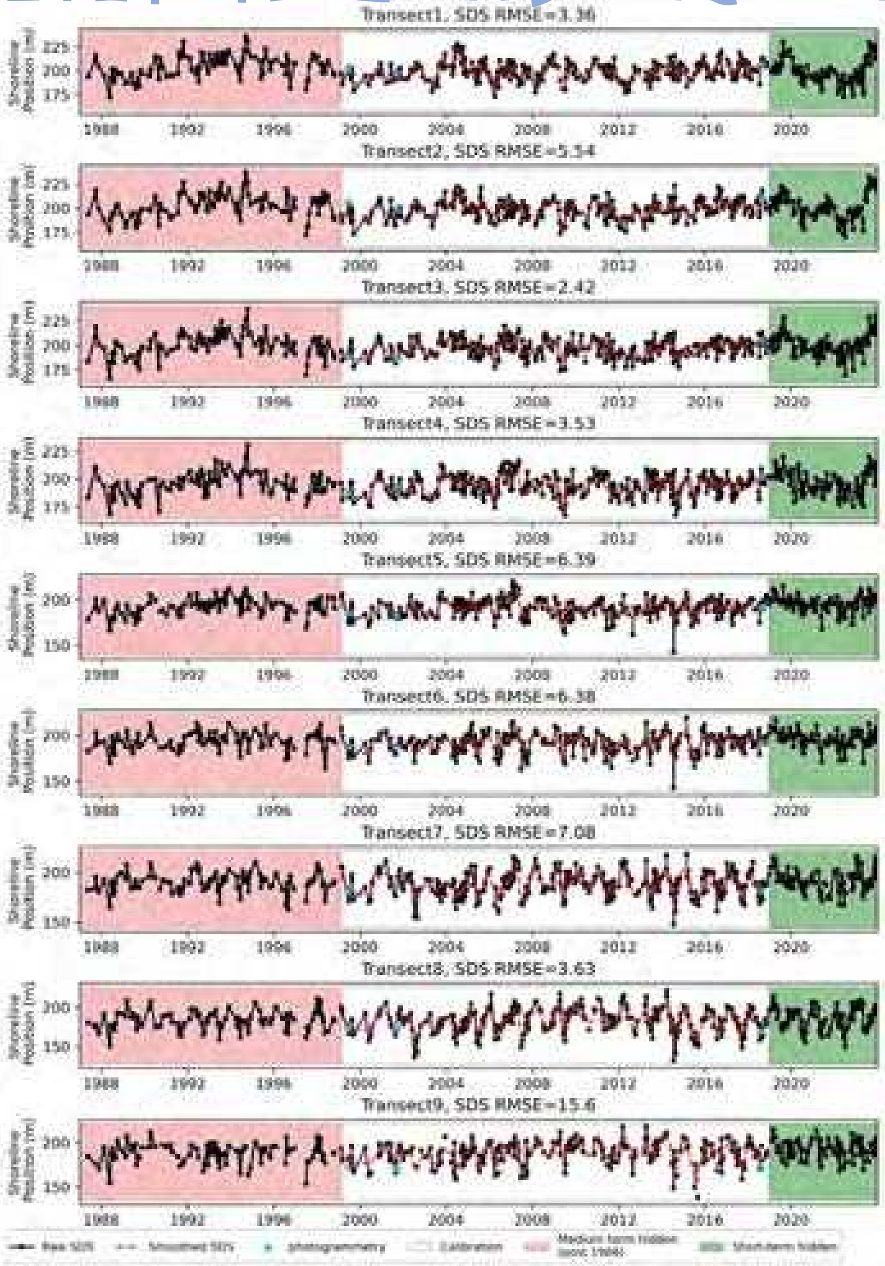


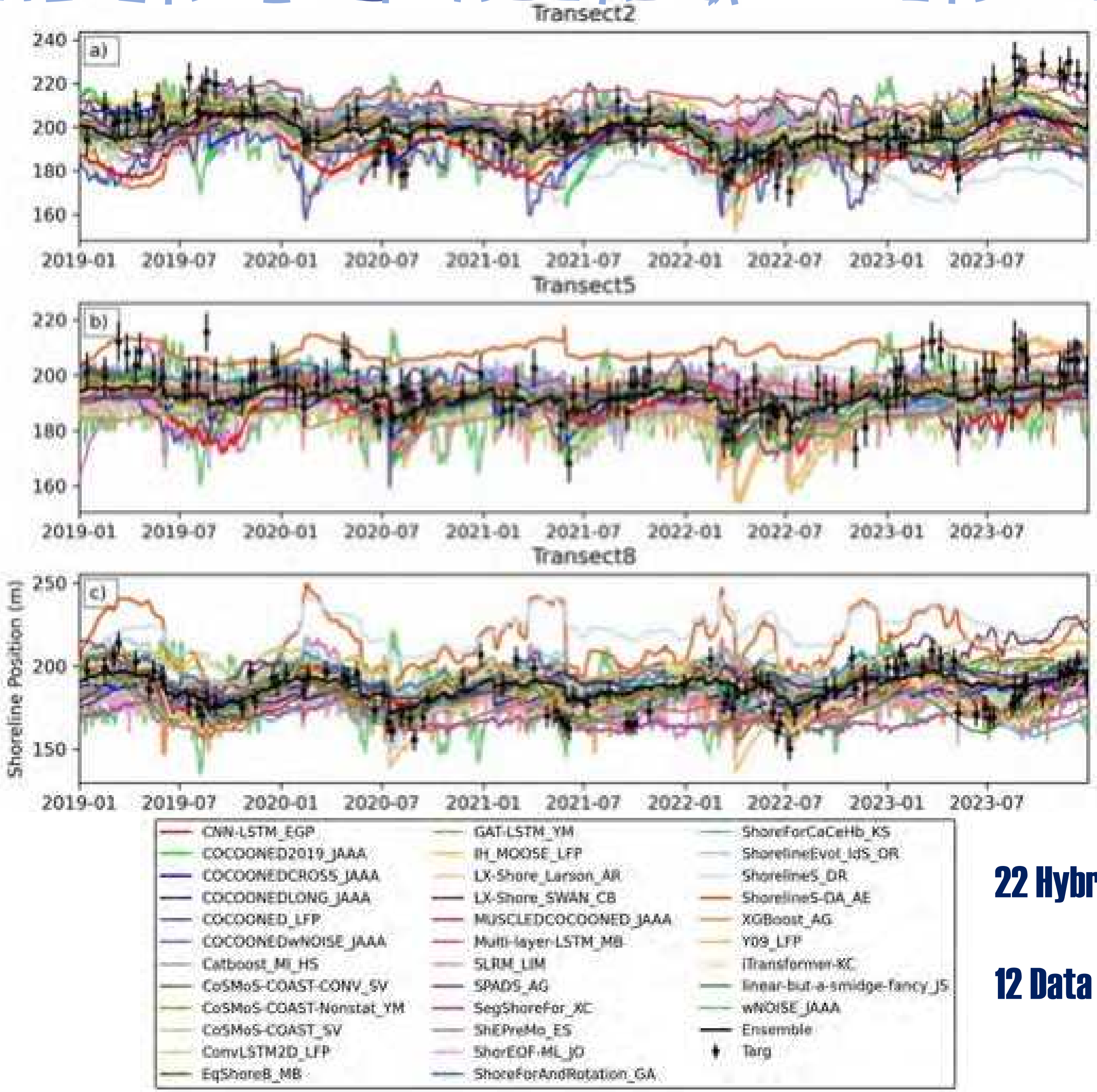





15 km
Shoreline
Nearshore wave
Transects
Beach X-Curl Curl
Sydney Buoy
SYDNEY
Bathymetry (m)
200 m
Main map extent
N
N-W
N-E
W
E
S-W
S-E
S
Hs (m)
[0.0 : 1.0)
[1.0 : 2.0)
[2.0 : 3.0)
>3.0
151.0
151.2
151.4
151.6
151.8
152.0
−33.7
−33.8
−33.9
−34.0
−34.1
−34.2
−34.3

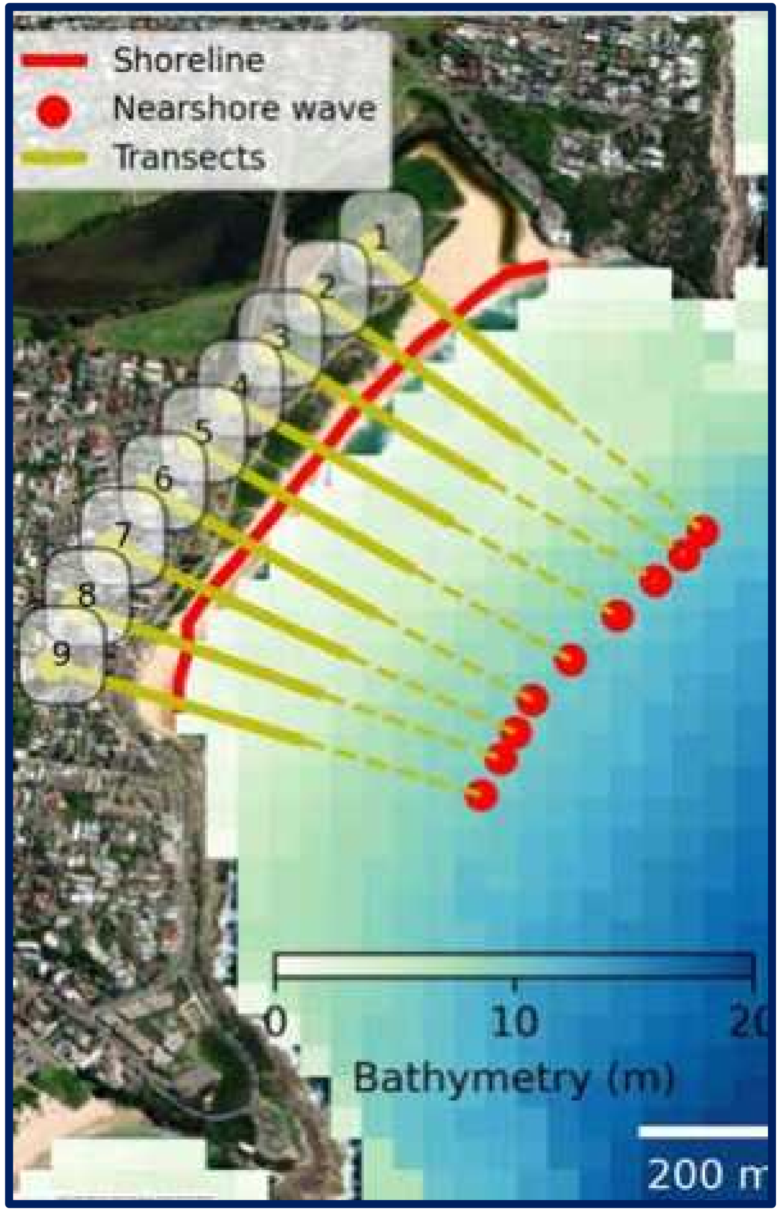

Medium-term hidden
Calibration
Short-term hidden
Relative shoreline position
1988-01
1992-01
1996-01
2000-01
2004-01
2008-01
2012-01
2016-01
2020-01
2024-01


Transect1, SDS RMSE=3.36
Transect2, SDS RMSE=5.54
Transect3, SDS RMSE=2.42
Transect4, SDS RMSE=3.53
Transect5, SDS RMSE=6.39
Transect6, SDS RMSE=6.38
Transect7, SDS RMSE=7.08
Transect8, SDS RMSE=3.63
Transect9, SDS RMSE=15.6
Shoreline Position (m)
Raw SDS
Smoothed SDS
photogrammetry
Calibration
Short-term hidden

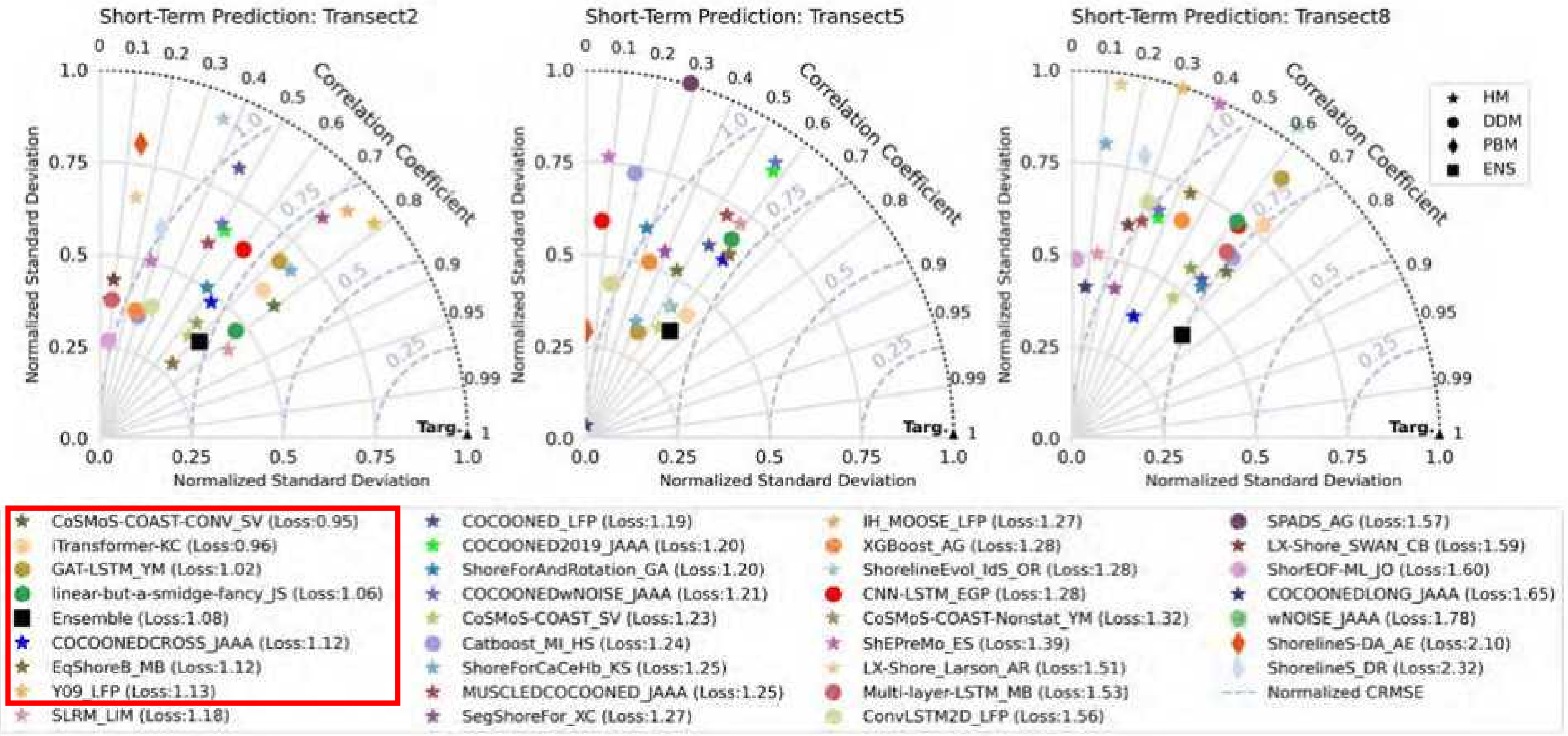


22 Hybrid

12 Data driven



$$L_i = \sqrt{(0 - RMSE_{norm})^2 + (1 - Corr)^2 + (1 - STD_{norm})^2}$$



Best models

1. **CoSMoS-COAST-CONV** — 1 convolution + 5 params
2. **iTransformer** — $> 10^6$ params
3. **GAT-LSTM** — $> 10^6$ params
4. **Bayesian Autoregression** — $> 10^2$ params
5. **Miller and Dean** — 3 params

Smoothed data

Hybrid models

DNN (attention based)

DD models

7 of the 10 best models were not AI models

What do we know so far?

There is no better model yet...

There are better modelers

Apparently, ensembles perform great...

But not for extreme events

Hybrid models are fast and stable...

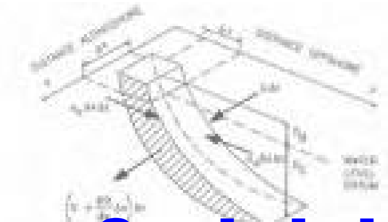
No “but” for this one

AI is coming with heavy guns...

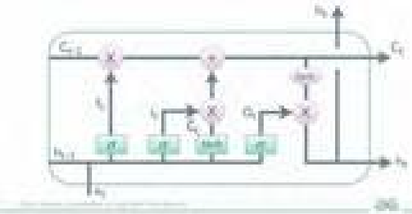
But you are what you eat

SDS are the present, and future...

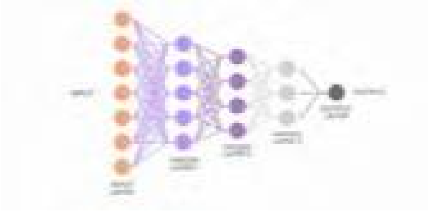
But the error is big



Can hybrid models be better explored?

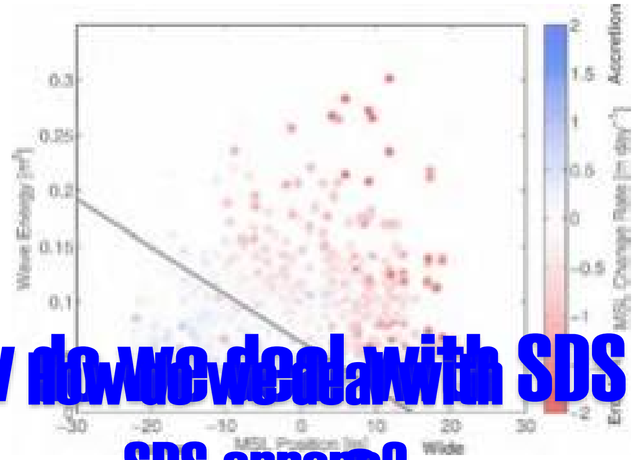


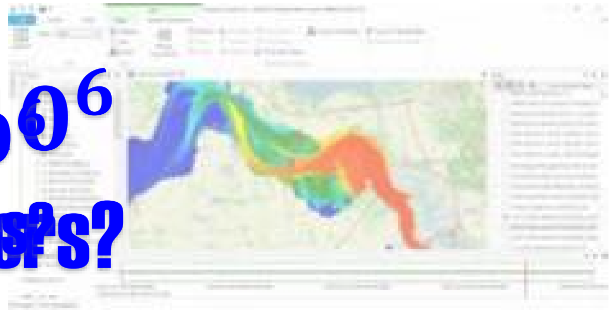
How we can improve the extreme events?



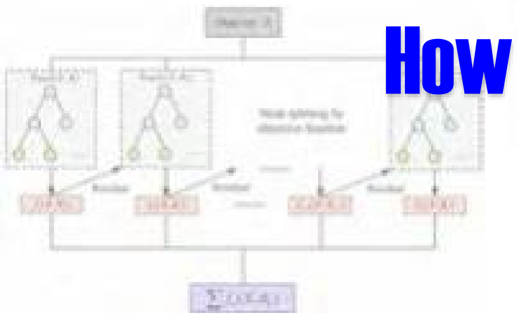
Where is my shoreline modelling research going?

$$\frac{\partial y_s}{\partial t} = -\frac{1}{(h_* + h_b)}\left(\frac{\partial Q_L}{\partial x} - q\right) + q_{FS}$$





What is between 10^6 and 10^0 parameters?



How do we deal with SDS errors?

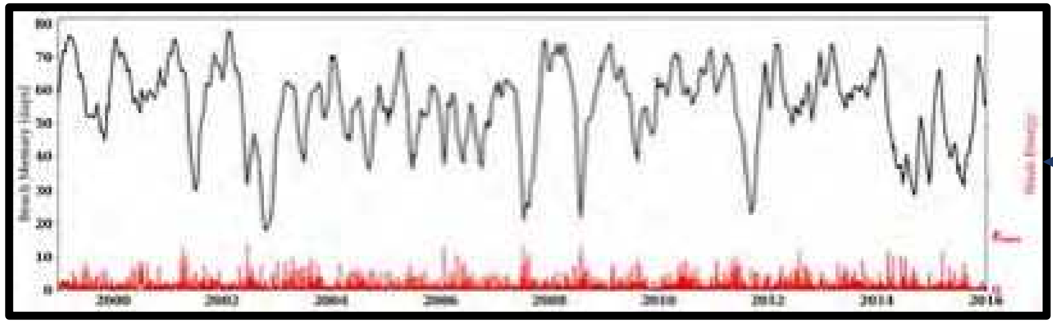
Can hybrid models be better explored?

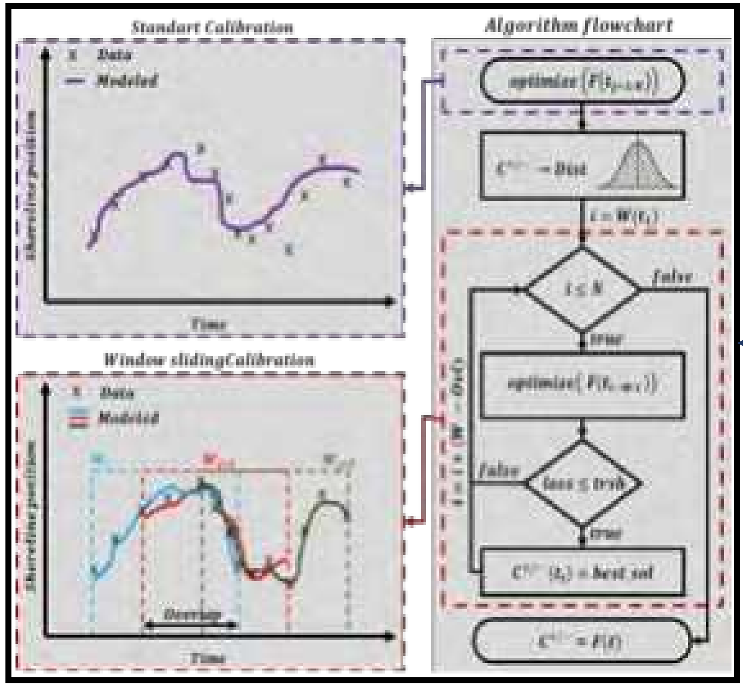
What is between 10^6 and 10^0 parameters?

How we can improve the extreme events?

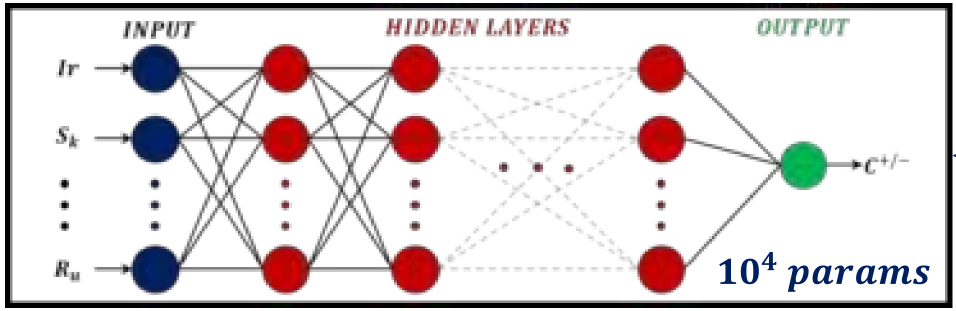
How do we deal with SDS errors?

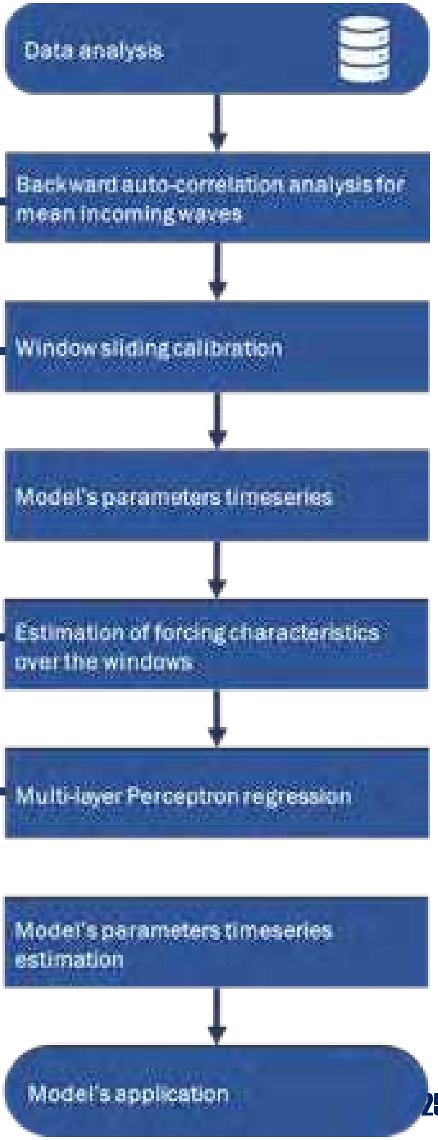
Increase their complexity





Irribarren number (Ir)	Wave swewness (S_k)
Wave power(P)	Number of storms (N_s)
Mean angle (θ_m)	Mean sea level (MSL)
Dean's parameter (Ω)	Wave energy (E)
Wave energy std. (σ_E)	Runnup (R_u)



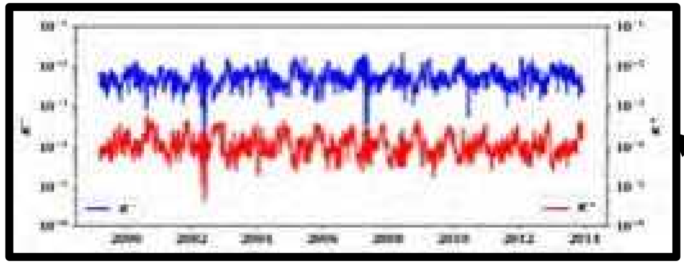


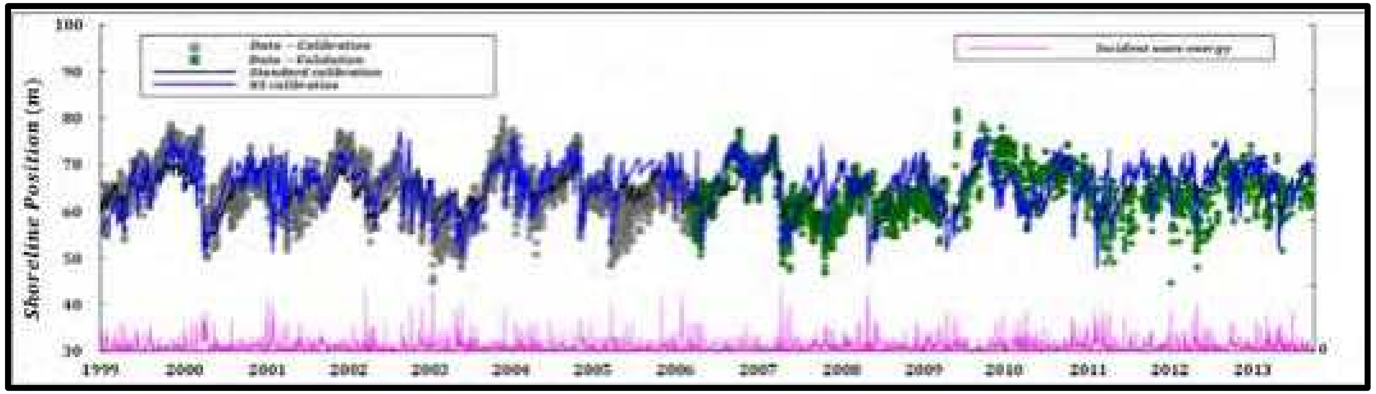
Can hybrid models be better explored?

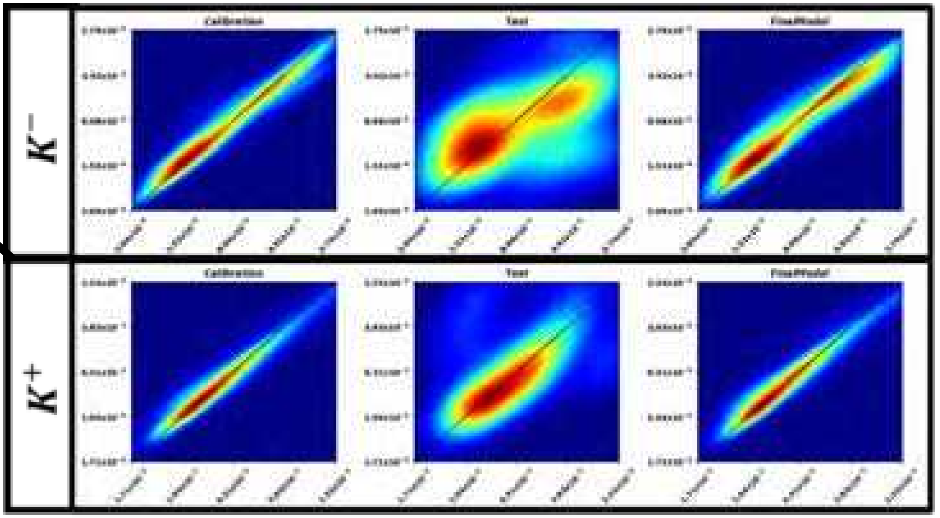
What is between 10^6 and 10^0 parameters?

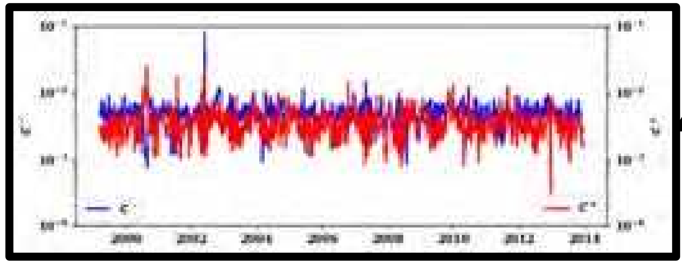
How we can improve the extreme events?

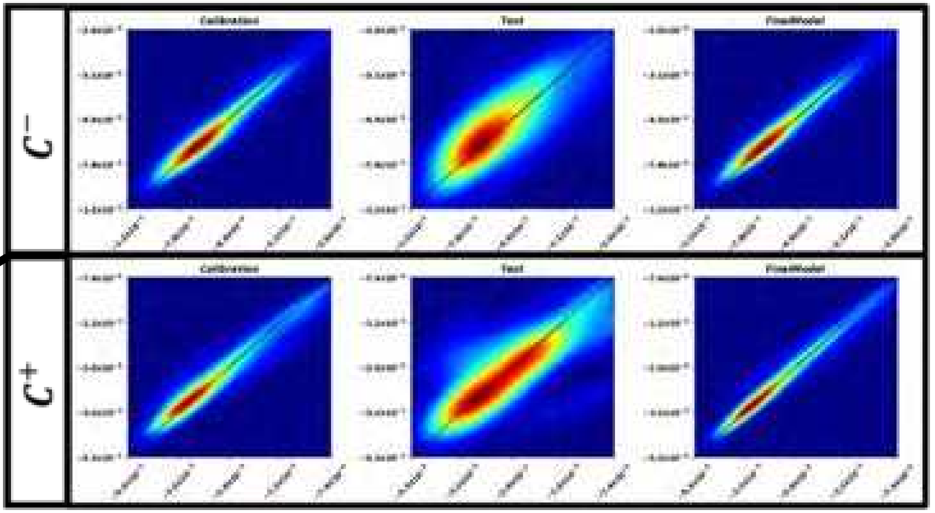
How do we deal with SDS errors?











Period	Metric	Standard Calibration	Proposed Methdology
Calibration	λ_M	0.38	0.58
	RMSE	4.58 m	4.38 m
Validation	λ_M	0.30	0.40
	RMSE	5.25 m	5.03 m

Can hybrid models be better explored?	**What is between 10^6 and 10^0 parameters?**	**How we can improve the extreme events?**	**How do we deal with SDS errors?**

COASTAL DYNAMICS 2025

7-11 April, Aveiro, Portugal

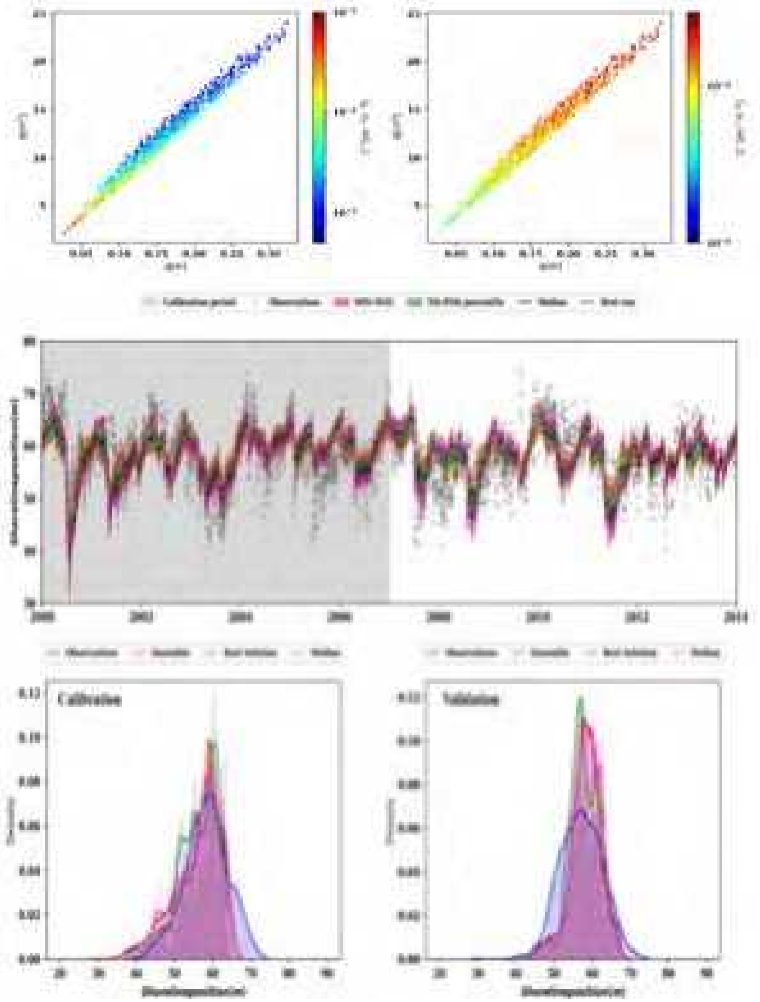
PROBABILISTIC FORECASTING OF SHORELINE EVOLUTION: A CASE STUDY USING GENETIC ALGORITHMS

Lucas de Freitas[1], Camilo Jaramillo[1], José A. A. Antolínez[2], Mauricio González[1], Raúl Medina[1]

[1] IHCantabria – Instituto de Hidráulica Ambiental de la Universidad de Cantabria, Santander, Spain.

[2] Hydraulic Engineering Department, Delft University of Technology, Delft, The Netherlands.

lucas.defreitas@unican.es

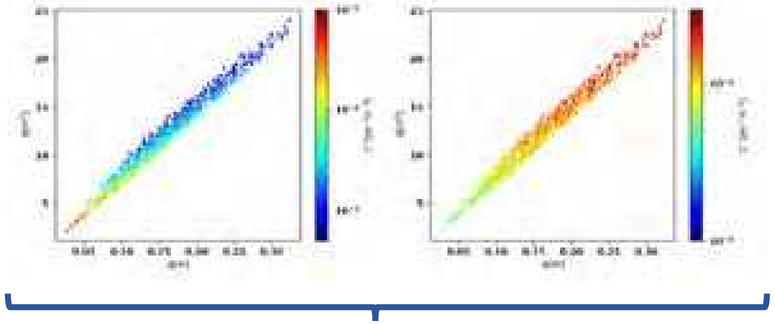


Can hybrid models be better explored?

What is between 10^6 and 10^0 parameters?

How we can improve the extreme events?

How do we deal with SDS errors?

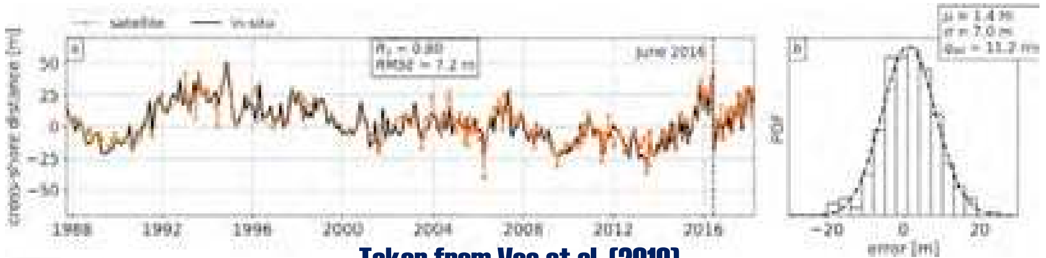


$Multivariate\ prior$

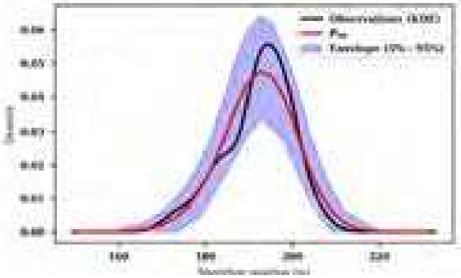
+

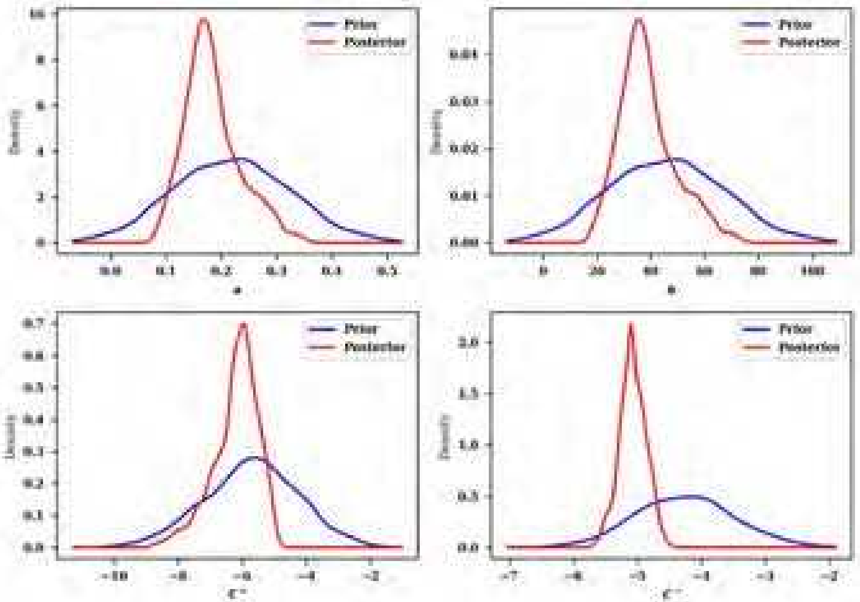
$\mathcal{N}(\epsilon_{obs})$

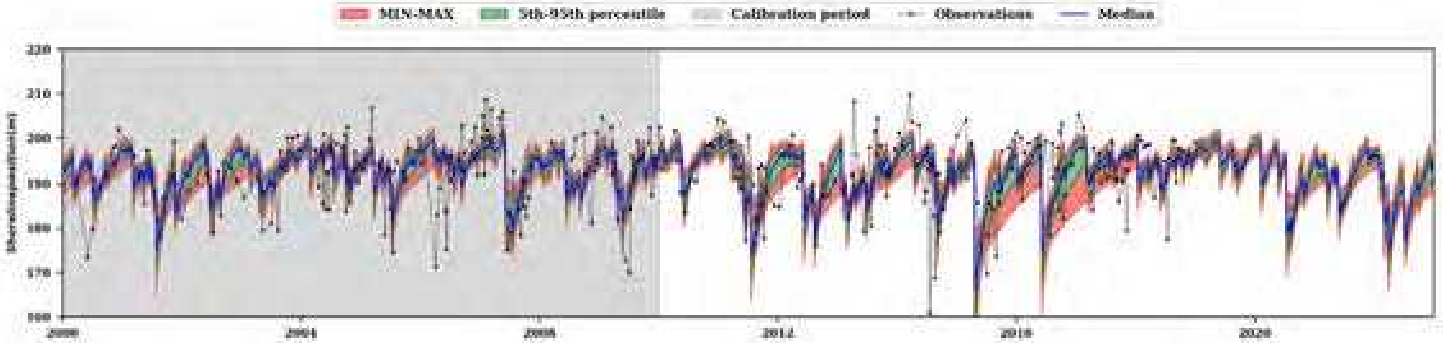
Bayesian inference



Taken from Vos et al. (2019).







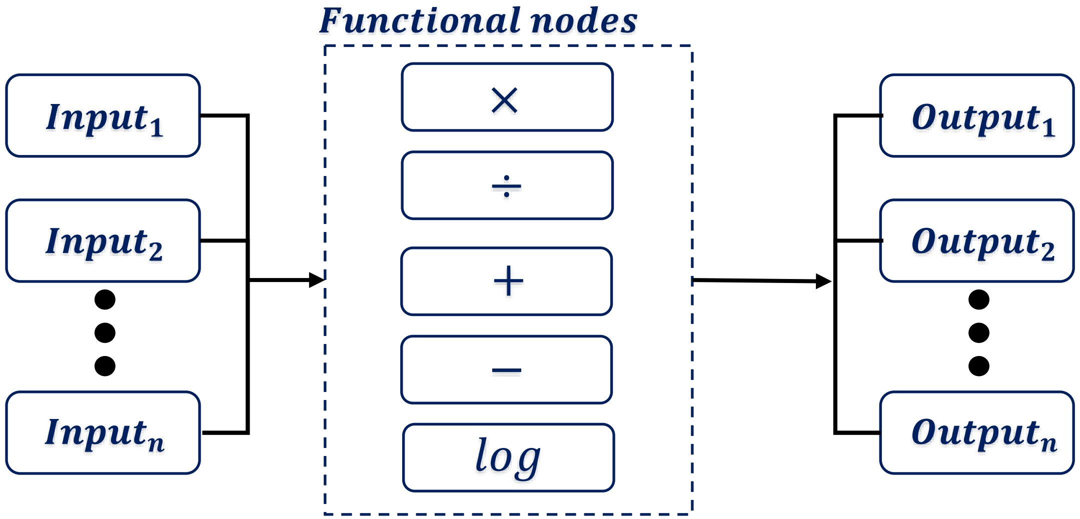
Can hybrid models be better explored?

What is between 10^6 and 10^0 parameters?

How we can improve the extreme events?

How do we deal with SDS errors?

$$\frac{dY}{dt} = \gamma\,\Delta\chi_{eq}$$ → Disequilibrium → Parameters



$$\forall\,\gamma \rightarrow \gamma = \theta + \epsilon(t, forcing)$$

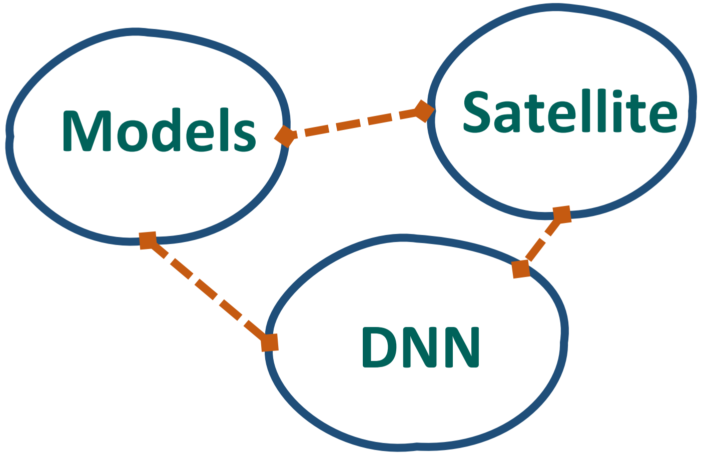
↓

Cartesian Genetic Programming

- Use EBSEM stability
- Add uncertainty to the ensemble
- Scalability (LS+CS)
- Increase complexity
- Improve extreme events prediction quality

Key takeaways

The present and the future



Our main challenges

- Deal with errors
- Extreme events

Where my thesis is going

- Hybridizing traditional models
- Statistical shoreline modeling
- Improving predictions
- Developing models aided by DNNs (ongoing)

DC Presentations

Morphodynamic Analysis of the upper confined and unconfined beach profiles during Episodic events

06/ 11/ 2024

SEDIMARE Workshop
Santander, Spain

Buckle Subbiah Elavazhagan

SEDIMARE – DC 05
IH-Cantabria, Universidad de Cantabria

Javier López Lara
Professor, Universidad de Cantabria

María Emilia Maza Fernández
Ass. Professor, Universidad de Cantabria

Currently in Month 13

Understanding on numerical simulations using bichromatic conditions from large scale experiment

New Experiments to be considered for the numerical study

Model development for vegetation case

01 INTRODUCTION

02 BACKGROUND IH2VOF-SED

03 IMPLEMENTING LABORATORY CASE

04 RESULTS

05 SUMMARY

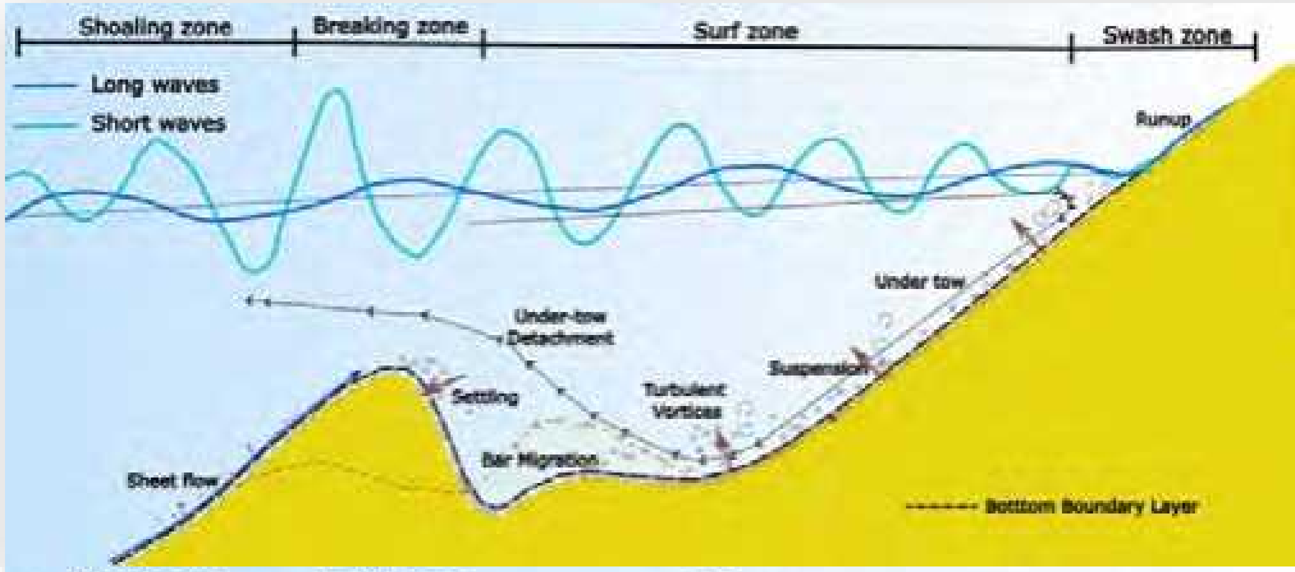
06 LABORATORY EXPERIMENTS CONSIDERED

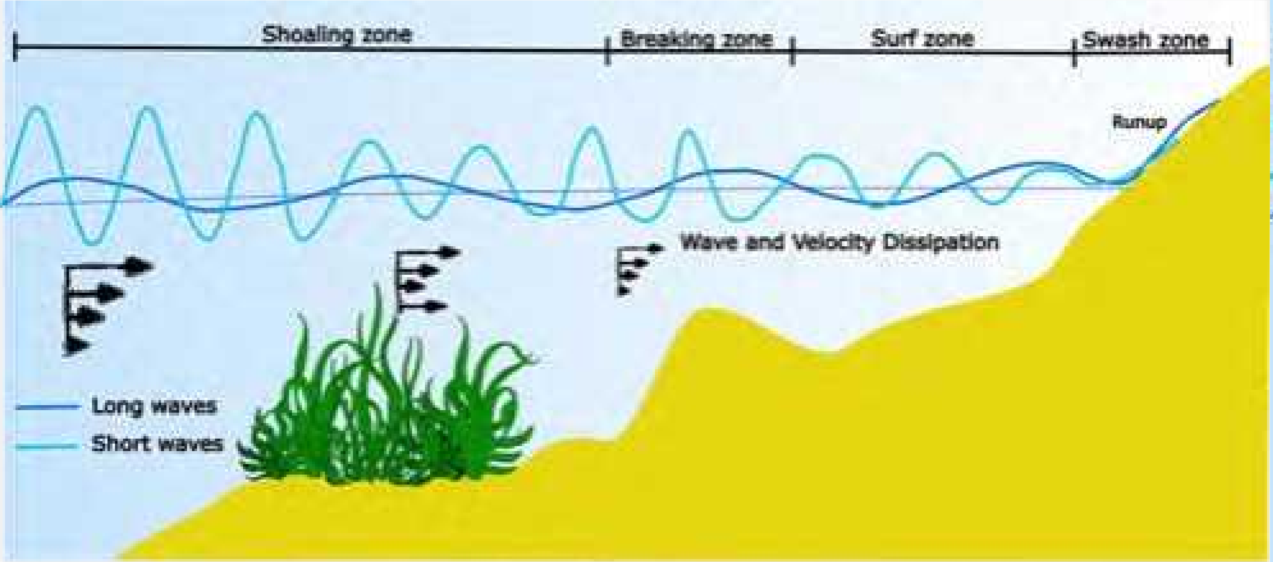
07 IMLEMENTING VEGETATION SCHEME

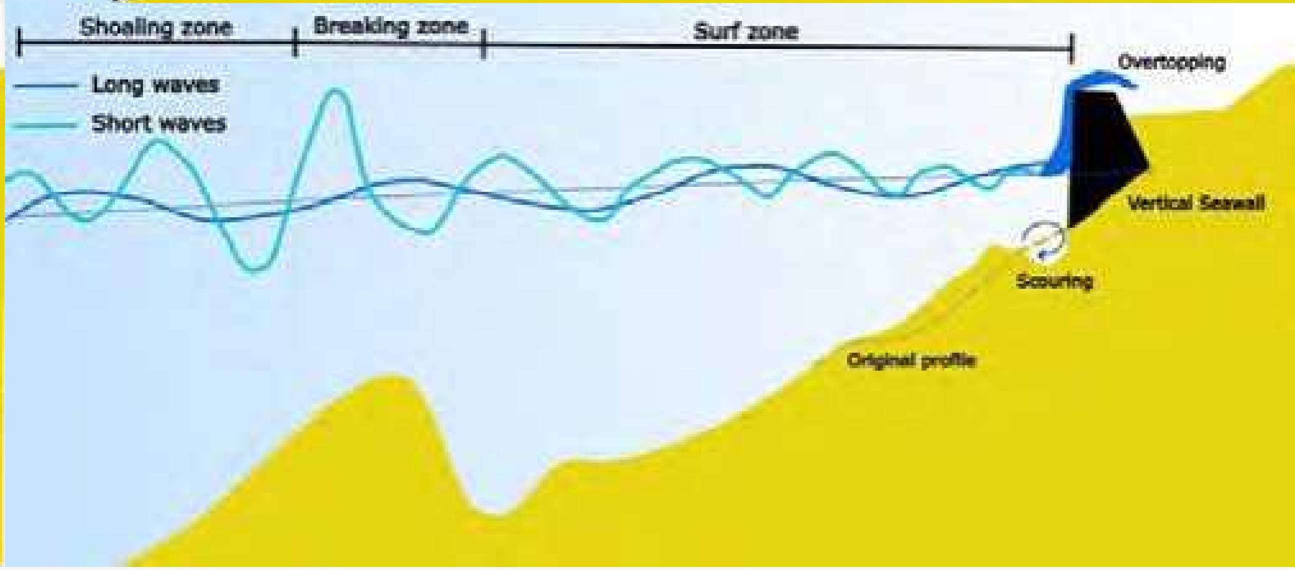
08 WHAT'S NEXT

I INTRODUCTION

Applying IH2VOF –SED model to model different morphodynamic processes and the governing hydrodynamics on different beach configurations and sustainable protection measures

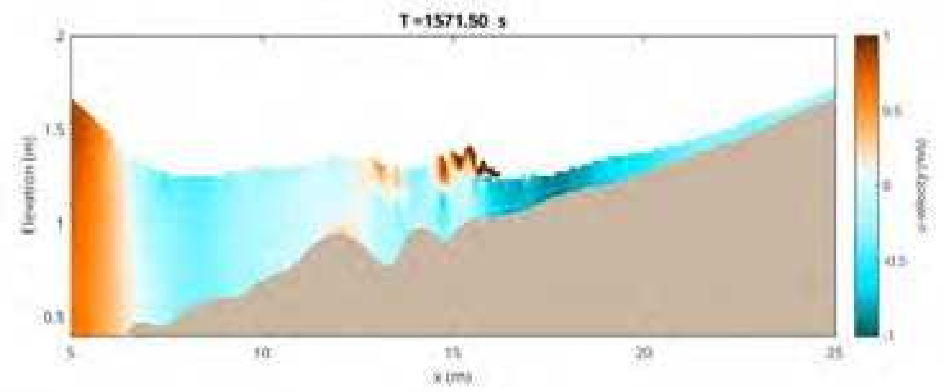


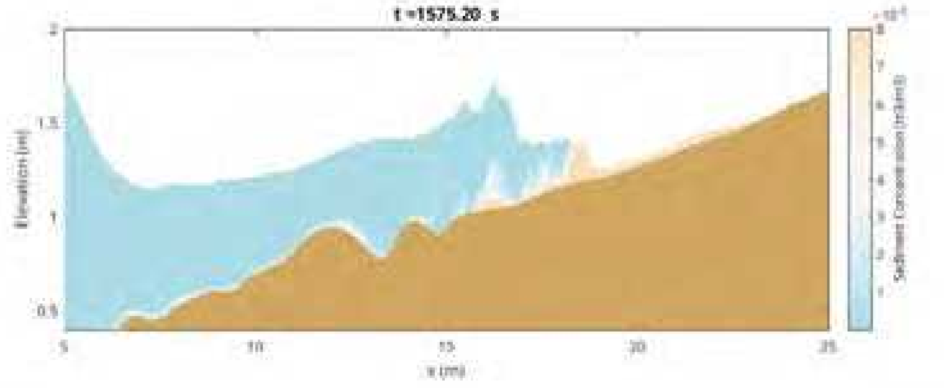




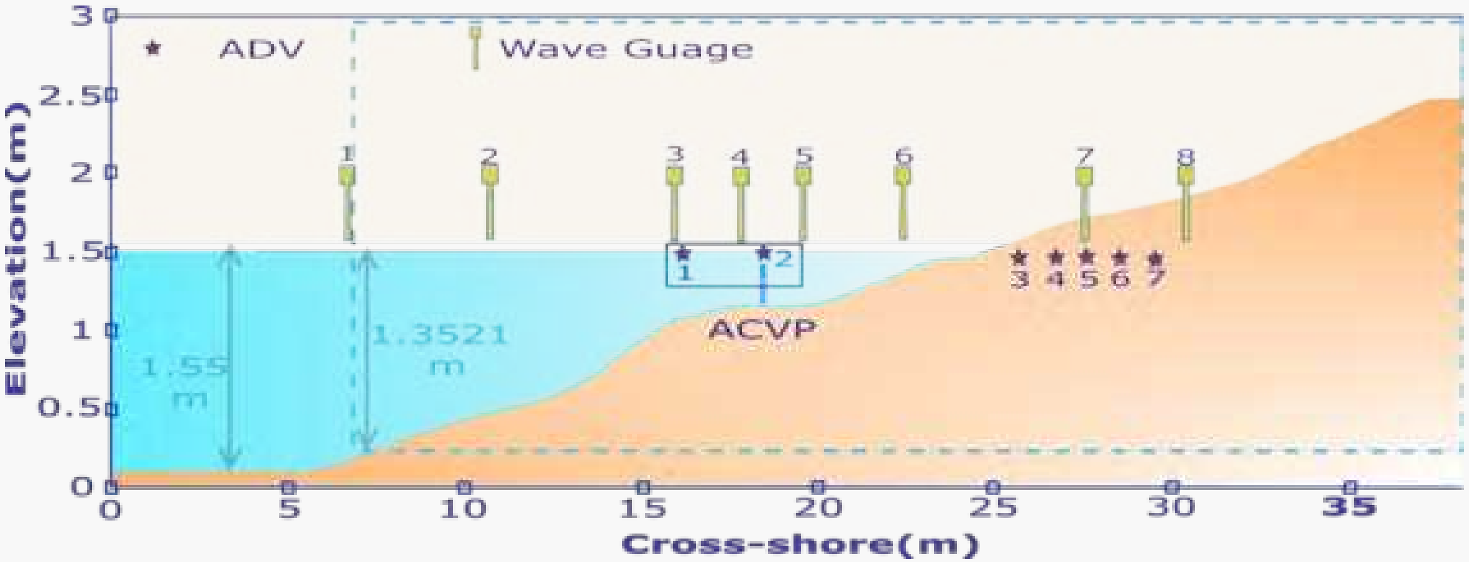
II Background IH2VOF-SED

- 2DV RANS based solver
- Turbulence is accounted using a k-ε closure model
- Finite difference computational approach in a structured orthogonal mesh
- Free surface reconstruction using Volume of Fluid technique
- Incorporation of solid boundary using partial cell treatment
- Two step projection method is used as numerical solving procedure
- Empirical formula by Roulond 2004 is used for Bed load Estimation
- Advective Diffusive equation is solved for Suspended load Estimation
- Two point friction velocity estimation is used





III Implementing Laboratory case



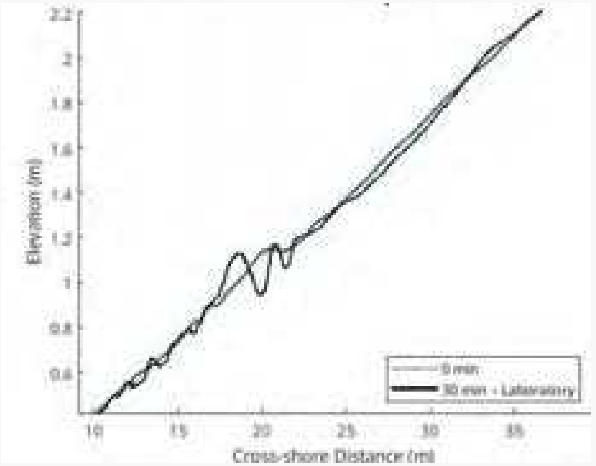
Near-Bed Sediment Transport during offshore bar migration in large-scale experiments . Florian Grossman et.al 2022

Erosive case using Bi-chromatic Waves

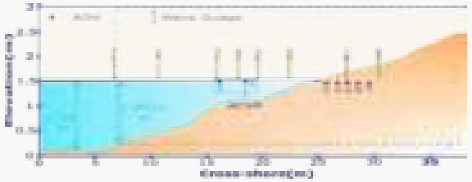
H1(m)	H2(m)	F1(Hz)	F2 (Hz)
0.245	0.245	0.3041	0.23657

Initial and final beach states

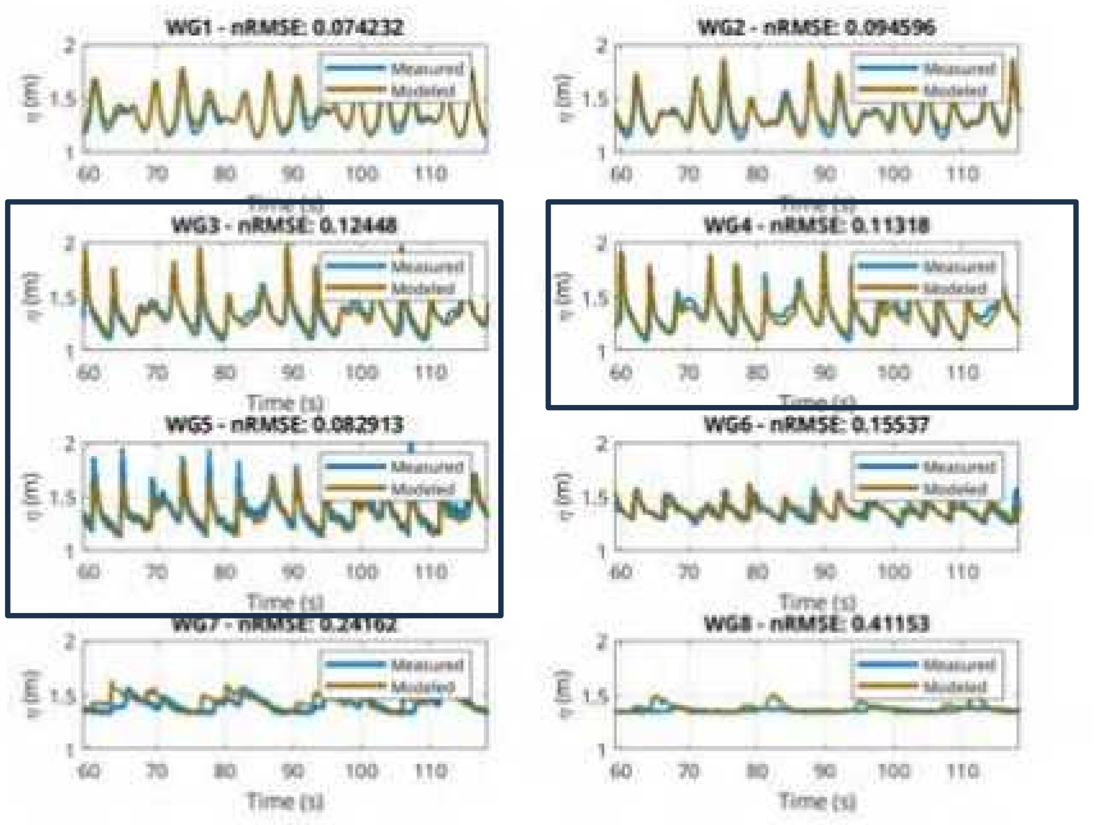
Bar formation



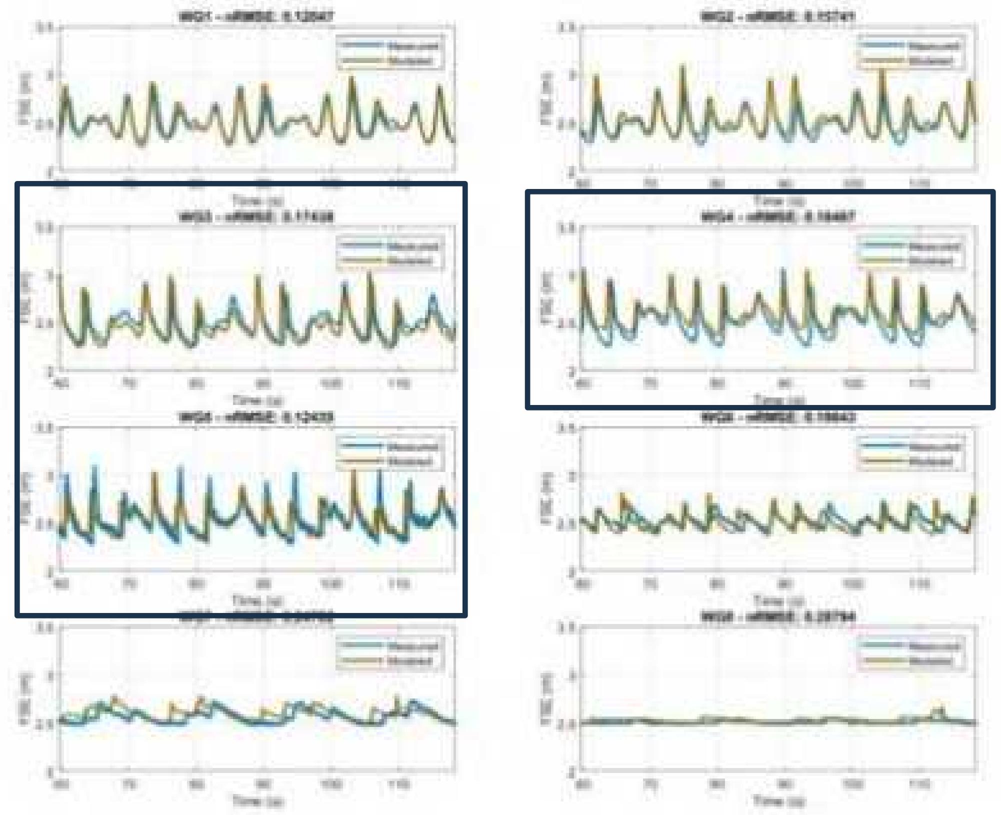
IV Results - Free Surface Elevation (First 4 wave groups)



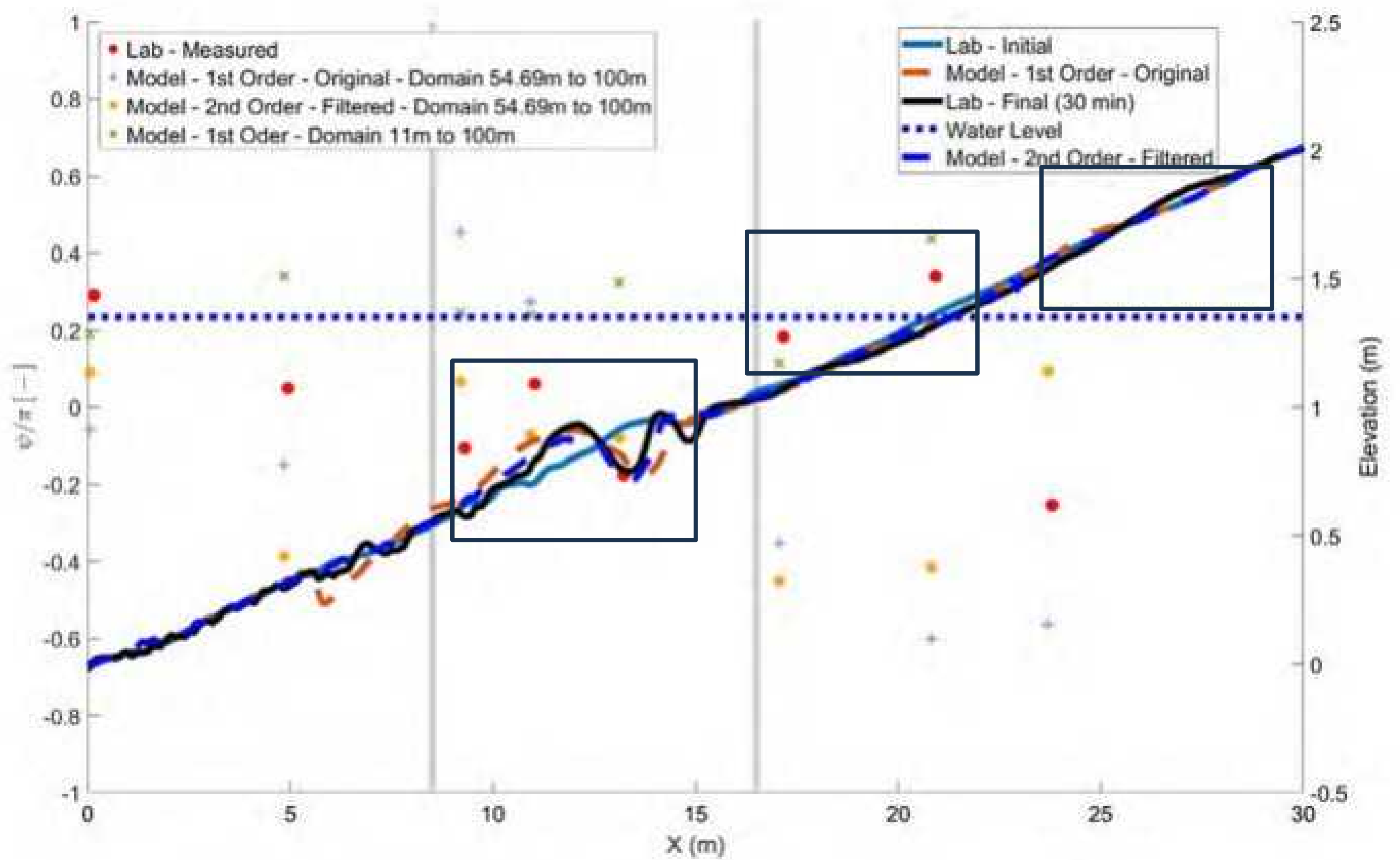
Origin 54 m from the wave maker



Origin 11 m from the wave maker



IV RESULTS- Phase Difference between long wave and short wave components and beach profile evolution



- Deviations in phase difference between long and short wave components of model and laboratory is significant
- Closer representation in breaking zone resulted in better bar formation when driven with theoretical 2nd order waves replacing existing components
- Overwash in the inshore is underestimated.

IV Results- Phase Difference between long wave and short wave components and beach profile evolution

J.W.M. Kranenborg et.al, 2024

Effects of free surface modelling and wave-breaking turbulence on depth-resolved modelling of sediment transport in the swash zone, Coastal Engineering.

The closest study using similar wave conditions.
The model is run using a fixed bed and only for 3 minutes with no bed evolution.
Wave maker signals are available in this case

Jose M Alsina et.al, 2016

Sediment transport and beach profile evolution induced by bi-chromatic wave groups with different group periods.

During shoaling process broad banded wave conditions tend to dissipate more and energy transformation into long wave components
It is observed ingoing free long wave is 27% of energy of the primary wave group

Baldock TE et.al, 2010

Sediment transport and beach morphodynamics induced by free long waves, bound long waves and wave groups.

Wave conditions with free long waves tend to increase offshore transport in the surf zone and onshore transport in the swash zone, but with bound longwave offshore transport is predominant in surf and swash zone.

V Summary

01 Phase difference between long wave and short wave components are different for laboratory and for numerical simulations

02 Using different wave gauge data and changing the domain length accordingly introduces different longwave components into model

03 Lack of Wave maker signal information is a deficiency for replicating the entire length of the flume

04 Breaking point decides the breaker bar formation

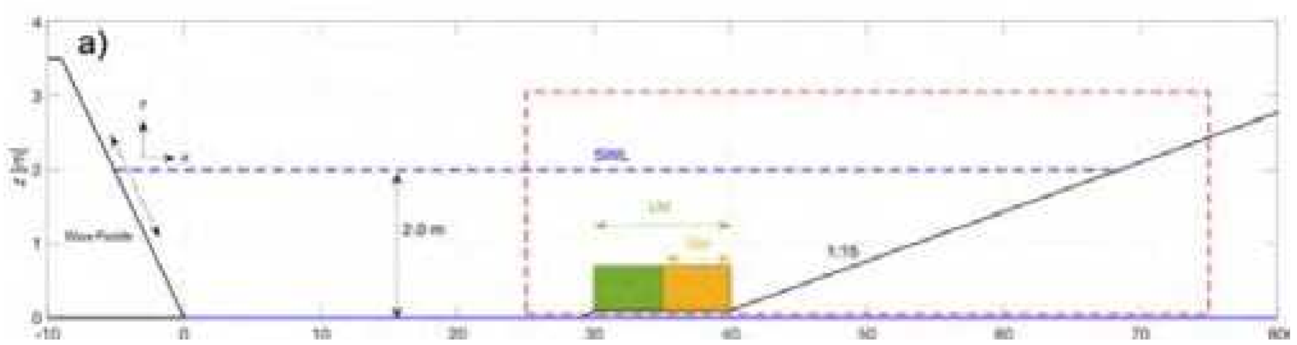
05 Longwave not exactly replicated reduces overwash deposition

06 Subsequent experiments are planned considering this impact

VI Morphodynamic evolution due to the presence of seagrass meadow

1. Development of Numerical scheme to incorporate the impact of Posidonia *Oceania*
2. Validation against CIEM Flume experiments which used a surrogate vegetation model
3. Evaluate the morphodynamic response due to the presence of the seagrass meadow

Validation case



Physical model setup - Astudillo et al., 2022; Astudillo-Gutierrez et al., 2024)

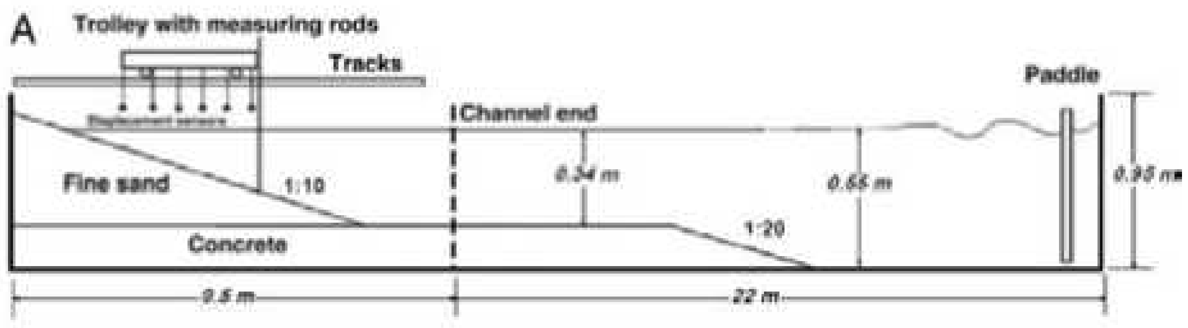
Key expected outputs

1. Functional numerical model incorporating submerged vegetation
2. Role of submerged meadow of different lengths in attenuating waves and velocities
3. Impact of vegetation in breaker bar dynamics

VI Sediment transport and beach morpho dynamics induced by free long waves, bound long waves and wave groups

1. Validation against medium scale experiments of Baldock et.al 2010
2. Experiments highlighted response of a beach profile to different wave conditions
3. Experiments include free long waves and bound long waves

Validation case



Physical model setup – Baldock et.al 2010

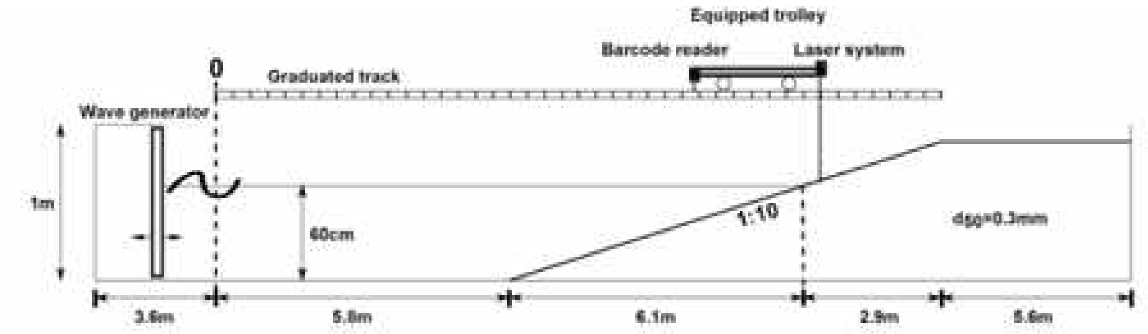
Key expected outputs

1. Role of free long waves and bound long waves in morphodynamic response of a beach profile

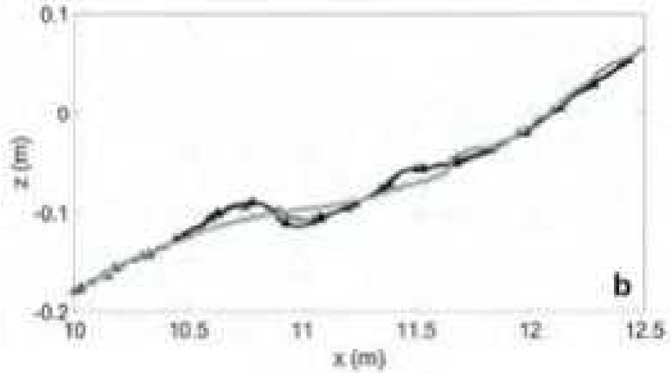
VI Study on dynamic equilibrium of a Beach profile

1. Validation against medium scale experiments of Baldock et.al 2017
2. Experiments about static and dynamic equilibrium of a beach profile
3. Erosive and accretive wave conditions are used cyclically

Validation case



Physical model setup – Baldock et.al 2017



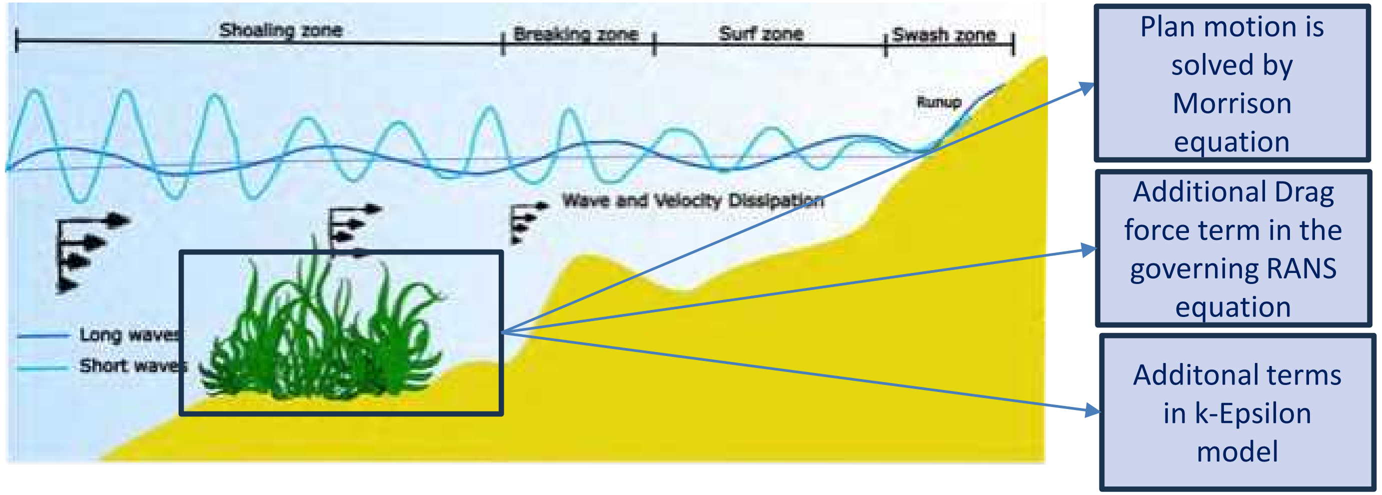
An example dynamic equillibrium state achieved in the experiments– Baldock et. Al 2017

Key expected outputs

1. Long term morphological responses of beach profile to reach a state of equilibrium
2. Cyclical wave conditions and dynamic equilibrium

VII Vegetation Implementation in the IH2VOF-SED model

1. Existing implementation by Maria Maza et.al 2013 will be modified and implemented within the IH2VOF-SED model
2. Existing implementation have provision for only implementing vegetation in defined rectangular shape horizontally
3. Provision will be made to include vegetation as complex orientations and geometries



$$F_{D,i} = \frac{1}{2} \cdot C_D \cdot a \cdot N \cdot \bar{u}_{rel,i} \cdot |\bar{u}_{rel,i}|$$

$$\frac{\partial u_i}{\partial t} + \bar{u}_j \frac{\partial u_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial p}{\partial x_i} + g_i + \frac{1}{\rho}\frac{\partial \tau_{ij}}{\partial x_j} - \frac{\partial \overline{(u'_i u'_j)}}{\partial x_j} - F_{D,i}$$

Drag force consideration in RANS equation

$$+\underbrace{\rho C_{kp} C_D a N \sqrt{\bar{u}_{rel,j}\bar{u}_{rel,j}}\, k}_{\xi_v}$$

$$+\underbrace{\rho C_{\varepsilon p} C_D a N \sqrt{\bar{u}_{rel,j}\bar{u}_{rel,j}}\, \varepsilon}_{\xi_{\varepsilon v}}$$

Dispersive stresses consideration in K-ε model

$$m_0 \cdot \frac{\partial^2 \xi}{\partial t^2} + C \cdot \frac{\partial \xi}{\partial t} + \left(E \cdot I \cdot \frac{\partial^4 \xi}{\partial z^4}\right) =$$
$$= \frac{1}{2} \cdot \rho \cdot C_D \cdot a \cdot \left(u - \frac{\partial \xi}{\partial t}\right) \cdot \left|u - \partial \frac{\xi}{\partial t}\right| + (\rho_p - \rho) \cdot g \cdot V_p \cdot \frac{\partial \xi}{\partial z} + \rho \cdot V_p \cdot \frac{\partial u}{\partial t} + \rho \cdot C_m \cdot V_p \cdot \left(\frac{\partial u}{\partial t} - \frac{\partial^2 \xi}{\partial t^2}\right)$$

Morrison equation for plant motion

VIII What's Next

01 Next case will be validating the model with a medium scale experiments by Baldock et.al. 2010 and 2017

02 Scheme for incorporating vegetation is implemented simultaneously

03 Validating the model with the large scale experiments with vegetation by C.Astudillo et.al 2022

04 Secondment at Deltares to be planned from September 2025 utilizing the vegetation implementation

05 Implementation of Structure and final case and subsequent second secondment in UNIVPM next year

06 The current is being communicated in RCEM 2025 Conference to be held Barcelona between 1st and 5th September 2025

Thank you!

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Initiation of motion for sand-mud bed types

Jowi Miranda
SEDIMARE

jowi.miranda@deltares.nl
p.s.miranda@utwente.nl
psmiranda

Deltares
UNIVERSITY OF TWENTE.
SEDIMARE

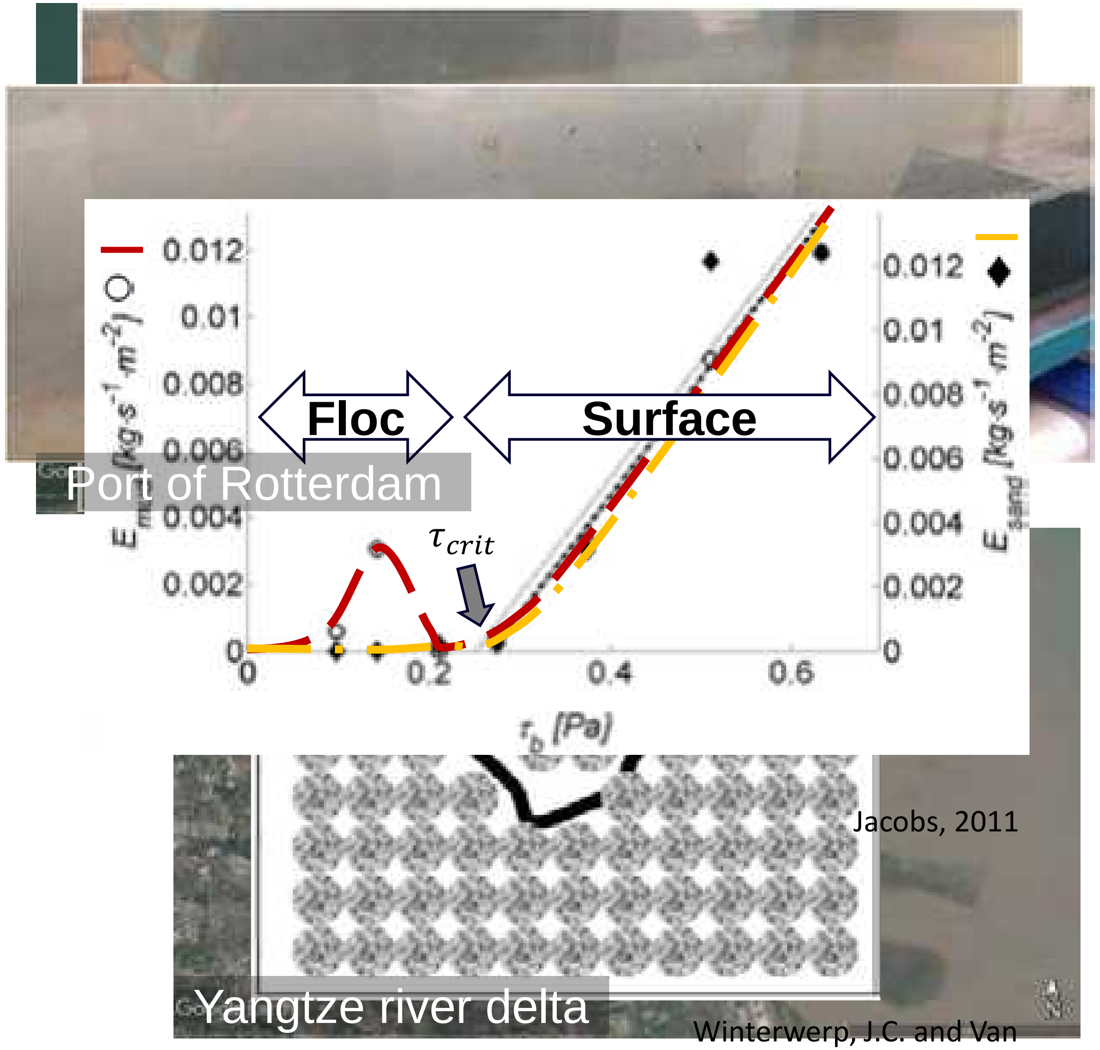
Outline

- **Sand-mud erosion and initiation of motion**
  - Study objectives
- **Data and framework selection**
- **Compiled dataset**
- **Bed type classification**
- **Conclusions**

Sand-mud erosion

- Sand erosion
- Mud erosion
  - Floc erosion
  - Surface erosion
  - Mass erosion
- Estimating sand-mud erosion requires a definition for initiation of motion for both sand and mud
  - E [kg/(m^{2}s)] vs τ_b (Pa)
  - Definition of τ_{crit}
- **Determining τ_{crit}** during erosion experiments remains **subjective**

van Rijn, 2020



Jacobs, 2011

Winterwerp, J.C. and Van Kesteren, W.G.M. 2004

Deltares UNIVERSITY OF TWENTE. SEDIMARE

Sand-mud erosion

- Current estimation methods for initiation of motion are a function of bulk geotechnical parameters:
  - Bulk or dry density, ρ_{bulk} or ρ_{dry}
  - Median grain size diameter, D_{50}
  - Mass fraction of mud or silt, P_{mud} or P_{silt}

Mitchener & Torfs, 1996

$$\tau_{cr} = 0.015(\boldsymbol{\rho_b} - 1000)^{0.73}$$

Van Rijn, 2007

$$\tau_{cr} = \begin{cases} (1 + P_{clay})^3 \tau_{cr,0} & : \quad d \geq 62\mu m \\ \left(\frac{c_{gel}}{c_{gel,s}}\right)\left(\frac{d_{sand}}{\boldsymbol{d_{50}}}\right)^{\gamma} \tau_{cr,0} & : \quad d < 62\mu m \end{cases}$$

Wu et al., 2018

$$\tau_{cr} = \begin{cases} 1.25\boldsymbol{P_{mud}}(\tau_{cr,0} - \tau_{cr,mud}) + \tau_{cr,mud} & \boldsymbol{P_{mud}} < 5\% \\ \tau_{cr,L} + (\tau_{cr,0} - \tau_{cr,L})exp\left[-\alpha\left(\frac{P_{sand}}{P_{mud}}\right)^{\beta}\right] & 0 < \boldsymbol{P_{mud}} < 100\% \\ 10.29r^{1.7} & Pure\ mud \end{cases}$$

Yao et al., 2022

$$\tau_{cr} = \begin{cases} \tau_{cr,0} & : \quad \boldsymbol{P_{silt}} \leq 35\% \\ (1 + \beta_{ss})\tau_{cr,0} & : \quad \boldsymbol{P_{silt}} > 35\% \end{cases}$$

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Study objectives

1. To combine results of sand-mud erosion experiments that used **wide variations in clay-silt ratios**.
2. To examine a framework that highlights the **contribution of each sediment fraction (i.e. sand, silt, clay)** in the initiation of motion process.

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Data selection

- Sediment sizes and cohesive properties
- Reported geotechnical parameters
- Flow type
- Calculation of bed shear stress
- Determination of critical bed shear stress

Straight flume

Boechat Albernaz, et al., 2022

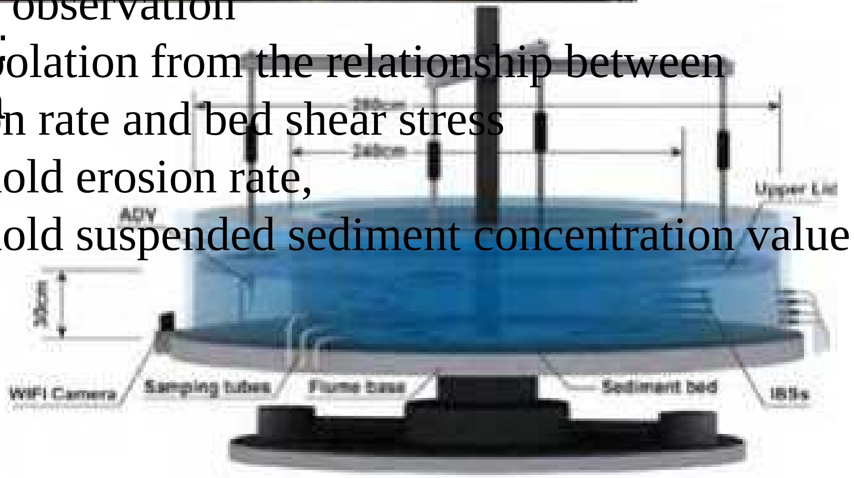
Calculating bed shear stress, τ_b:

- from law of the wall velocity profiles
- from the measured near-bed turbulence

Calculating critical bed shear stress, τ_{crit}:

- visual observation
- extrapolation from the relationship between erosion rate and bed shear stress
- threshold erosion rate,
- threshold suspended sediment concentration value

- Sand:
- Silt: a
- Clay:



Yao, et al., 2022

Annular flume

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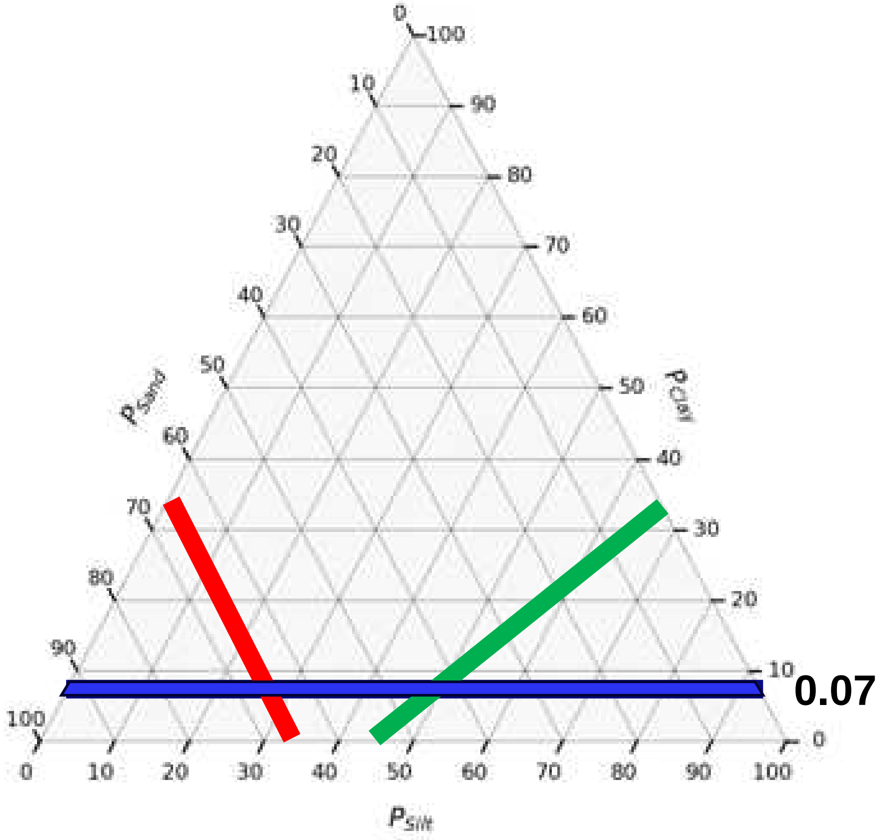
Framework selection

- Van Ledden bed types (Van Ledden et al., 2003)
  - Based on information from ternary diagram and volume fraction of water, ϕ_{water}
  - Framework characteristics:
    1. Cohesion
    2. Network structure

- Cohesion
  - Based on mass fraction of clay
  - Literature suggests a lower limit of 5-10%
    $P_{clay} = 5 - 10\%$



Mass fractions: $1 = P_{sand} + P_{silt} + P_{clay} = P_{sand} + P_{mud}$

Volume fractions: $1 = \phi_{sand} + \phi_{silt} + \phi_{clay} + \phi_{water}$

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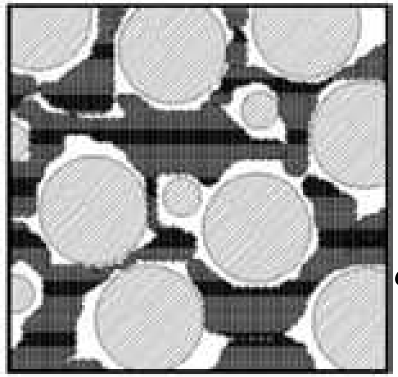
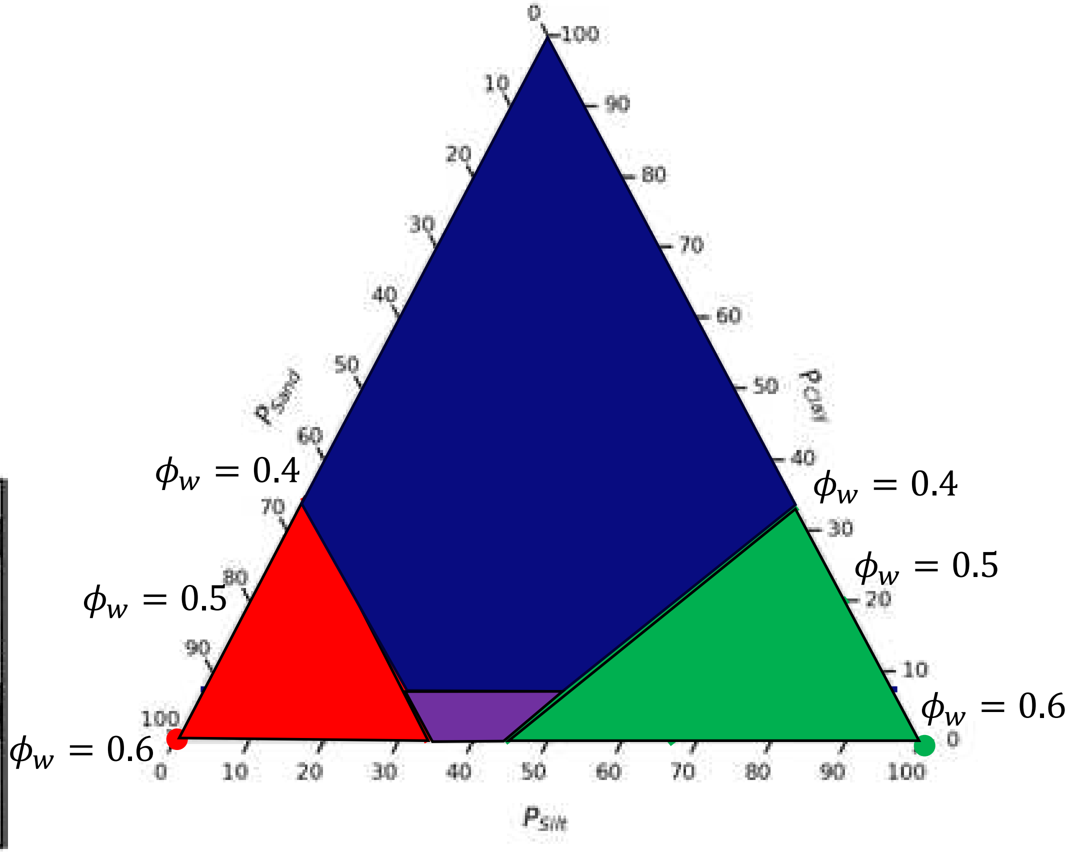
Framework selection

- Network structure
  - Interaction of sediment particles and volume fraction of water, ϕ_{water}.
  - Sand-dominated network structure:
    $$\phi_{sand} \geq 40\%$$
  - Silt-dominated network structure:
    $$\frac{\phi_{silt}}{(1-\phi_{sand})} \geq 40\%$$
  - Other network structures:
    1. Clay-water matrix
    2. Mixed structures



Jacobs, 2011



Mass fractions: $1 = P_{sand} + P_{silt} + P_{clay} = P_{sand} + P_{mud}$

Volume fractions: $1 = \phi_{sand} + \phi_{silt} + \phi_{clay} + \phi_{water}$

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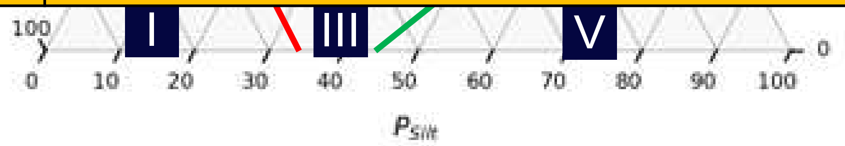
Framework selection

Van Ledden bed types		Cohesion: Non-cohesive ($P_{clay} < 7\%$)	Cohesion: Cohesive ($P_{clay} \geq 7\%$)
Network Structure	Sand $\phi_{sand} \geq 40 - 50\%$	**Type 1:** Sand-dominated, non-cohesive sediment bed	**Type 2:** Sand-dominated, cohesive sediment bed
	Silt $\frac{\phi_{silt}}{(1-\phi_{sand})} \geq 40 - 50\%$	**Type 5:** Silt-dominated, non-cohesive sediment bed	**Type 6:** Silt-dominated, cohesive sediment bed
	Clay ϕ_{sand} AND $\frac{\phi_{silt}}{(1-\phi_{sand})} < 40 - 50\%$	**Type 3:** Mixed structure, non-cohesive sediment bed	**Type 4:** Clay-water matrix, cohesive sediment bed

I. Sand-dominated non-cohesive
II. Sand-dominated cohesive
III. Mixed structure non-cohesive
IV. Clay-water matrix cohesive
V. Silt-dominated non-cohesive
VI. Silt-dominated cohesive



Mass fractions: $1 = P_{sand} + P_{silt} + P_{clay} = P_{sand} + P_{mud}$
Volume fractions: $1 = \phi_{sand} + \phi_{silt} + \phi_{clay} + \phi_{water}$

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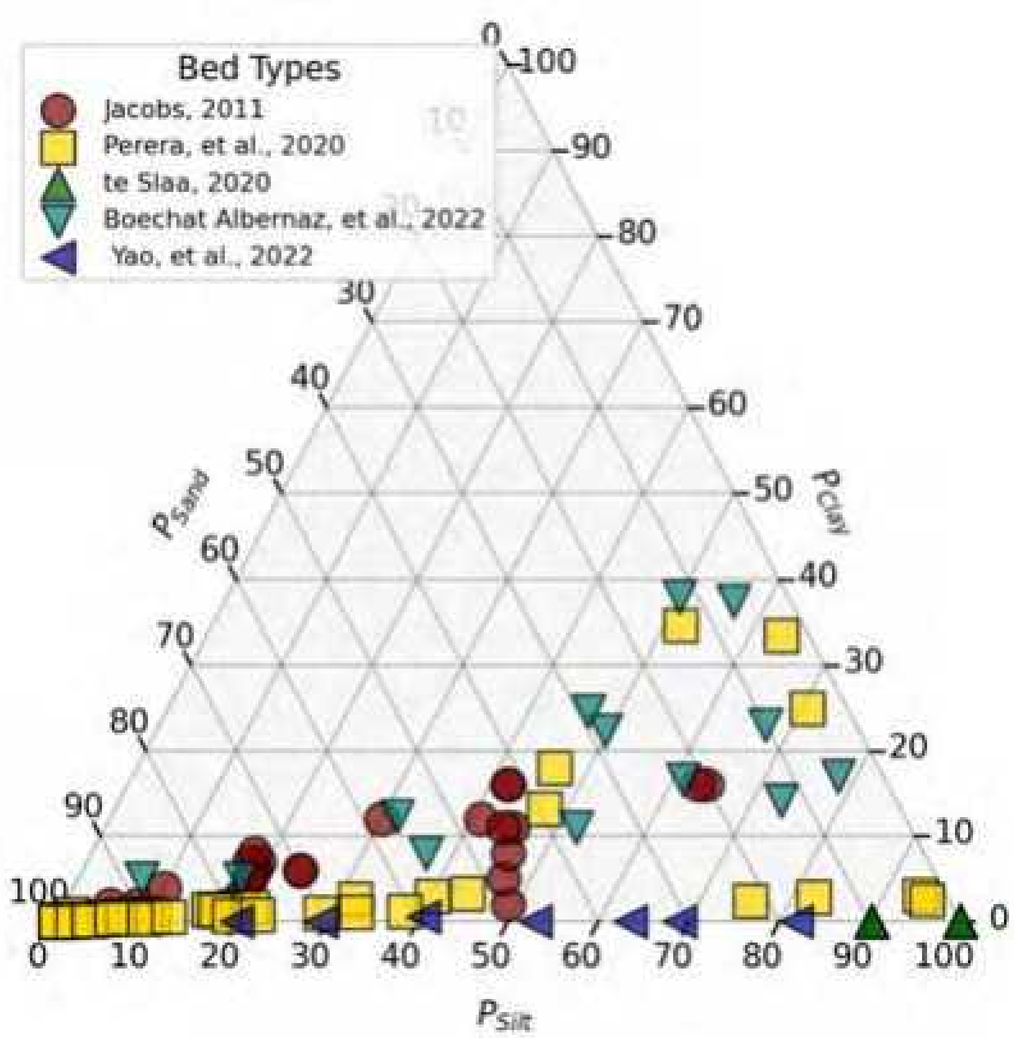
Compiled dataset



Mass fractions: $1 = P_{sand} + P_{silt} + P_{clay} = P_{sand} + P_{mud}$

Volume fractions: $1 = \phi_{sand} + \phi_{silt} + \phi_{clay} + \phi_{water}$

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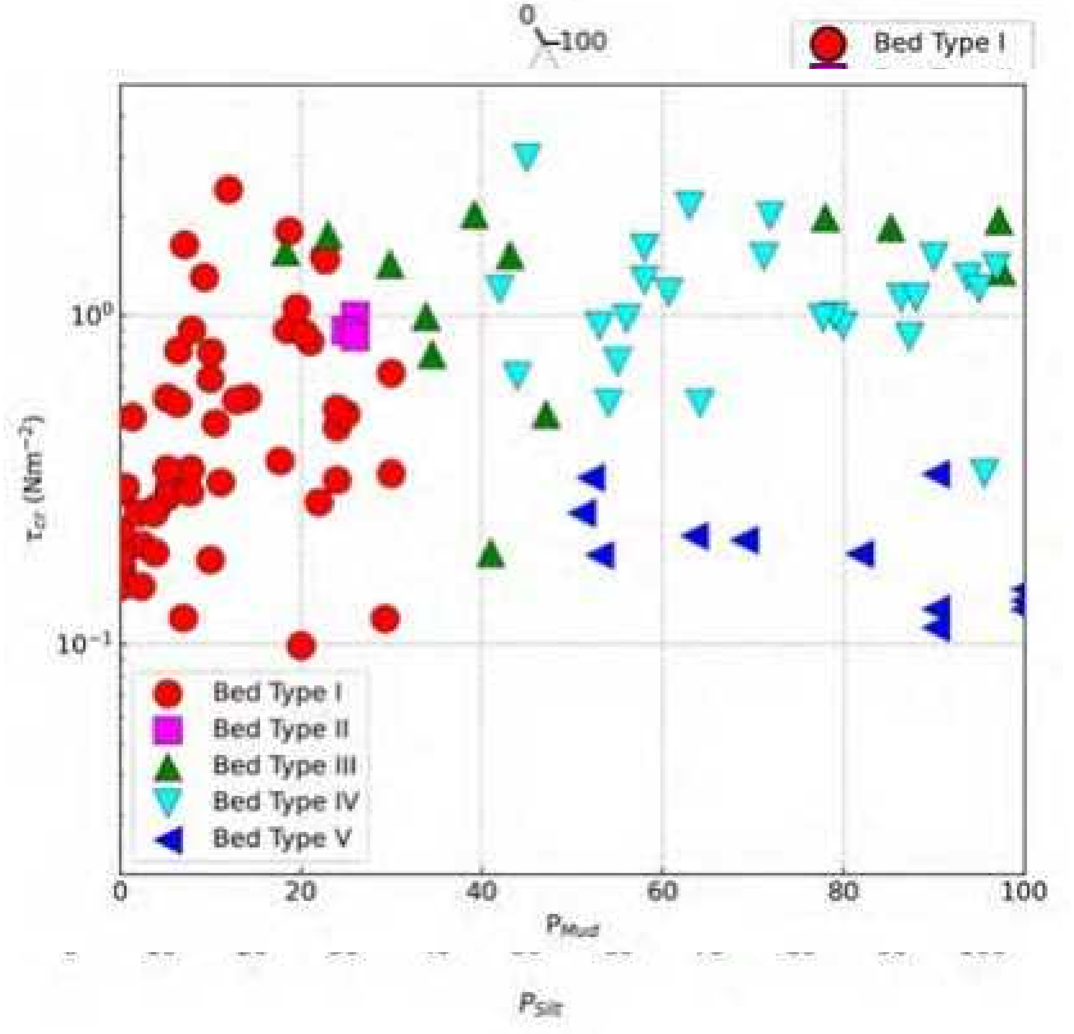
Bed type classification

- Classified dataset:
  - Sand-dominated, non-cohesive (I): **54**
  - Sand-dominated, cohesive (II): **3**
  - Mixed-structure, non-cohesive (III): **13**
  - Clay-water matrix, cohesive (IV): **25**
  - Silt-dominated, non-cohesive (V): **12**
  - Silt-dominated, cohesive (VI): **0**
- Behavior per bed type:
  - Median grain size, d_{50}
  - Mass fraction of mud, P_{mud}



Mass fractions: $1 = P_{sand} + P_{silt} + P_{clay} = P_{sand} + P_{mud}$

Volume fractions: $1 = \phi_{sand} + \phi_{silt} + \phi_{clay} + \phi_{water}$

Conclusions

- Built dataset with large spectrum of **sand-silt-clay combinations** and other **bulk geotechnical parameters**
- Classification into bed types
  - **Reduced complexity** within each bed from a physical basis
  - Bed types help **focus** research **on dominant parameters** in initiation of motion process

Initiation of motion for sand-mud bed types

Jowi Miranda
SEDIMARE

jowi.miranda@deltares.nl
p.s.miranda@utwente.nl
psmiranda

Deltares
UNIVERSITY OF TWENTE.
SEDIMARE

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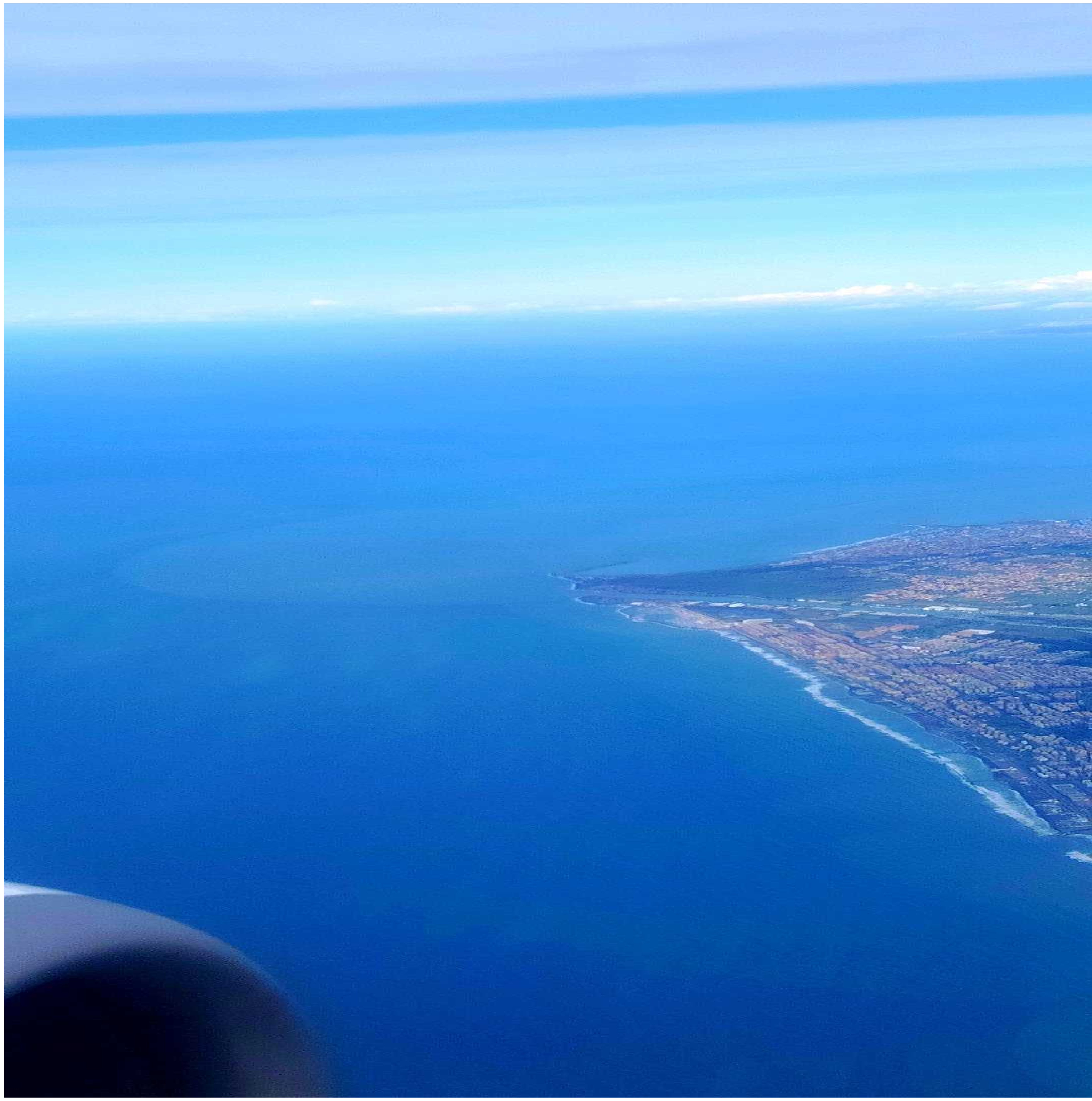


Nasim Soori

Supervisors:
Prof. Maurizio Brocchini – UNIVPM
Prof. Athanassios Dimas – UPATRAS
Prof. Matteo Postacchini – UNIVPM

DC 4: Mixing and transport in the coastal area

SEDIMARE
Sediment Transport and Morphodynamics in Marine and Coastal Waters with Engineering Solutions

This project has received funding from the European Union’s (EU) Horizon Europe Framework Programme (HORIZON) under Grant Agreement No 101072443 as a MSCA Doctoral Network (HORIZON-MSCA-2021-DN-01).

Marie Skłodowska-Curie Actions

11 Mar., 2025, IHCantabria - Spain

Model Particle Trajectories

1. Governing Equations

Calculate the position of each particle (xp, yp) over time using a discrete time-stepping approach based on velocity components

$$x_{p,n} = x_{p,n-1} + u_{p,n-1}\Delta t$$
$$y_{p,n} = y_{p,n-1} + v_{p,n-1}\Delta t$$

- ✓ up and vp are velocity components at the particle's location,
- ✓ Δt is the time step.

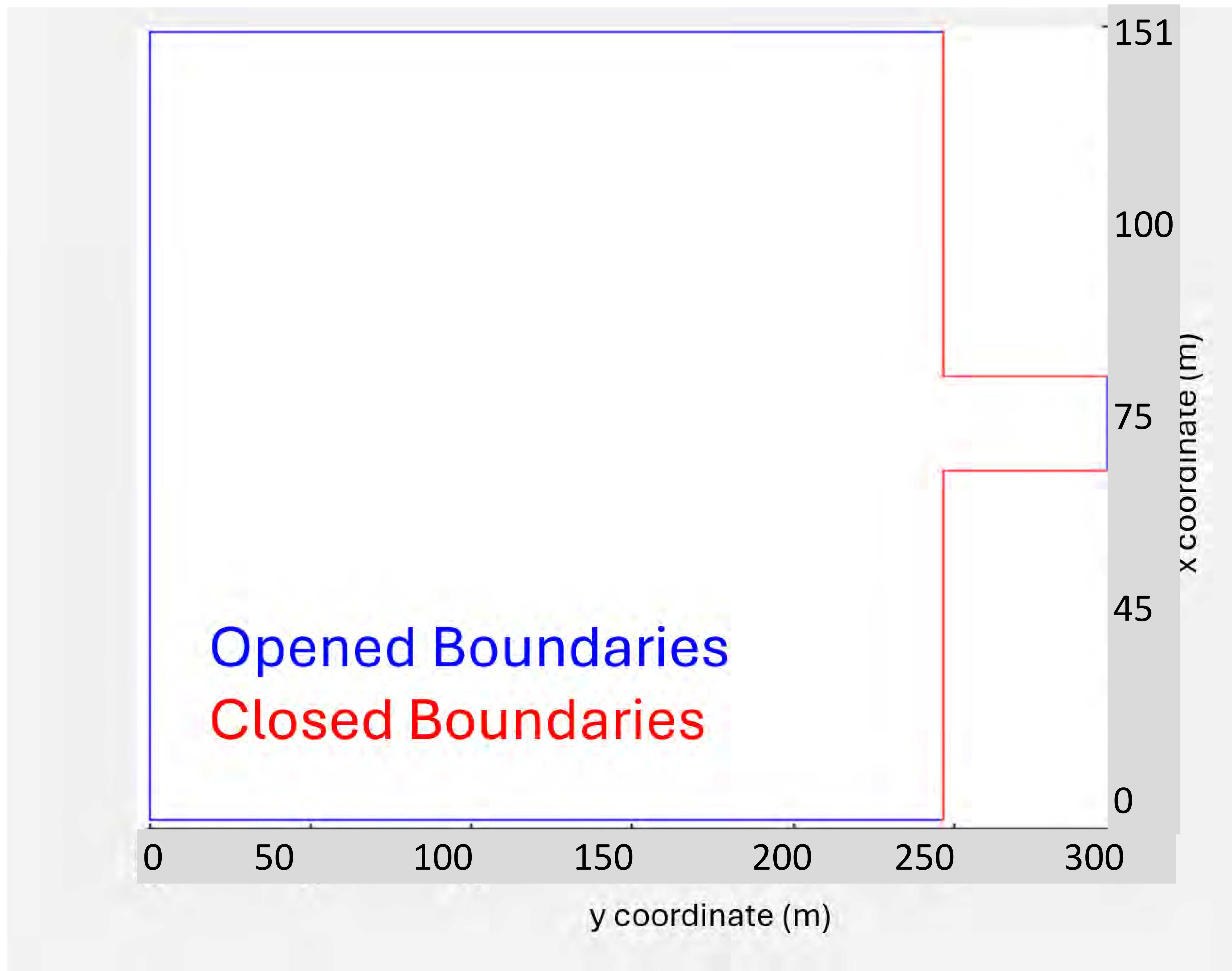
This method follows the **Lagrangian approach**, meaning we track individual particles as they move with the flow.

2. Boundary Conditions

To ensure realistic movement:

- ➢ Inside the estuary:
- ➢ Outside the estuary:

If a particle hits the shoreline (yp outside bounds), it reflects back within valid limits.



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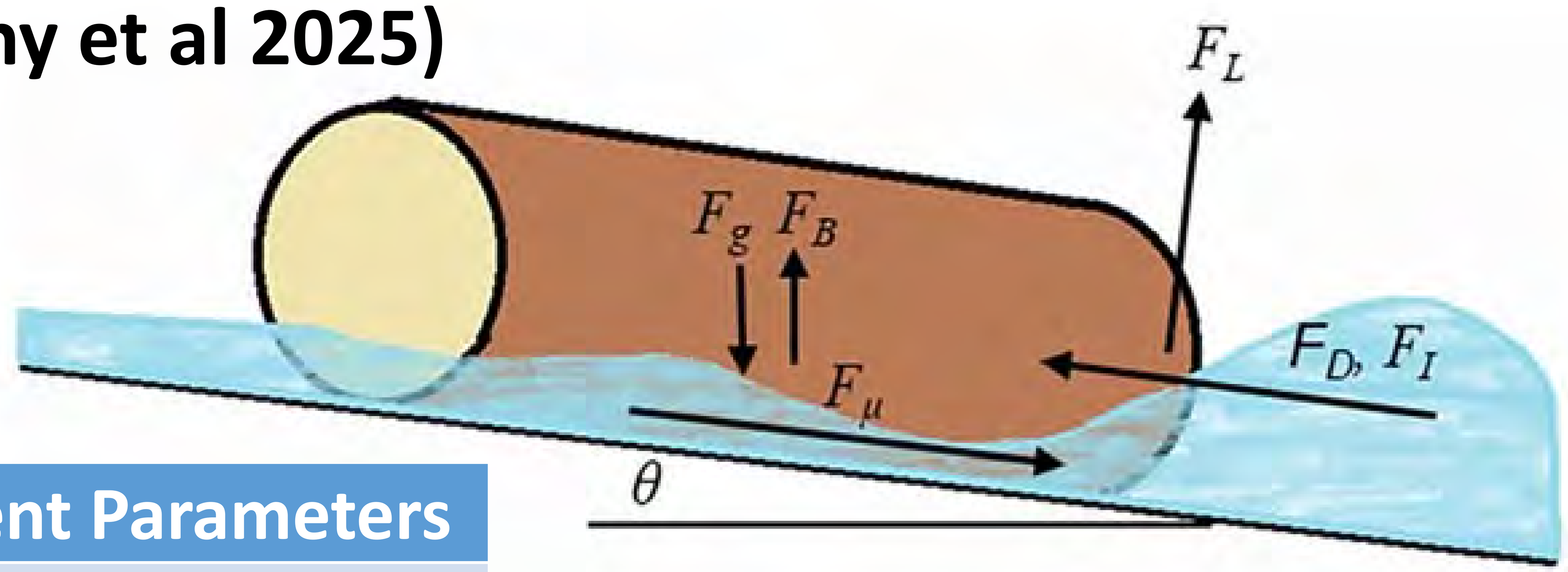
Forces acting on woods (Murphy et al 2025)



$$F_H = F_D + F_I$$

Forces	Formula	Dependent Parameters
Drag	$F_D = \frac{1}{2}\rho\, C_D D_p L_p U \mid U \mid \cos\alpha$	ρ_f, D_p, L_p, U
Inertia	$F_I = \frac{\pi}{4}\rho\, C_M {D_p}^2 L_p \frac{\partial U}{\partial t}\cos\alpha$	ρ_f, D_p, L_p, U
Lift	$F_L = \frac{1}{2}\rho\, C_L D_p L_p U \mid U \mid \cos\alpha$	ρ_f, D_p, L_p, U

CD=drag coefficient;
CM=inertia coefficient;
U=local velocity (including the wave induced current);
α=angle between the local velocity vector and the long axis of the driftwood.
CL=lift coefficient

The displacement of each particle:

$$\frac{dX_p}{dt} = \text{Adv} + \text{Disp}$$

✓ $Adv = U_p$ $\qquad U_p = U(x, y, z, t)$

✓ $Disp = \frac{R}{\Delta t}\sqrt{2K\Delta t}$

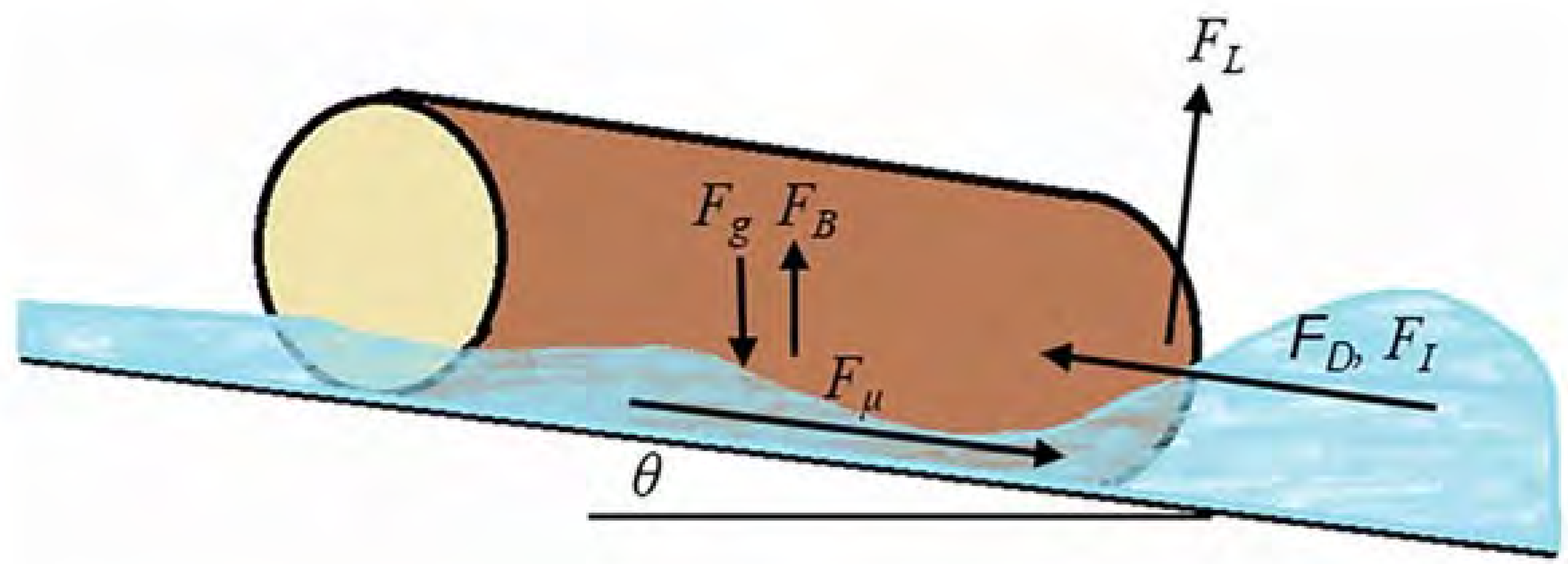
- U_p : The deterministic component is based on the Eulerian flow field (fluid velocity),
- R : Random number from a normal distribution,
- K : Eddy diffusivity or dispersion coefficient from the hydrodynamic model,
- Δt : Time step

- In WOODRIFTSIM, U_p is calculated as:

$$u_p = u(x_p, y_p, t)\ , v_p = v(x_p, y_p, t)\ \ , w_p = 0$$

✓ u and v are the fluid velocity components interpolated from the hydrodynamic model at the particle location.
✓ wp=0 because driftwood is assumed buoyant and remains at the water surface.

✓ Fμ acts in the opposing direction to the resultant destabilizing force parallel to the bed, which **is the sum of** the inline (drag and inertia) forces and the net buoyancy/gravitational component parallel to the bed: (FD+FI+(Fg−FB)sinθ).



Forces	Formula
Friction	$F_\mu = \mu F_N$ $F_N = \left(F_g - F_B\right)\cos\theta - F_L$
Lift	$F_L = \frac{1}{2}\rho\, C_L D_p L_p U \mid U \mid \cos\alpha$
Buoyancy	$F_B = \rho g A_s L_p$

θ= bed slope in the direction of in-line forces acting on the driftwood,
μ = a coefficient of (static or dynamic) friction.

- The **stabilizing frictional force** mobilized at the sloping bed is **the product of the normal force at the wood–bed interface**, FN.

❑ **Condition**:

✓ If |Fμ|≥|FD +FI +(Fg −FB)sinθ|, the driftwood is beached and stationary; all associated particles retain their positions at the next time step.

✓ If |Fμ| < |FD + FI + (Fg − FB)sinθ| and |FD+FI|>|(Fg−FB)sinθ|, contact with the bed does not result in beaching, wave-driven hydrodynamics, control driftwood motion, and particles are advected and dispersed.

✓ If |Fμ| < |FD+ FI +(Fg −FB)sinθ| and |FD+FI|≤|(Fg−FB)sin θ|, the beached driftwood motion is controlled by gravity (i.e., sliding or rolling), and particles are translated at a velocity determined by the resultant net force and Newton's second law :

$$U_p = \frac{|\left(F_g - F_B\right) \sin\theta| \pm |F_D + F_I| - |F_\mu|}{\rho_D \frac{\pi D_p{}^2}{4} L_p}$$

❑ The particle displacement over one time-step is:

$$\begin{aligned} x_{p,n} &= x_{p,n-1} + u_{p,n-1}\Delta t \\ y_{p,n} &= y_{p,n-1} + v_{p,n-1}\Delta t \\ z_{p,n} &= z_{p,n-1} + w_{p,n-1}\Delta t \end{aligned}$$

✓ Releasing particles at the same location (x0=270, y0=75) , u= 0.6 m/s

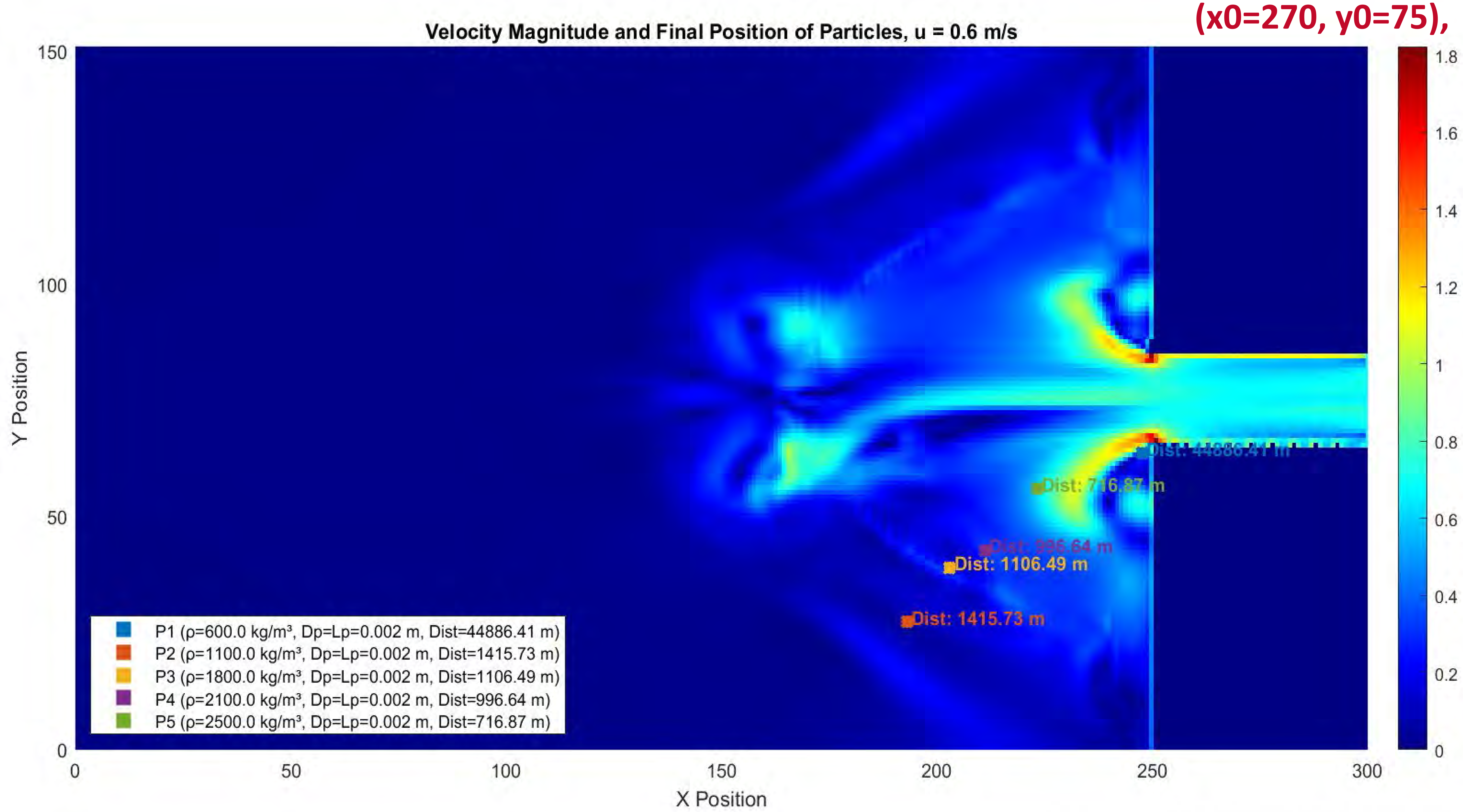
Number of particles = 5

density (kg/m^3) ρ_(wood) = [600, 1100, 1800, 2100, 2500];

diameter (m), Dp = [0.002, 0.002, 0.002, 0.002, 0.002];

length (m), Lp = [0.002, 0.002, 0.002, 0.002, 0.002];

(x0=270, y0=75), u= 0.6 m/s



Total Distance Traveled by Each Particle (Sorted: Most to Least):

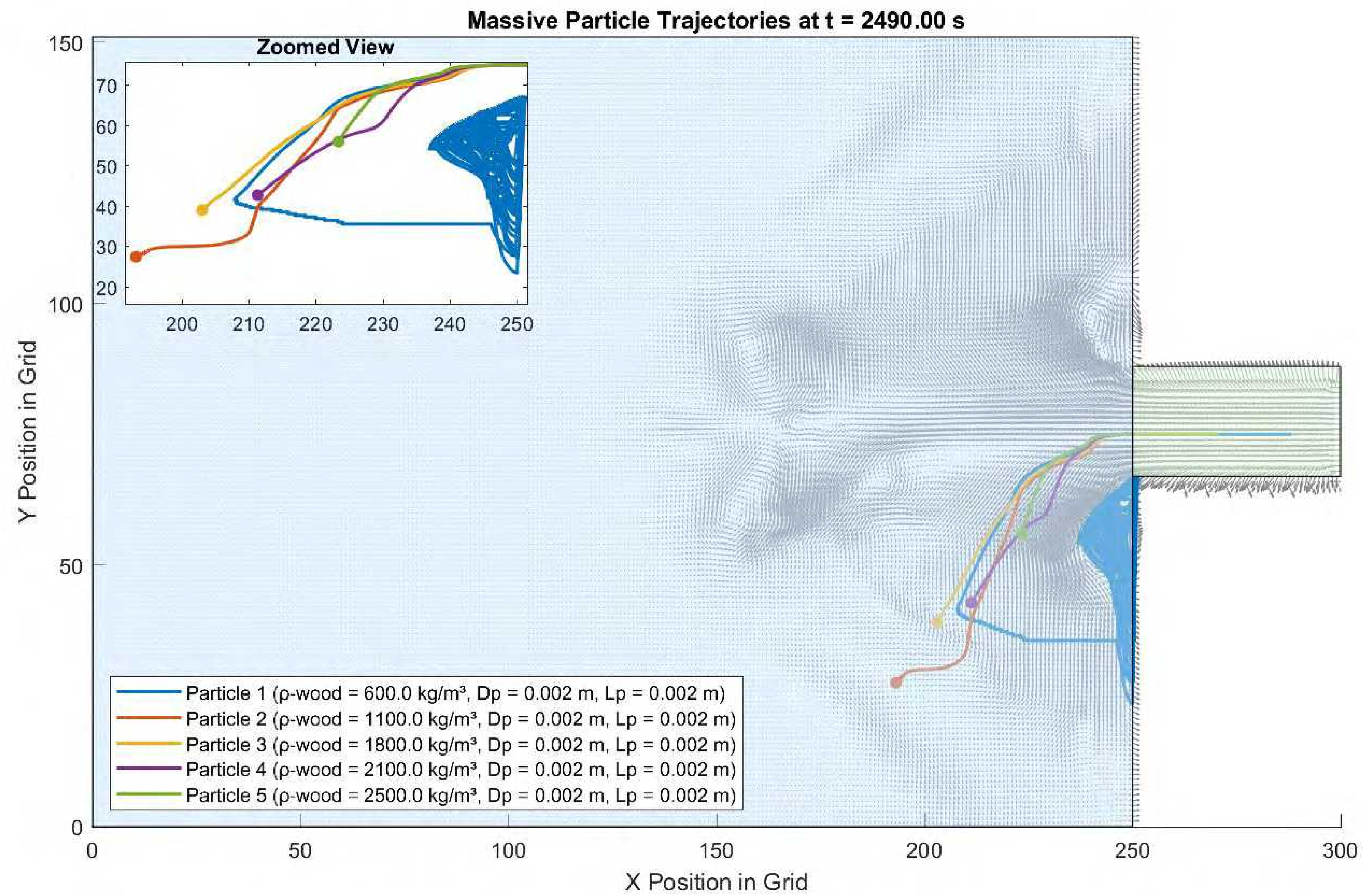
Particle 1 (ρ_(wood) = 600.0 kg/m³, Dp = Lp = 0.002 m): 44886.41 m

Particle 2 (ρ_(wood) = 1100.0 kg/m³, Dp = Lp = 0.002 m): 1415.73 m

Particle 3 (ρ_(wood) = 1800.0 kg/m³, Dp = Lp = 0.002 m): 1106.49 m

Particle 4 (ρ_(wood) = 2100.0 kg/m³, Dp = Lp = 0.002 m): 996.64 m

Particle 5 (ρ_(wood) = 2500.0 kg/m³, Dp = Lp = 0.002 m): 716.87 m



(x0=270, y0=75), u= 0.6 m/s

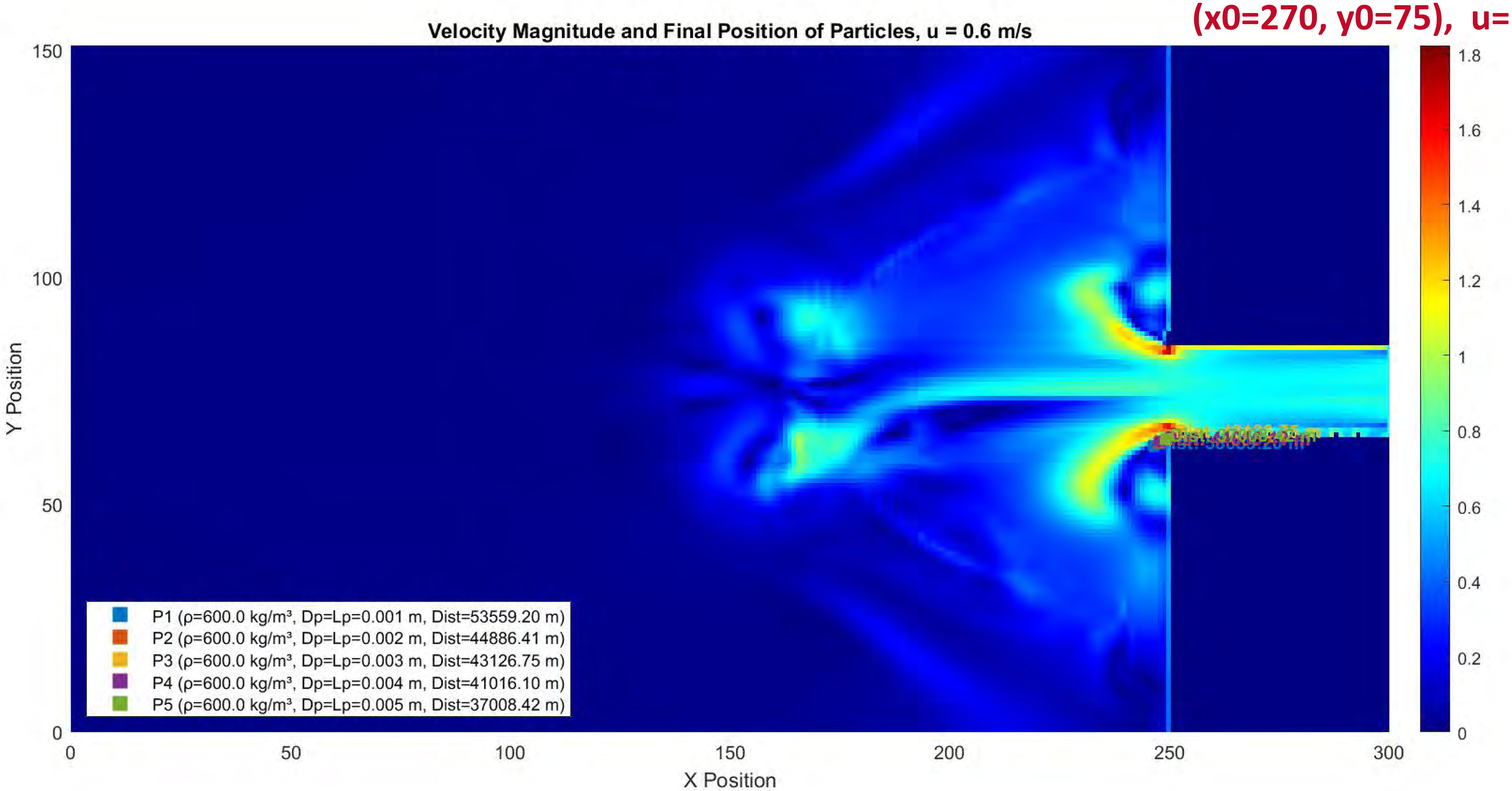
Number of particles = 5

density (kg/m³) ρ_(wood) = [600, 600, 600, 600, 600] ; less than water density

diameter (m), Dp = [0.001, 0.002, 0.003, 0.004, 0.005];

length (m), Lp = [0.001, 0.002, 0.003, 0.004, 0.005];

(x0=270, y0=75), u= 0.6 m/s



Total Distance Traveled by Each Particle (Sorted: Most to Least):

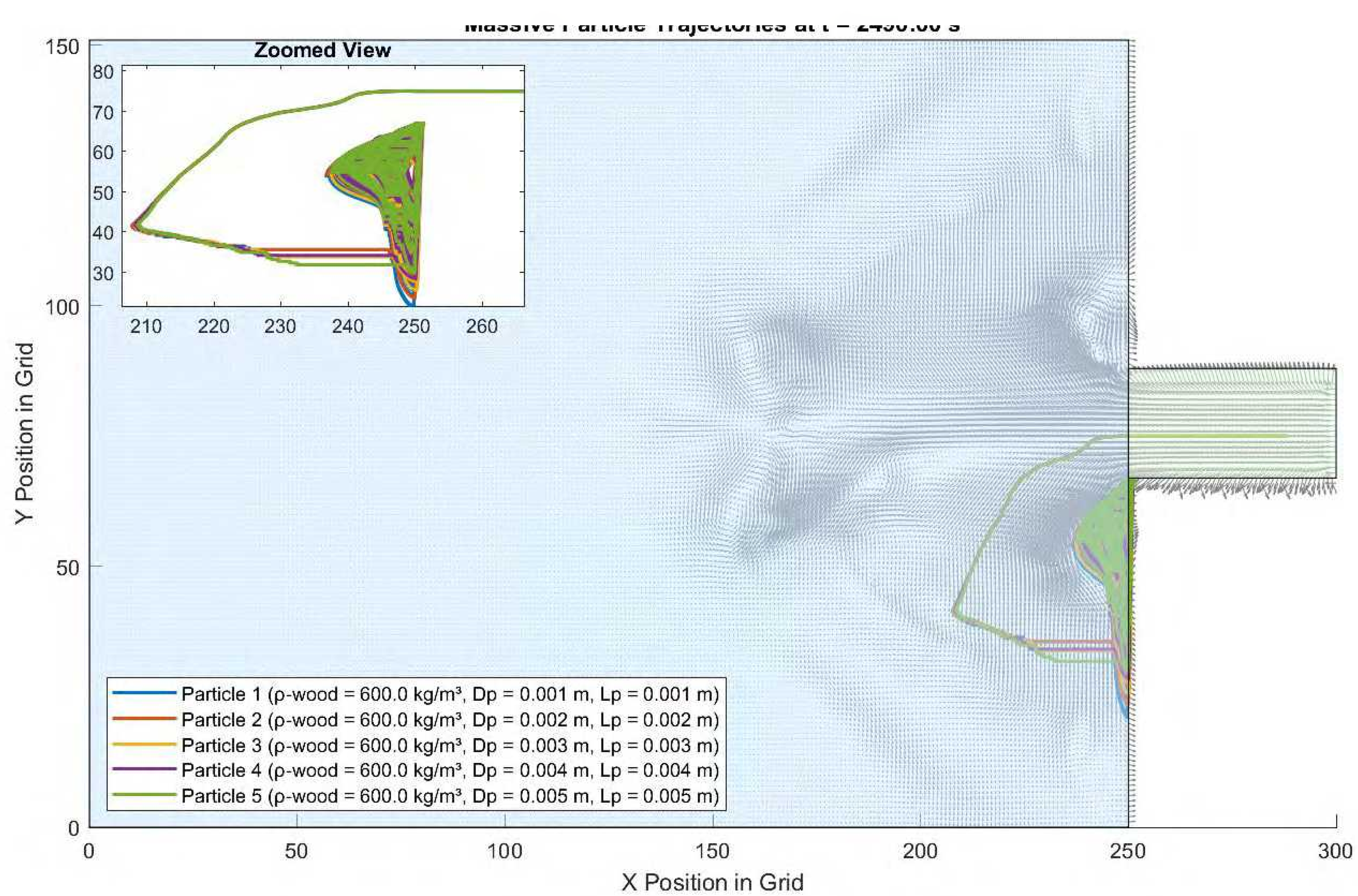
Particle 1 (ρ_(wood) = 600.0 kg/m³, Dp = Lp = 0.001 m): 53559.20 m

Particle 2 (ρ_(wood) = 600.0 kg/m³, Dp = Lp = 0.002 m): 44886.41 m

Particle 3 (ρ_(wood) = 600.0 kg/m³, Dp = Lp = 0.003 m): 43126.75 m

Particle 4 (ρ_(wood) = 600.0 kg/m³, Dp = Lp = 0.004 m): 41016.10 m

Particle 5 (ρ_(wood) = 600.0 kg/m³, Dp = Lp = 0.005 m): 37008.42 m



(x0=270, y0=75), u= 0.6 m/s

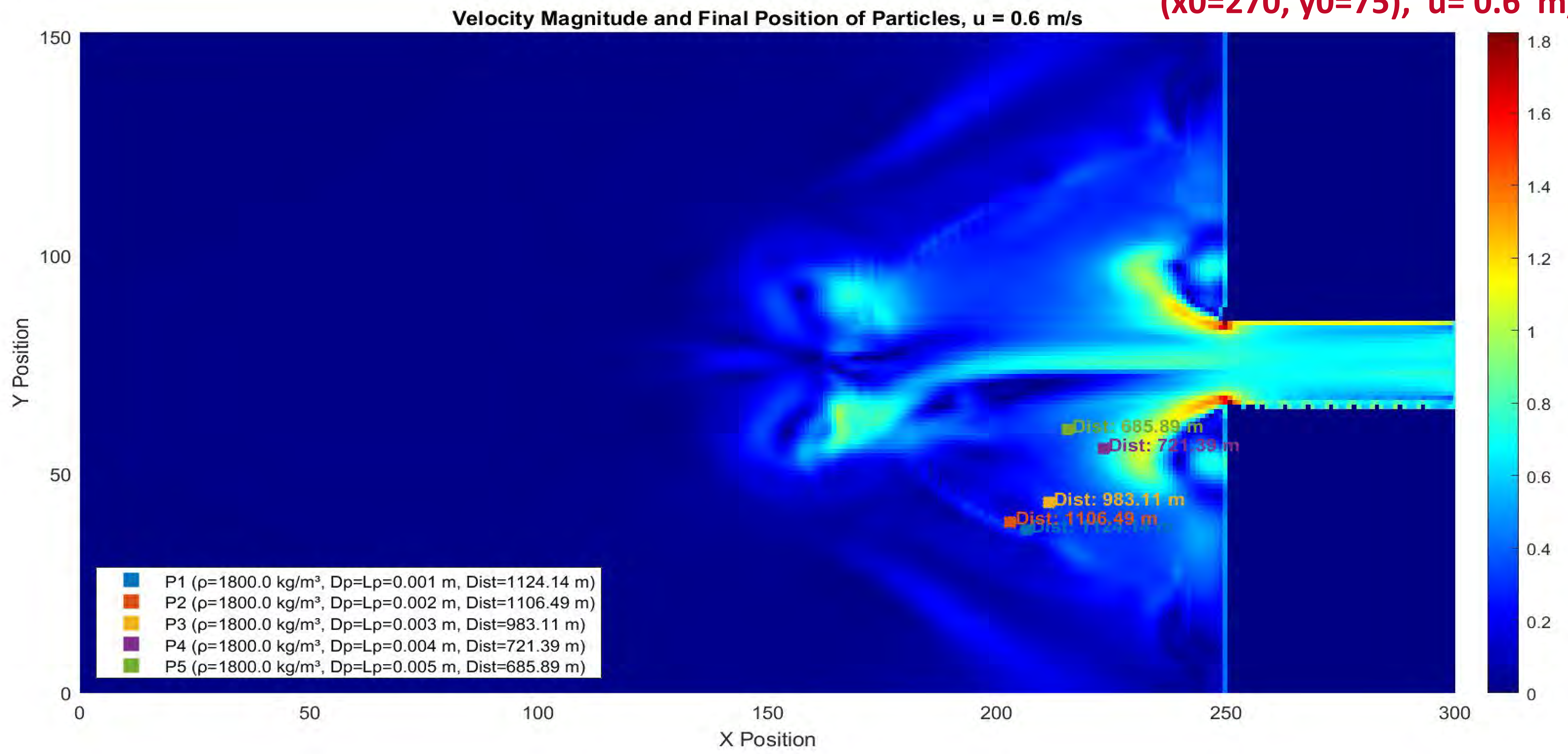
Number of particles = 5

density (kg/m³) ρ_(wood) = [1800, 1800, 1800, 1800, 1800] ; more than water density

diameter (m), Dp = [0.001, 0.002, 0.003, 0.004, 0.005];

length (m), Lp = [0.001, 0.002, 0.003, 0.004, 0.005];

(x0=270, y0=75), u= 0.6 m/s



Total Distance Traveled by Each Particle (Sorted: Most to Least):

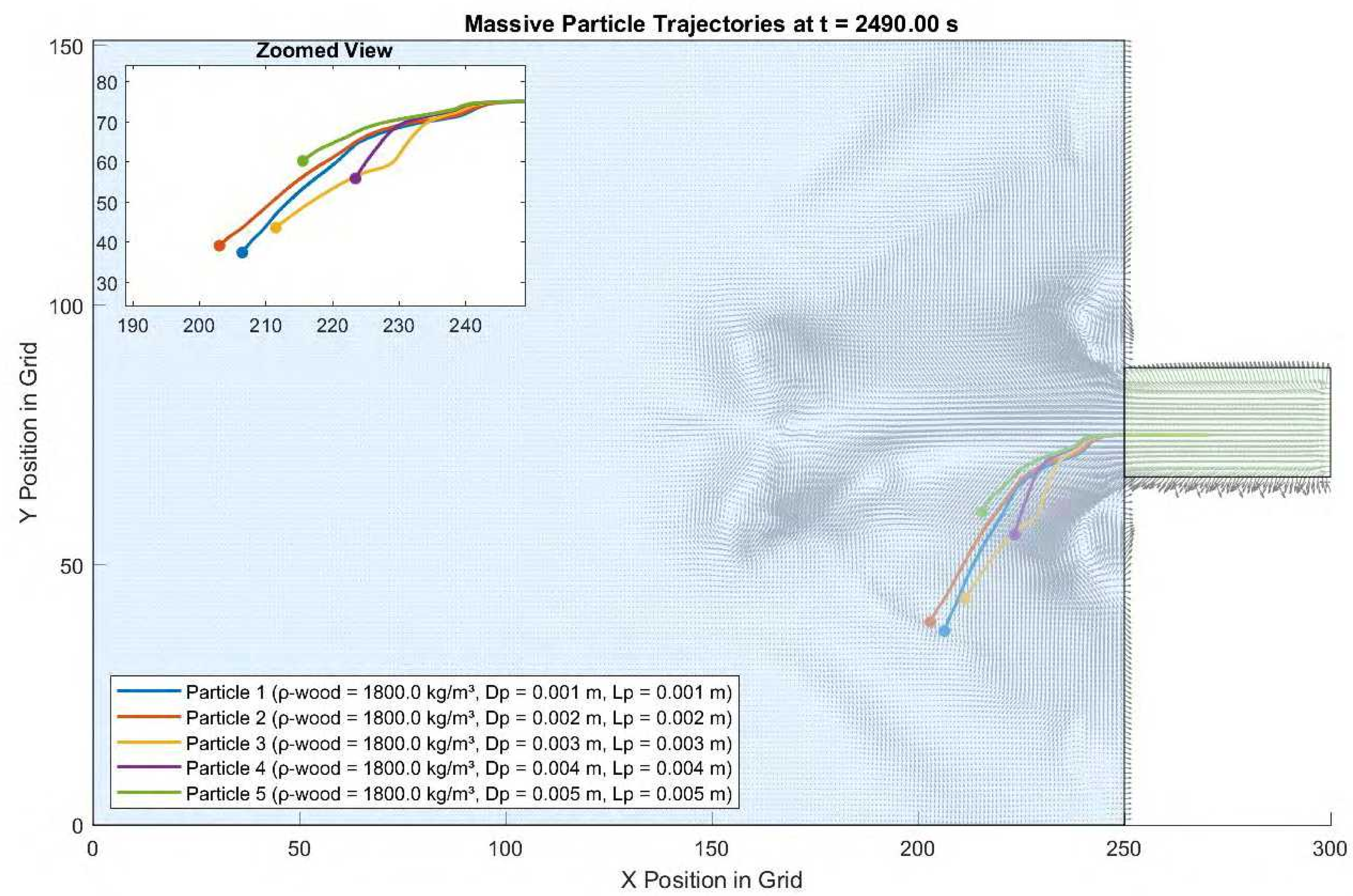
Particle 1 (ρ_(wood) = 1800.0 kg/m³, Dp = Lp = 0.001 m): 1124.14 m

Particle 2 (ρ_(wood) = 1800.0 kg/m³, Dp = Lp = 0.002 m): 1106.49 m

Particle 3 (ρ_(wood) = 1800.0 kg/m³, Dp = Lp = 0.003 m): 983.11 m

Particle 4 (ρ_(wood) = 1800.0 kg/m³, Dp = Lp = 0.004 m): 721.39 m

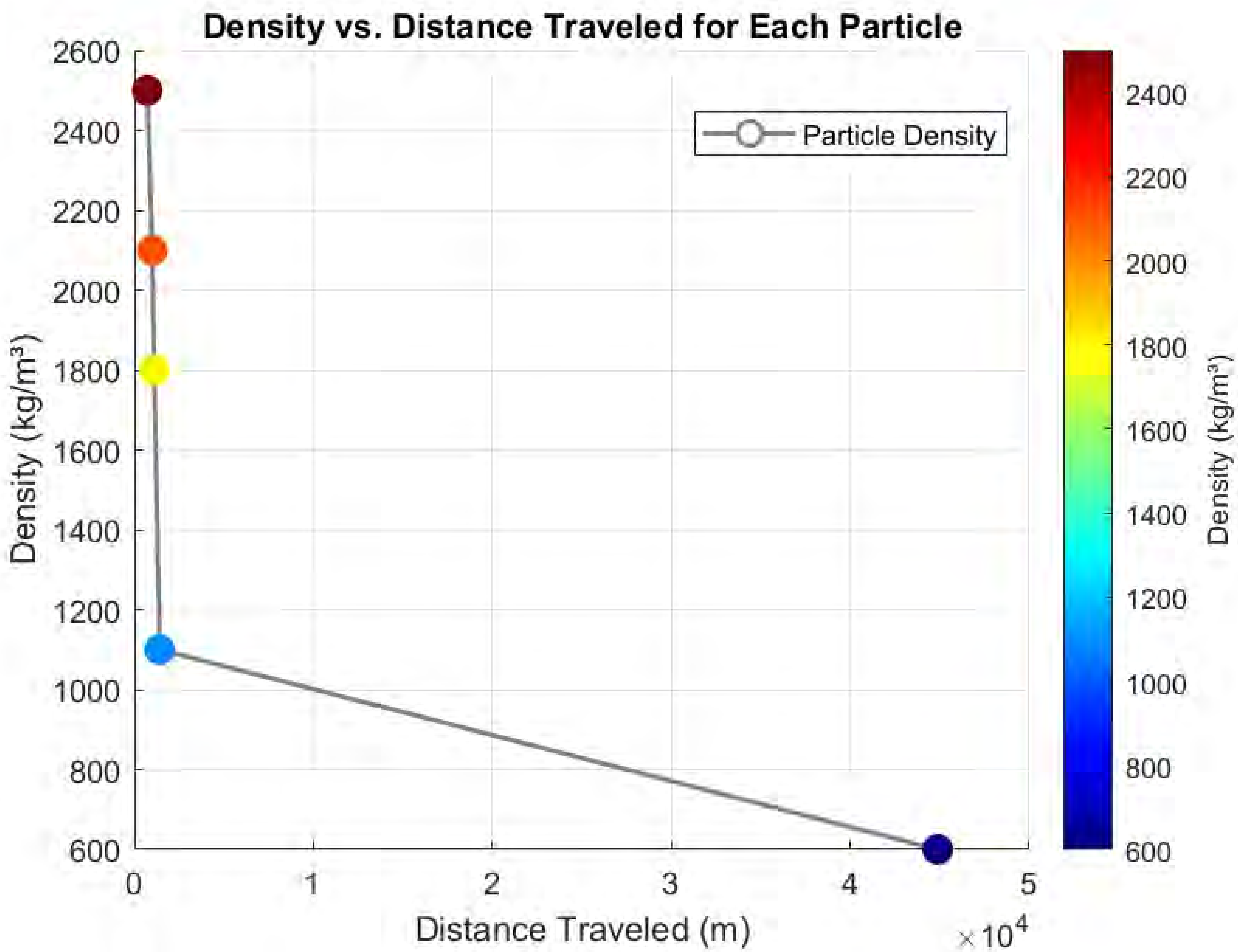
Particle 5 (ρ_(wood) = 1800.0 kg/m³, Dp = Lp = 0.005 m): 685.89 m



❑ Effect of Changing Particle Density

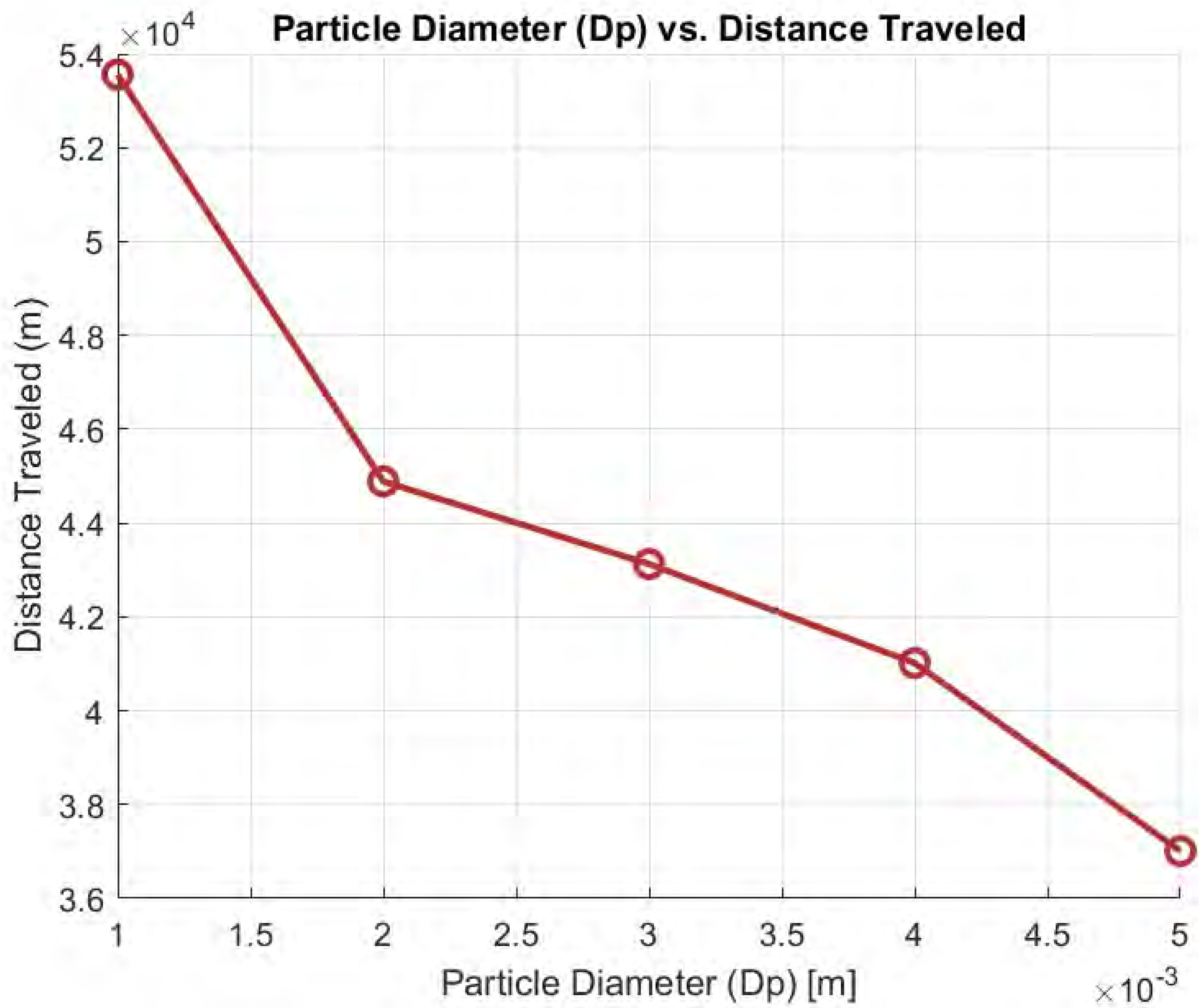
- **Higher Density Particles:**
  - Experience stronger gravitational pull, leading to faster settling.
  - Have lower buoyancy forces, making them sink faster.
  - Travel shorter distances before settling at the bottom.

- **Lower Density Particles:**
  - Remain suspended longer due to higher buoyancy.
  - Travel farther as they are carried by currents before settling.
  - Are more influenced by turbulent flow and diffusion.



❑ Effect of Changing Particle Diameter

- **Larger Particles:**
  - Have greater mass and higher settling velocity, sinking quickly.
  - Experience stronger drag, limiting their horizontal transport.
  - Settle closer to the source.
- **Smaller Particles:**
  - Are more affected by drag and turbulence, staying in suspension longer.
  - Travel farther before settling.
  - Are more likely to be carried by estuarine flows.



❖ Summary

❖ Impact on Distance Traveled

The combination of **density** and **diameter** determines whether a particle moves short distances (settling quickly) or long distances (remaining in suspension).

- ✓ **High-Density, Large Particles → Short Distance**
- ✓ **Low-Density, Small Particles → Long Distance**

By varying **density** and **diameter**, we can predict how different particles will move in water environments.

- ✓ This understanding is essential for sediment transport modeling, environmental protection, and predicting pollutant dispersion.

❑ Next Steps

Validation step is crucial to ensure that the script can be used confidently for practical applications in coastal engineering and environmental analysis.

- Apply this model to a real case study, comparing the model's predicted trajectories with observed or simulated particles paths,
- Assess the accuracy of the approach and refine the model parameters as needed.
- Consider the effect of wave on travelled distance of particles.

- **Reference:** Murphy, E., Cornett, A., Nistor, I., & Pilechi, A. (2025). Development and Experimental Validation of a Lagrangian Particle-Tracking Model to Simulate Wave-Driven Transport of Coastal Driftwood. Journal of Waterway, Port, Coastal, and Ocean Engineering, 151(3), 04025003.
- olabarrieta, m., geyer, w.r., & kumar, n. (2014). the role of morphology and wave-current interaction at tidal inlets: an idealized modeling analysis, journal of geophysical research: oceans. 119(12), 8818–8837.

Thank you
for your attention!

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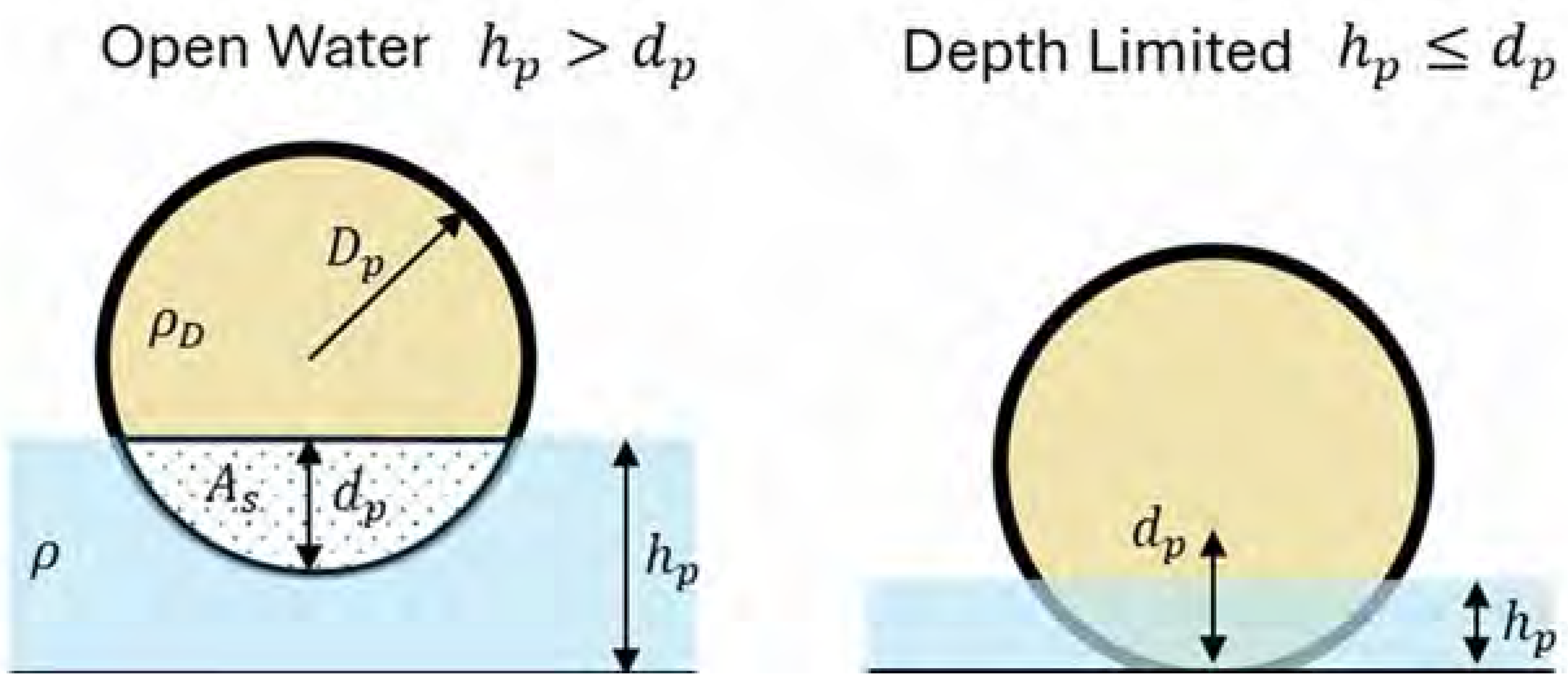

Fig. 4. Schematic showing: (a) calculation of submerged area, theoretical open-water draft; and (b) criteria for assessing contact with the bed.

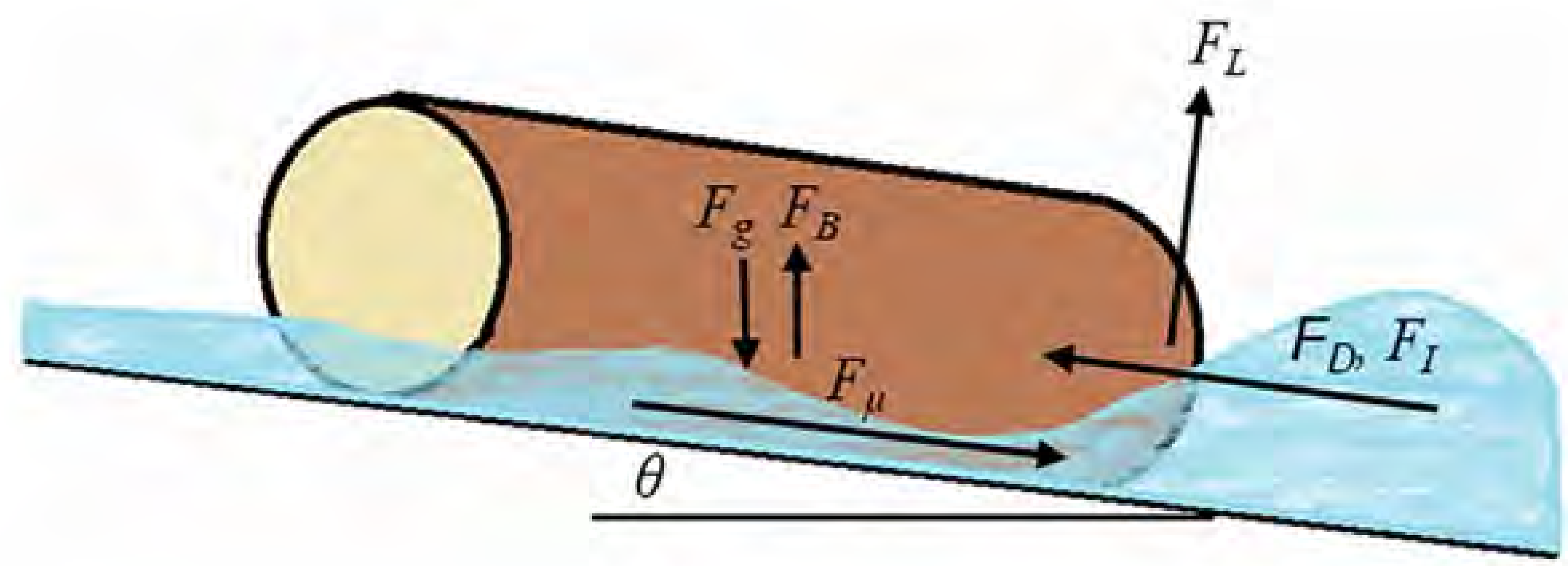

Fig. 3. Forces acting on a piece of driftwood in contact with a sloping beach and exposed to waves.

$$\frac{A_S}{\pi D_p^2/4} = \frac{\rho_D}{\rho}$$

$$A_s = \frac{D_p^2}{4}\cos^{-1}\left(1 - \frac{2d_p}{D_p}\right) - \left(\frac{D_p}{2} - d_p\right)\sqrt{\frac{D_p^2}{4} - \left(\frac{D_p}{2} - d_p\right)^2}$$

Setting the submerged cross-sectional area, As, equal to the area of a circular segment in the force balance then yields [Fig. 4(a)].

- Force balance in a system involving a submerged circular segment:

✓ The equation is derived based on the assumption that *the* ***submerged cross-sectional area (As)*** is equal to the area of a circular segment.
✓ The force balance likely considers buoyancy forces acting on the submerged portion of the circle.
✓ The goal is to determine dp, the depth of submergence.

SEDIMARE

Sediment Transport and Morphodynamics in Marine and Coastal Waters with Engineering Solutions

Multi-model approach to scour in dynamic areas

Nishchay Tiwari
HR Wallingford, UK

Supervisors and Advisors:
Michiel A.F. Knaapen
Sina Haeri
Richard Whitehouse

SEDIMARE 3rd Training School at Santander 11-13 March 2025

Marie Curie Grant Agreement Number: 101072443

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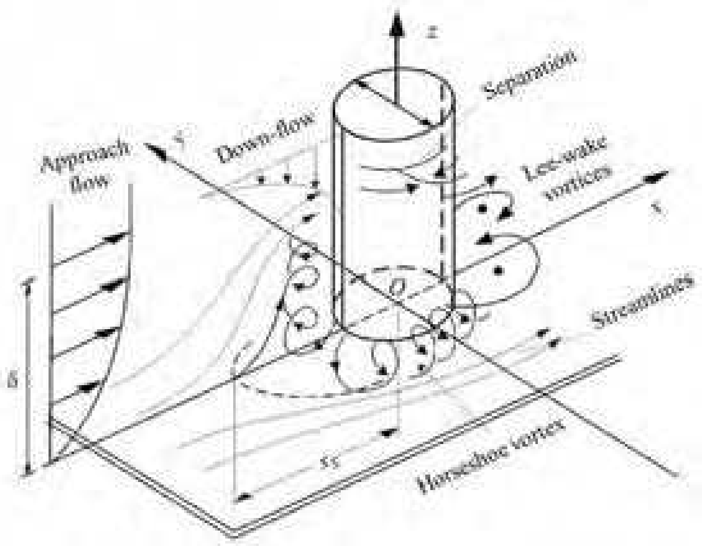
Contents

Scour Phenomenon

Hydrodynamic Forces

- *Flow Acceleration :*
  - Structures disrupt flow, creating high-velocity zones and turbulence.
  - Flow accelerates around the structures, increasing bed shear stress.
- *Vortex Formation :*
  - Horseshoe vortices at the base of structures erode sediment.
  - Wake vortices downstream deepen scour holes.



Sediment Transport Dynamics

- *Erosion :* High shear stress lifts sediment particles into suspension.
- *Deposition :* Sediment settles in low-energy zones (e.g., downstream of structures).

hr wallingford

sedFoam: Methodology

Inputs

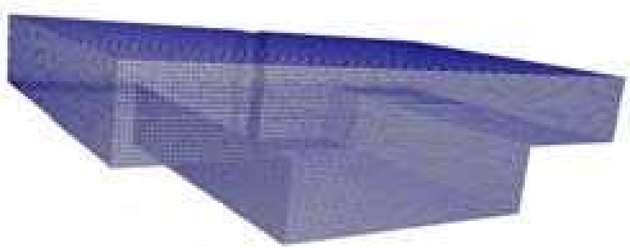
Experimental Data

- Obtaining the transport properties of sand and water phase used in Flumes experiment.
- Use the geometrical dimensions of cofferdam models.
- Using the input flow velocity

Solver

Two-phase Eulerian RANS OpenFOAM

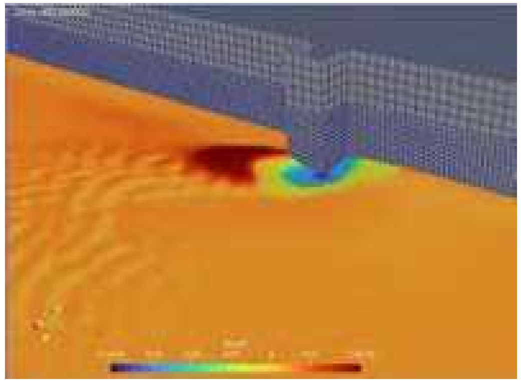
- Creating 3D domain
- Using sedFoam :
  - Granular Rheology properties (muI)
  - Interfacial properties (drag model)
  - Transport properties
  - Modified Two-phase RAS equations



Outputs

Scour Depth

- Estimation of volume fraction of water and sand to predict the bed formation.
- Comparison with experiments



Main Features

Closure Models for Stress Tensors

- **Turbulence Models**
  - SedFoam uses different turbulence closures for fluid flow, such as k-ϵ, **k-ω**, and a simple mixing length model, to capture the effects of turbulent eddies on sediment transport.

- **Granular Stress Models**
  - SedFoam implements granular stress models to simulate dense granular flows. The kinetic theory of granular flows and the **μ(I)-rheology** (derived from the Jop et al., 2006 model) are commonly used.
  - In dense flows, the granular stress is influenced by **particle-particle collisions** and **inter-particle friction**, represented by the effective viscosity, which is a function of the shear rate and pressure.
  - Unlike the kinetic theory of granular flows (which works well for dilute conditions), the μ(I) rheology is phenomenological and based on dimensional analysis, focusing on frictional contacts.

$$\tau_{ij}^{a} = \mu(I)\, p^{a} \frac{S_{ij}^{a}}{\sqrt{2S_{ij}^{a} \cdot S_{ij}^{a}}}$$

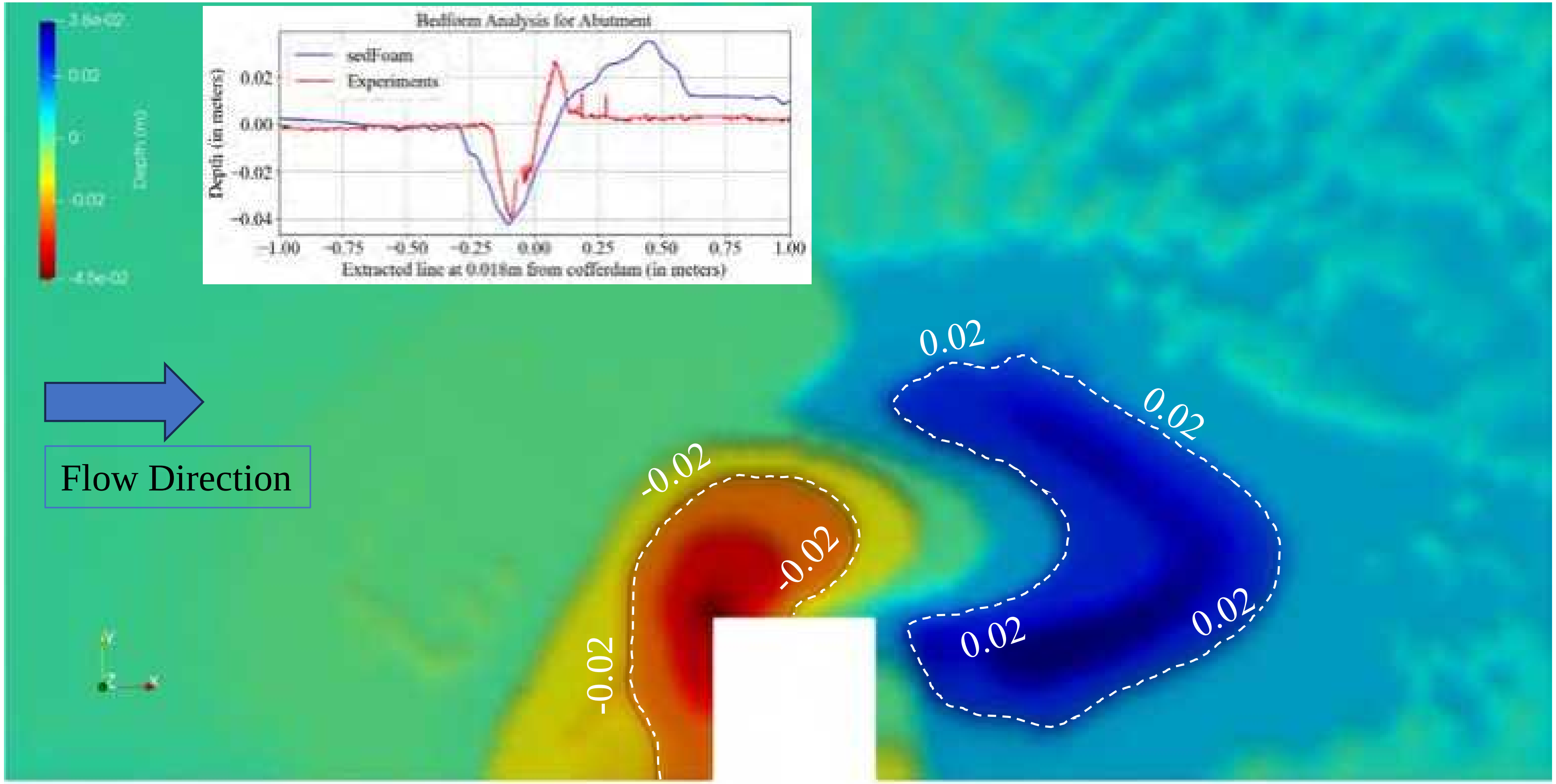
Dynamic Friction Coefficient

Inertial Number

Deviatoric Strain Rate Tensor : Represents the deformation rate hrwallingford

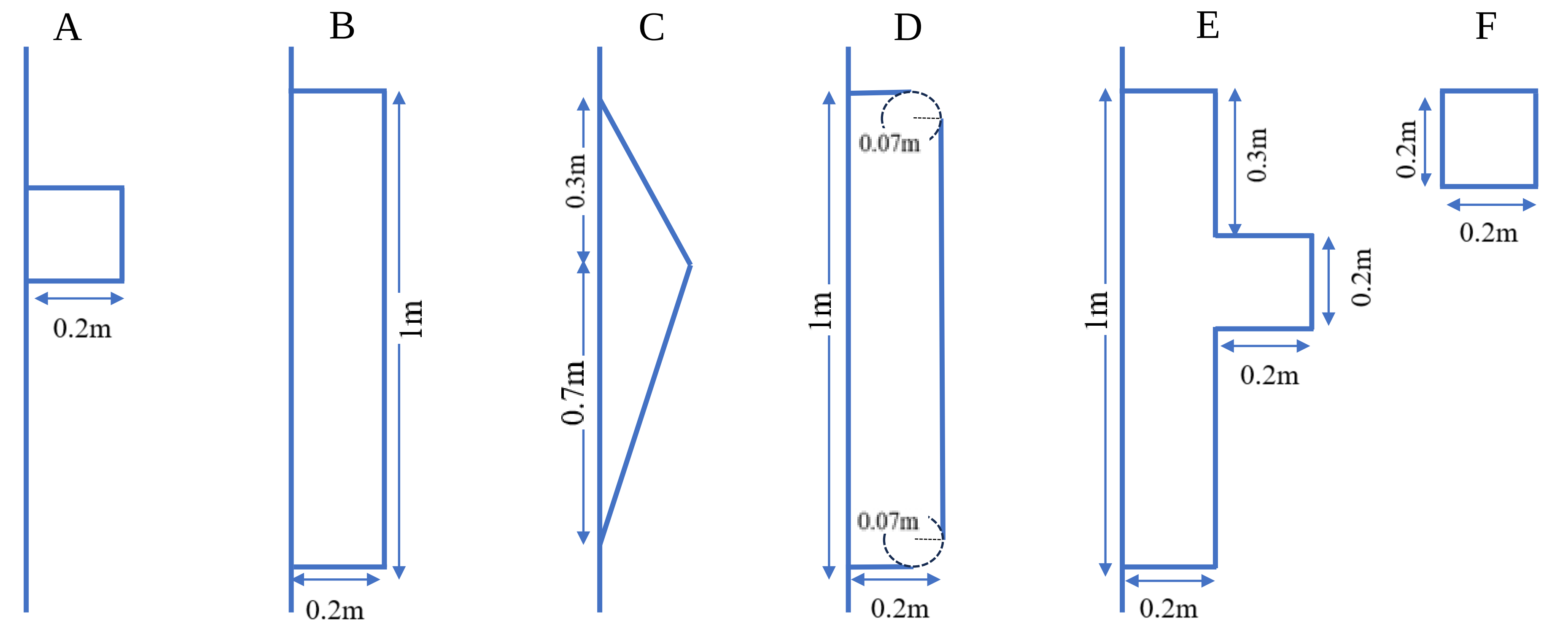
Results

Sand bed after 1hr, U = 0.244 m/s



Results

Different cofferdam geometries



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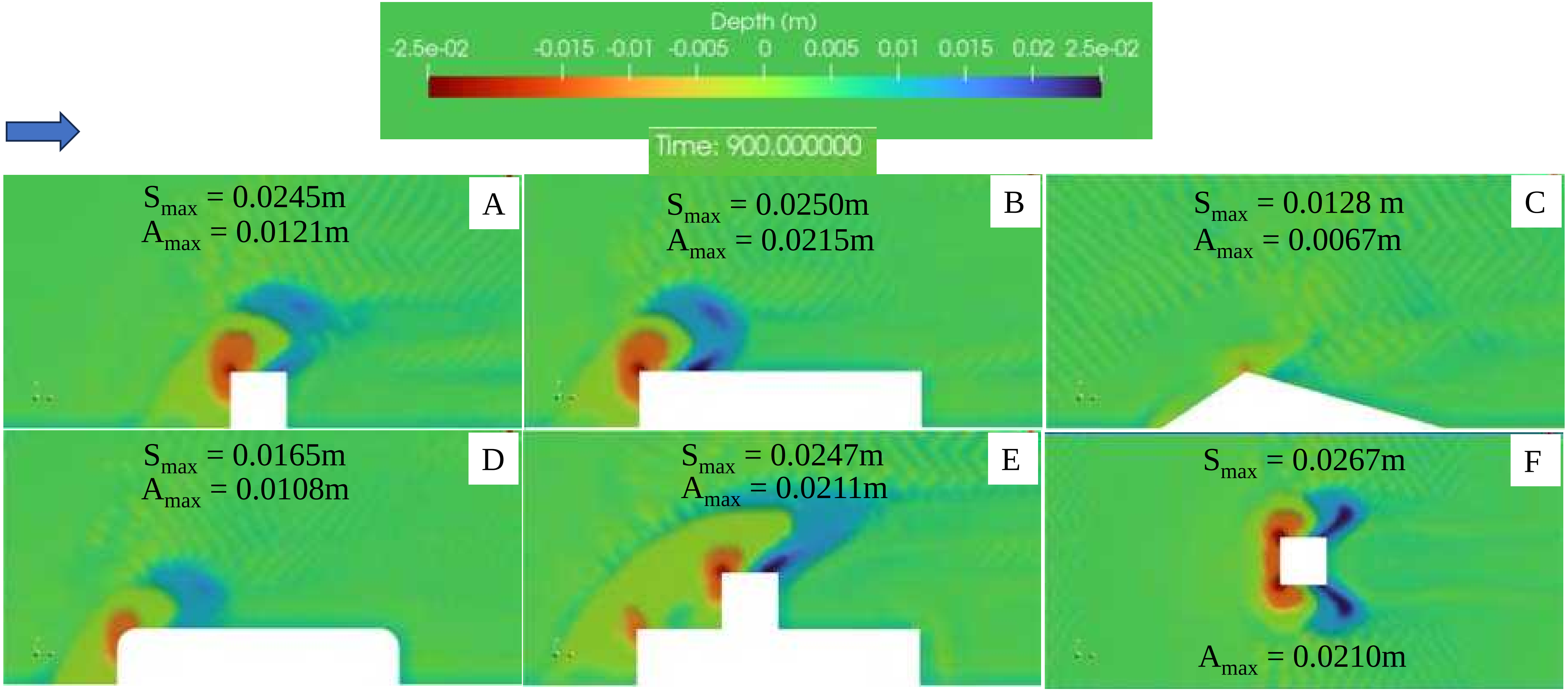
Max Scour and Max Accretion

After 900 seconds, U = 0.17m/s



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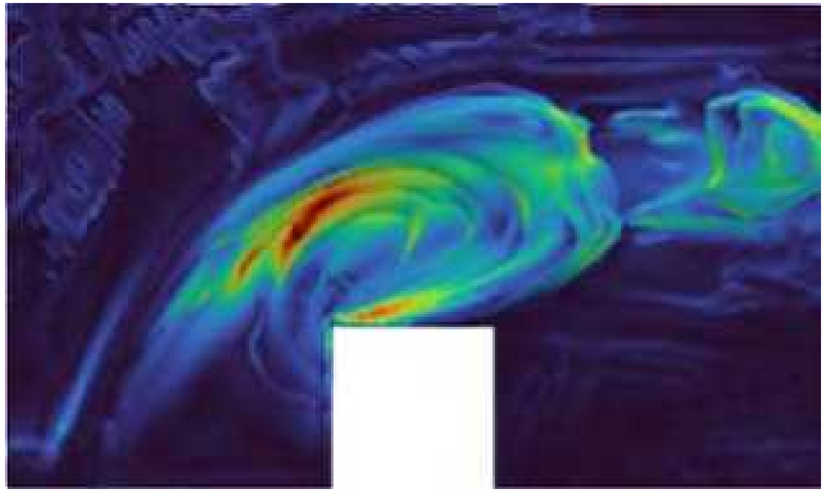
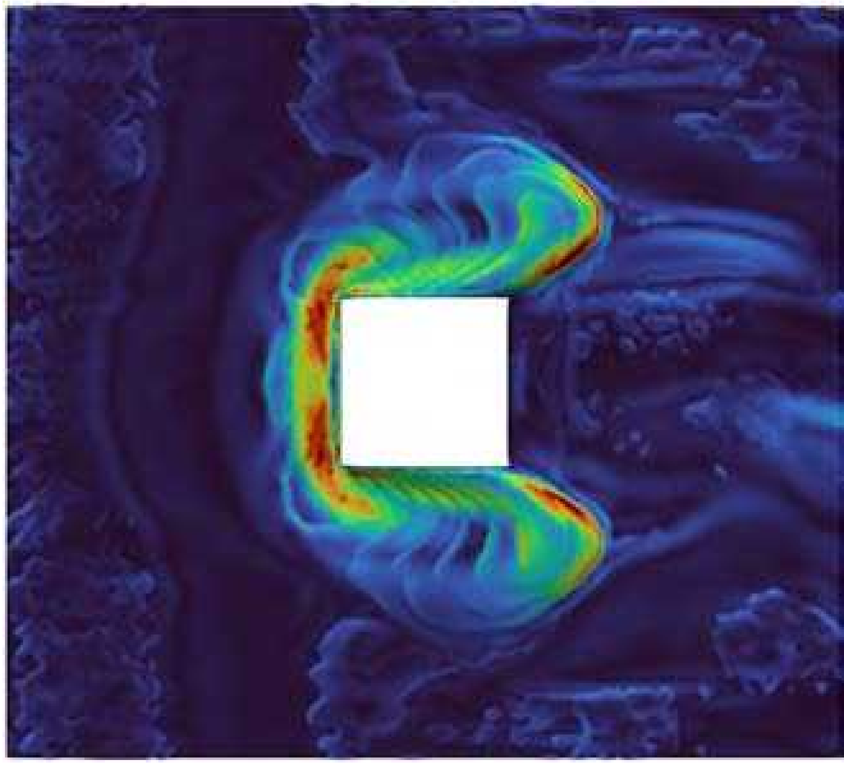
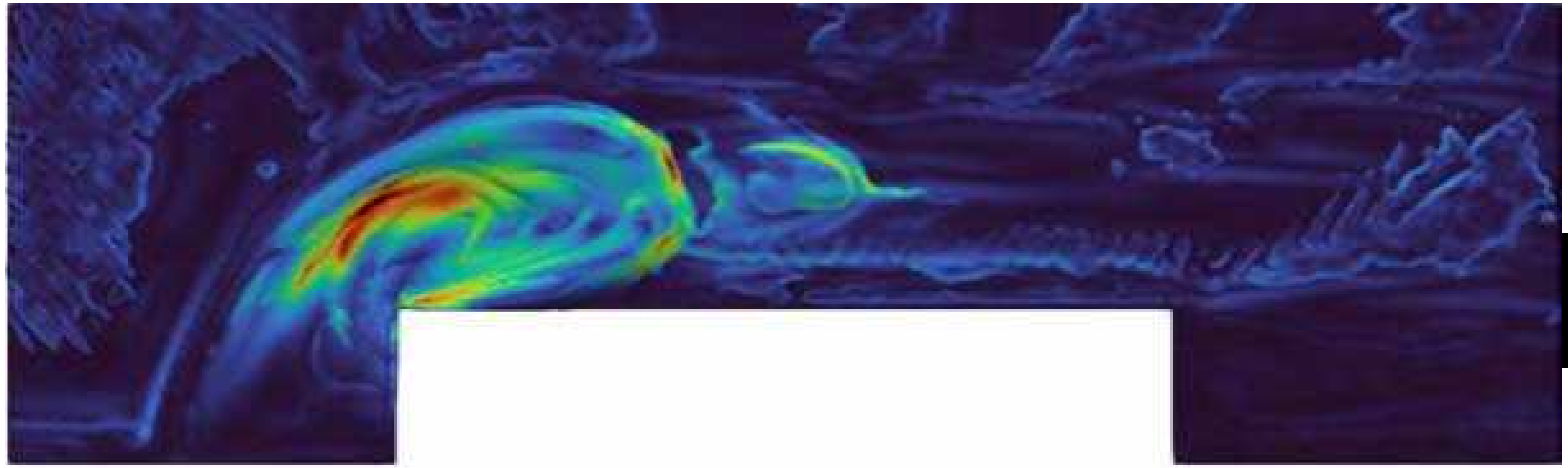
Bed Shear Stress

After 450 seconds, U = 0.17 m/s

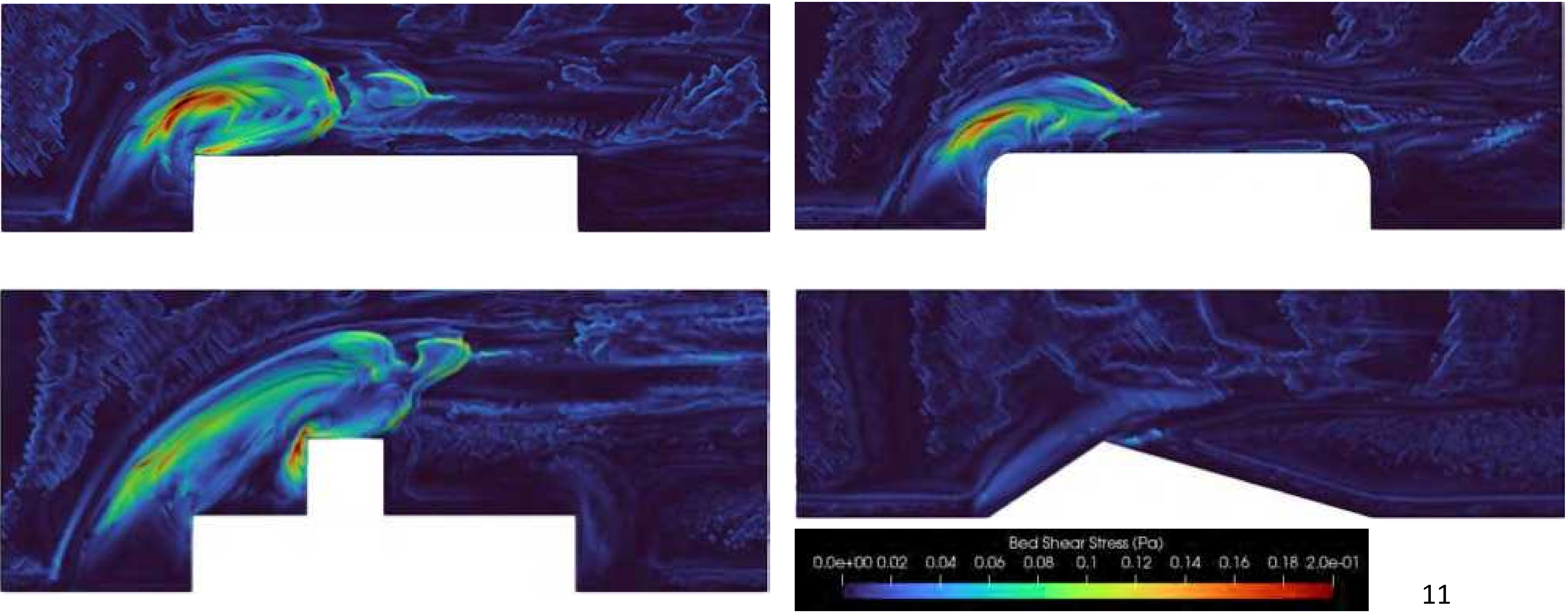






Bed Shear Stress

After 450 seconds, U = 0.17 m/s



sedInterFoam: Methodology

Inputs

Experimental Data

- Obtaining the transport properties of sand and water phase used in Flumes experiment.
- Use the geometrical dimensions of monopile models.
- Using the 3 input flow velocities

Solver

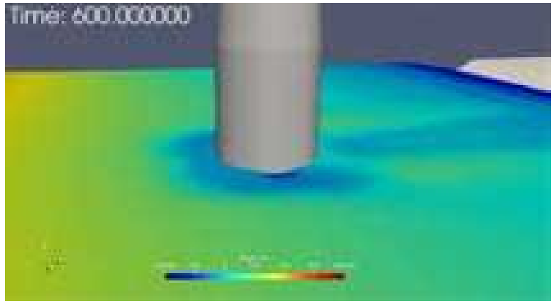
Three-phase Eulerian RANS OpenFOAM

- Creating 3D domain
- Using sedInterFoam :
  - VOF for water-air interface
  - Granular Rheology properties (muI)
  - Interfacial properties (drag model)
  - Transport properties
  - Modified Two-phase RAS equations

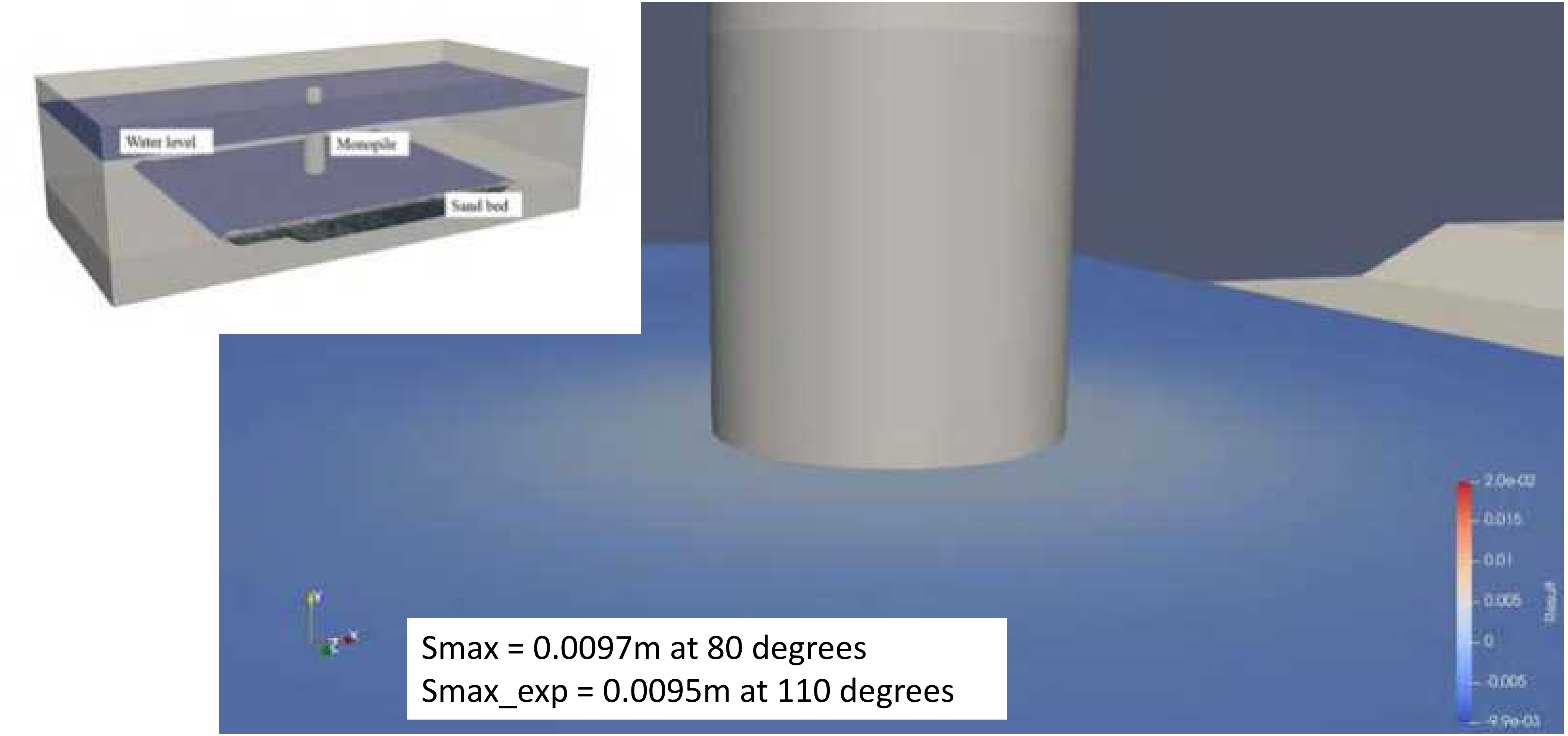
Outputs

Scour Depth

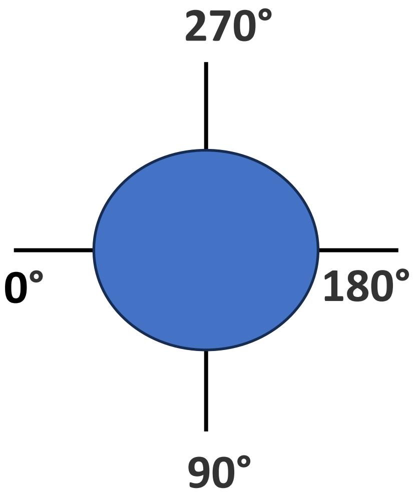
- Estimation of volume fraction of water and sand to predict the bed formation.
- Comparison with experiments



Preliminary Results (Current only)



Smax = 0.0097m at 80 degrees
Smax_exp = 0.0095m at 110 degrees



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Conclusions

- **sedFoam Validation :**
  - Successfully captured scour patterns around cofferdams.
  - Demonstrated the role of turbulence models (k-ω) and granular rheology (μ(I)-model) in simulating bed evolution.

- **sedInterFoam Preliminary Results :**
  - Initial validation for monopile scour under currents showed close agreement with experiments.
  - Highlighted the importance of VOF for air-water interface tracking in three-phase flows.

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Future Work

- **Vortex Dynamics and Flow Structures :**
  - Use Q-criterion and λ2-method to analyse vortex evolution and its impact on sediment mobilization, enhancing understanding of scour mechanics.
- **Wave-Current Interaction Modeling :**
  - Expand Case 2 (monopile scour) to include combined wave-current interactions using waves2Foam for wave generation.
  - Investigate turbulence-sediment coupling under cyclic wave loading to refine predictions of vortex shedding and horseshoe vortex dynamics.
- **Field-Scale Applications :**
  - Scale simulations to real-world scenarios by integrating bathymetric and hydrodynamic field data.
  - Validate against field measurements to assess model robustness in complex environments.

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Dissemination

- **Conference Presentations and Proceedings**
  - *Upcoming:* Paper presentation at Coastal Dynamics 2025, Aveiro, Portugal. Tiwari, N., Knaapen, M., Haeri, S., & Whitehouse, R. (2025, April 7–11). Numerical modelling for scour near cofferdams using Eulerian two-phase flow model.
- **Outreach Activities**
  - *Completed:* Presentation at ARC conference at The Open University in Milton Keynes, UK (2024, 27–28 Nov)

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Thank You

The project has received funding from Horizon Europe Marie Skłodowska-Curie Actions, Grant Agreement no. **101072443 - SEDIMARE**. Experimental data is taken from the Fast Flow Facility at Froude Modelling Hall, HR Wallingford Ltd.

European Commission

Marie Skłodowska-Curie Actions

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European Commission

SEDIMARE DC MEETING

11.03.2025–13.03.2025

Santander, Spain

Nearshore Wave Processes by Remote Sensing

Name	Muhammed Said Parlak (#2)
Supervisors	Maurizio Brocchini Nicholas Dodd Matteo Postacchini

Processing SGS Data

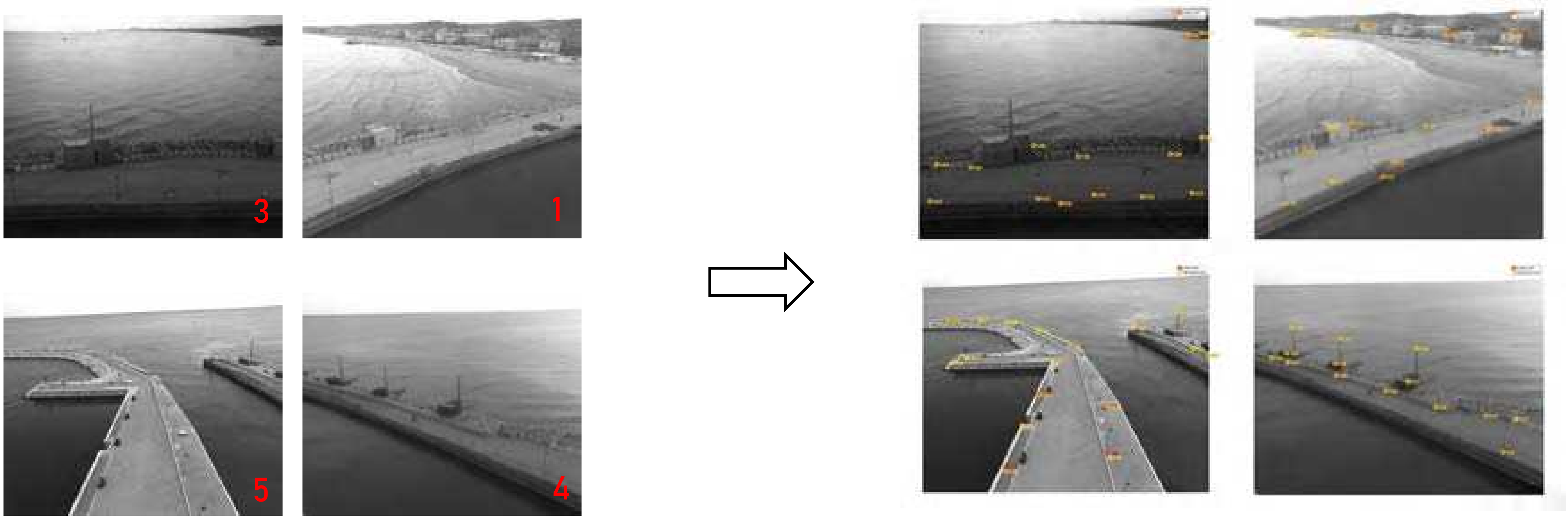
→ SGS (Sena Gallica Speculator) is a fixed multi-camera monitoring system.

- 10 mins recording for each 60 mins.
- 5 cameras, 2 Hz sampling rate.

Processing SGS Data

→ SGS (Sena Gallica Speculator) is a fixed multi-camera monitoring system.

- Images need to be orthorectified for geometric consistency.
- Quantitative Coastal Imaging Toolbox is utilized to complete the procedure*.

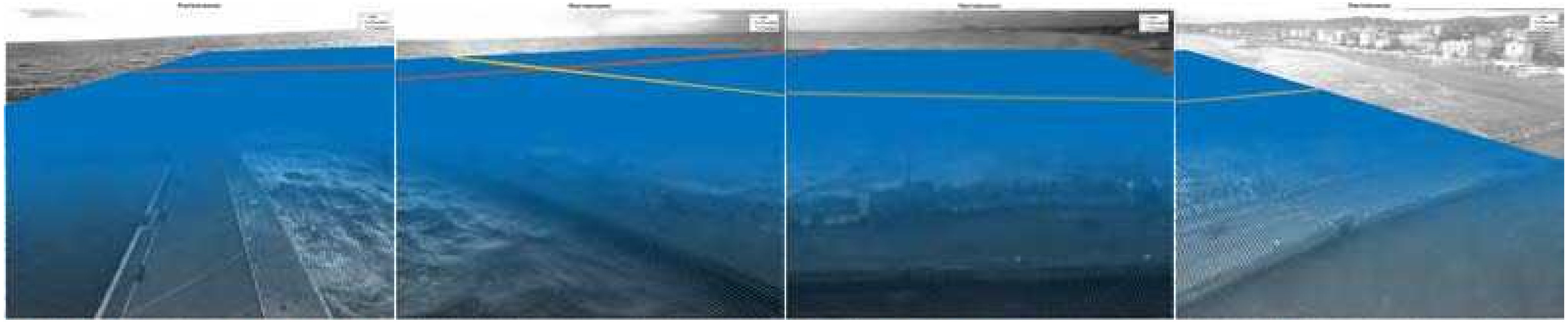


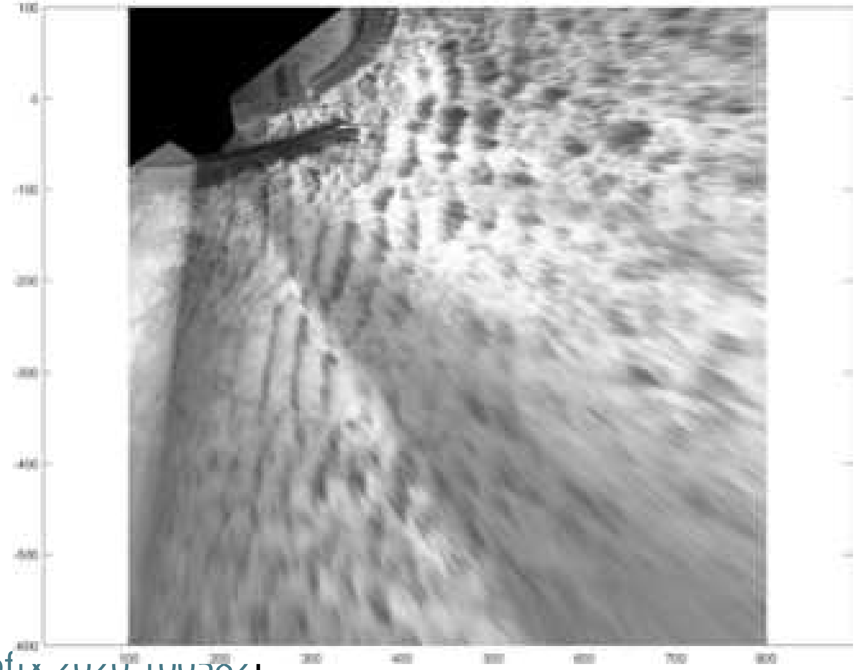
[Bruder & Brodie, 2020, https://doi.org/10.1016/j.softx.2020.100582]

Processing SGS Data

→ SGS (Sena Gallica Speculator) is a fixed multi-camera monitoring system.

- Grids and stacks are extracted from the processed images.

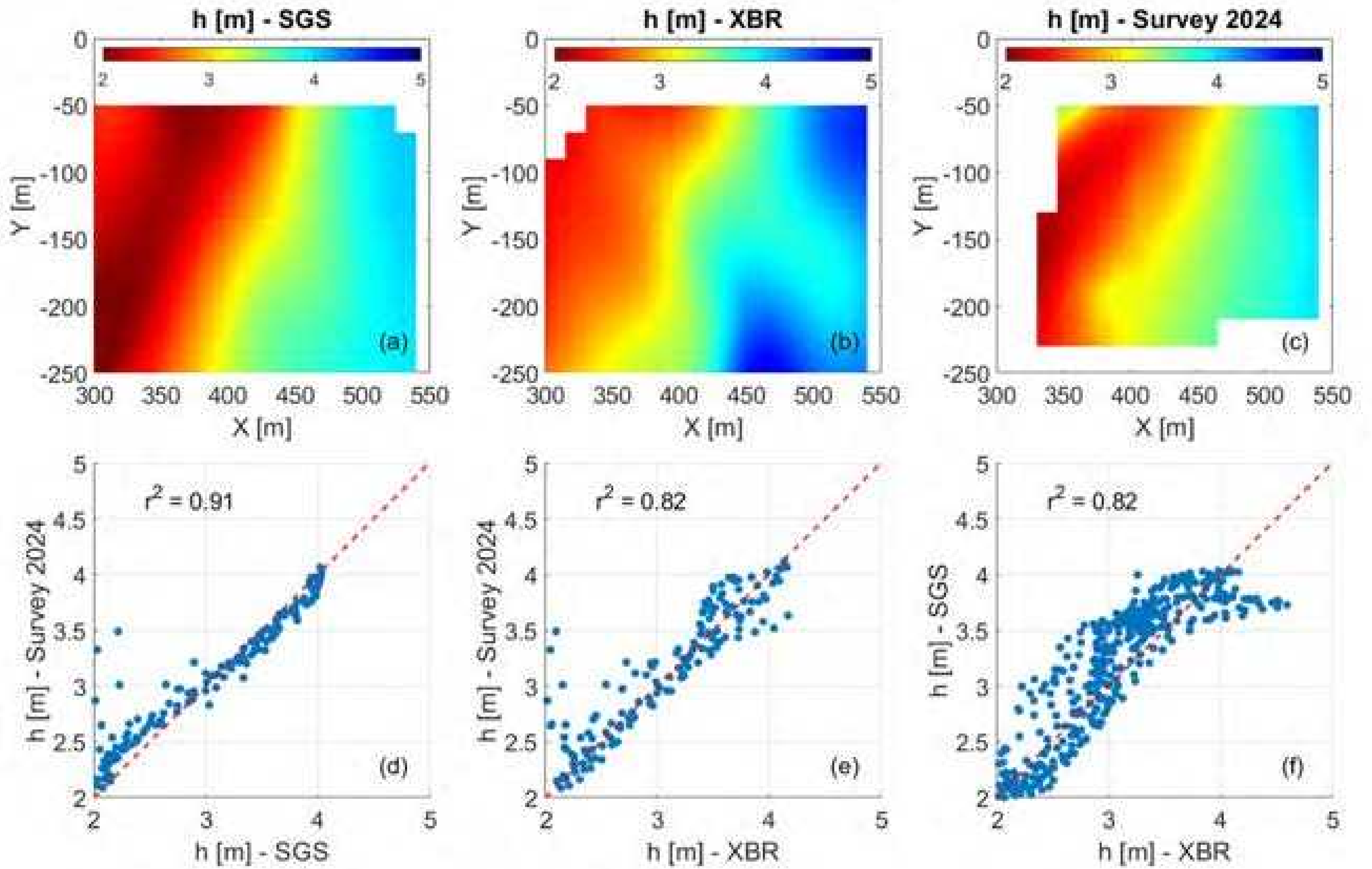




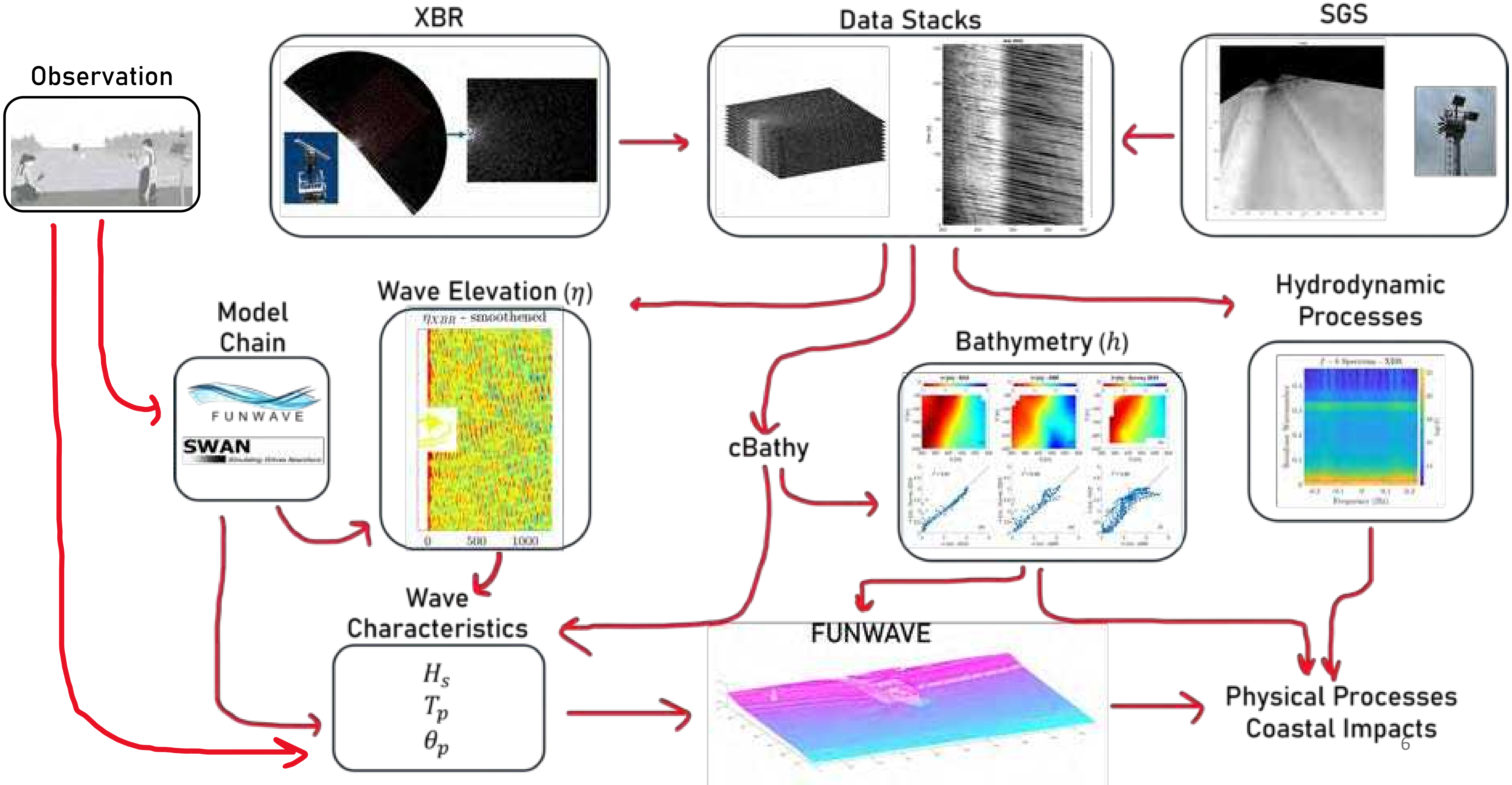
[Bruder & Brodie, 2020, https://doi.org/10.1016/j.softx.2020.100382]

Processing SGS Data

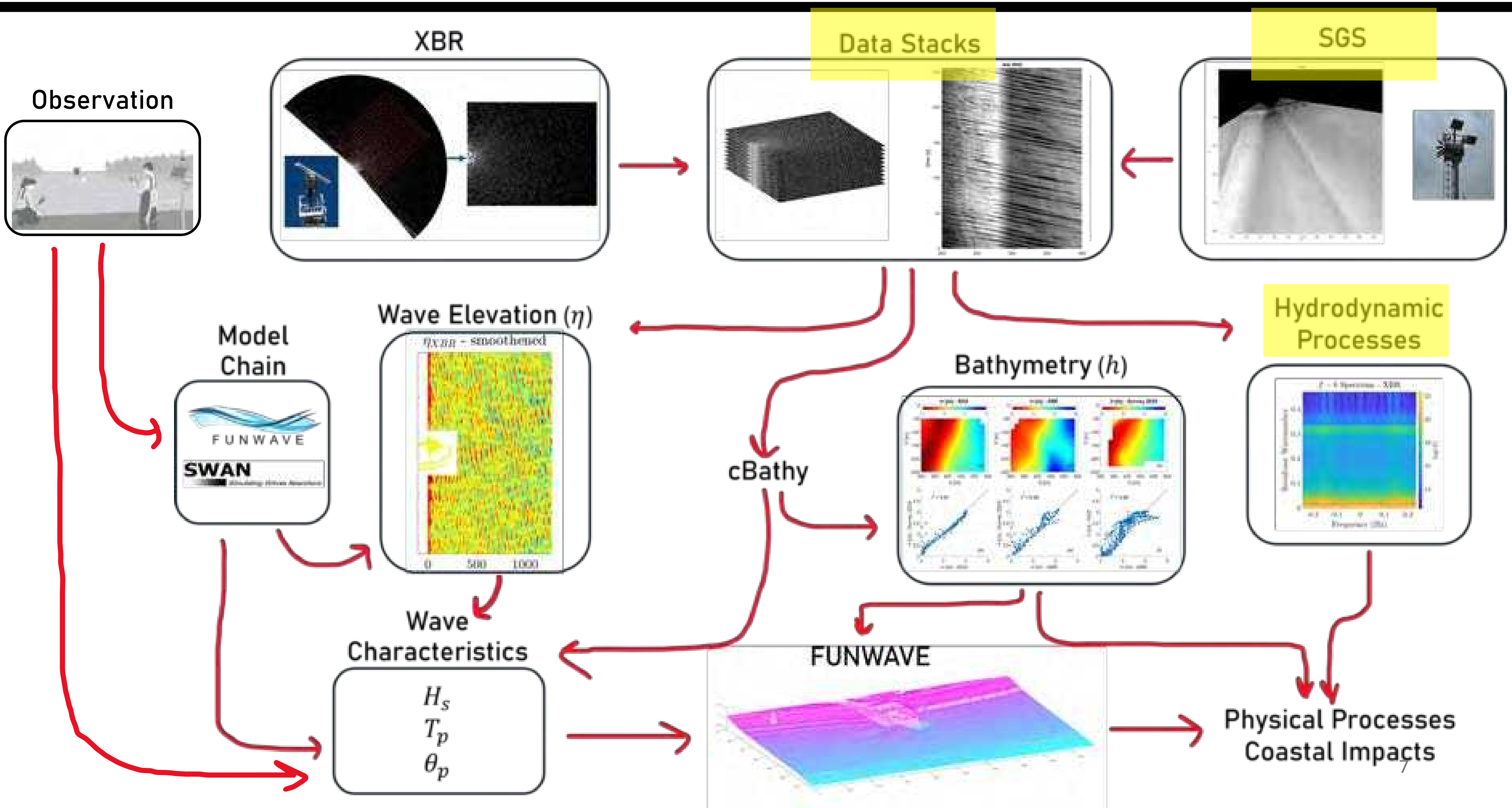
→ SGS (Sena Gallica Speculator) is a fixed multi-camera monitoring system.
- Quality assessment is done by comparing bathymetry result to field observation and results from X-Band RADAR (XBR).



Framework for Nearshore Dynamics

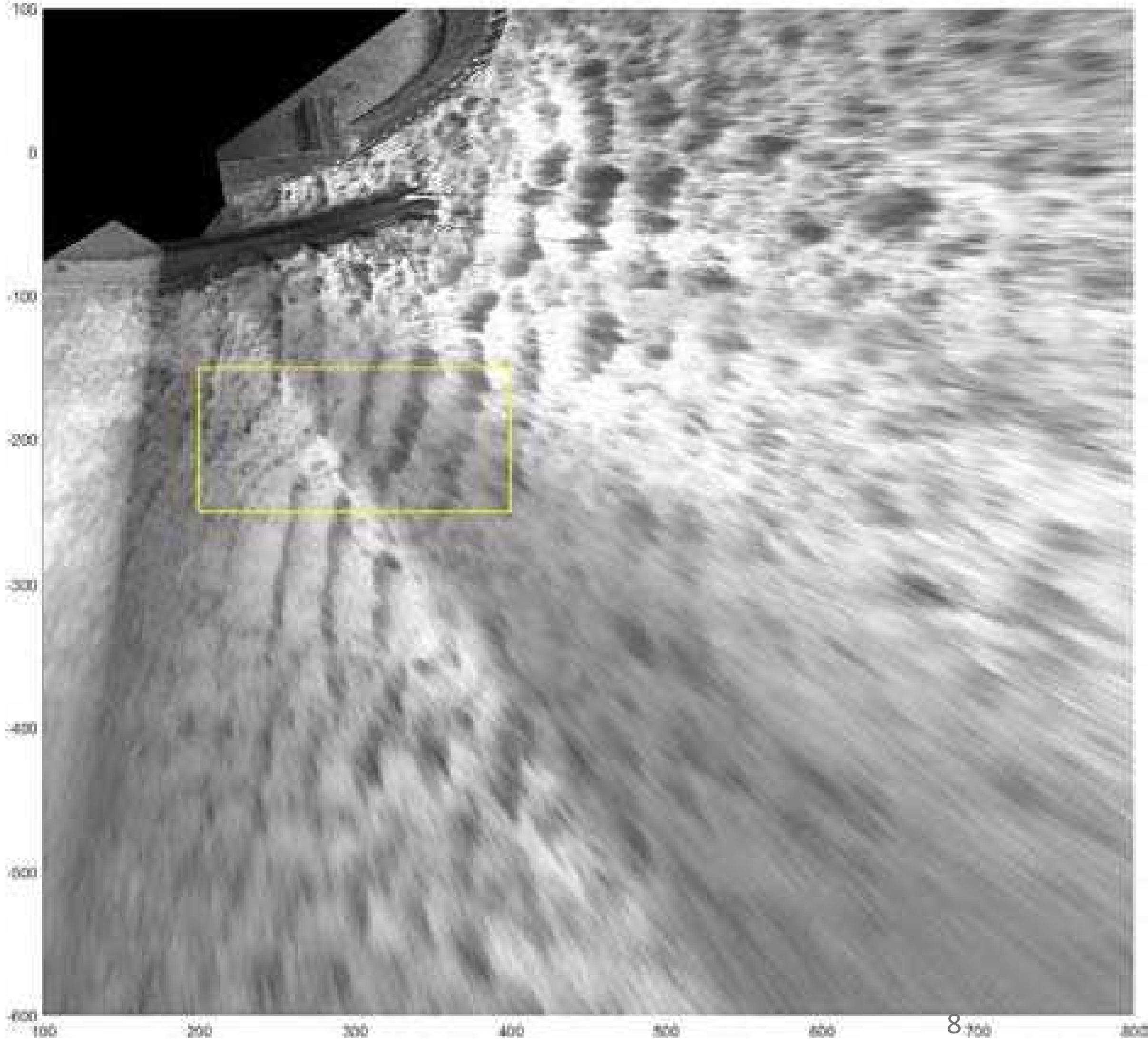


Framework for Nearshore Dynamics



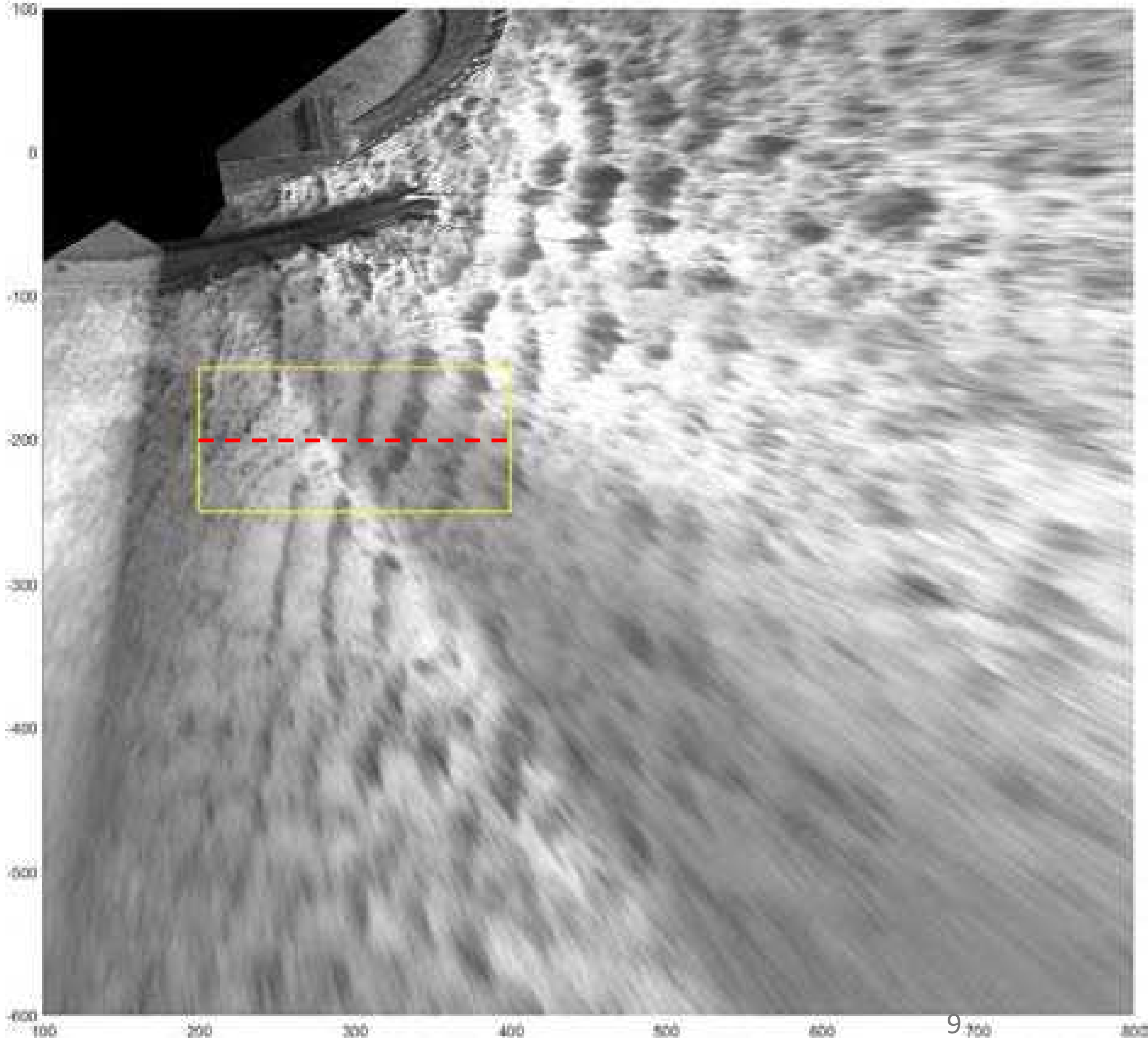
Processing SGS Data

→ Image processing with SGS data to extract information
  - Small patch is chosen.



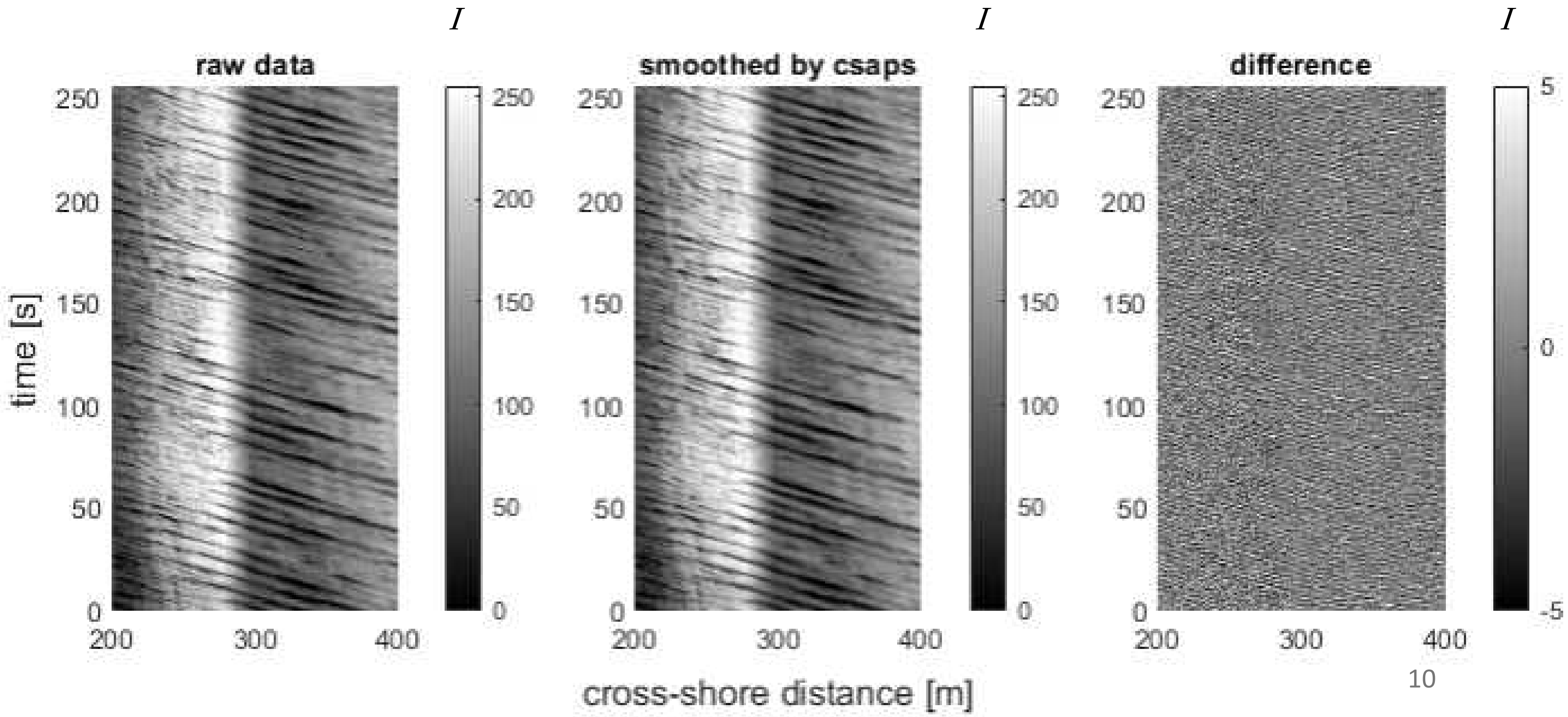
Processing SGS Data

→ Image processing with SGS data to extract information
- Small patch is chosen.
- Time-stacked image is created(---).



Processing SGS Data

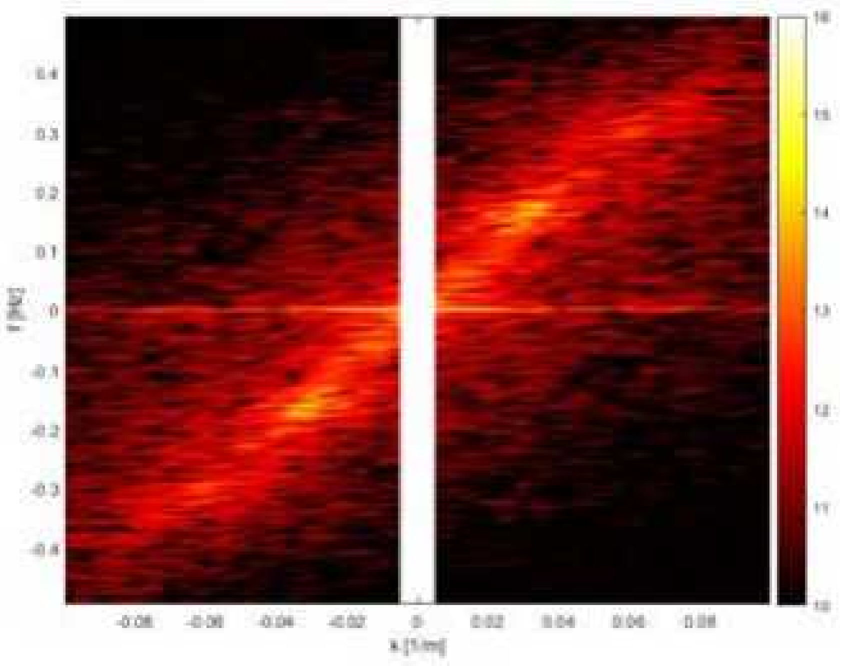
→ Image processing with SGS data to extract information
  - Data is smoothed to eliminate noise (cubic smoothing spline, csaps).



Processing SGS Data

→ Image processing with SGS data to extract information

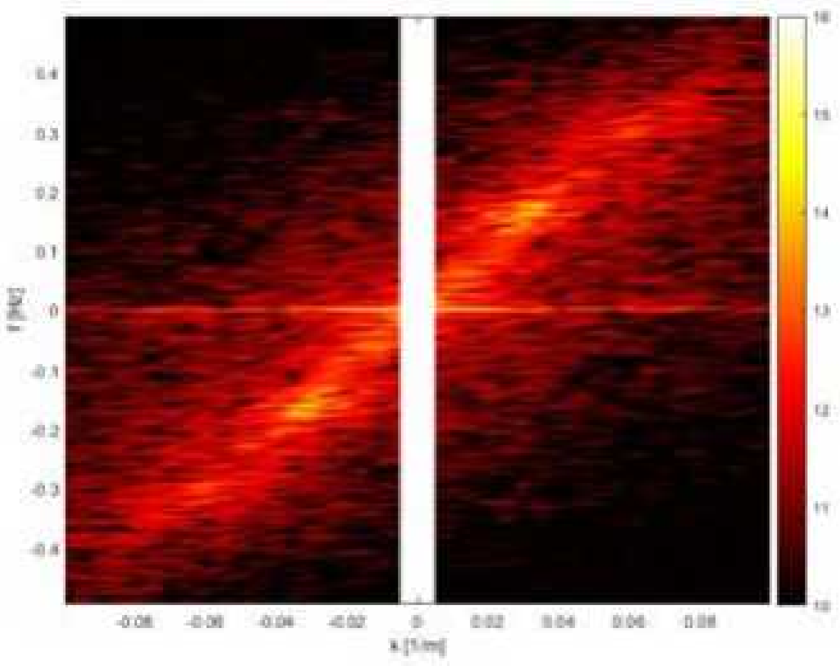
- Data is smoothed to eliminate noise (cubic smoothing spline, csaps).
- *f-k* spectrum is obtained by FFT

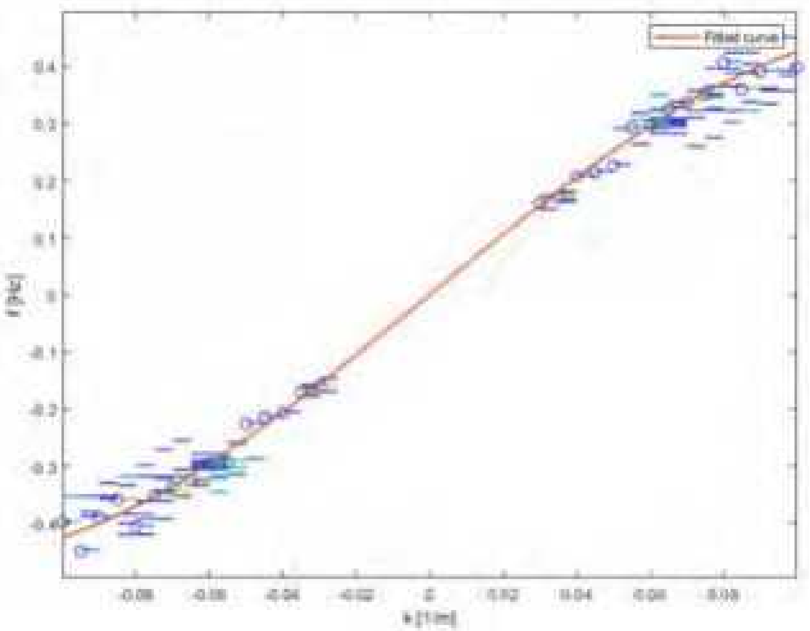


Processing SGS Data

→ Image processing with SGS data to extract information

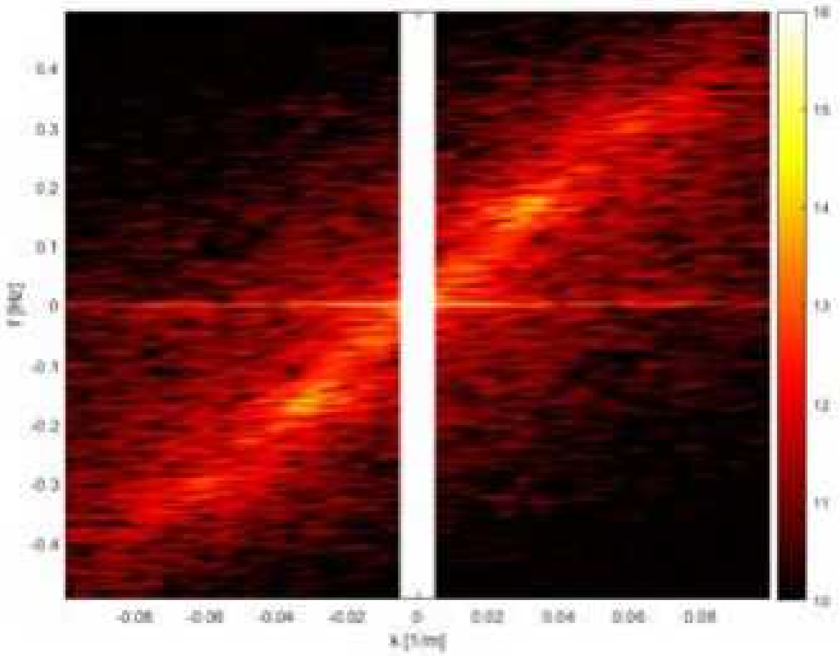
- Data is smoothed to eliminate noise (cubic smoothing spline, csaps).
- *f-k* spectrum is obtained by FFT
- Maxima locations are extracted and fitted with 3° order polynomial.

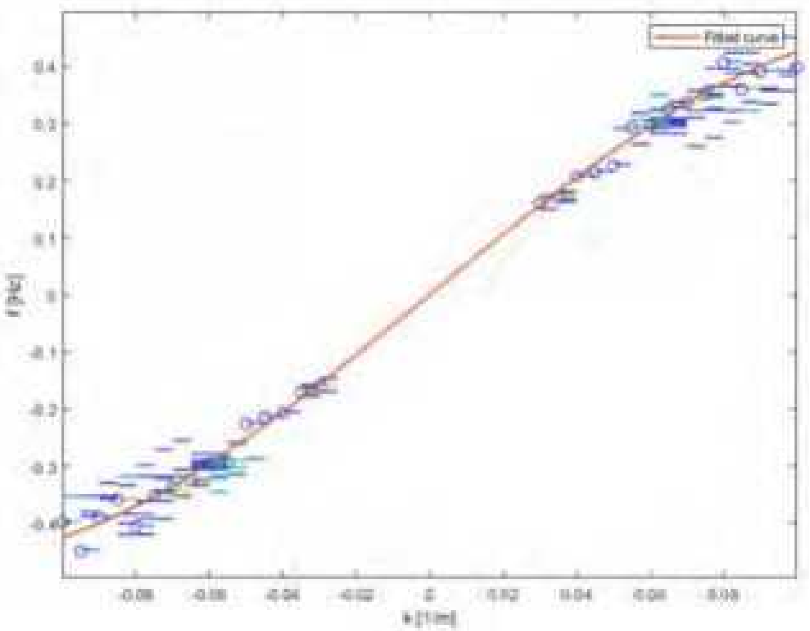


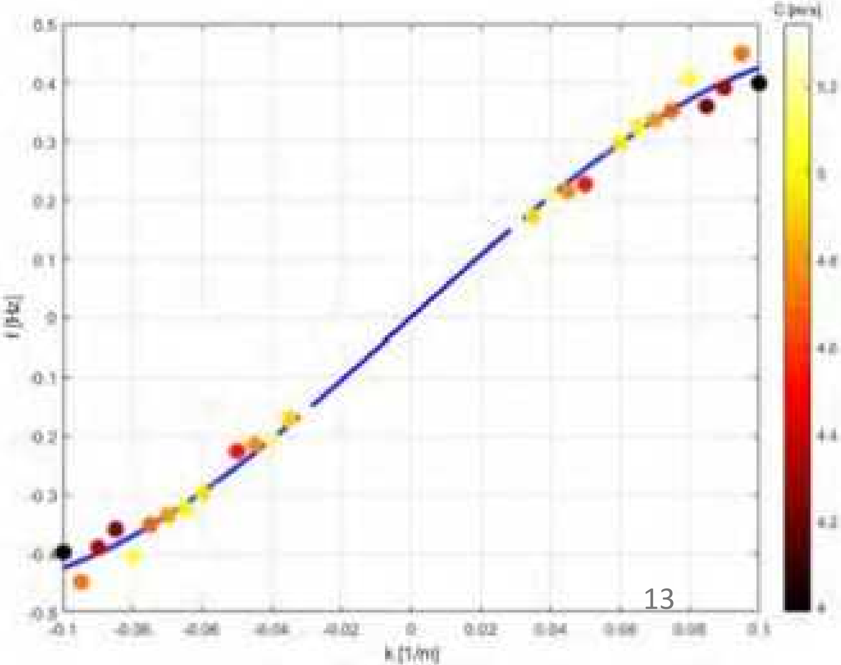


Processing SGS Data

→ Image processing with SGS data to extract information
- Data is smoothed to eliminate noise (cubic smoothing spline, csaps).
- *f-k* spectrum is obtained by FFT
- Maxima locations are extracted and fitted with 3° order polynomial.
- Celerity is calculated by $C = \omega/k$



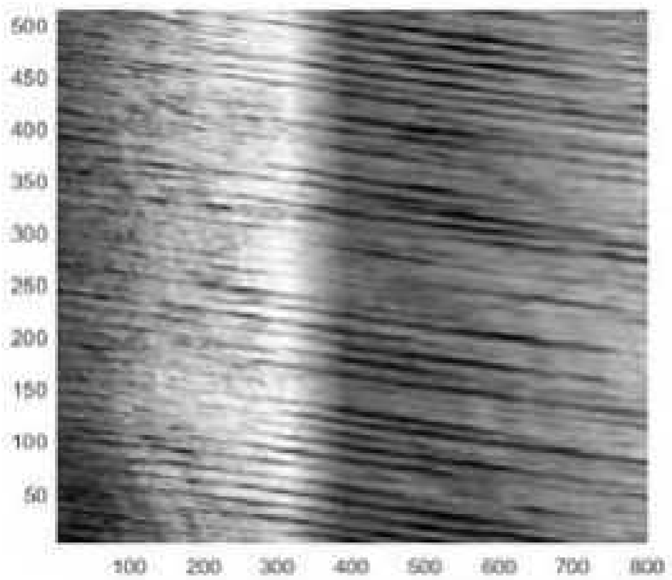




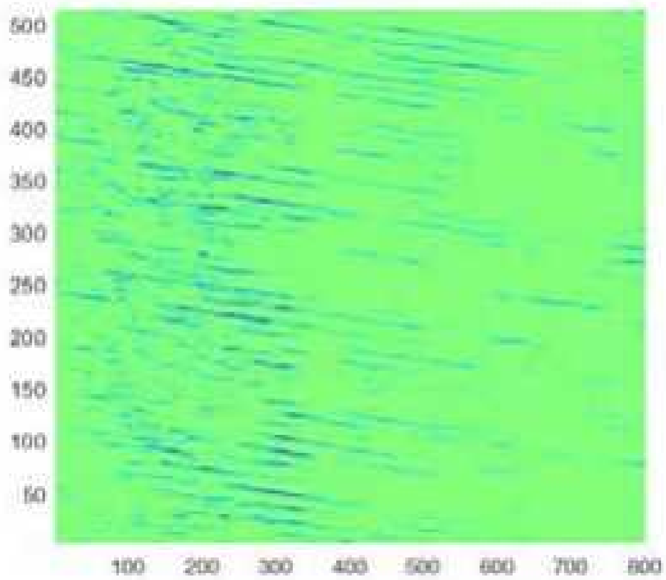
Celerity by Wave Crest Tracking

→ Development of a tracking algorithm
- Two gradient matrices based on different thresholds.
- FX2: Identification of dominant gradients.
- FX: Collection of sample points.

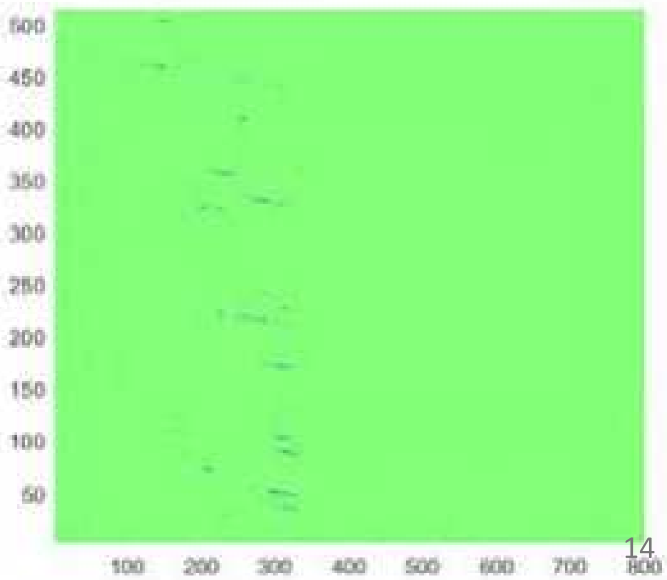
Data



FX: Gradient (<-25)



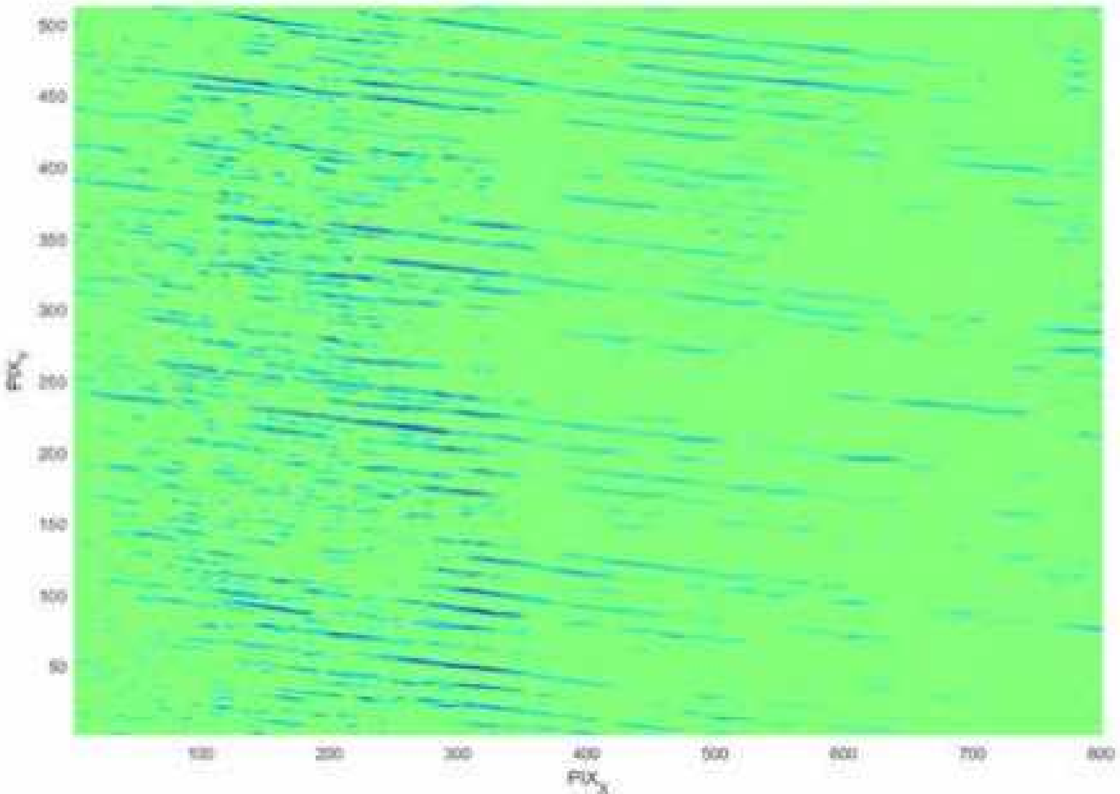
FX2: Gradient (<-70)



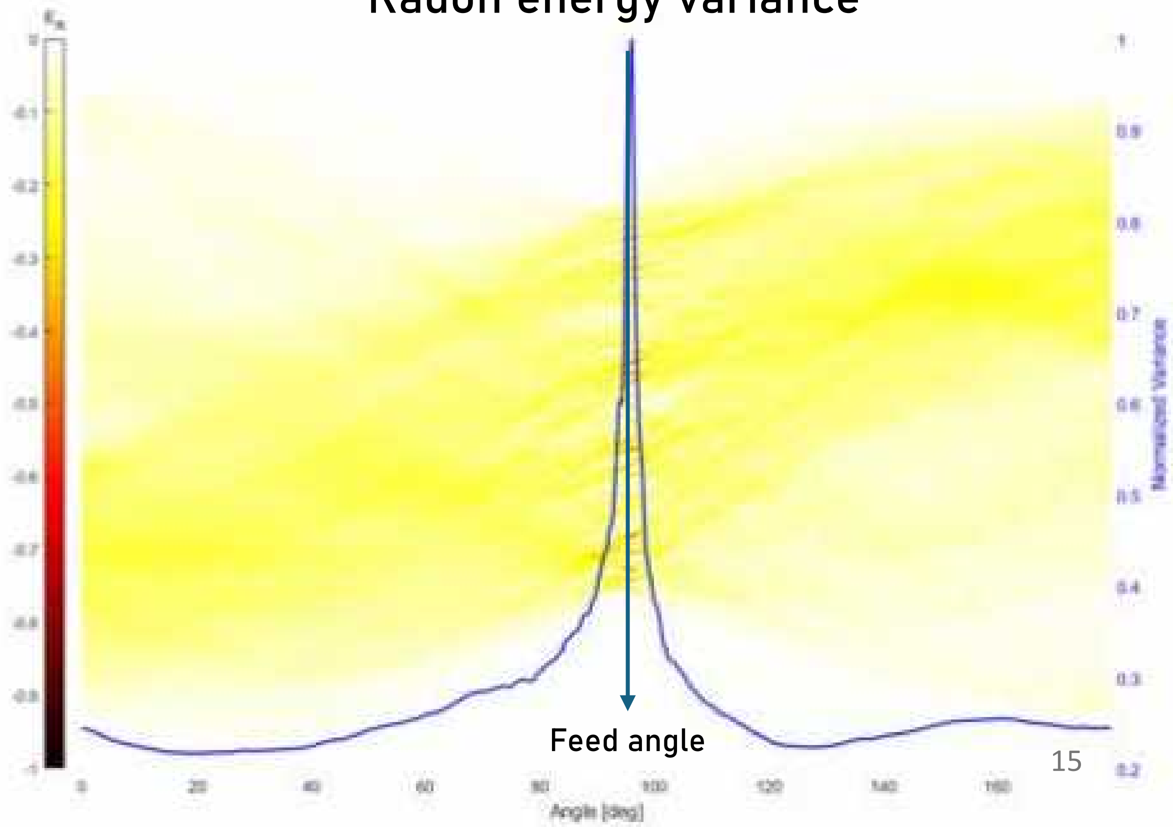
Celerity by Wave Crest Tracking

→ Development of a tracking algorithm
- Two gradient matrices based on different thresholds.
- FX2: Identification of dominant gradients.
- FX: Collection of sample points.
- Radon transformation to determine feed angle.

FX: Gradient (<-25)

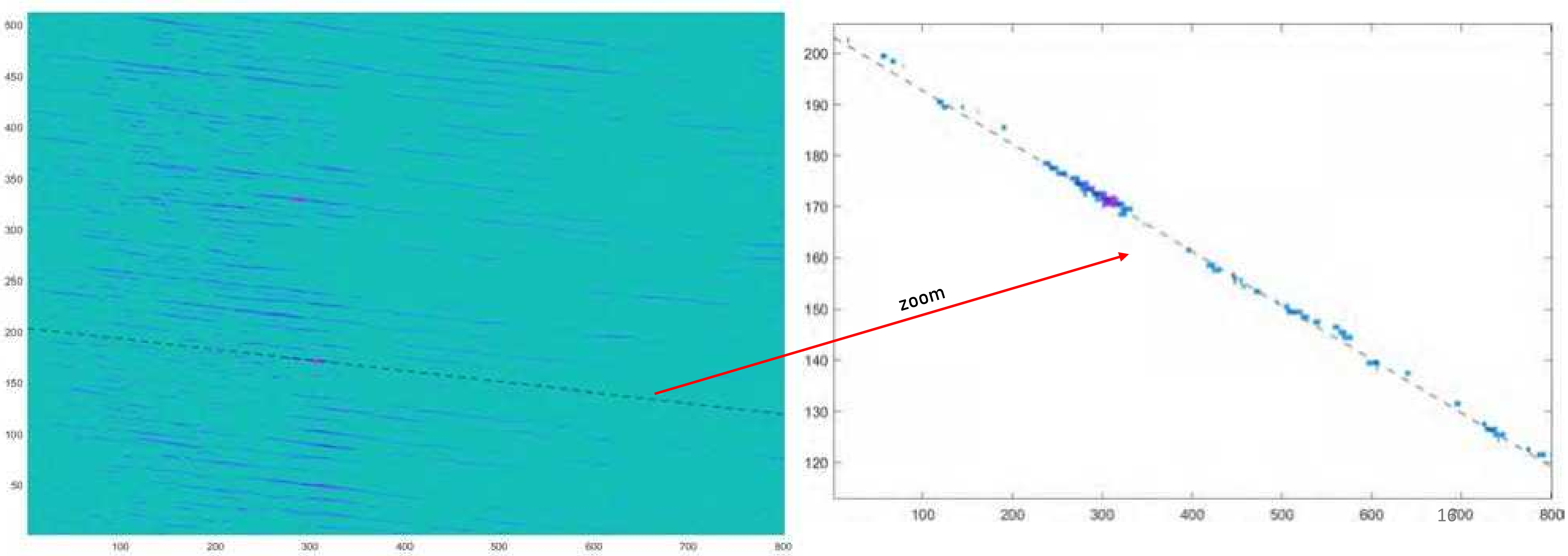


Radon energy variance



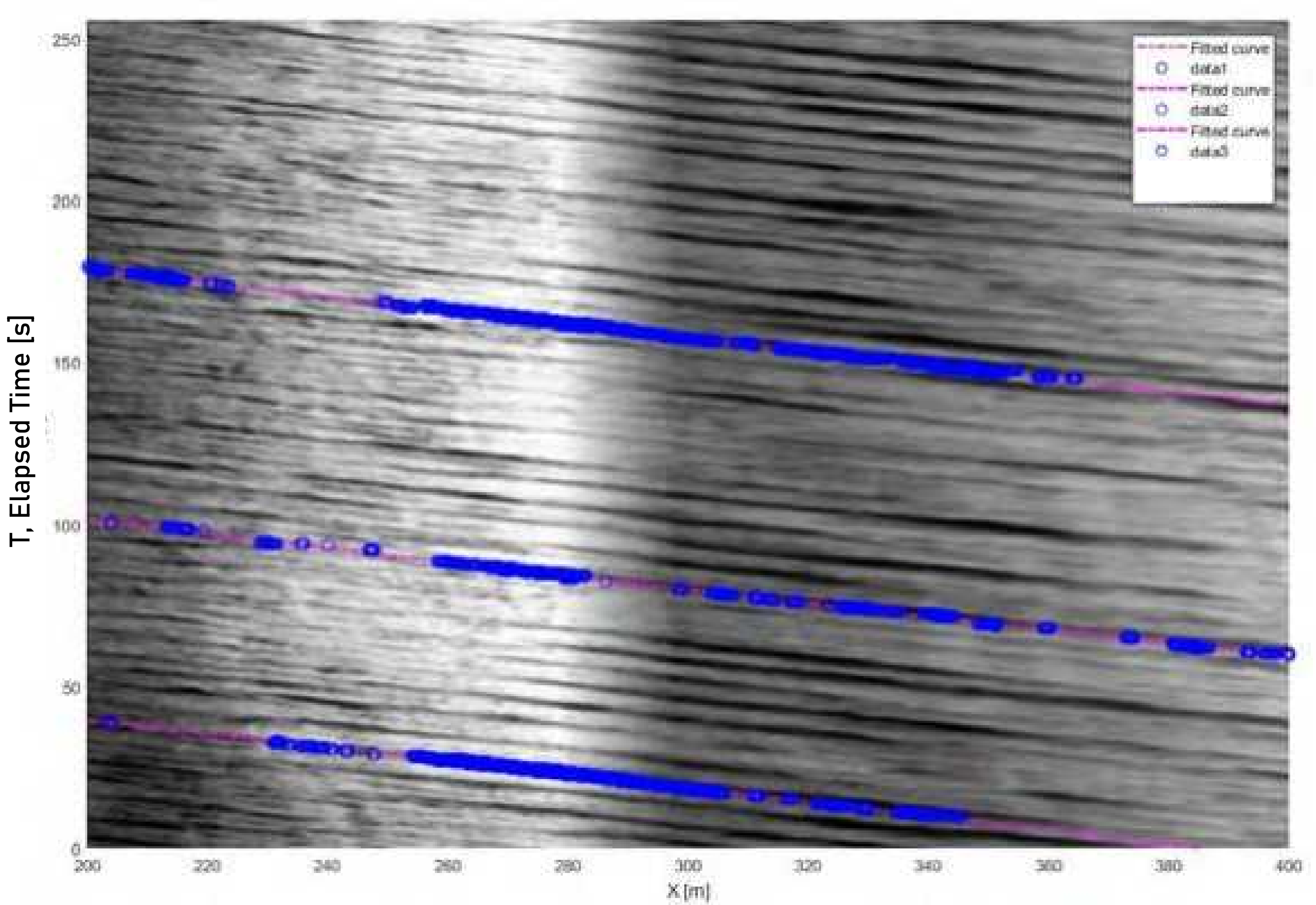
Celerity by Wave Crest Tracking

→ Development of a tracking algorithm
  - Approximation line constructed based on feed angle.



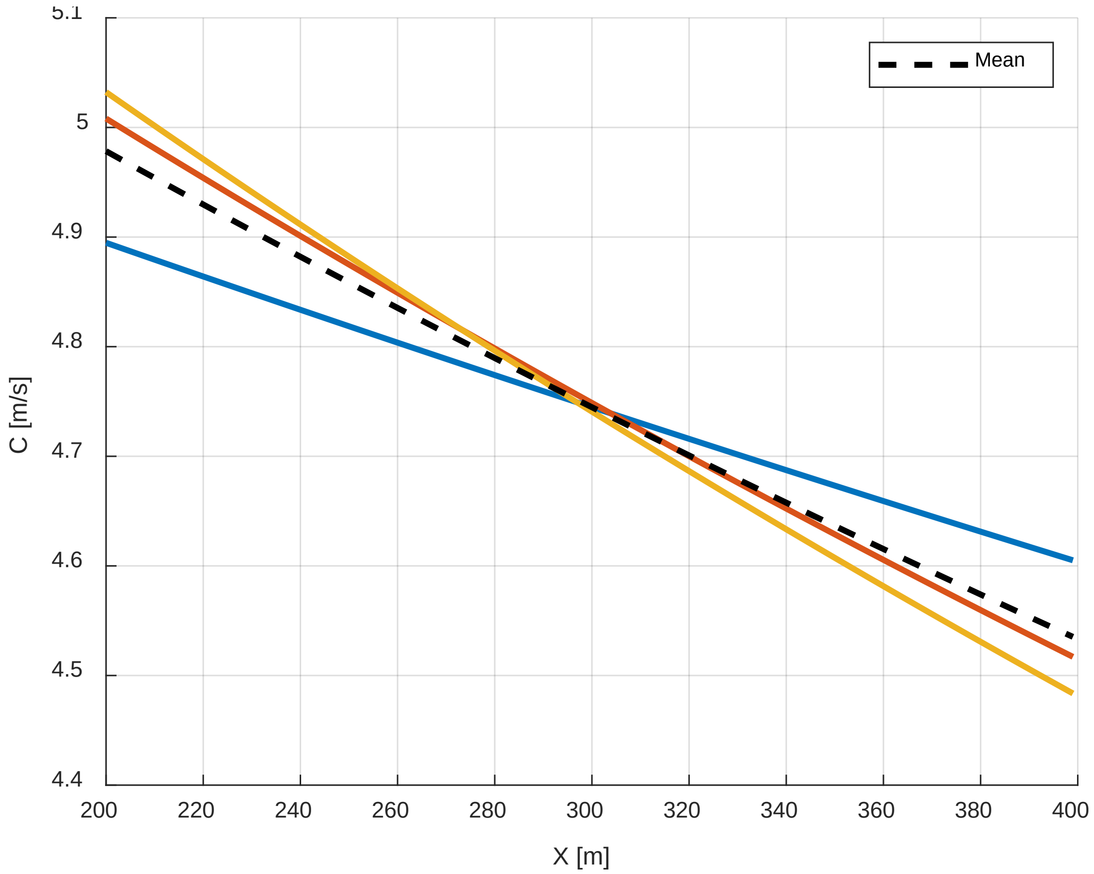
Celerity by Wave Crest Tracking

→ Development of a tracking algorithm
- Approximation line constructed based on feed angle.
- Fitted 2nd order polynomials for X[m], T[s] relation (displacement, velocity, acceleration).



Celerity by Wave Crest Tracking

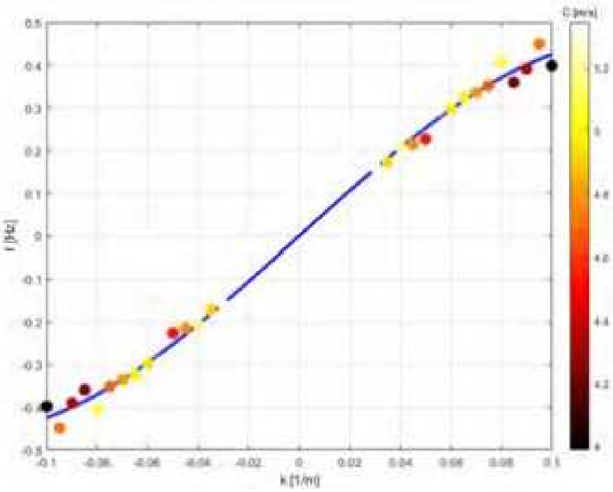
→ Development of a tracking algorithm
- Approximation line constructed based on feed angle.
- Fitted 2nd order polynomials for X[m], T[s] (elapsed time) relation (displacement, celerity, acceleration).

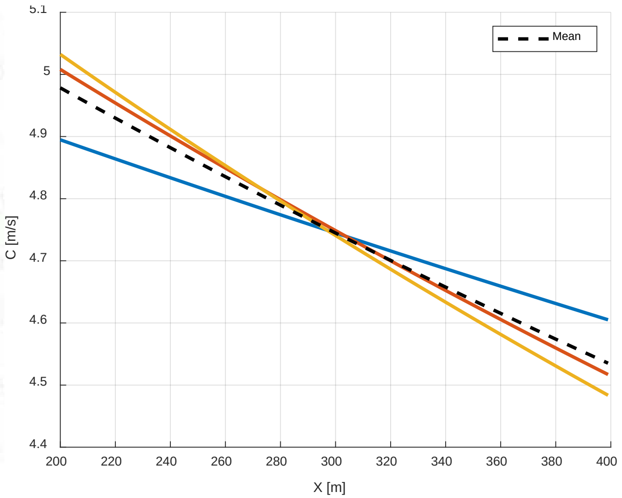


What is Next?

- → Coupling information between methodologies.
- → Flow field estimation by wave-current interaction.

$\sigma = \omega - \vec{k}\vec{U}$ → Doppler shift

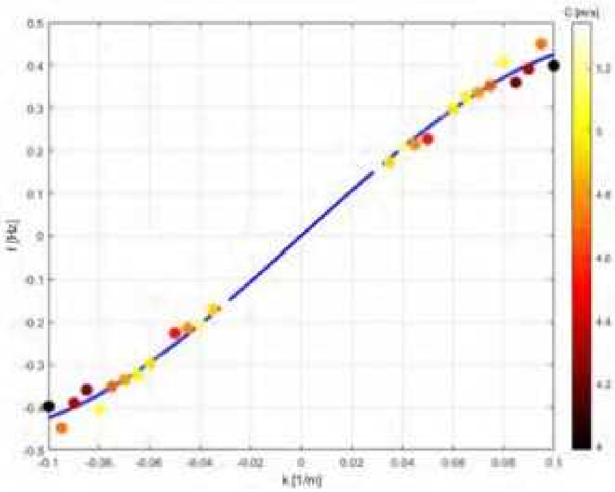


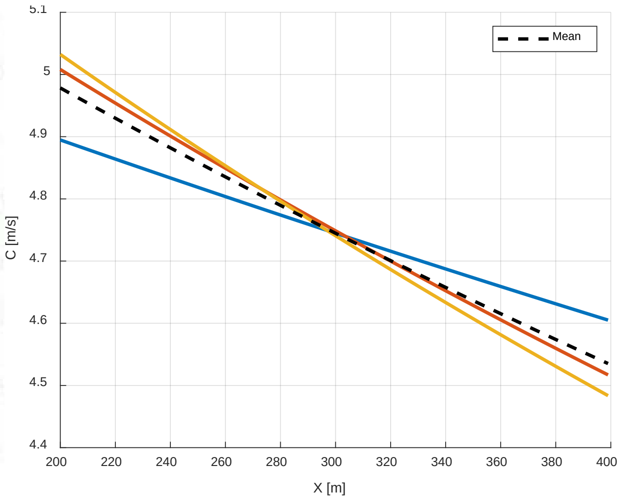


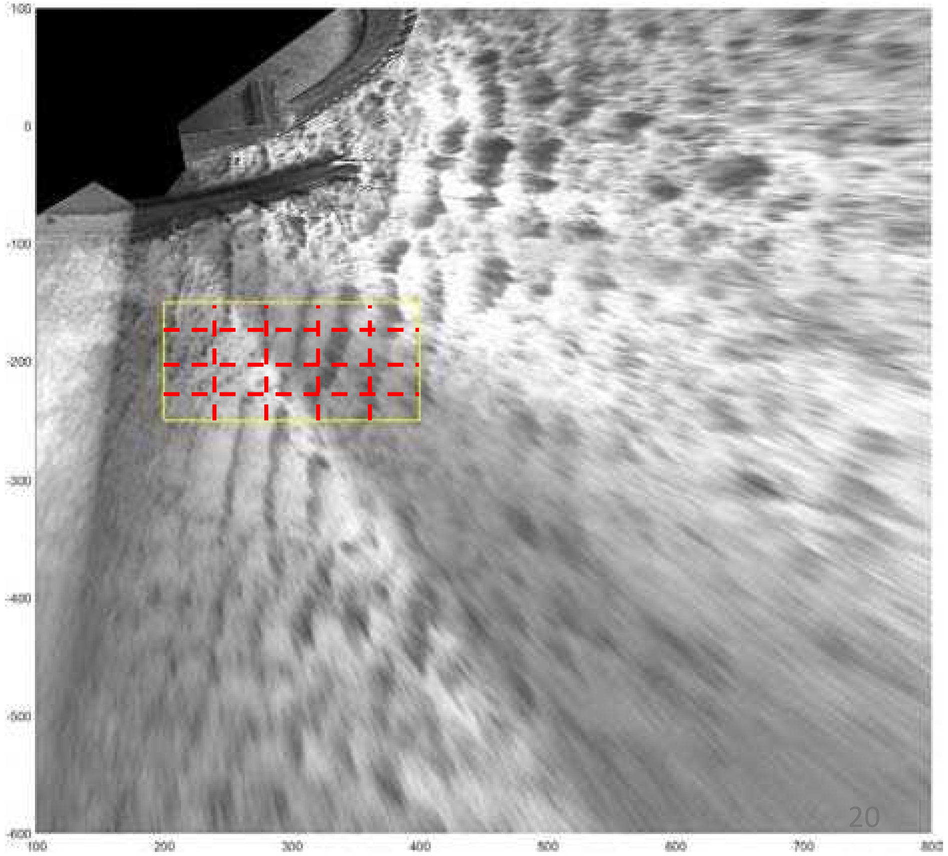
What is Next?

→ Coupling information between methodologies.
→ Flow field estimation by wave-current interaction.
→ Increasing sampling to work on 2D evolution of characteristics from offshore to nearshore.

$\sigma = \omega - \vec{k}\vec{U}$ → Doppler shift

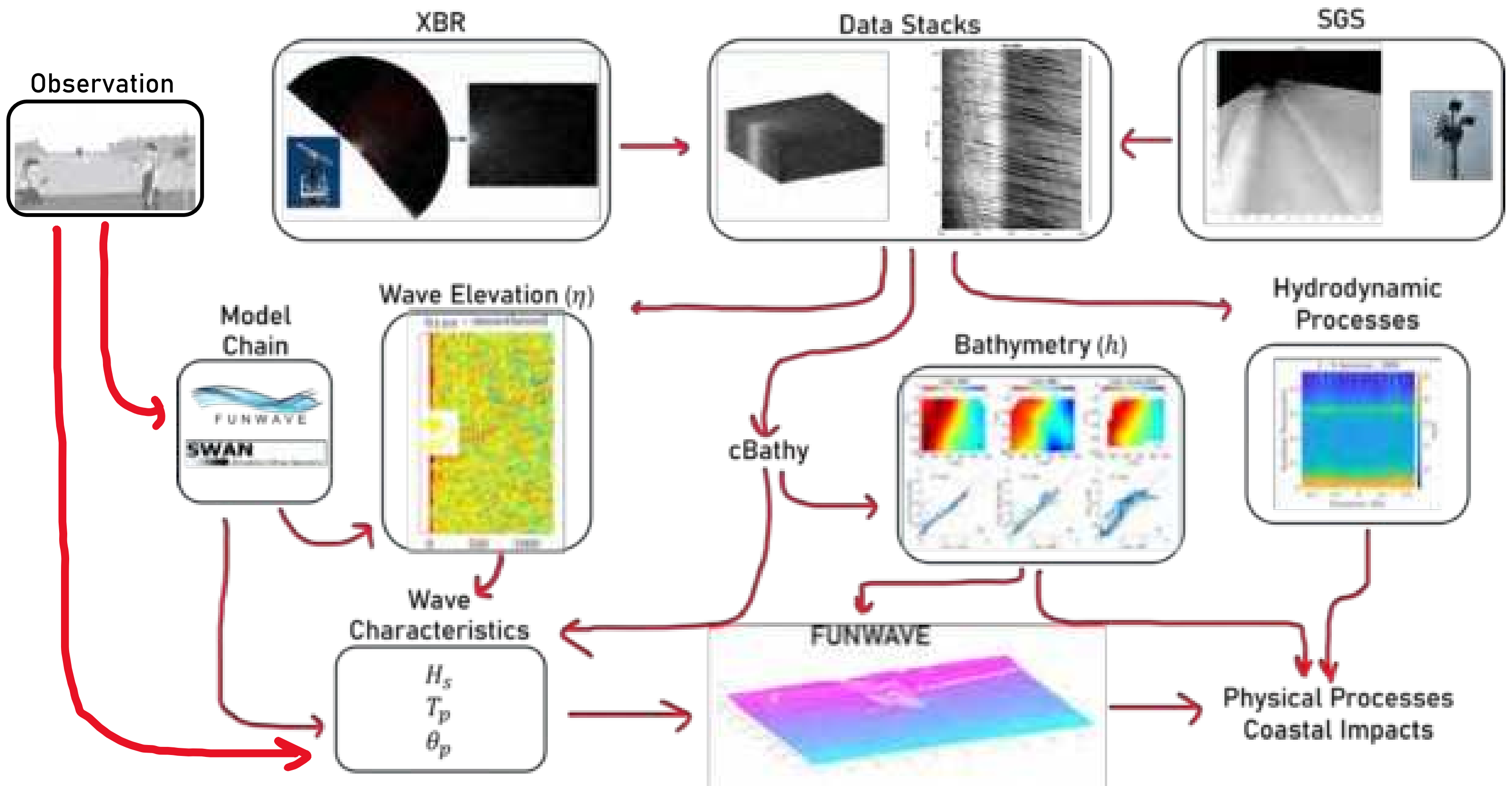






What is Next?

→ Coupling information between methodologies.
→ Flow field estimation by wave-current interaction.
→ Increasing sampling to work on 2D evolution of characteristics from offshore to nearshore.
→ Investigation on incorporation and combination of Artificial Intelligence (AI) to enhance performance



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SEDIMARE DC MEETING

11.03.2025-13.03.2025

Santander, Spain

Nearshore Wave Processes by Remote Sensing

Muhammed Said Parlak
m.s.parlak@univpm.it

https://sedimare.eu

Acknowledgement: This project has received funding from the European Union's (EU) Horizon Europe Framework Programme (HORIZON) under Grant Agreement No 101072443 as a MSCA Doctoral Network (HORIZON-MSCA-2021-DN-01) of

UNIVERSITY OF TWENTE.

SEDIMARE 2023 - 2027

Sediment Transport and Morphodynamics in Marine and Coastal Waters with Engineering Solutions

SEDIMARE PROJECT_DC #3

Santander Meeting

TRANSPORT AND WAVE RIPPLES DEVELOPMENT OF SAND-SILT MIXTURES

PhD Candidate: Nguyen, Thi To Van (Van)
Promotor: P.C. Roos (Pieter)
Co-promotor: J.J. van der Werf (Jebbe)

Date: 2025 March 12th

Contents

1. Introduction

In nature, especially in coastal and fluvial systems, most of sediments are mixes of sand and fines (clay and silt).

Recently, there have been more studies focusing on the transport of sand-mud mixtures. However, most of these studies treated clay and silt collectively as mud (*Mitchener and Torfs, 1996; Van Ledden, 2003; Jacobs, 2011; Winterwerp et al., 2012; Colina Alonso et al., 2023*).

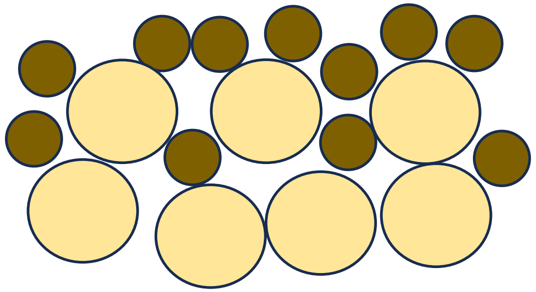
Silty sediments in Mekong Delta, Vietnam
[Photo by MangLub project]

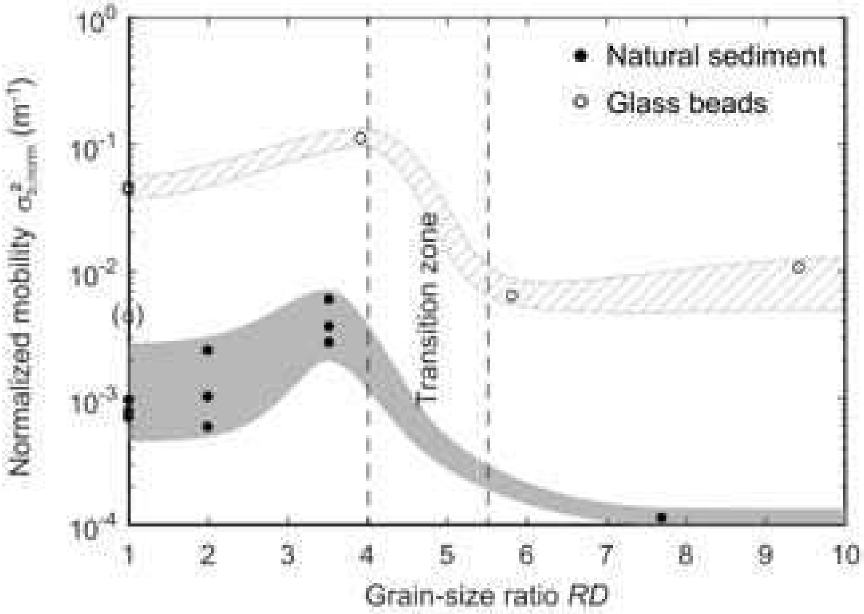
Mudflat, Wadden Sea, Netherlands.

Satellite images of the Mekong Delta taken by Envisat

1. Introduction

Small RD



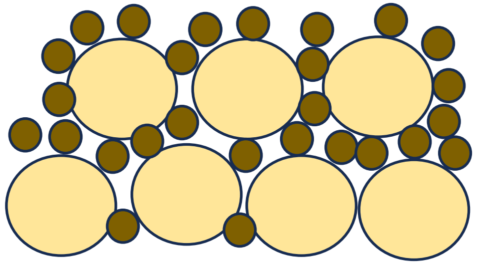


Normalized mobility (logarithmic scale), with varying grain-size ratio (Staudt et al., 2019)

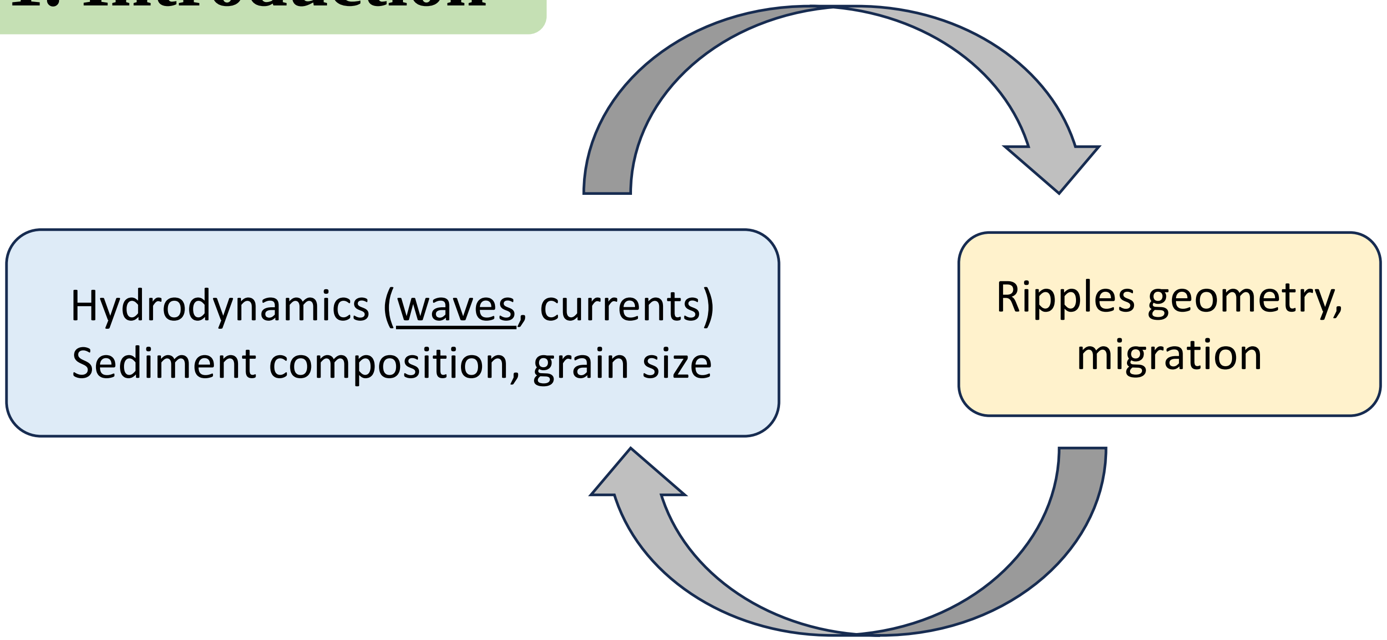
4

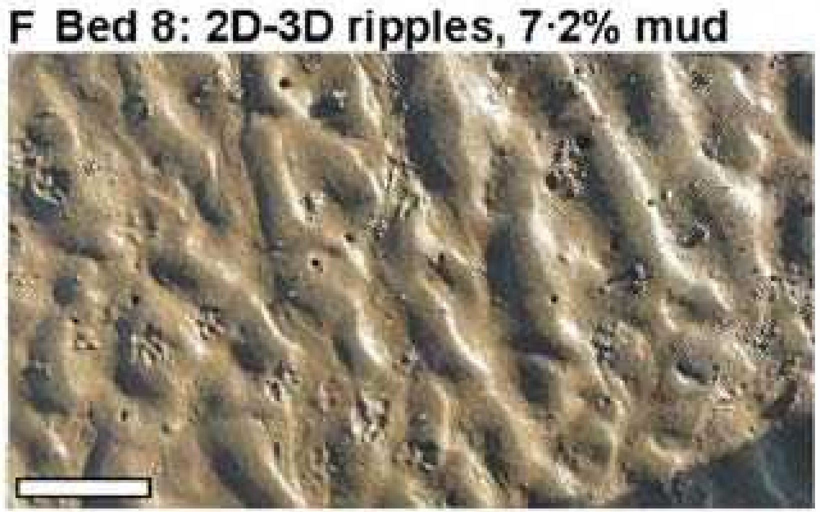
63

Large RD (grain-size ratio)



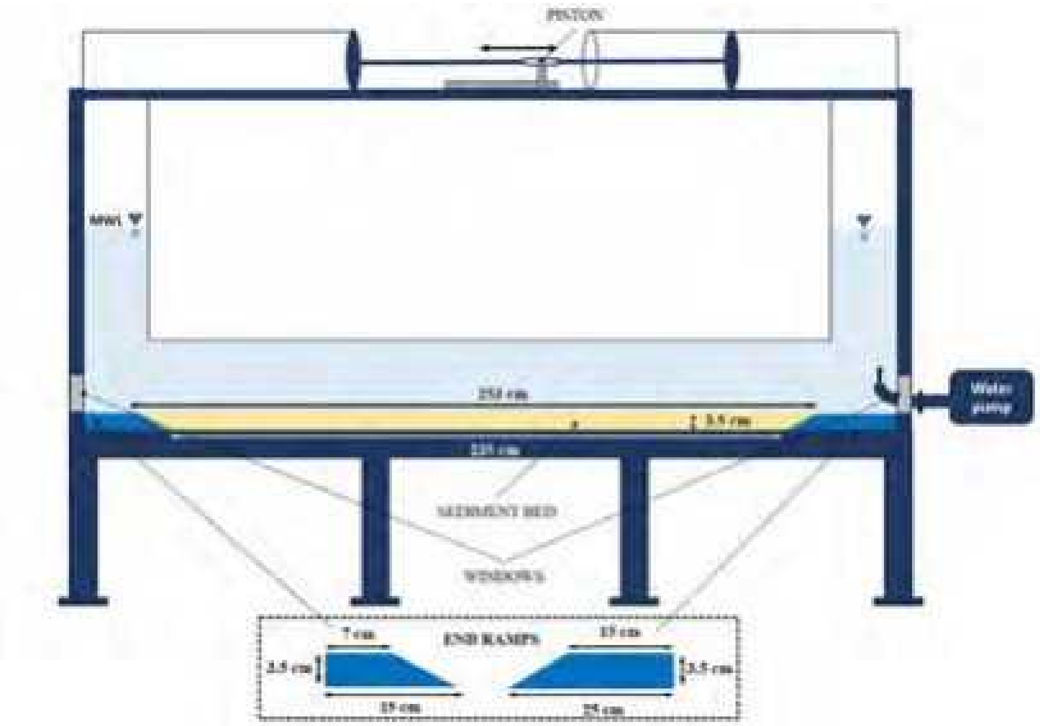
1. Introduction





Field examples of 2D–3D ripples (percentages denote subsurface mudcontents, the scale bar is 200 mm long (Baas et al., 2019)

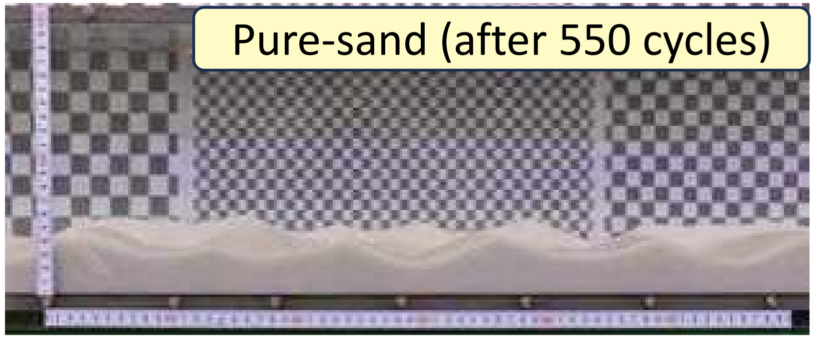
2. Sand-silt experiments

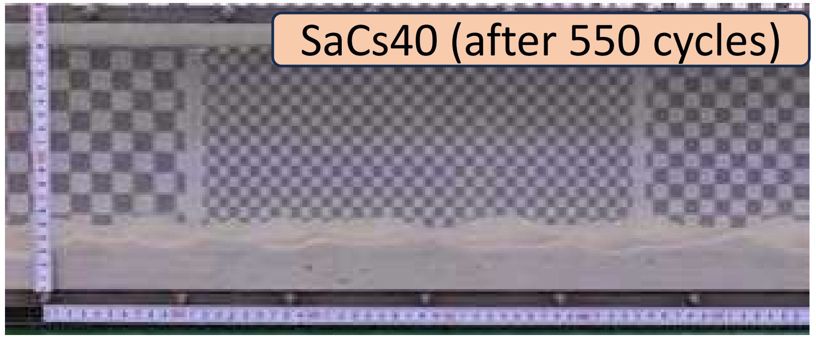


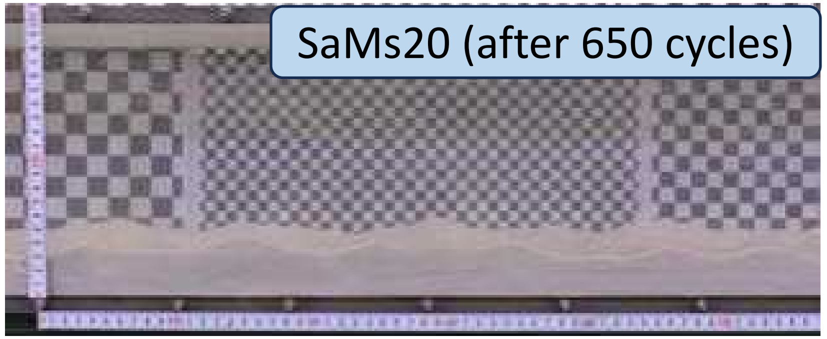
Previous preparatory experiment in the Mini tunnel

Observations

Experiences







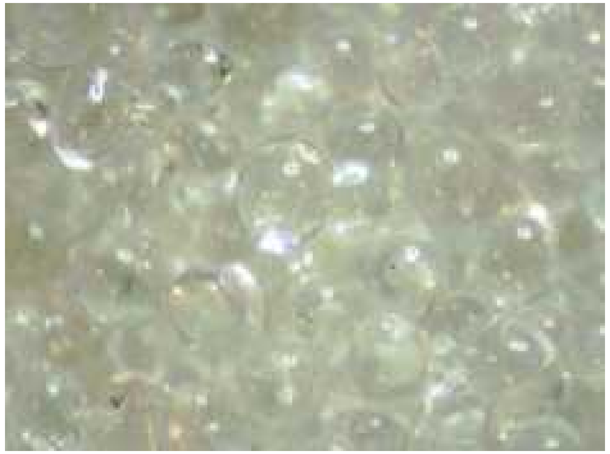
RQ1: What is the effect of silt (e.g., silt contents, grain-size ratio, compaction of the bed) on the initial motion of sand-silt mixtures?

RQ2: What is the effect of silt on the transport processes of sand-silt mixtures?

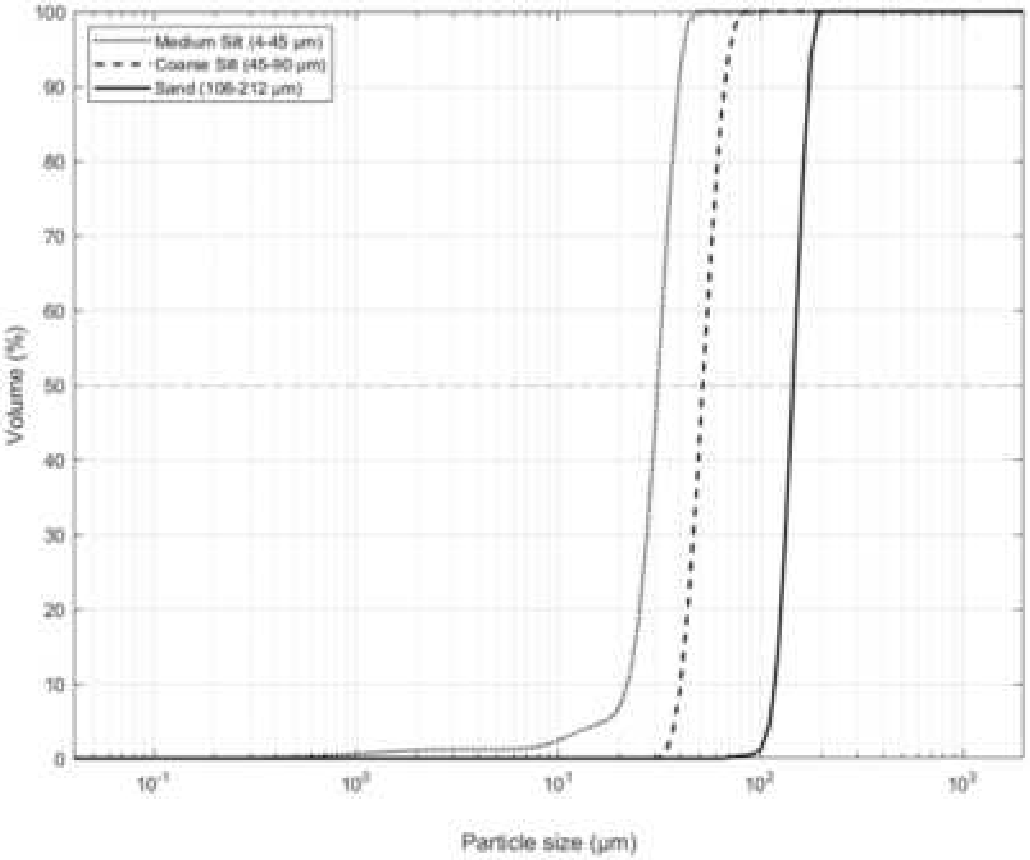
RQ3: What are the effects of silt and sand-silt interactions on the development and geometry of bedforms?

2. Sand-silt experiments

Sediment fractions	D_{10} (µm)	D_{16} (µm)	D_{50} (µm)	D_{84} (µm)	D_{90} (µm)	σ_g (-)
Medium silt	21.90	24.12	30.95	37.62	39.27	1.25
Coarse silt	40.17	42.30	51.76	62.90	66.54	1.22
Sand	117.03	123.09	144.34	167.49	173.15	1.17



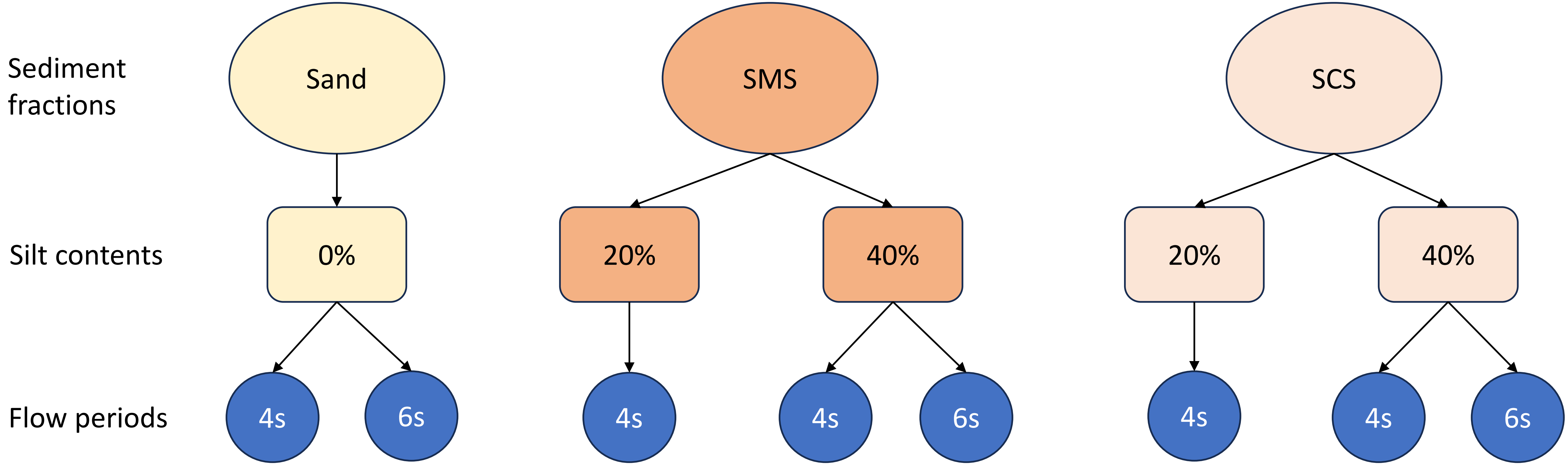
Glass Bead is a chemically inert soda lime glass that is round in shape, well-sort in distribution and has main composition is silica ($\rho_s = 2500 \text{ kg/m}^3$).



Particle-size distributions of glass beads using a laser diffraction particle size analyzer (Beckman Coulter LS13320)

2. Sand-silt experiments

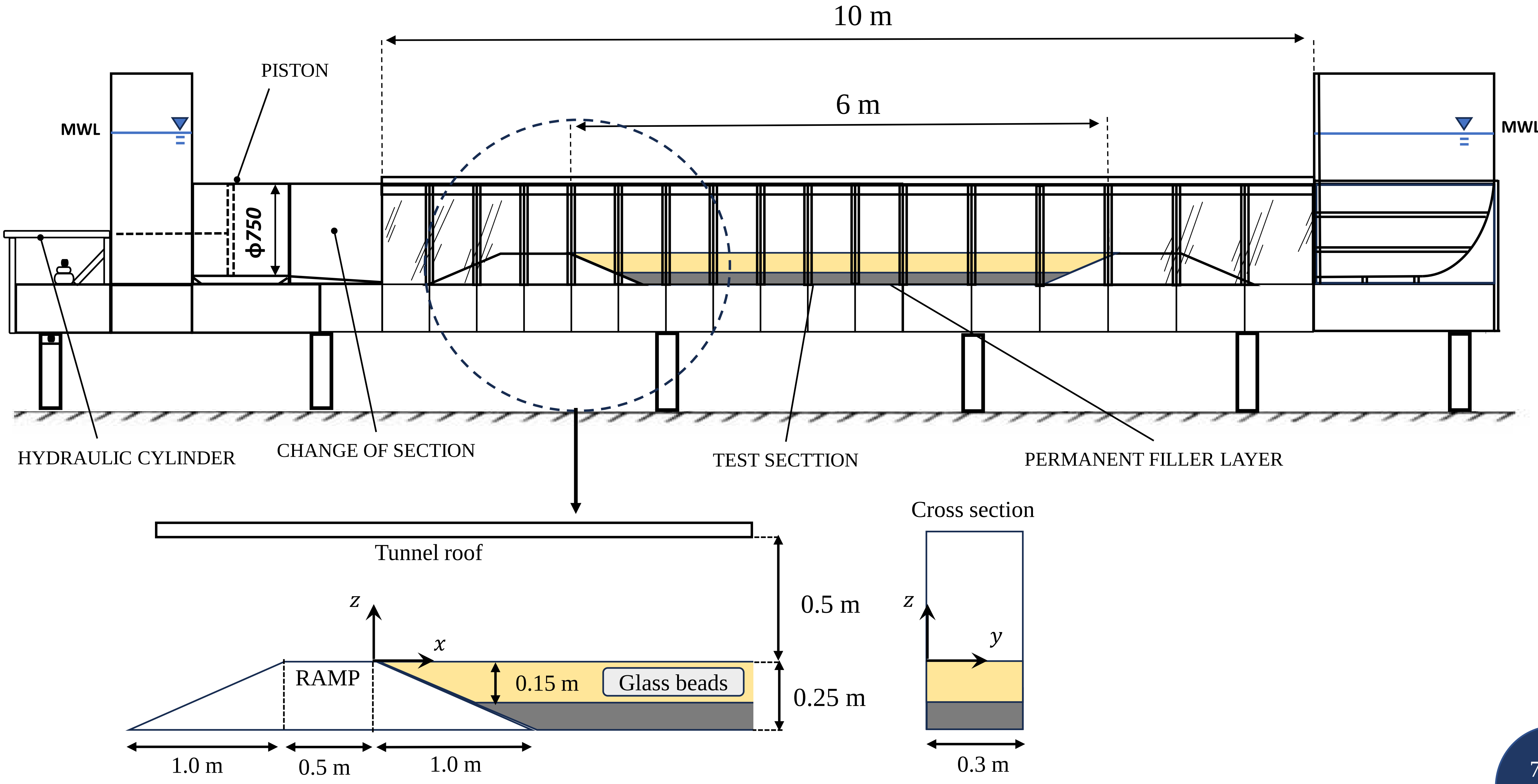
Experimental conditions



Flow velocities

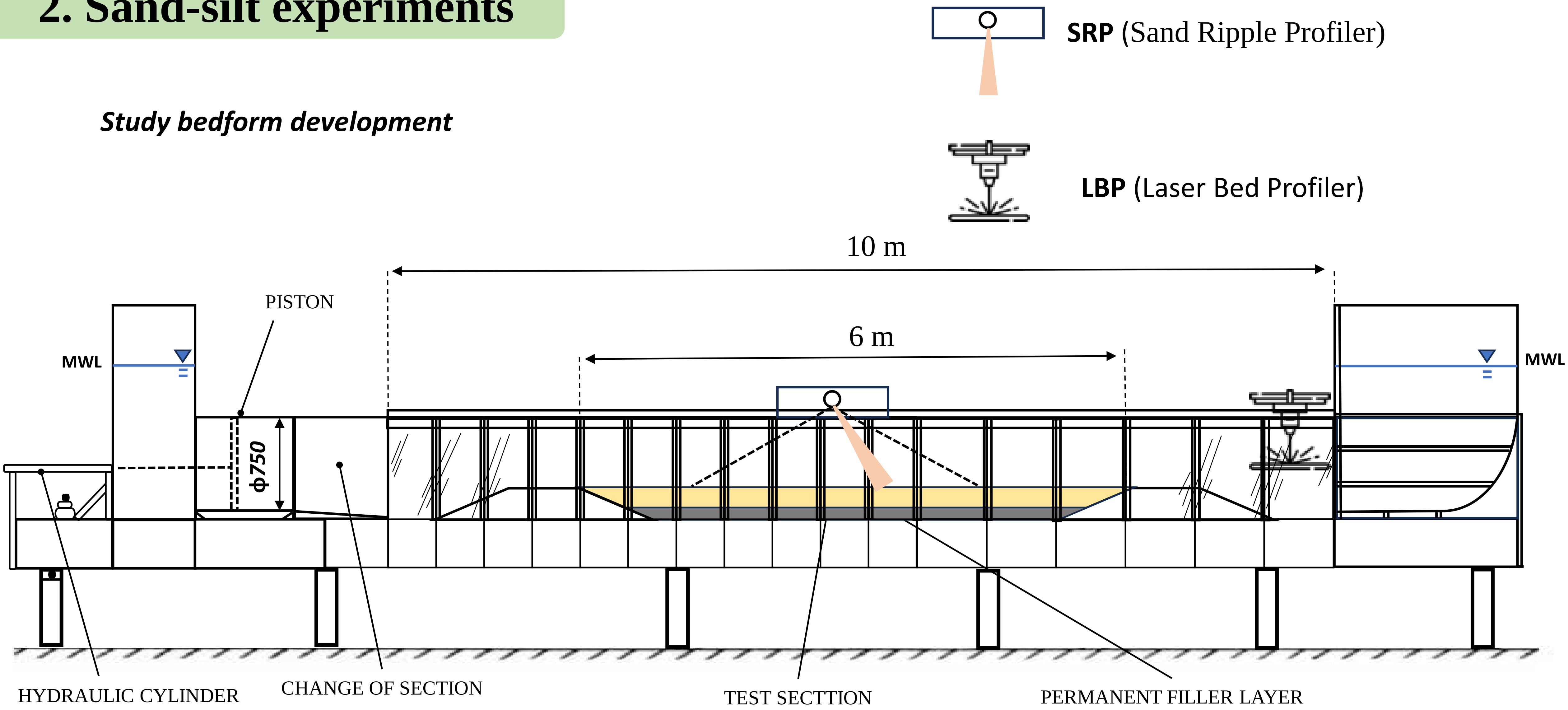
All will be tested with three velocities conditions: 0.2, 0.3 and 0.4 m/s.
=> In total, there will be 24 tests excluding some repetitions.

2. Sand-silt experiments

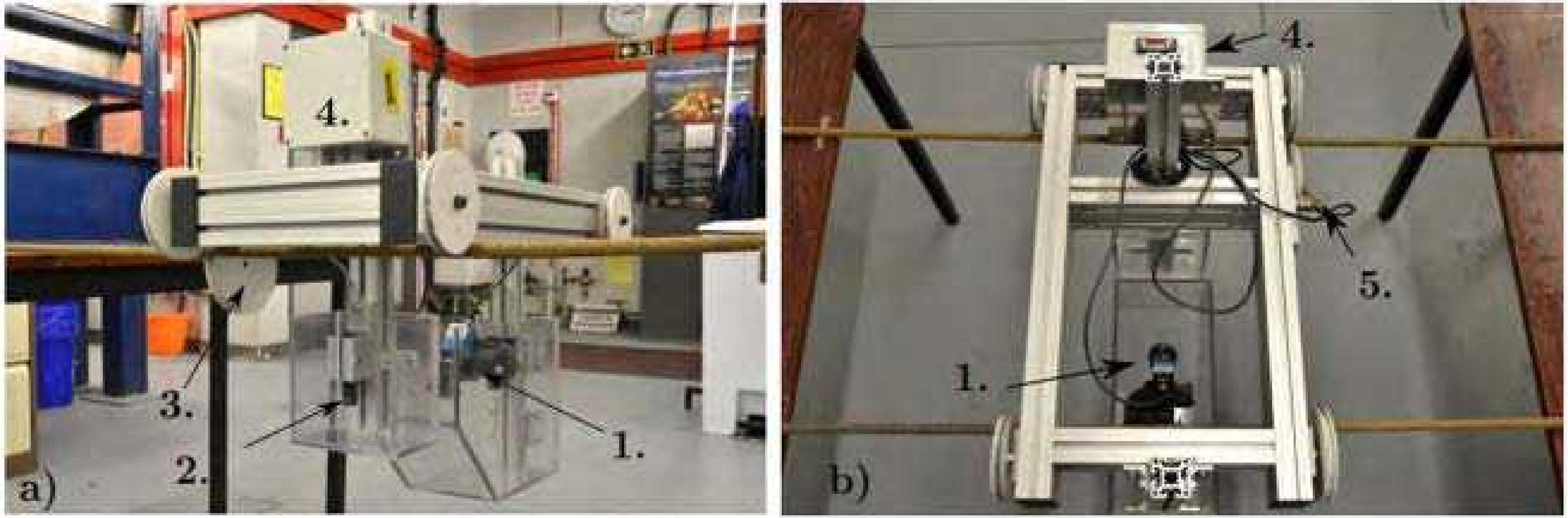


2. Sand-silt experiments

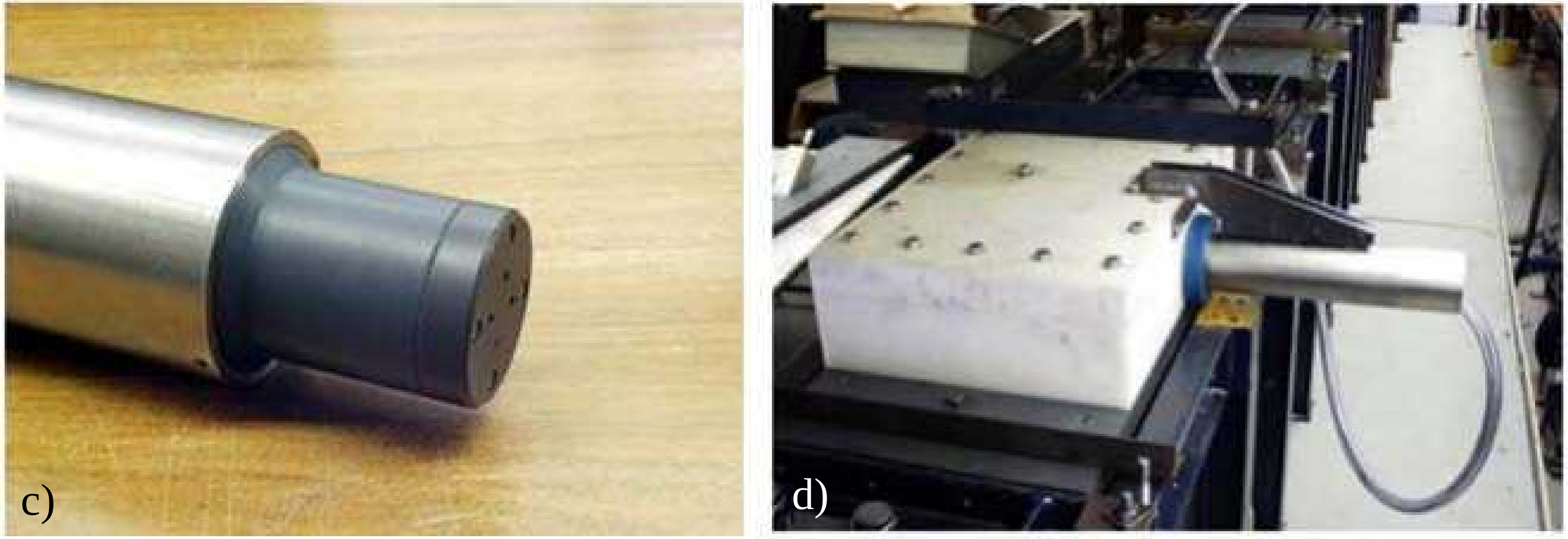
Study bedform development



2. Sand-silt experiments



(a) In-house built Laser Bed Profiler; (b) top view of the LBP (Boscia, 2021)



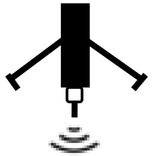
(c) Sand Ripple Profiler head probe; (d) SRP tunnel mounting (pictures taken from Boscia (2021))

2. Sand-silt experiments

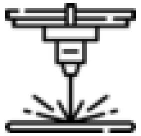
Detailed measurements of velocity and SSC after the bed reaches its equilibrium state

TSS (Transverse Suction System)

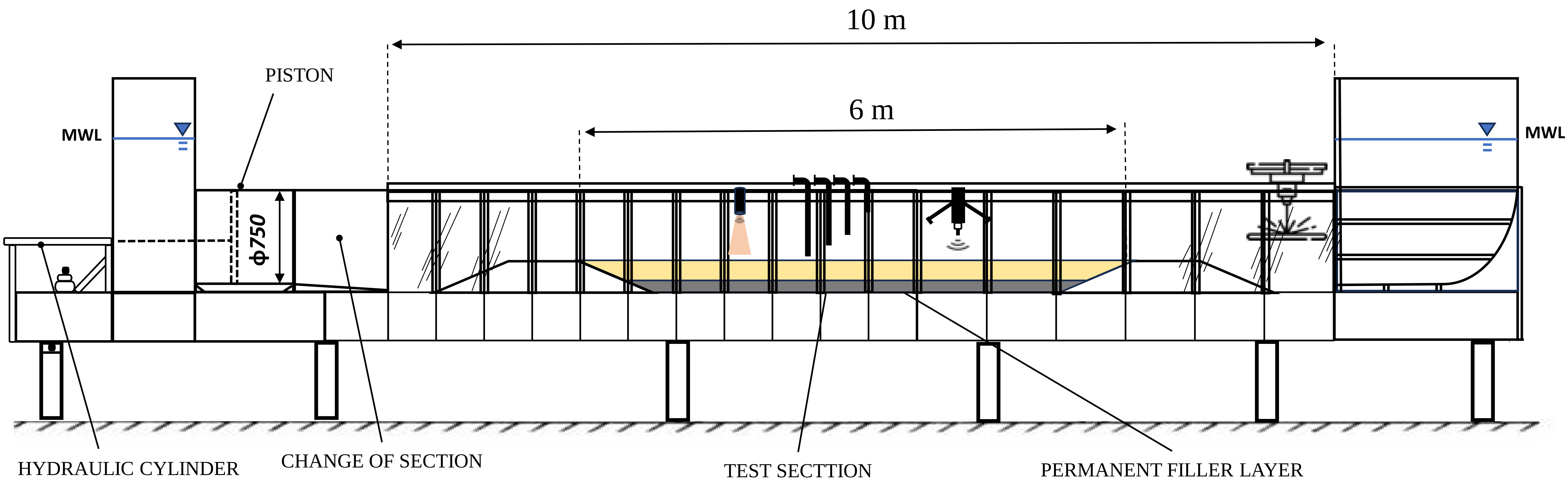
ABS (Acoustic Backscatter System)



Ubertone (commercial ACVP – Acoustic Concentration and Velocity Profiler)



Laser system



2. Sand-silt experiments

(a) TSS nozzles in position in the tunnel.
(b) Peristaltic pump (Boscia, 2021)

UB-Lab 2C main components (Boscia, 2021)

2. Sand-silt experiments

Experiment phase	Instruments	Output	Research question
Phase 1	Ubertone, ABS, TSS, camera	SSC and velocity profiles, videos.	RQ1: Initiation motions
Phase 2	SRP, LBP	Time-varying, pre- and post experiment bed levels	RQ3: Development and geometry of bedforms
Phase 3	Ubertone, ABS, TSS, LBP	SSC and velocity profiles, sand mass from traps in two ends	RQ2: Transport processes

3. Conclusion

- There is still a lack of knowledge about the effect of silt on transport and ripple characteristics in sand-silt mixtures.
- There are very few experimental studies on the development of ripples in sand-silt mixed beds.

We are now working on the main experiment and expect to finish it by July 2025.

THANK YOU FOR YOUR ATTENTION

Source: freepik

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SEDIMARE

Formulating guidelines for the design of breach experiments

Siyuan Wang

s.wang-4@utwente.nl

Supervised by:

Dr. Ir. P.C. Roos (UT)

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12 March 2025

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Ebrahimi et al. (2024)

Overview

1. Problem investigation
2. Research objective and steps
3. Methodology
4. Planning


Ebrahimi et al. (2024)

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Dam breaching


image by Mrs. Eunice Olson, courtesy of A. G. Sylvester


ASCE Review Panel 2007

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Main causes: overtopping and piping

Hanson et al. (2005)

Hanson et al. (2010)

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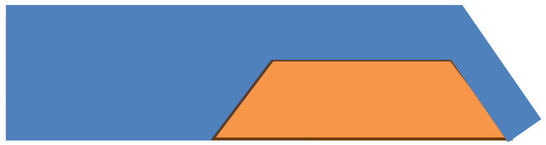
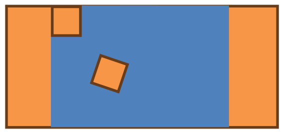
Overtopping dam breaching



Side view



Downstream view

(a) 9:10 July 31, 2018
(b) 9:30 July 31, 2018
(c) 9:40 July 31, 2018
(d) 10:00 July 31, 2018
(e) 10:15 July 31, 2018
(f) 10:50 July 31, 2018

dam breach process of Sheyuegou Dam in China

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Overtopping dam breaching experiments

Scale

- Small scale < 1m
- Medium scale 1m – 3m
- Large scale > 3m

Cohesion

- Non-cohesive
- Cohesive
- Wide grain size distribution

Hydraulic forcing

- Constant inflow
- Constant upstream water level

Measurements

- Photogrammetry
- Laser-sheet
- Ultrasonic gauges
- …

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Problem statement

Key challenges

- Lack of parameterization
- Differences in experiment setups
- Lack of systematic criteria
- Challenge of measuring the key variables

Consequences

- Hindered model calibration and validation
- Reduced comparability of results
- Difficult in deriving reliable and generalized conclusions

Problem

Absence of systematic guidelines for overtopping dam breaching experiments to repeat the same experiment

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Main goal:

Develop **systematic guidelines** for overtopping **dam breaching experiments** to standardize experimental **setup procedures** and provide clear **decision criteria**, ensuring experiments provide reliable, comparable, and sufficient data for **numerical model** calibration and validation.

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Design step 1: What are the current practices and methodologies used in dam breaching experiments?

Design step 2: How can dam breaching experiments be systematically designed to better support numerical modelling?

Design step 3: Do the guidelines clearly explain how to design dam breaching experiments and provide parameters for modelling?

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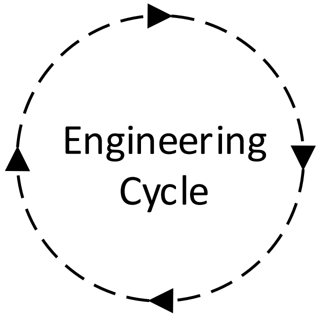
D1/D5 Problem Investigation / Implementation Evaluation
- Stakeholders? Goals?
- Mechanisms? Effects?
- Lack of contribution to goals?

D2 Treatment Design
- Specify requirements!
- Requirements contribute to goals?
- Available treatments?
- Design new ones!



D3 Design Validation
- Effects of treatment in this context?
- Effects satisfy requirements?
- Trade-offs?
- Sensitivity for different contexts?

D4 Treatment Implementation
- Utilize in practice!

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Design step 1: What are the current practices and methodologies used in dam breaching e

a asurements conduc

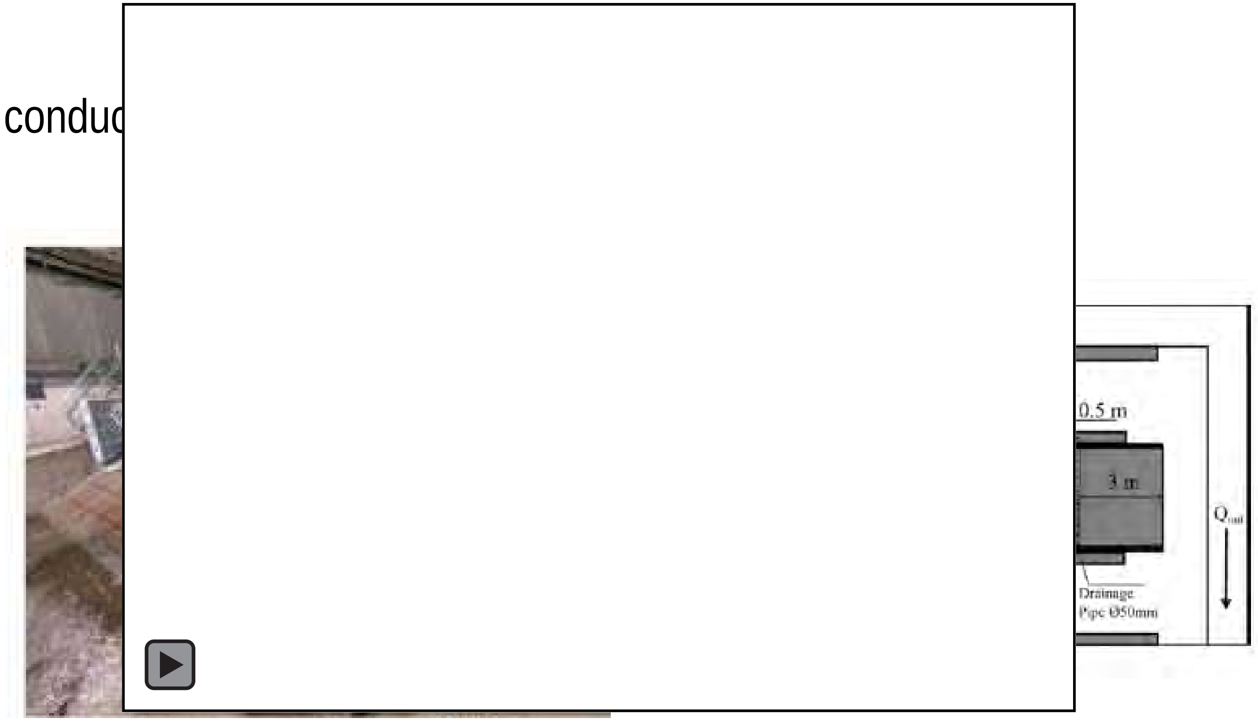
Small scale

Non-cohesive

Constant inflow

Laser-sheet, Current meter and Water level gaugues

Delpierre et al. (2024)



Medium scale

Non-cohesive

Constant water level or constant inflow

Photogrammetry, Pore pressure, Hydrostatic and Ultrasonic gauges

Ebrahimi et al. (2024)

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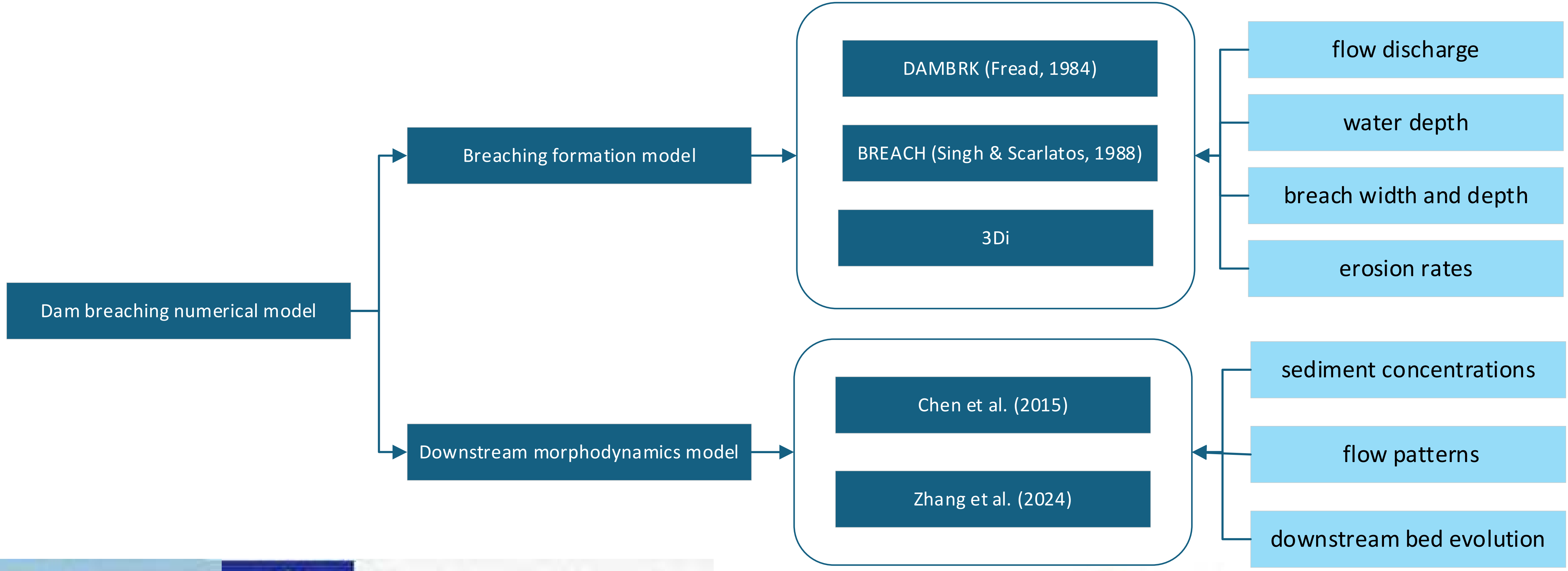
Design step 1: What are the current practices and methodologies used in dam breaching experiments?

b. What **parameters** are required to meet the needs of different types of **numerical modelling**?



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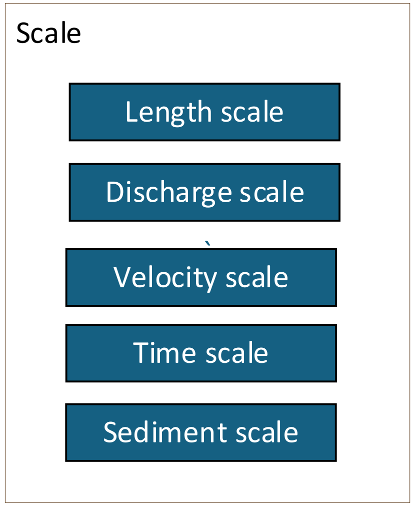
Design step 2: How can dam breaching experiments be systematically designed to better support numerical modelling?

a. How can **experimental dimensions** be defined, and how can data from different scales be normalized?



Dynamic similarity: Froude similarity

$$Fr = \frac{V}{\sqrt{gL}}$$

$$\lambda_L = \frac{L_{model}}{L_{prototype}}$$

$$\lambda_V = \lambda_L^{0.5}$$

$$\lambda_t = \lambda_L^{0.5}$$

$$\lambda_Q = \lambda_L^{2.5}$$

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Design step 2: How can dam breaching experiments be systematically designed to better support numerical modelling?

b. How can **measurement settings** and techniques be effectively selected?

c. What **procedural steps** are necessary to ensure experimental setups are consistent, reliable, and reproducible?

Procedural steps

- Construction dams
- Calibrating measurements
- Controlling hydraulic forces

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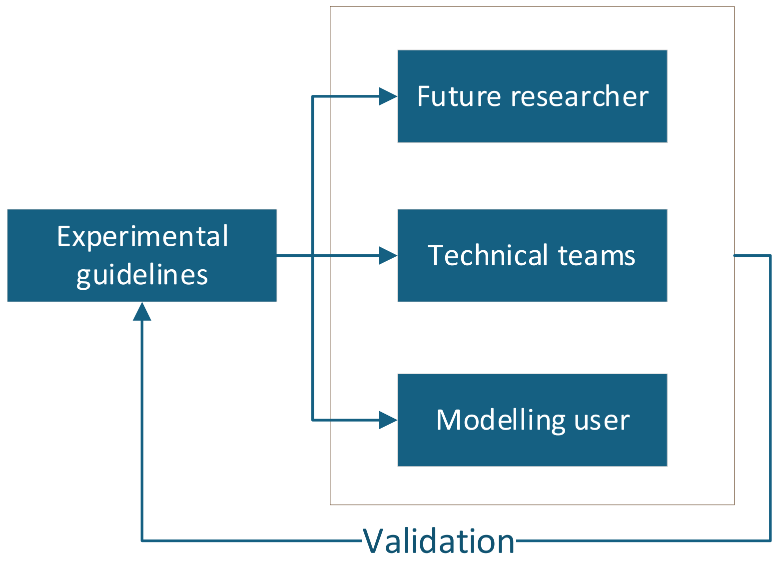
Design step 3: Do the guidelines clearly explain how to design dam breaching experiments and provide parameters for modelling?

a. How effectively does the **guidelines** provide a systematic approach to **designing** dam breaching **experiments** with comparable results across different scales?

b. To what extent do the experimental results provide sufficient **parameters** for calibration and validation of **numerical models**?



- Reliability
- Repeatability
- Scalability
- Feasibility

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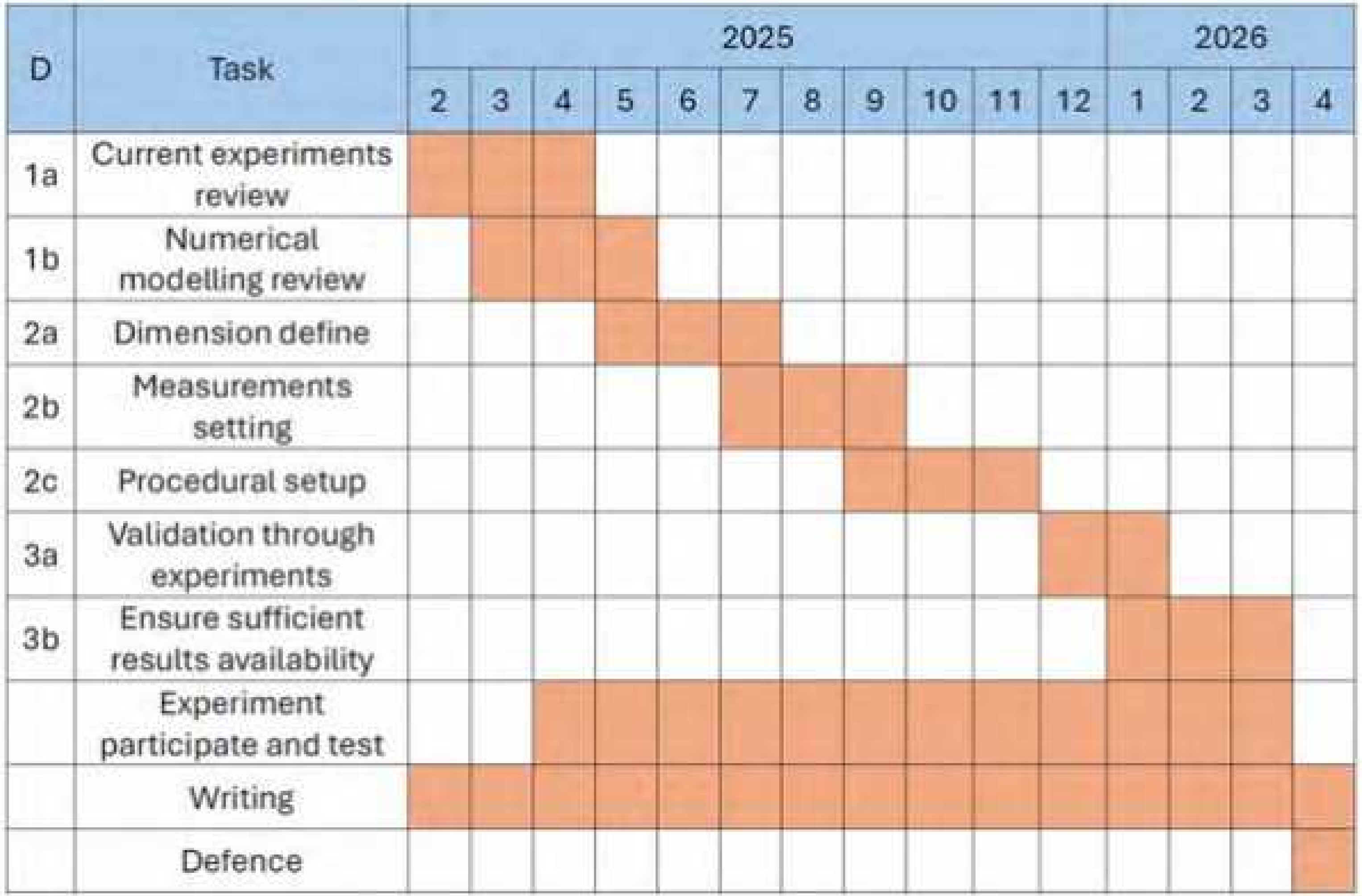

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Formulating guidelines for the design of breach experiments

Siyuan Wang
s.wang-4@utwente.nl

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Ebrahimi et al. (2024)

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Santander Workshop

Characterization of stratification and near-bed dense layers in high-density sediment-laden flow

D.C 9- Eloah Rosas

Promoter

Benoît Spinewine

Sandra Soares

This project has received funding from the European Union's (EU) Horizon Europe Framework Programme (HORIZON) under Grant Agreement No 101072443 as a MSCA Doctoral Network (HORIZON-MSCA-2021-DN-01).

UCLouvain

FUGRO

Sediment transport shapes coastlines, sustains ecosystems, and challenges engineering—understanding its dynamics is key to predicting and managing our changing environment.

High-Density Sediment Laden Flow

Sediment-laden flow is characterized by unsteady, highly dense sediment concentrations and vertical stratification.

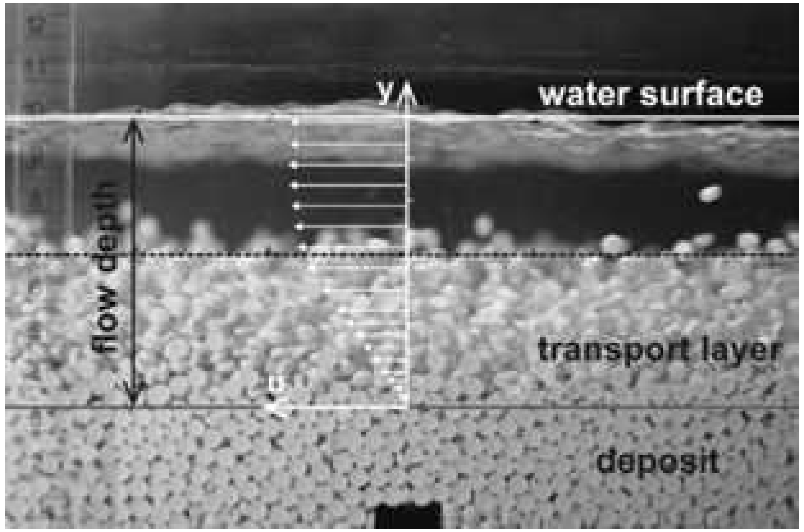
High-density sediment-laden flows is common in natural systems like rivers, deltas and coastal environments, and it can be initiated by natural or anthropogenic factors in the marine environment, such as:

Tsunamis, Earthquakes, Storms waves, Submarine Landslides, Dredging.

High Density Sediment Laden

Debris Flow

Turbidity Flow



Sheet Flow

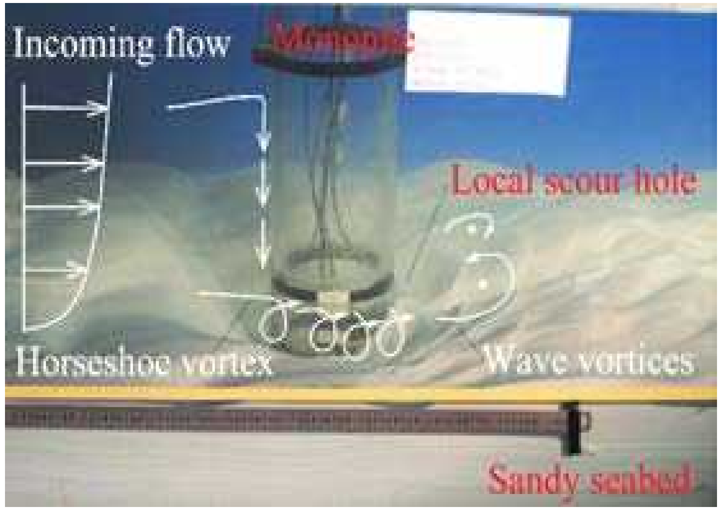
Threats of High-Density Sediment Laden

Damage Power Cables and Pipelines

Turbidity currents
debris flows
submarine landslides

Shoreline Retreat or Dune Instability

Storm induced sheet flow



Gao, F., & Qi, W. (2022).

Local Scour hole around Infrastructures

Waves-induced flow

Sheet Flow: High-Density Sediment Flow

Sheet flow occurs when intense shear stress mobilizes a dense, near-bed sediment layer, creating a high-concentration transport regime.

1. Vertical Density Structure

•Composed of two layers:

- A **dense, mobile sediment layer** near the bed.
- An **upper clearer water layer** free of sediment

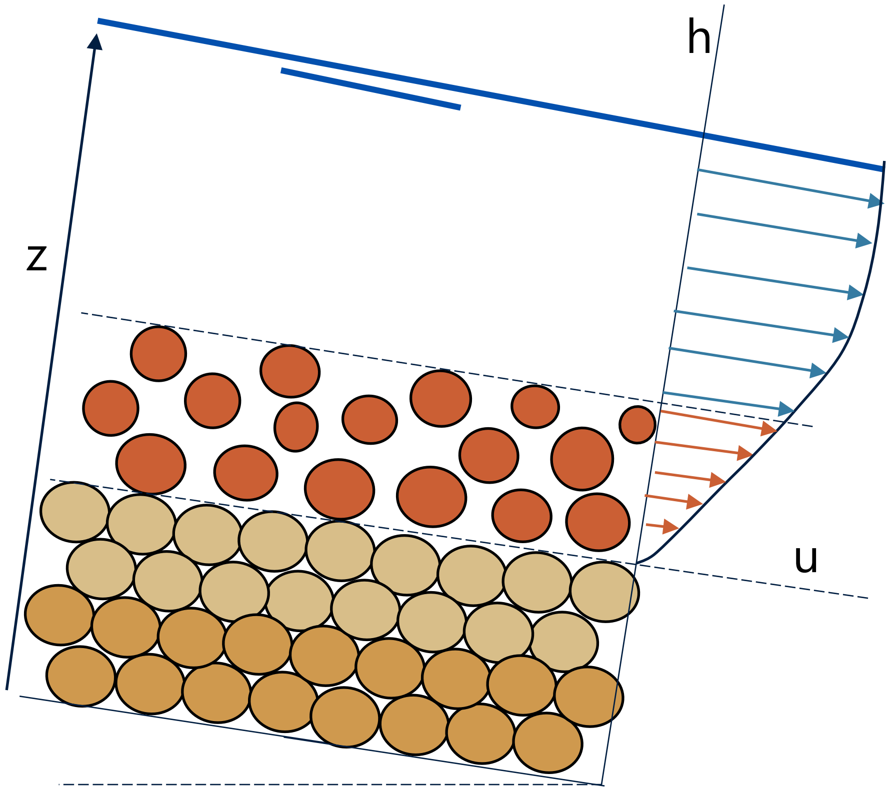
2. Velocity Profile

•**Near-bed velocity is close to zero**, increasing with height.

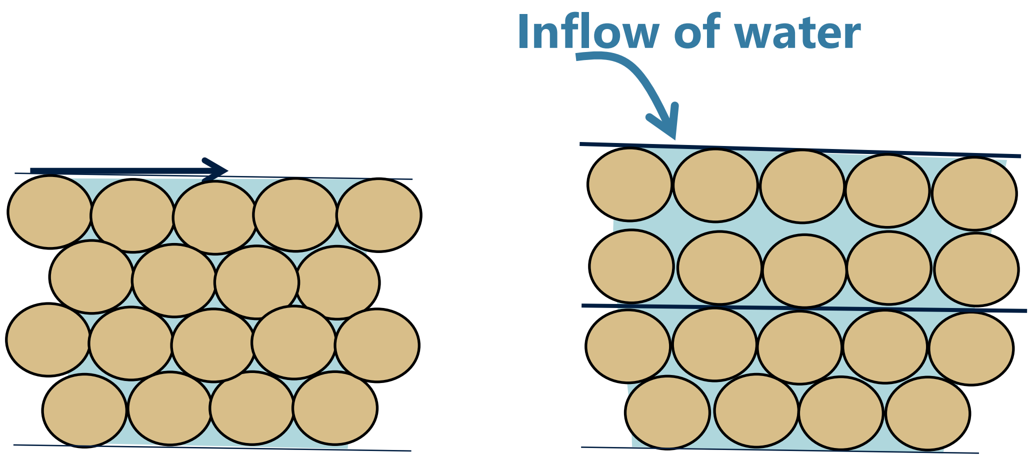
•**Logarithmic velocity distribution** in the water layer.

•**More linear velocity profile** within the transport layer.

3. Dilatancy & Particle Mobility



Process Governing Vertical layer
Granular Dilatancy



Dilatancy refers to the increase in volume or expansion of the sediment matrix when the sediment undergoes shear deformation.

Key Factors Affecting Flow Dynamics:

1. **Pore Pressure Relaxation Effect**
When sediment is sheared, pore pressure can fluctuate. Relaxation of pore pressure may reduce resistance between particles, facilitating flow in the sediment bed.

2. **Suspension**
As the sediment undergoes shear deformation, fine particles may become suspended in the flow

3. **Vertical Mass and Momentum Exchange**
The exchange of mass and momentum between the sediment bed and the overlying fluid layer impacts the velocity profile of the flow.

Turbidity Flow: Gravity-Driven Sediment Transport

Turbidity currents are sustained by a **density contrast** between sediment-laden water and the surrounding fluid, allowing them to propagate under gravity.

1. Density Stratification

•The leading edge of the flow has a **high sediment concentration**, creating a sharp density contrast with ambient water.

•Suspended particles generate a **vertical density gradient**, influencing flow stability and mixing.

2. Velocity Profile

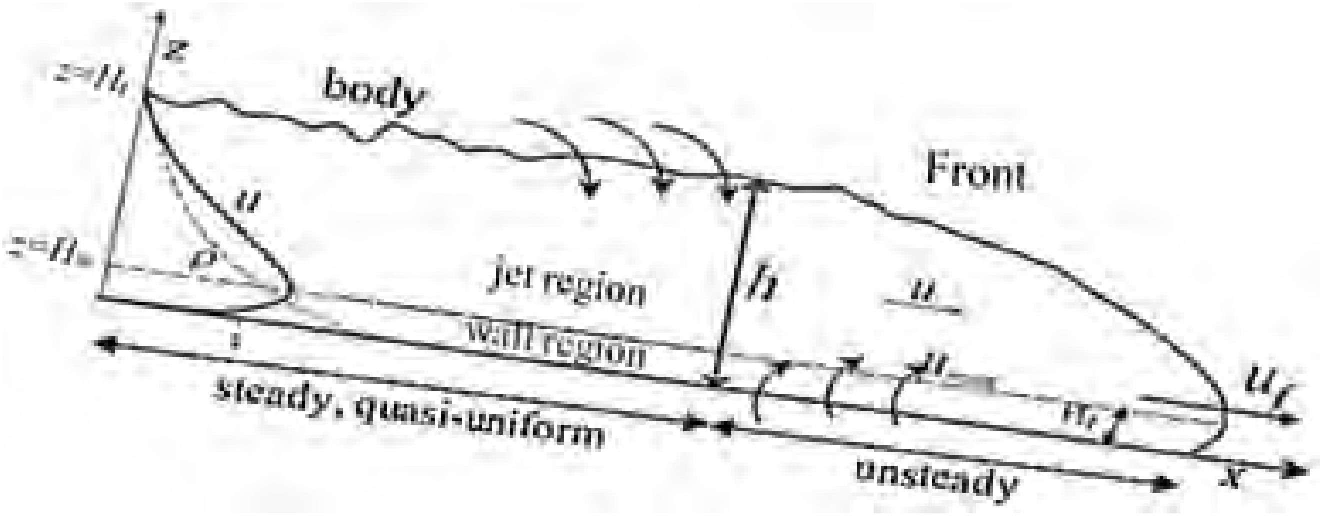
•The flow follows a **layered velocity structure**.

•**Maximum velocity occurs at an intermediate depth**, rather than at the bed or surface.

3. Entrainment of Water and Particles

•The current **entrains ambient water**, altering its density and momentum.

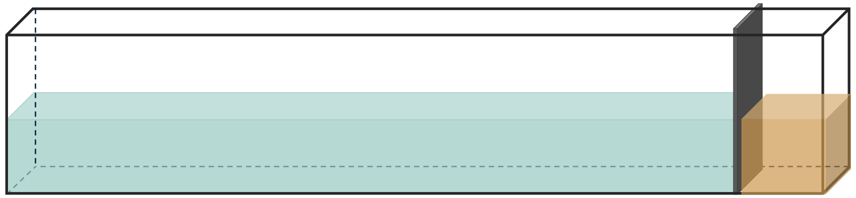
•**Sediment resuspension and settling** continuously adjust the flow's composition and behavior.



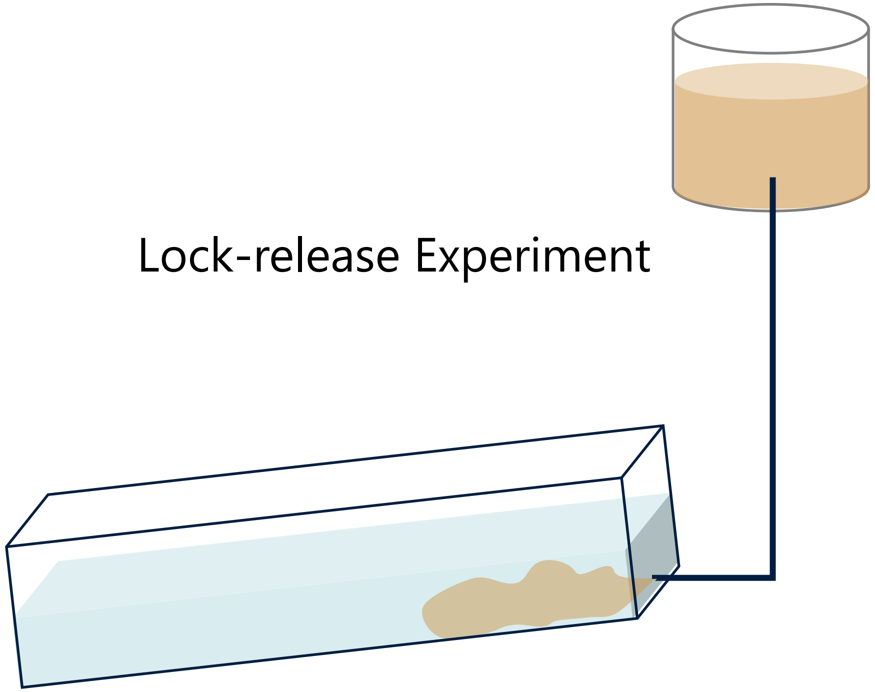
Methods to study High-density Sediment Flow

Laboratory experiments

Lock-exchange Experiment



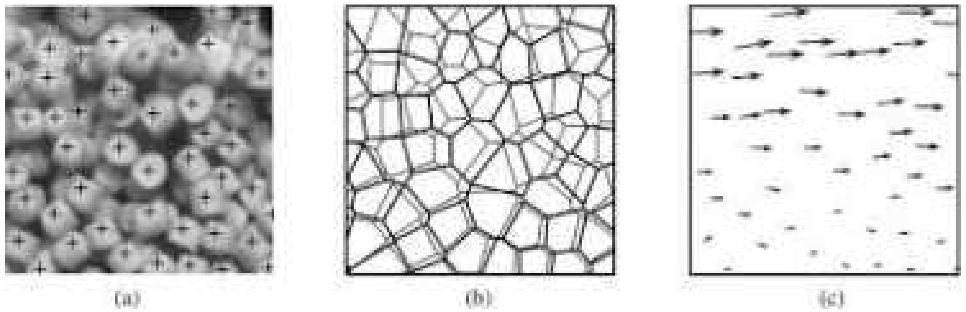
Lock-release Experiment

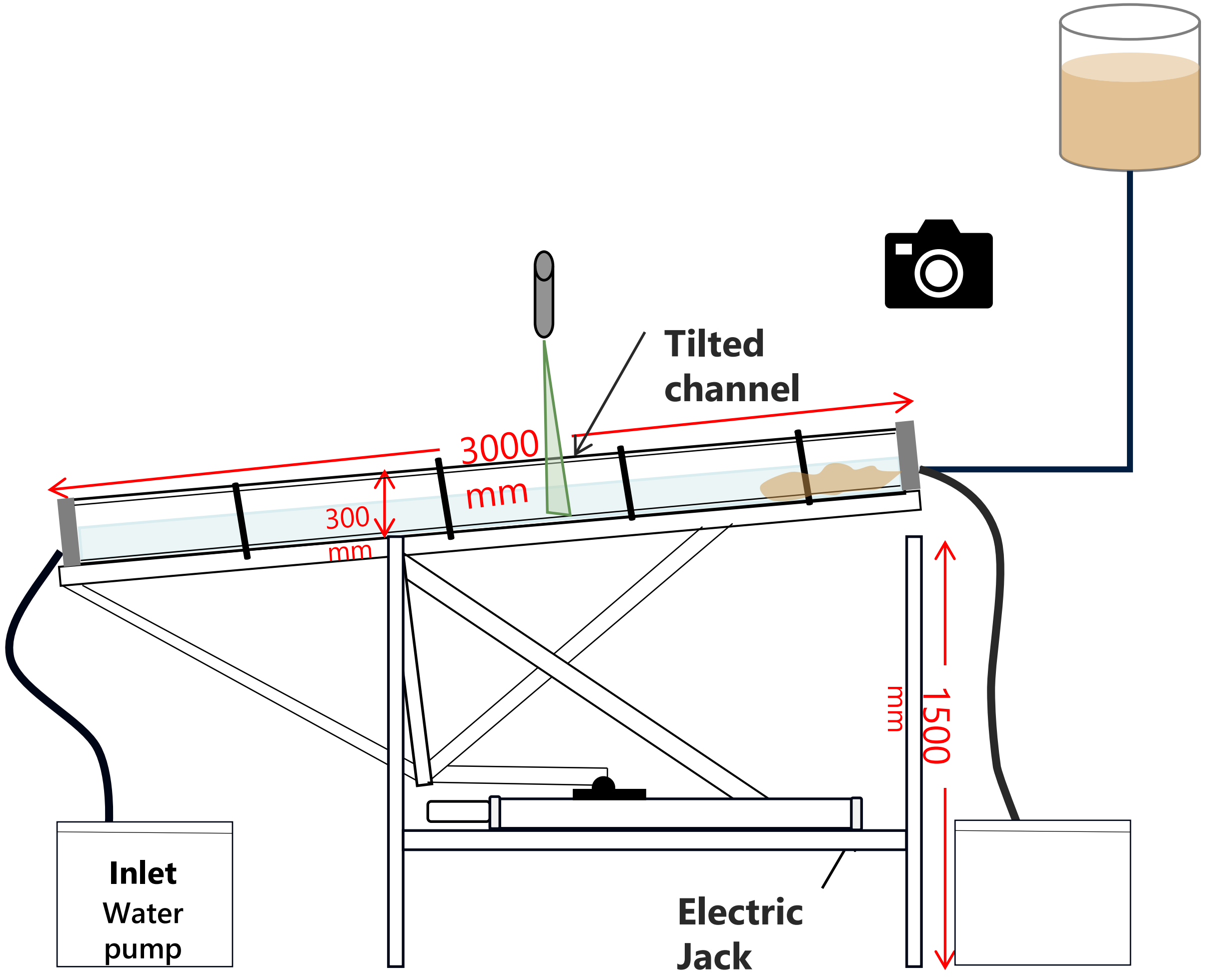


Methods to study High-density Sediment Flow

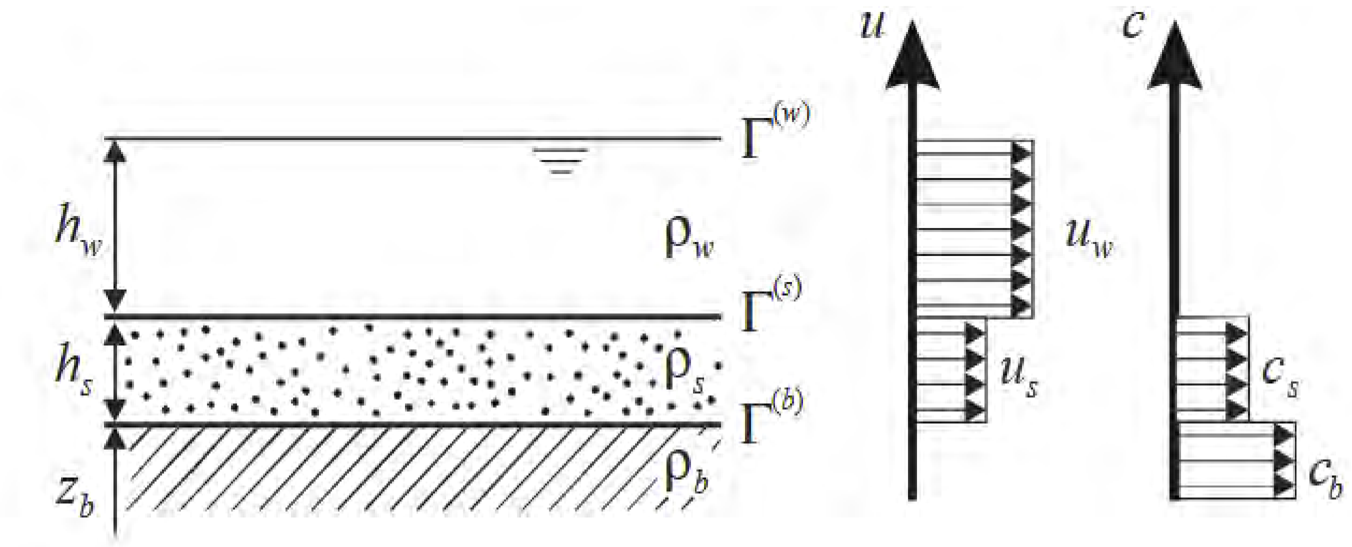
Laboratory experiments

Voronoi Pattern-based For Particle Tracking





Modelling the Sediment Transport



Two-layer Shallow water Model

$$\frac{\partial h_w}{\partial t} + \frac{\partial (h_w u_w)}{\partial x} = 0$$

$$\frac{\partial h_s}{\partial t} + \frac{\partial (h_s u_s)}{\partial x} = 0$$

Mass Conservation

$$\frac{\partial (h_w u_w)}{\partial x} + \frac{\partial}{\partial x}\left(h_w u_w^2 + \frac{g h_w^2}{2}\right) + g h_w \frac{\partial\left(\boldsymbol{z}^{(\boldsymbol{b})} + h_s\right)}{\partial x} = 0$$

$$\frac{\partial (h_s u_s)}{\partial x} + \frac{\partial}{\partial x}\left(h_s u_s^2 + \frac{g h_s^2}{2}\right) + g h_s \left(\frac{\partial \boldsymbol{z}^{(\boldsymbol{b})}}{\partial x} + \frac{\rho_w}{\rho_s}\frac{\partial h_w}{\partial x}\right) = 0$$

Momentum conservation

Governing Equations

Vertical exchange of the Mass and Momentum

Dilatancy – Erosion and Deposition Rate

Evolution of the bed

$$\frac{\partial z_b}{\partial t} = -e^b$$

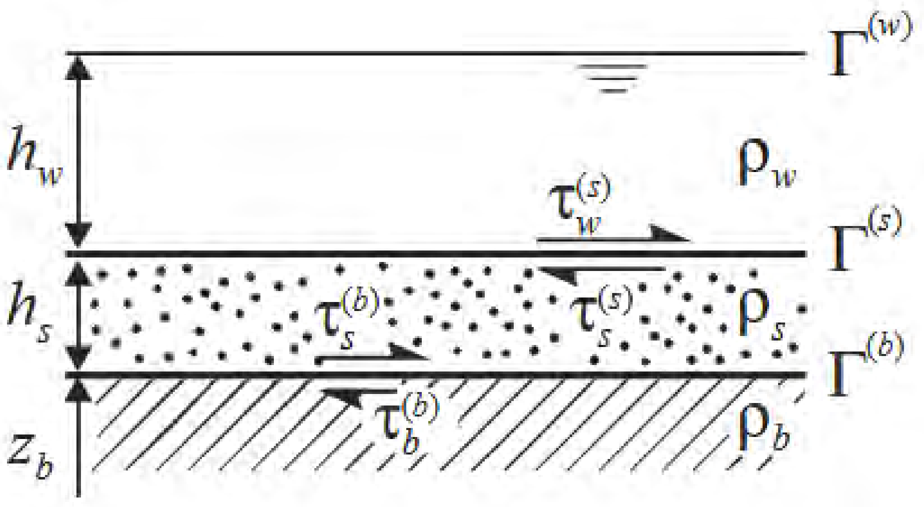
$$e^{(b)} = \frac{1}{\rho_b u_s}\left(\tau_s^{(b)} - \tau_b^{(b)}\right)$$

$e^{(b)} > 0$ **EROSION**

$e^{(b)} < 0$ **DEPOSITION**

Sediment Transport Layer

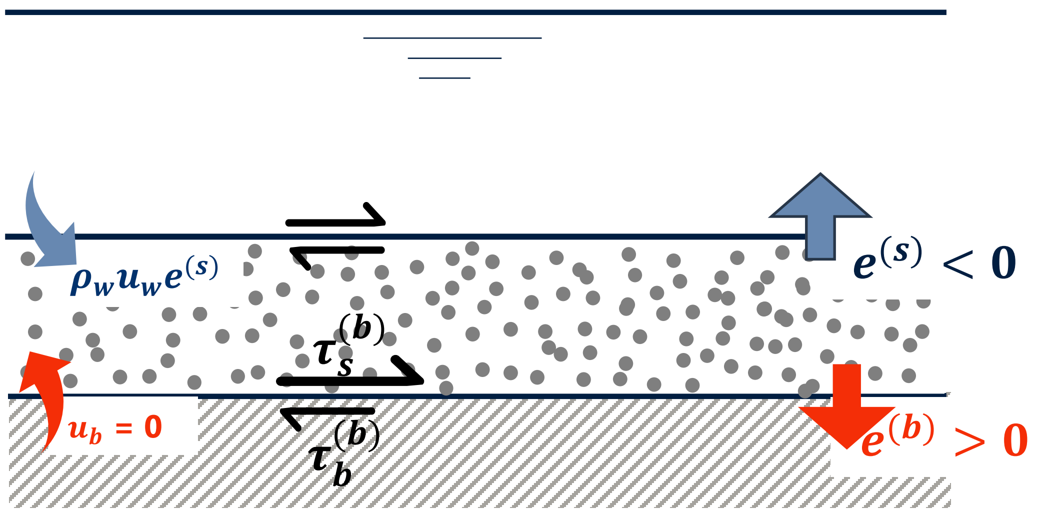
$$e^{(s)} = -\frac{\rho_b - \rho_s}{\rho_s - \rho_w} e^{(b)}$$



Governing Equations

Vertical exchange of the Mass and Momentum

Erosion



$$\boldsymbol{\tau_s^{(b)}} \geq \boldsymbol{\tau_b^{(b)}}$$

Mass Transfer

$$\frac{\partial h_w}{\partial t} = e^{(s)}$$

$$\frac{\partial h_s}{\partial t} = e^{(b)} - e^{(s)}$$

$$\frac{\partial z^{(b)}}{\partial t} = -e^{(b)}$$

Momentum Transfer

$$\frac{\partial (h_w u_w)}{\partial t} = \boldsymbol{u_w}\, e^{(s)} - \frac{\tau_w^{(s)}}{\rho_w}$$

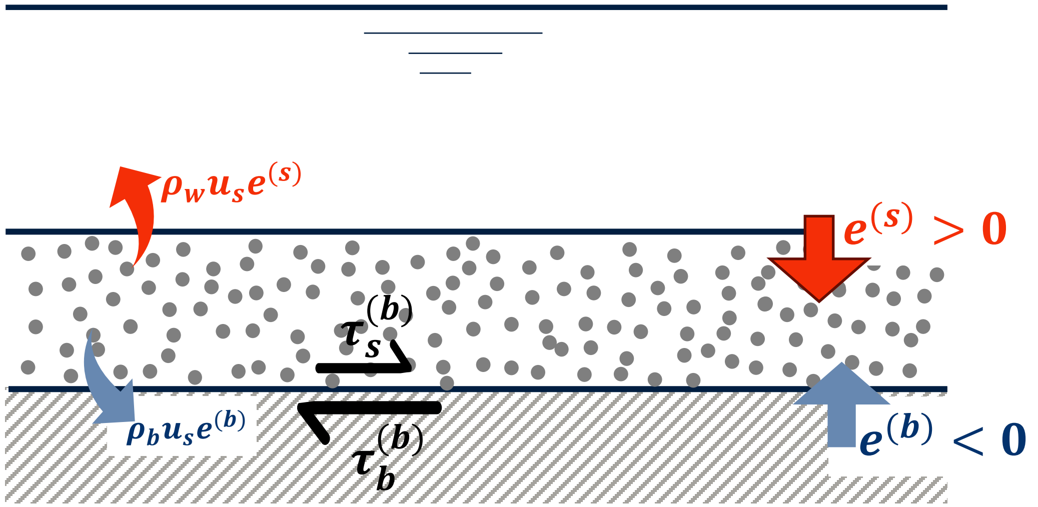
$$\frac{\partial (h_s u_s)}{\partial t} = -\frac{\rho_w}{\rho_s} u_w e^{(s)} + \frac{\tau_w^{(s)}}{\rho_s} - \frac{\tau_b^{(b)}}{\rho_s} + \mathbf{0}$$

Governing Equations

Mass and Momentum Transfer

Deposition

$$\boldsymbol{\tau_s^{(b)}} < \boldsymbol{\tau_b^{(b)}}$$

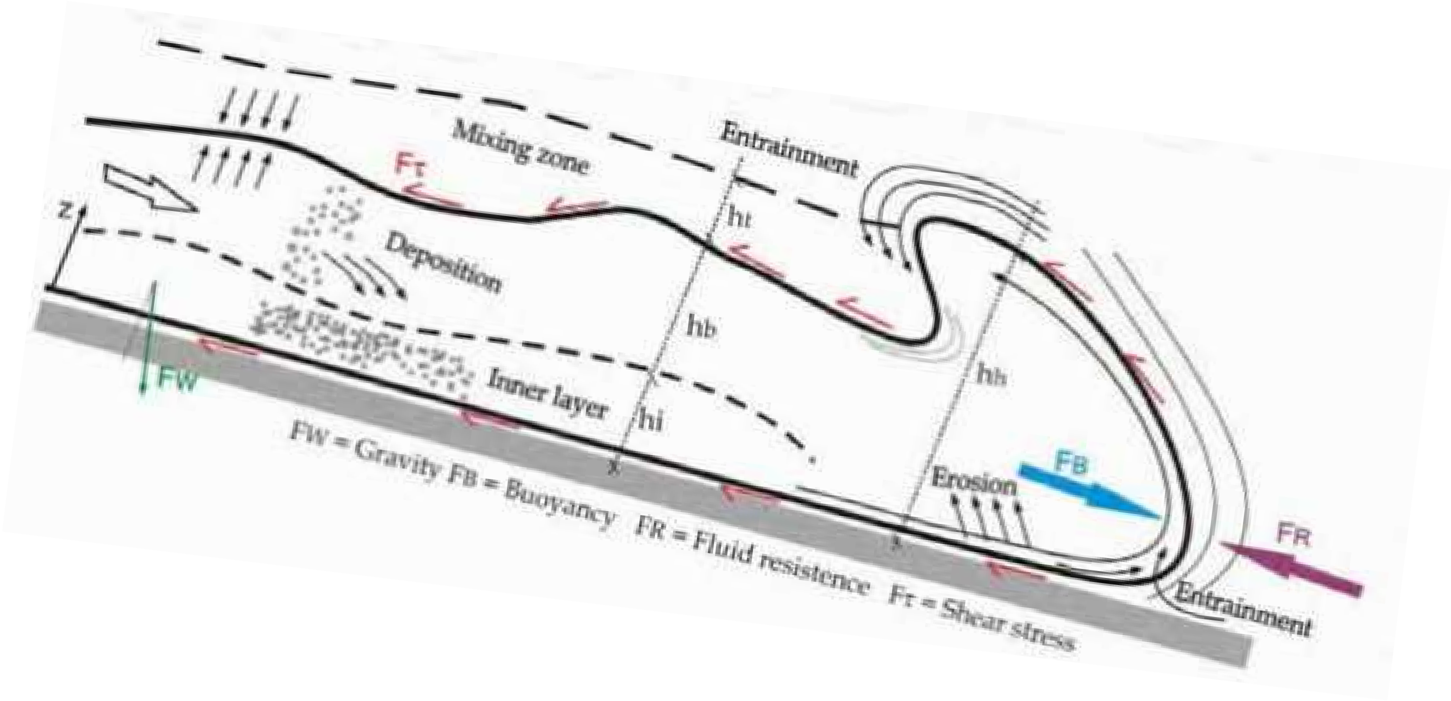


$$\frac{\partial(h_w u_w)}{\partial t} = \boldsymbol{u_s} e^{(s)} - \frac{\tau_s^{(s)}}{\rho_w}$$

$$\frac{\partial(h_s u_s)}{\partial t} = -\frac{\rho_w}{\rho_s} u_s e^{(s)} + \frac{\tau_s^{(s)}}{\rho_s} - \frac{\tau_s^{(b)}}{\rho_s} + \frac{\boldsymbol{\rho_b}}{\boldsymbol{\rho_s}} \boldsymbol{u_s e^{(b)}}$$

Governing Equations

Entrainment

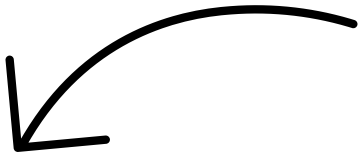


$$\frac{\partial h}{\partial t} + \frac{\partial Uh}{\partial x} = e_w \mathrm{U}$$

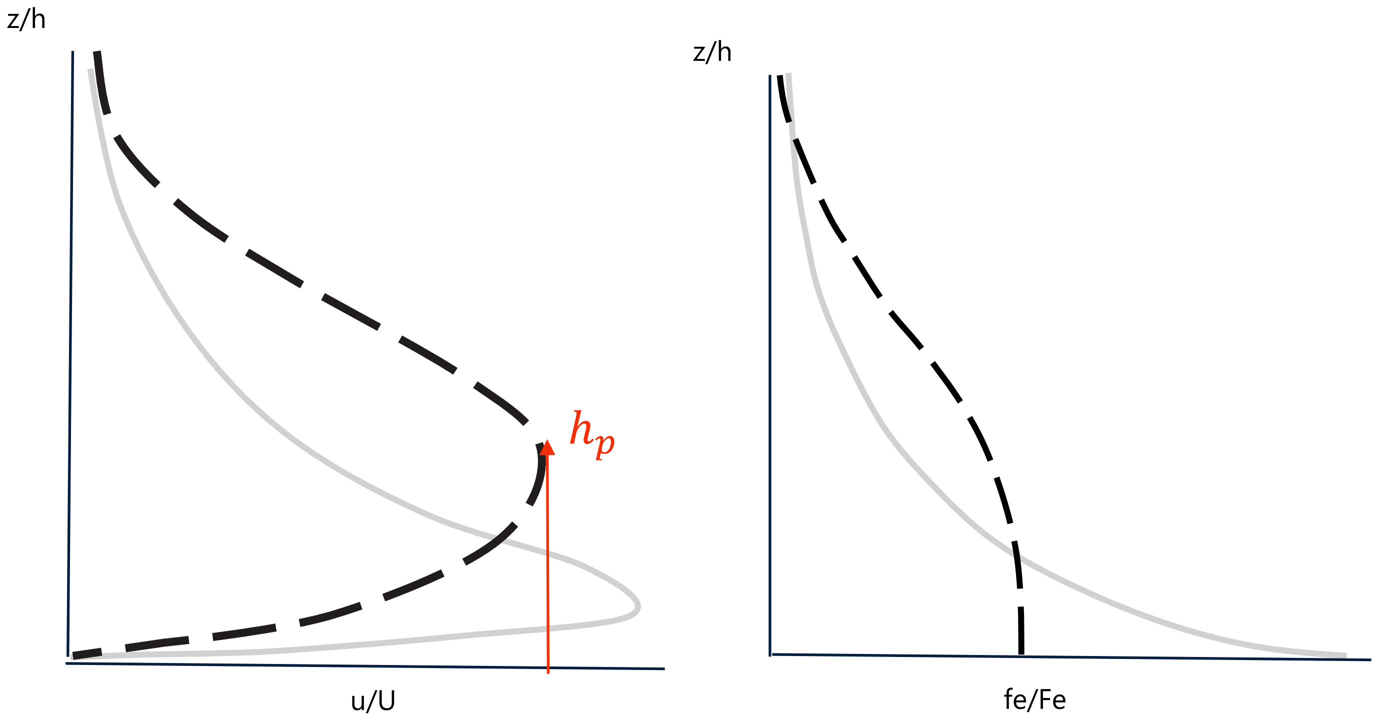
$$e_w = \frac{0.075}{\sqrt{1 + 718\left(1/F_d^{4.8}\right)}}$$

Parker et al. 1987

Vertical dynamics – Velocity and concentration profile

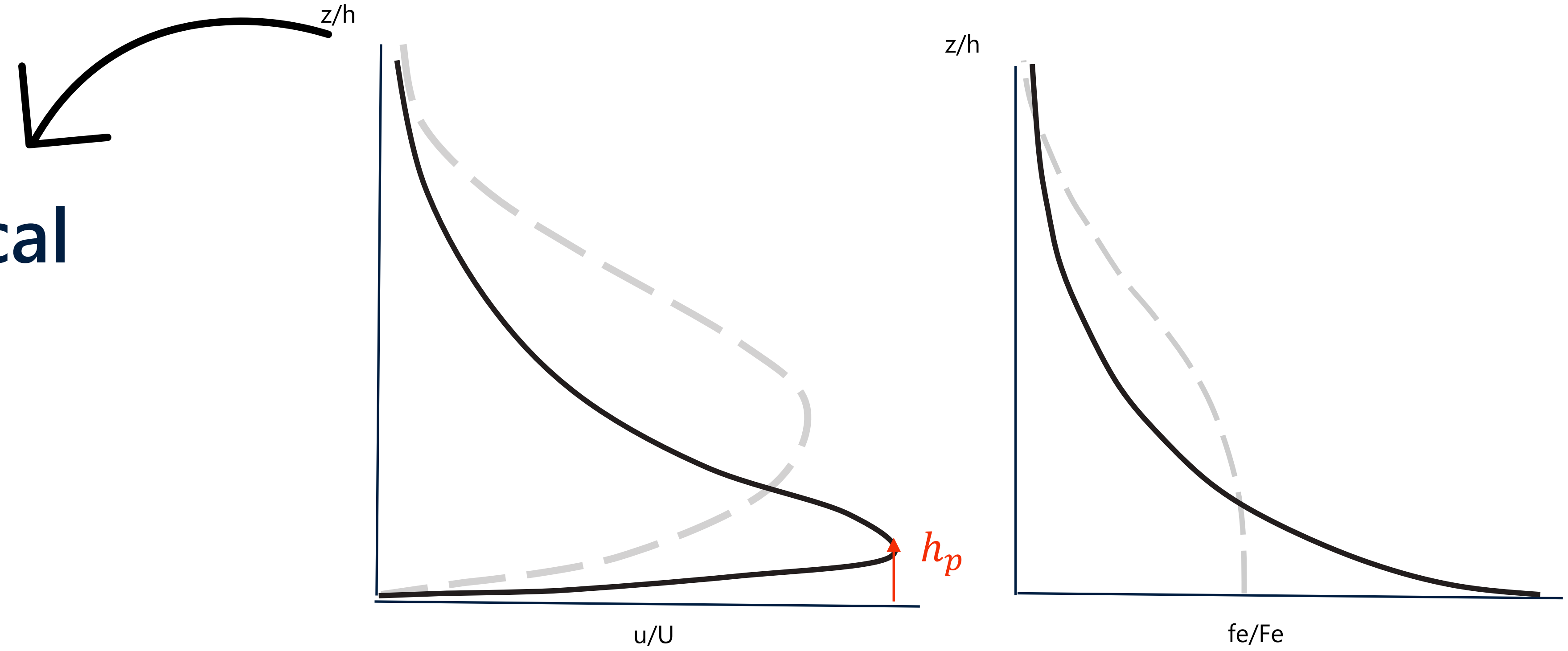


Subcritical

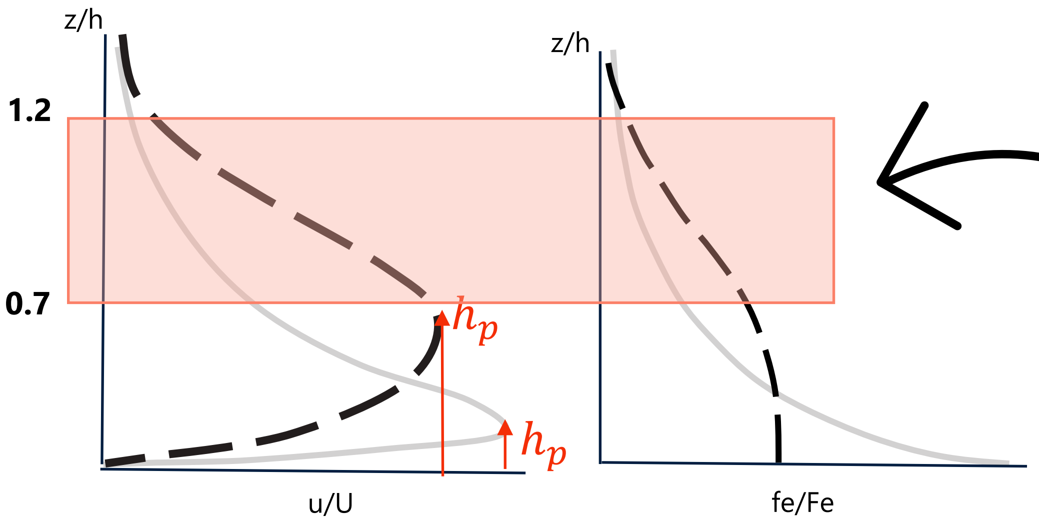


Vertical dynamics –
Velocity and concentration profile

Supercritical



Vertical dynamics – Water Entrainment

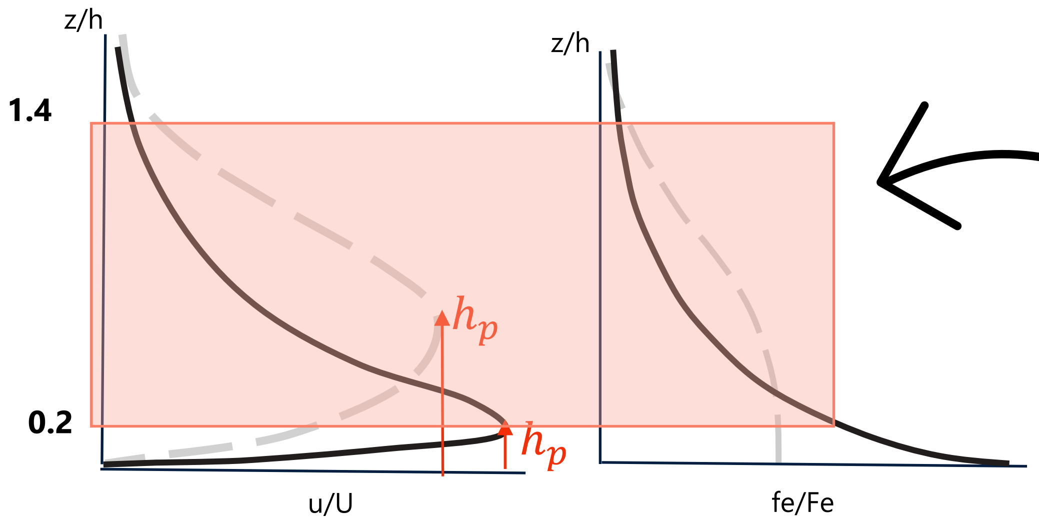


$$Ri_{gi} = -\frac{g(\partial\rho/\partial z)}{\rho(\partial u/\partial z)^2}$$

Ri < 0.25
Turbulence
e_w

1.0 <Ri > 0.25
Strongly turbulence damped
e_w reduced

Vertical dynamics – Water Entrainment



$$Ri_{gi} = -\frac{g(\partial\rho/\partial z)}{\rho(\partial u/\partial z)^2}$$

Ri < 0.25
Turbulence
e_w

1.0 <Ri > 0.25
Strongly turbulence damped
e_w reduced

Next Steps & Ongoing Work

1. **Experimental Setup & Data Collection**

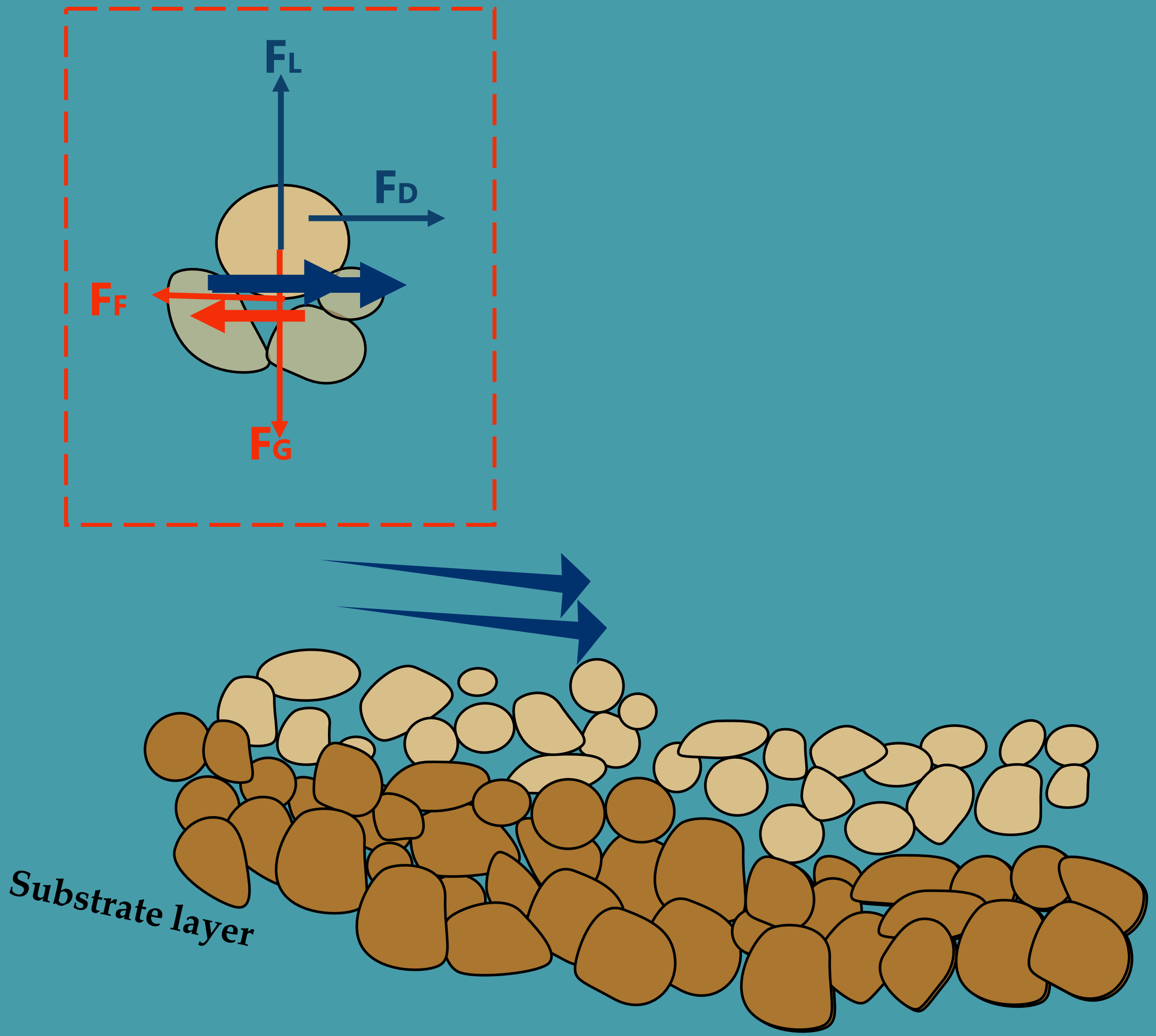
- Finalizing modifications to the flume system.
- Preparing initial high-density sediment-laden flow experiments for data collection.

2. **Numerical Modelling**

- Testing and familiarizing with the two-layer shallow water model
- Implementing the entrainment process based on literature and initial parameter assumptions

Unlocking **Insights**
from **Geo-data**

Sediment Transport



Overtopping Breakwater For Energy Conversion (OBREC)

Saeed Osouli

Supervisors:

Prof. Matteo Postacchini – UNIVPM

DR. Ivan Sabbioni – MAC

Prof. Maurizio Brocchini – UNIVPM

SEDIMARE

3rd Network Training School: Advanced Integrated Coastal Zone Monitoring and Management

IHCantabria/Santander

11-13 March 2025

Model Chain

Selecting Waves

- Mean Waves and Joint PDF waves based on buoy were selected.

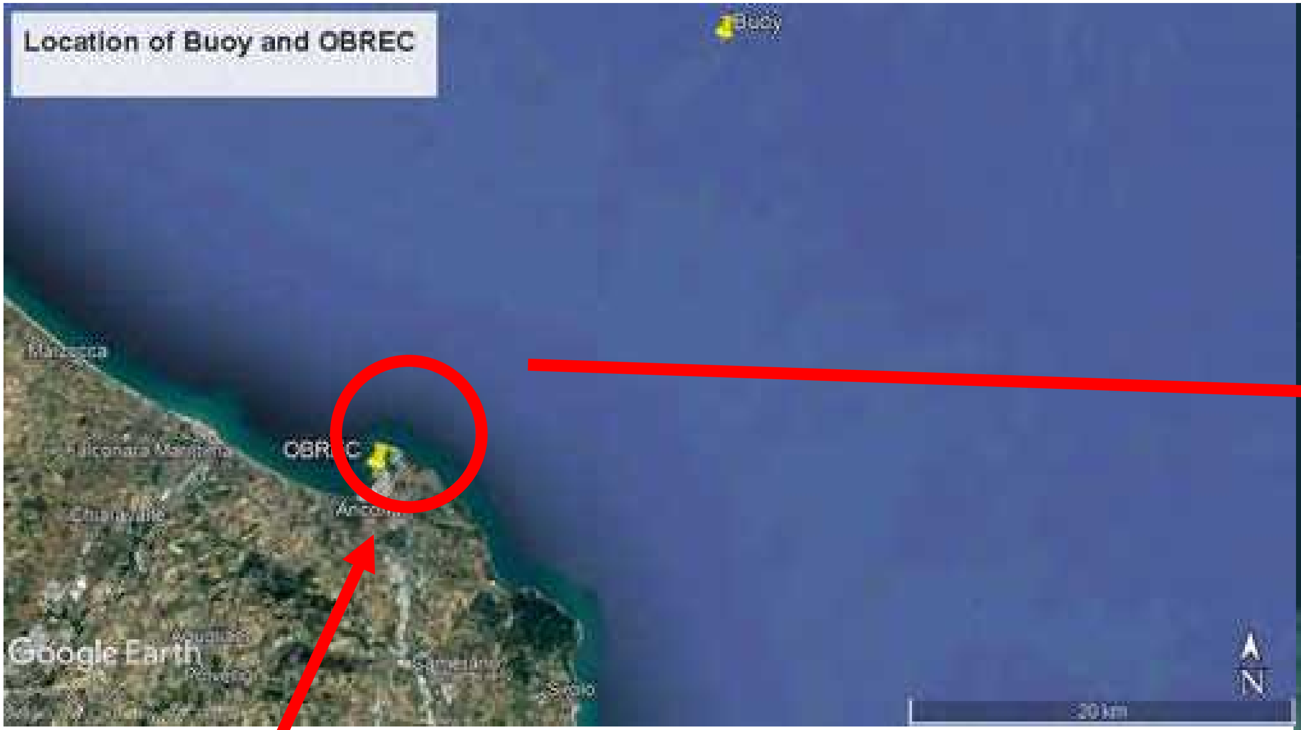
Transforming Waves

- Analytical approach (Goda) from offshore to near shore.
- Wave resolving model inside the port.

Designing the Device and Construction

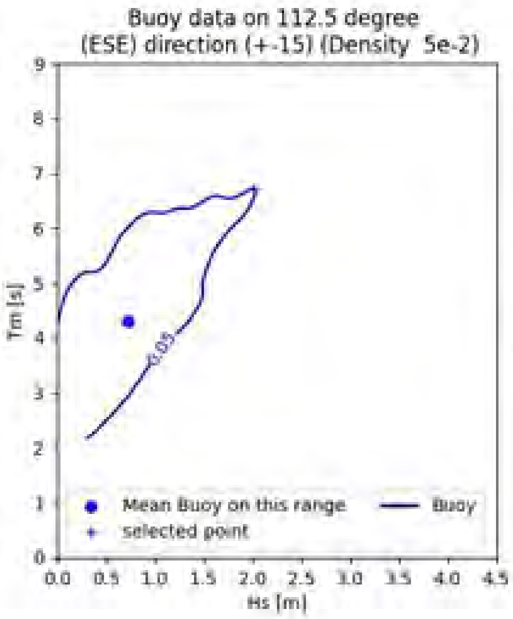
- Designing Ramp, Turbine and construct them.
- Monitor the functioning.

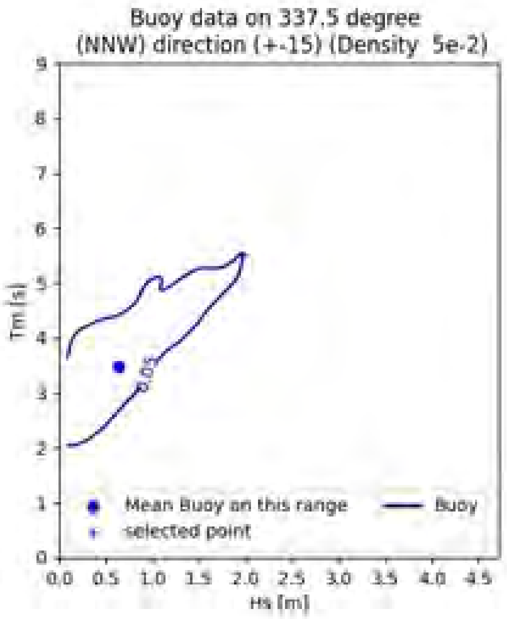
From the offshore to the port



Inclination due to the boundary.

•

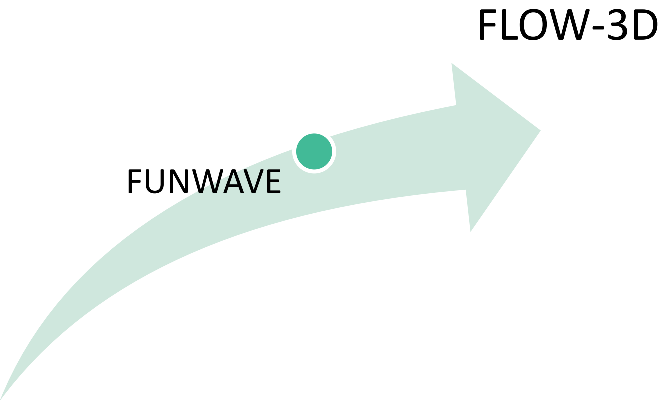




Applying Goda

		NNE	NNW
Mean	Hs (m)	0.90	0.59
	Tp (s)	5.13	4.12
	Tm (s)	4.35	3.49
	ap,h1 [°]	56.00	35.00
Density 0.05	Hs (m)	2.53	1.67
	Tp (s)	7.81	6.51
	Tm (s)	6.62	5.52
	ap,h1 [°]	35.00	27.00
Density 0.005	Hs (m)	2.74	2.68
	Tp (s)	7.87	7.62
	Tm (s)	6.67	6.46
	ap,h1 [°]	35.00	23.00

Wave characteristics at nearshore after applying Goda.



FUNWAVE-TVD

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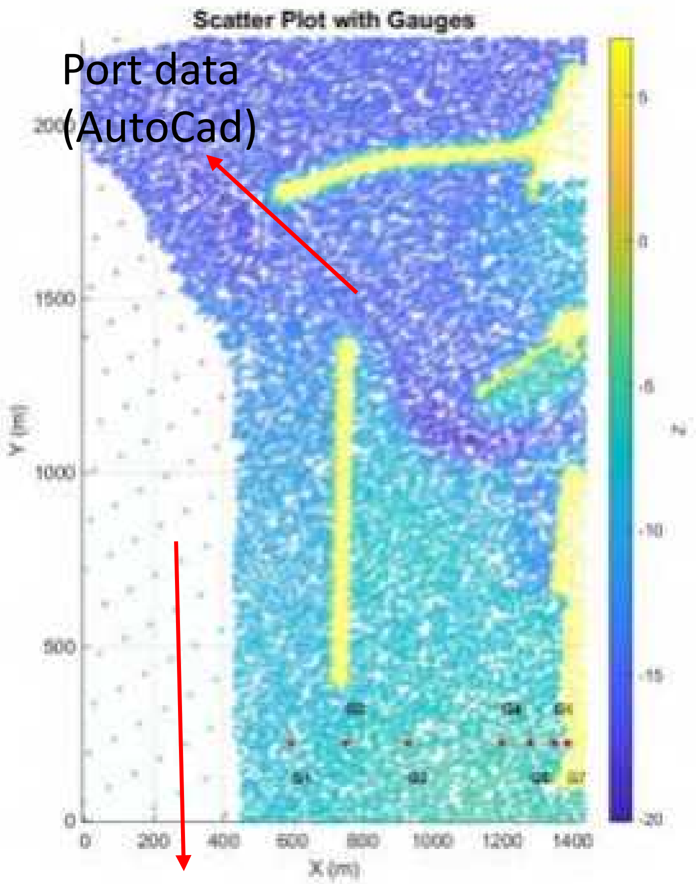
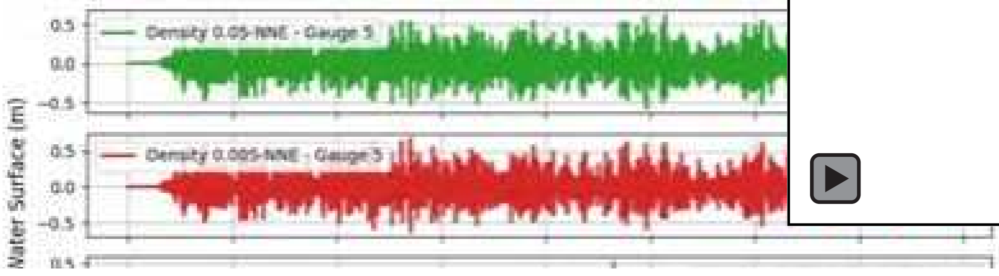
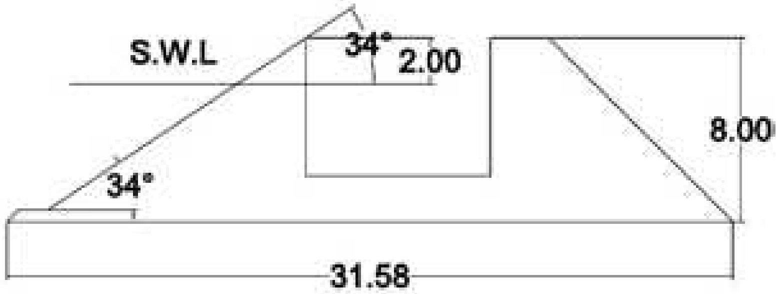
- Bathymetry
- Simulation
- Outputs

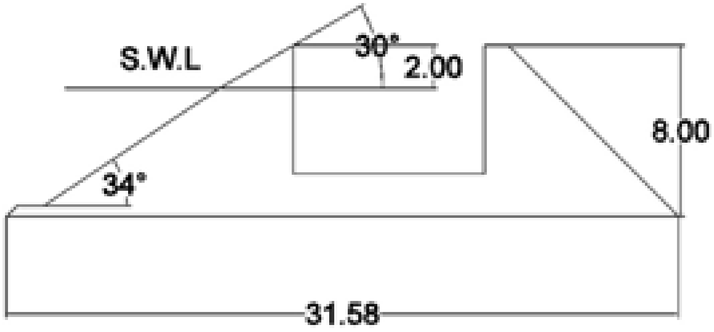




Ramp Design

- Eurotop
- Effect of wave steepness and front slope





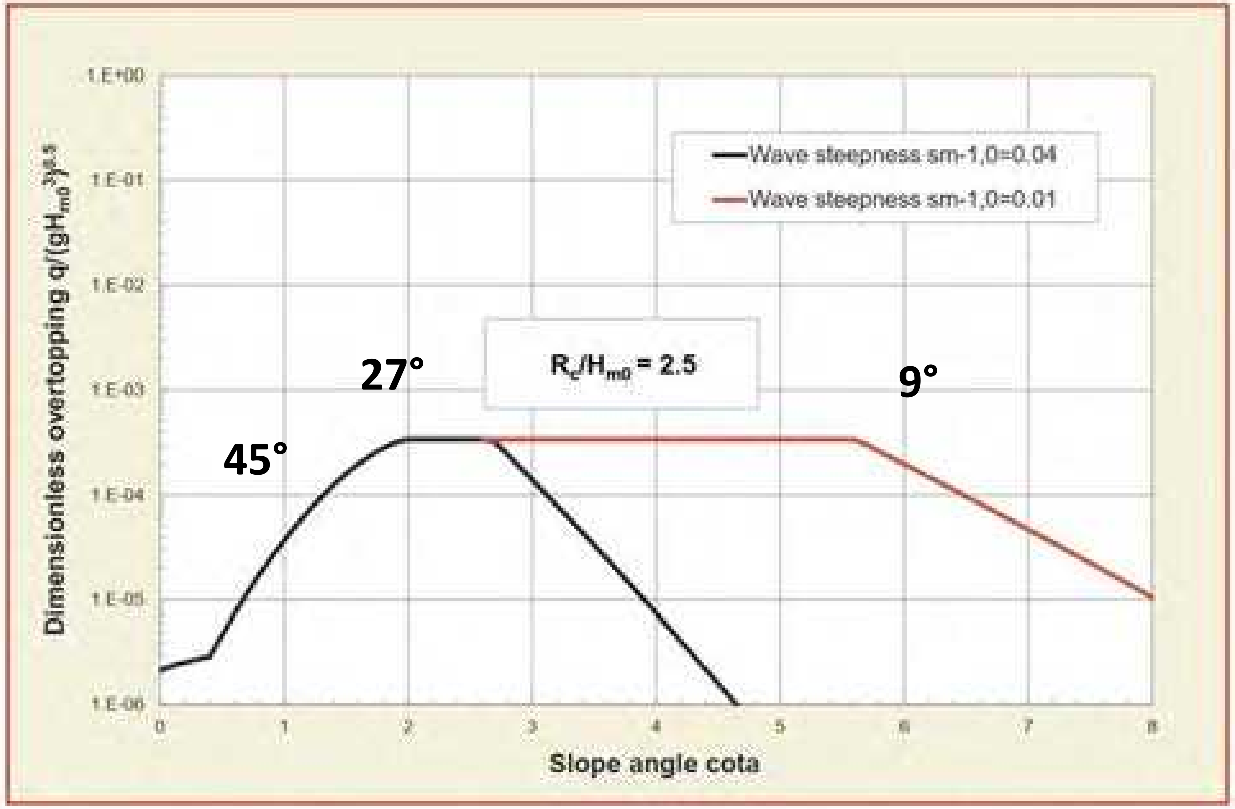


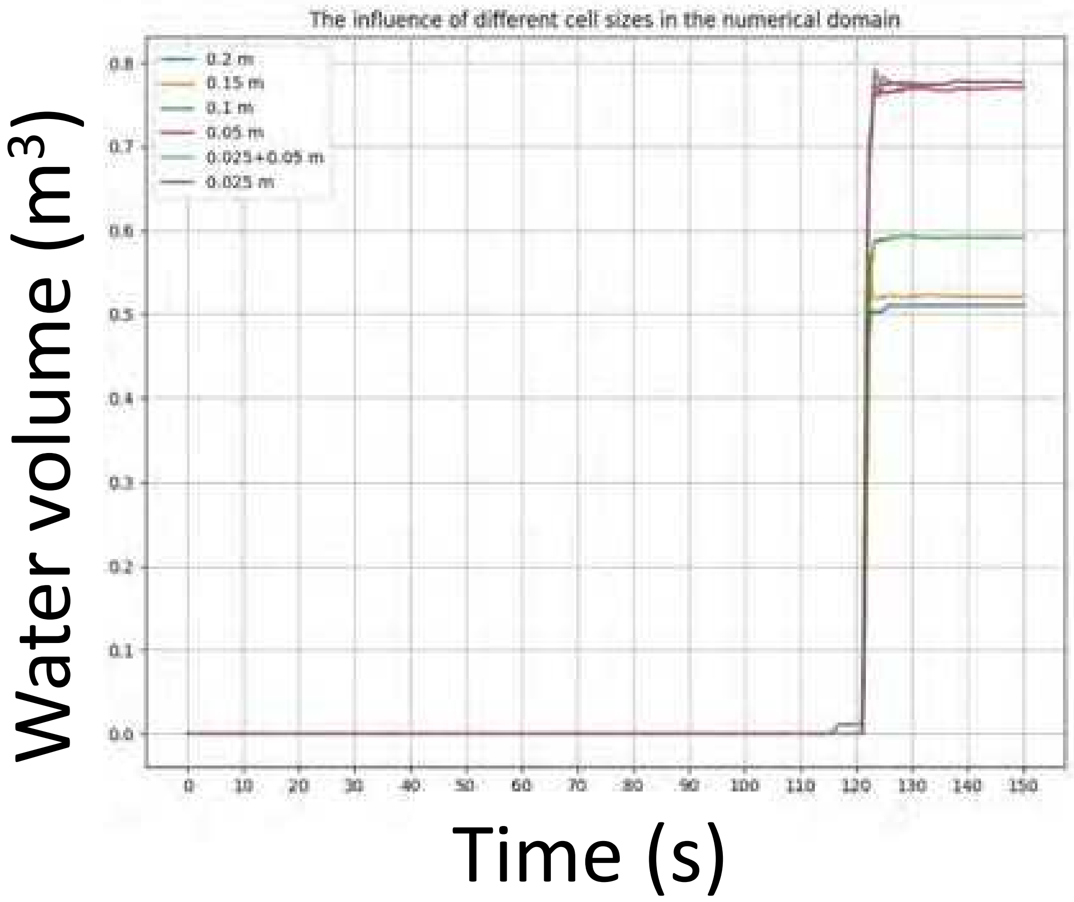
Figure 4.4: Comparison of wave overtopping as function of slope angle

There is a clear trend in Figure 4.4. Steep slopes around 1:2 to 1:3 give the largest overtopping, but for gentler slopes with much longer waves large overtopping is still observed, due to the fact that waves are still surging (non-breaking). Vertical structures with cotα = 0, but without an influencing foreshore, give quite low overtopping and this increases only slightly for battered walls, say up to cotα = 0.5. With

FLOW-3D – 2D approach

Sensitivity analysis

- Domain size: 72*1*10 m, cell size in y direction is 1m (one cell)
- Simulation Time: 150 seconds



Cell size in x and z	0.2 m	0.15 m	0.1 m	0.05 m	0.05 +0.025	0.025 m
Total number of cells	18000	32160	72000	288000	793200	1152000
Time duration	3 minutes	5 minutes	9 minutes	50 minutes	~3 hours	~7 hours
Water volume(m^3)	0.51	0.57	0.59	0.77	0.79	0.78
Hardware	Processor: Intel(R) Core(TM) i9-14900KF 3.20 GHz (8 cores), RAM: 128GB					

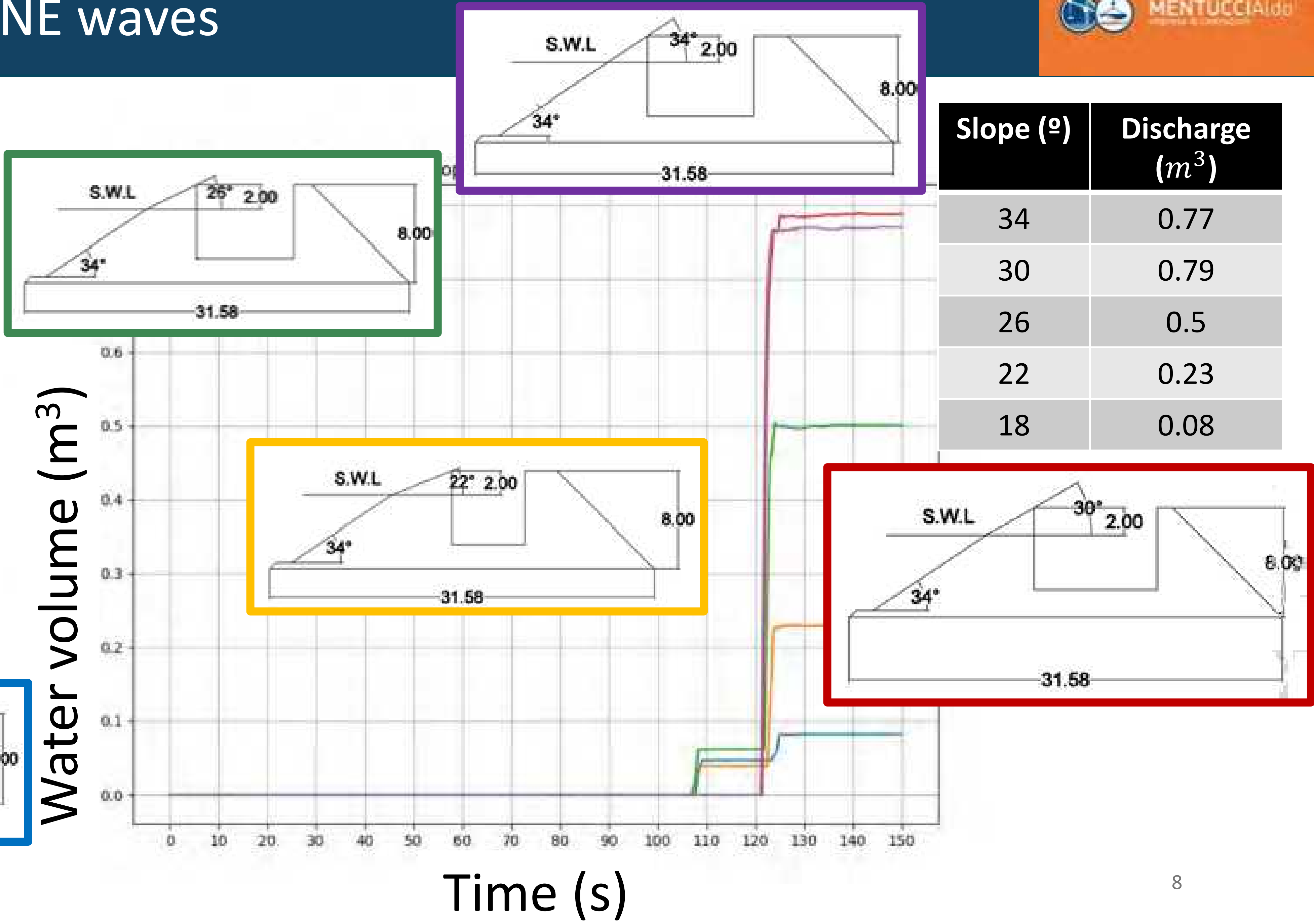
FLOW-3D-NNE waves

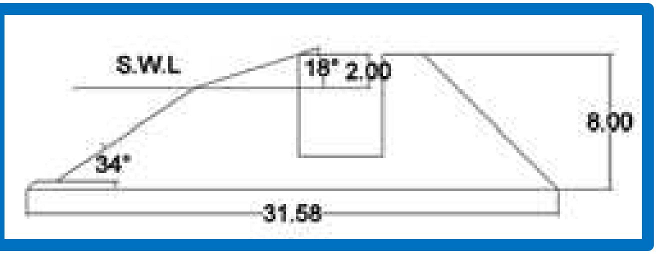
Wave characteristics

NNE scenario

- Hs= 0.81m
- Tp= 7.02 s
- h_{toe}=6 m
- Freeboard=2 m

Slope (º)	Discharge (m^3)
34	0.77
30	0.79
26	0.5
22	0.23
18	0.08





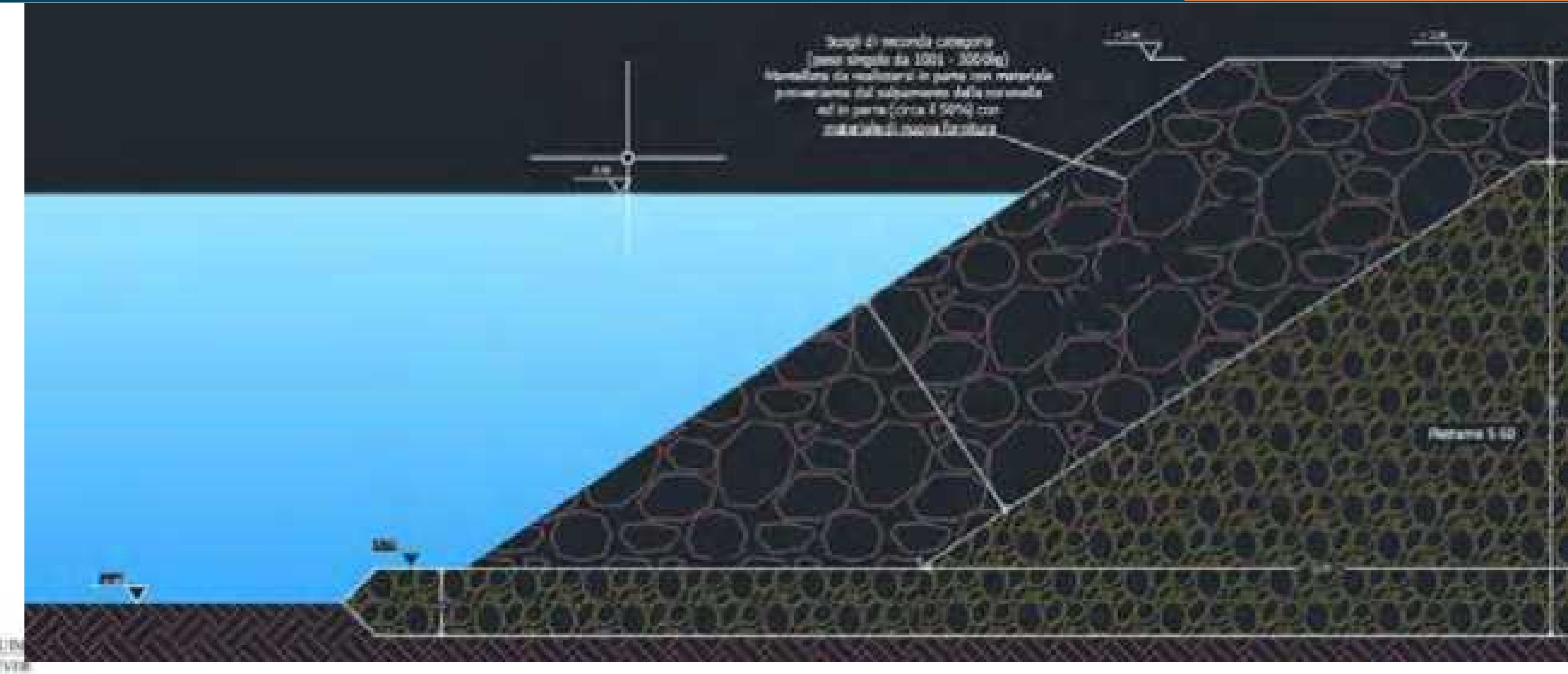
FLOW-3D- Results for NNW Waves

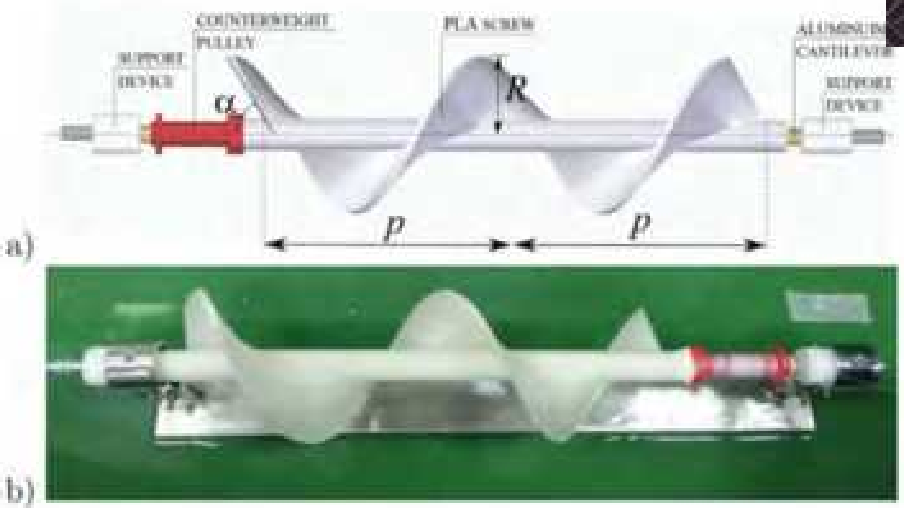
Location and the potential cross section

Location

Location and the potential cross section

- Cross-section of actual breakwater





Hydrokinetic Archimedes turbine Zitti et al. (2020)

Designing Turbine

Efficiency evaluation of a ductless Archimedes turbine: Laboratory experiments and numerical simulations (Zitti et al.) 2020

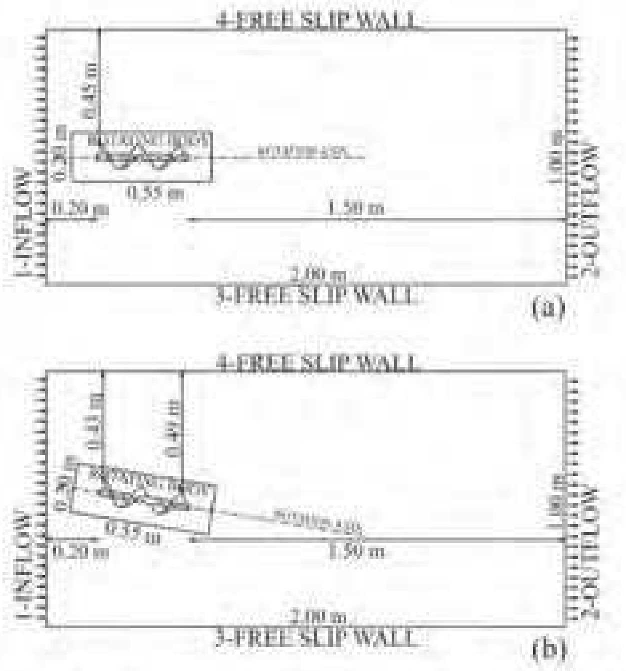
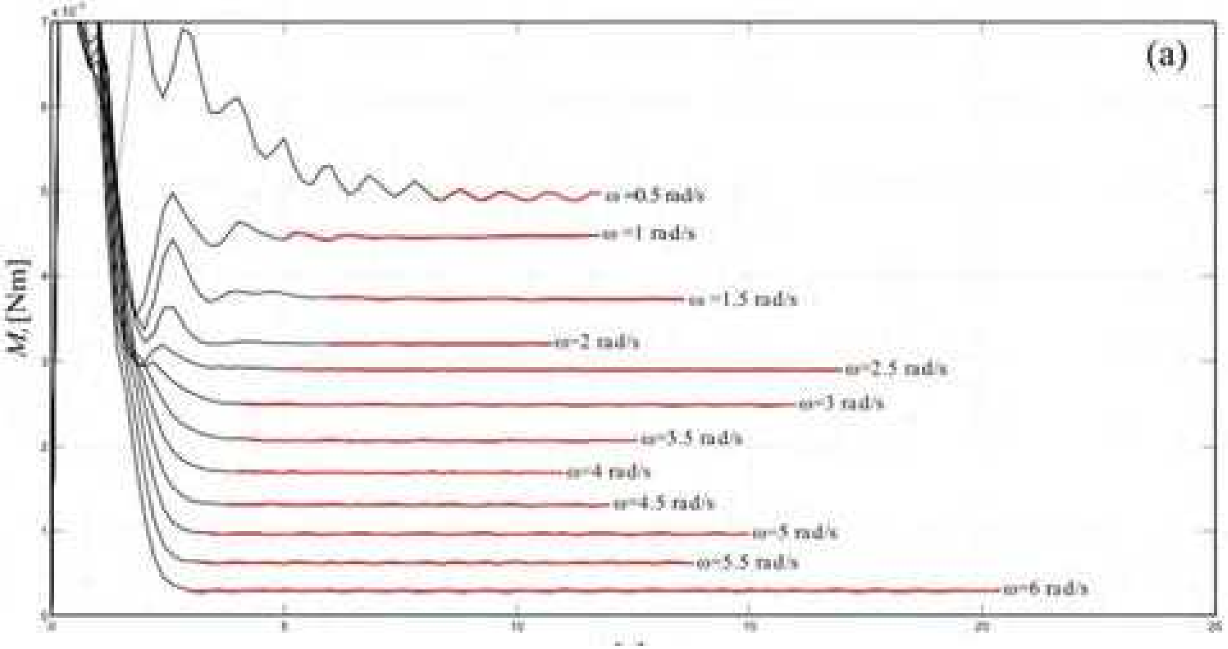
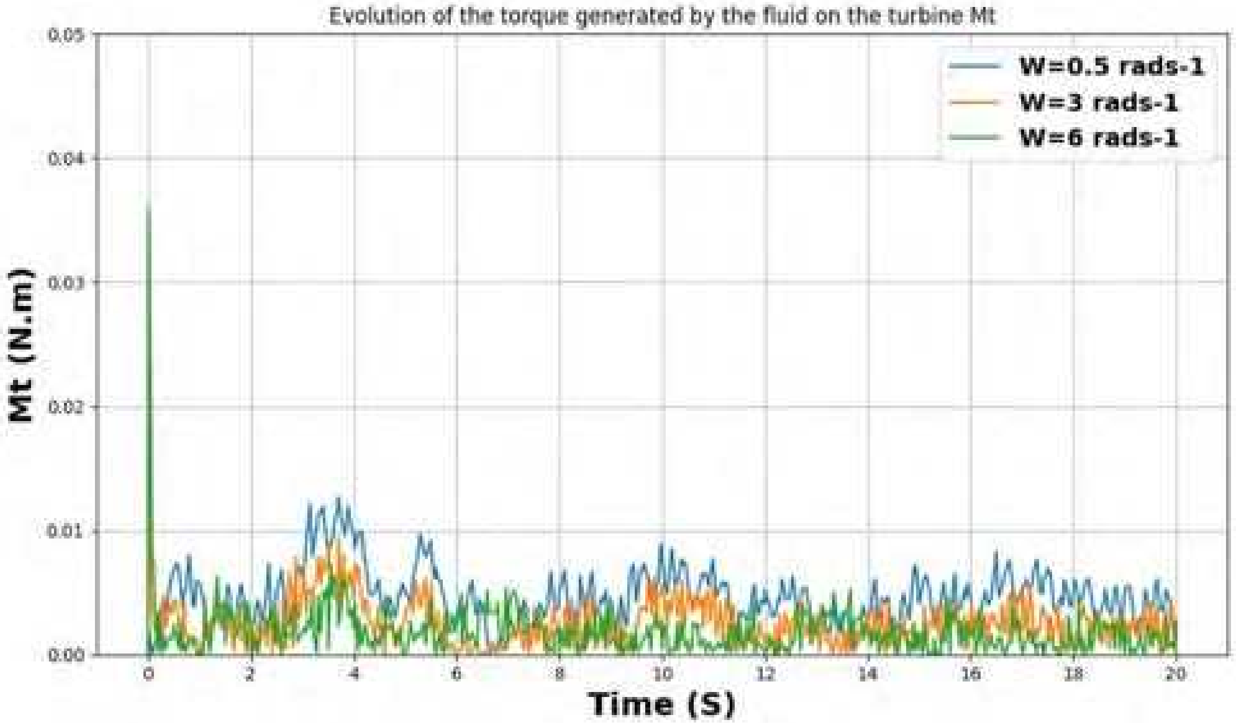


Fig. 5. Sketch of the horizontal plane of the geometry of the domains used in the numerical simulations. a) aligned turbine ($\theta = 0°$); b) inclined turbine ($\theta = 10°$).

Designing Turbine



(Zitti et al.) 2020



Modeling and experimental results of an Archimedes screw turbine (Rohmer et al (2016))

Analytical Model for Water Inflow of an Archimedes Screw Used in Hydropower Generation (Dirk M. Nuernbergk1 and Chris Rorres 2013)

- pitch ratio= λ , Ptan(β)/ 2ORπ
- radius ratio =ρ , IR/OR

$$1.36\ \mathrm{m}^3\ /1\mathrm{m} \xrightarrow{2\ m\ width\ of\ ramp\ and\ devided\ by\ 150} Q = 0.018\ \mathrm{m}^3\ /s$$

- $OR = \left(\frac{0.018\times \tan 10}{10.362\times 0.06}\right)^{3/7} = 0.104\ m$
- $P = \frac{2\pi\times .104\times 0.21}{\tan 10} = 0.778\ m$
- $IR = \rho \times OR = 0.053\ m$

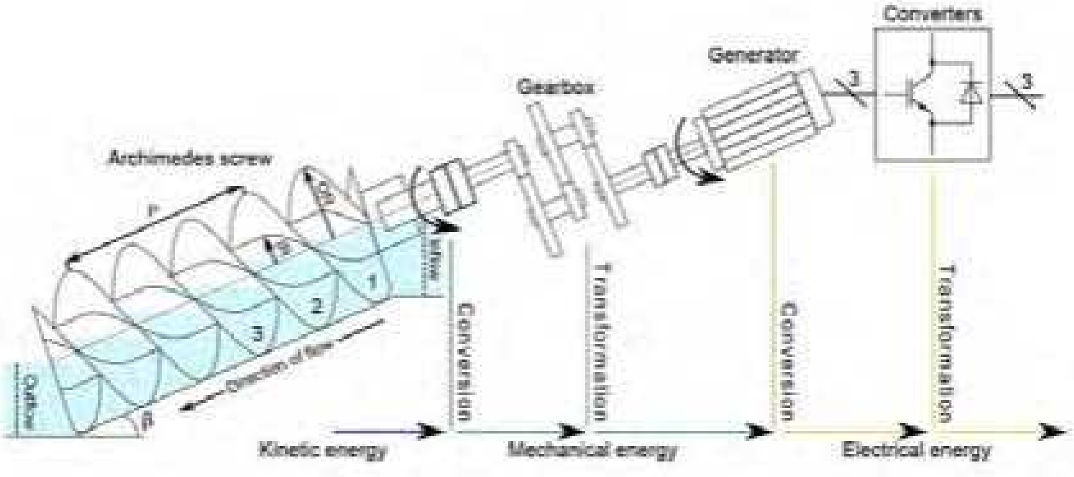


Fig. 1. General principle of an Archimedes screw plant.

Conclusions

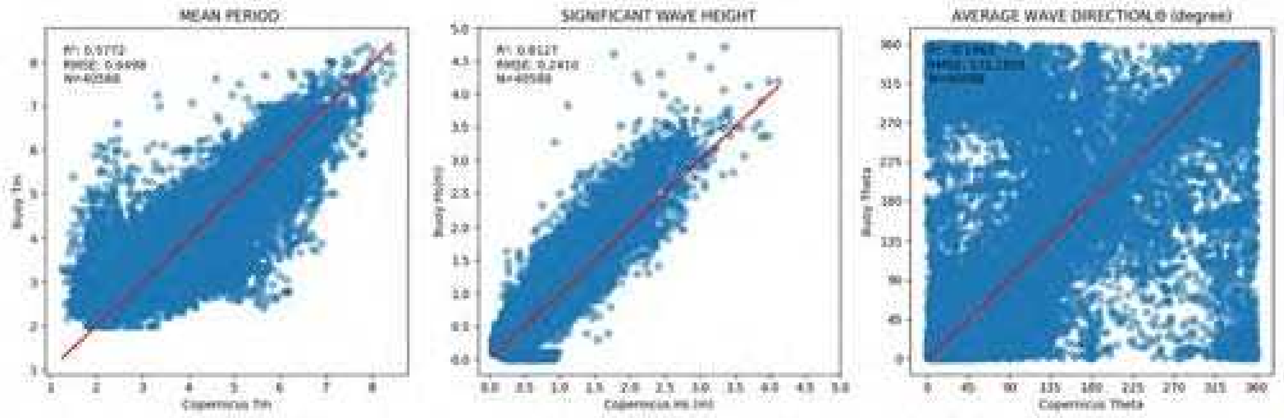
- Selecting waves based on 3 scenarios based on Buoy data.
- Transferring waves into Shallow water using Goda.
- Using FUNWAVE-TVD as the shallow water solver.
- FLOW-3D is used to simulate wave and structure interaction as a CFD tool.
- Archimedes Hydrokinetic turbine will be analyzed as a part of the conveying system.
- The device will be built in the port of Ancona and the performance will be monitored.

FUTURE WORK:

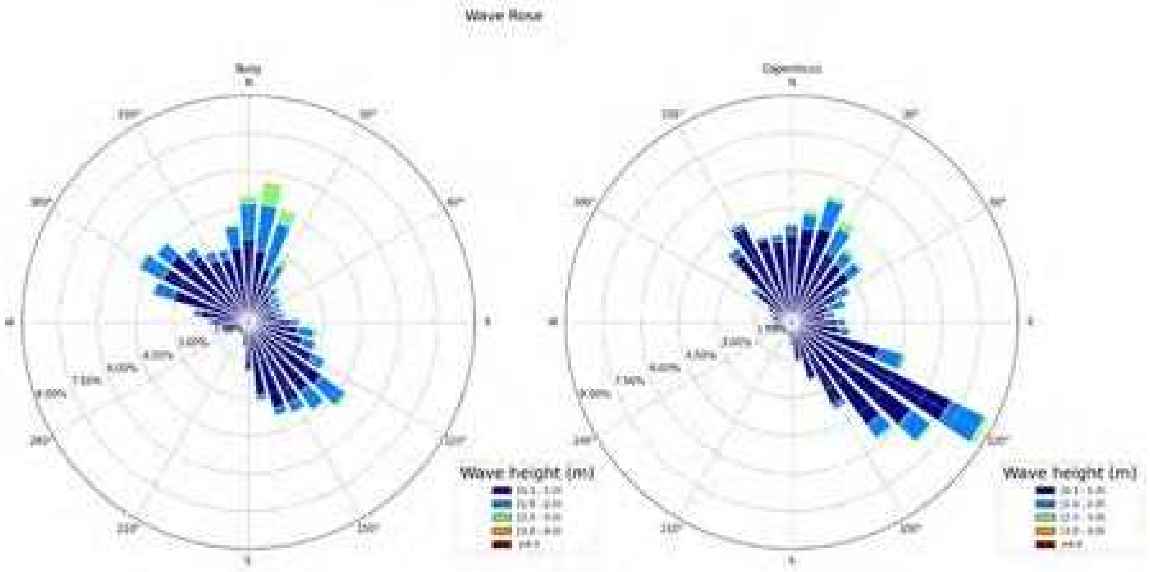
planned construction of ramp and reservoir, design of turbine.

Thank you for your attention!

Observed and Model data



Comparison of wave parameters from buoy and Copernicus.



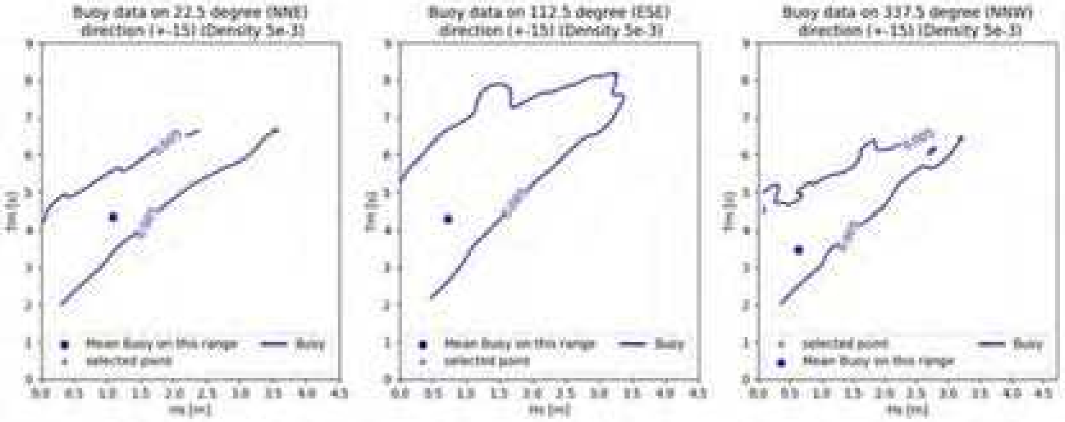
Wave Roses.

FUNWAVE-TVD

	dx (m)	dy (m)	simulation time (s)	Total number of Grids	Stability Condition	Condition: Smoothing (n)	Smoothing (Command)	obstacle height (m)	depth of WK and Spectrum	offshore platform	FroudeCap	CFL and min depth	Wall or Periodic boundary	VISCOSITY_BREAKING
1	2	2	1000	806,314	stable	7	smoothdata2/sgolay/movmean	7	8 - monochromatic	no	1	0.5/0.01	P.B	no
2	2	2	1,000	806,314	stable	7	smoothdata2/sgolay/movmean	7	12 - monochromatic	no	1	0.5/0.01	P.B	no
3	2	2	1,000	806,314	stable	7	smoothdata2/sgolay/movmean	7	16 - monochromatic	no	1	0.5/0.01	P.B	no
4	2	2	1000	806,314	stabe but a instability sign could be seen in the domain around 810 s	7	smoothdata2/sgolay/movmean	7	12 - monochromatic	no	1	0.5/0.1	P.B	no
5	2	2	4292	806,314	stable	7	smoothdata2/sgolay/movmean	7	12 - monochromatic	no	1	0.5/0.01	P.B	yes/ Cbrk1 = 0.45 Cbrk2 = 0.35
6	2	2	7870	374,468	stable	7	smoothdata2/sgolay/movmean	7	12 - monochromatic	no	1	0.5/0.01	P.B	no- small domain
7	2	2	467	806,314	instable (it happens around 330 s)	5	smoothdata/sgolay/sgolay	5	12 - monochromatic	no	1	0.5/0.01	P.B	no
8	2	2	734	806,314	instable (it happens around 180 s)	5	smoothdata/sgolay/sgolay	7	12 - monochromatic	no	1	0.5/0.01	P.B	no

	dx (m)	dy (m)	simulation time (s)	Total number of Grids	Stability Condition	Condition: Smoothing (n)	Smoothing (Command)	obstacle height (m)	depth of WK and Spectrum	offshore platform	FroudeCap	CFL and min depth	Wall or Periodic boundary	VISCOSITY_BREAKING
9	2	2	936	806,314	instable (it happens around 480 s)	7	smoothdata/sgolay/sgolay	5	12 - monochromatic	no	1	0.5/0.01	P.B	no
10	1.5	1.5	399	1,432,629	instable (it happens around 150 s)	7	smoothdata2/sgolay/movmean	7	12 - monochromatic	no	1	0.5/0.01	P.B	no
11	1.5	1.5	185	1,432,629	instable (it happens around 122 s)	7	smoothdata2/sgolay/movmean	7	16 - monochromatic	no	1	0.5/0.01	P.B	no
12	1.5	1.5	151	1,432,629	instable (it happens around 120 s)	7	smoothdata2/sgolay/movmean	7	16 - monochromatic	no	3	0.5/0.01	P.B	no
13	2	2	7870	806,314	instable (it happens around 930 s)	7	smoothdata2/sgolay/movmean	7	12 - monochromatic	no	1	0.5/0.01	Wall boundary	no
14	3	3	7870	358,771	stable	7	smoothdata2/sgolay/movmean	7	12 - monochromatic	no	1	0.5/0.01	P.B	no
15	5	5	7870	129,312	stable	7	smoothdata2/sgolay/movmean	7	12 - monochromatic	no	1	0.5/0.01	P.B	no
16	2	2	7870	806,314	stable	7	smoothdata2/sgolay/movmean	7	12	yes	1	0.5/0.01	P.B	no
17	2	2	7870	806,314	stable	7	smoothdata2/sgolay/movmean	7	16	Yes	1	0.5/0.01	P.B	no

Port



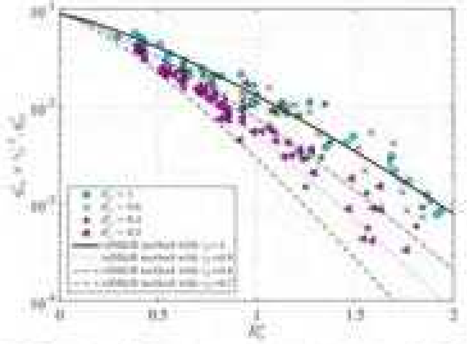
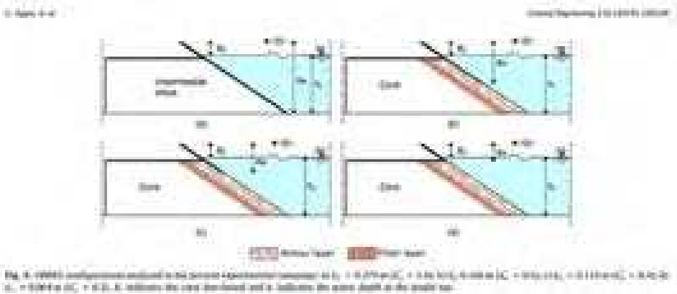
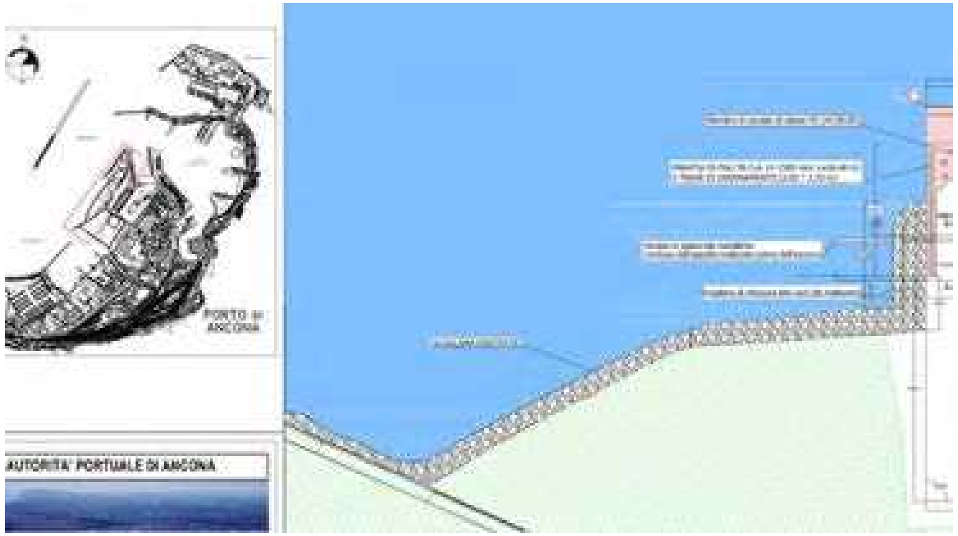


Fig. 8. Comparison of the average wave overtopping rates measured for all configurations tested in the present tests and those estimated by the prediction method of van der Meer and Bruce (2013) adopting four different values of γ_f. The experimental data were corrected using the coefficient γ_b.





Rorres and Nuernbergk

With the previous coefficients, it is possible to determine the optimal outer radius OR of the Archimedes screw with the following equation [10,14,15]:

$$OR = \left(\frac{Q \cdot tan(\beta)}{K_1 \cdot (\lambda r)}\right)^{3/7} \quad (1)$$

where K_1 is a constant between 10.362 and 11.606. According to Rorres and Nuernbergk, the thread pitch P and the inner radius IR can be calculated by equation (2) [10,14,15]:

$$P = \frac{2\pi \cdot OR \cdot \lambda}{tan(\beta)} \quad IR = \rho \cdot OR \quad (2)$$

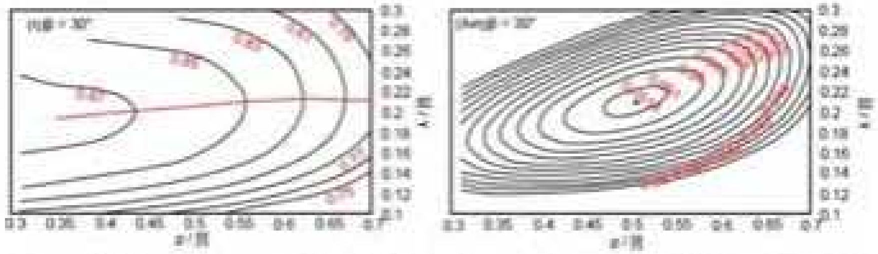


Fig. 2. Mechanical efficiency and optimal geometric parameters for a three-bladed Archimedes screw (N = 3) with an inclination β of 30° as a function of the pitch λ and radius ρ ratio [10,14,15].

Table 2
Performance ratios for optimisation.

Name	Ratio/relationship
Diameter ratio	$\delta = d/D$
Pitch ratio	$Pr = P/D$
Length ratio	$Lr = L/D$

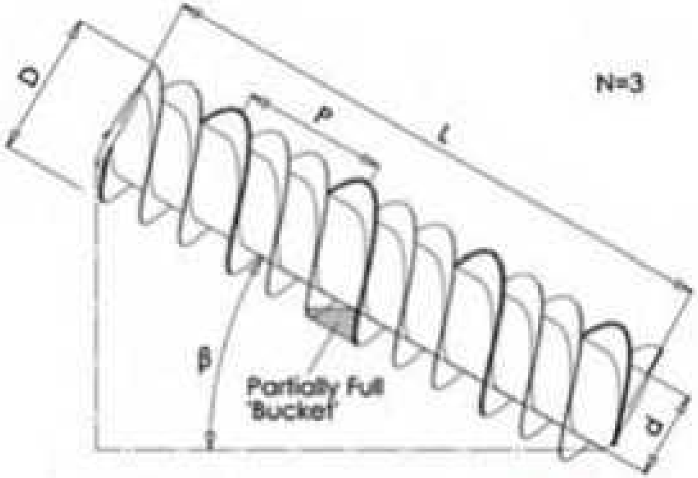


Fig. 4. Geometry of Archimedes Screw [41].

Table 1
Geometric Identities for Archimedes screw.

Symbol	Name	Internal (I)/External (E)
D	Outer diameter	E
d	Inner diameter	I
P	Pitch	I
L	Length of screw	E
θ	Angle of inclination	E
N	Number of flights	I
G	Thickness of spiral profile	I
n	Rotational speed	
Q	Flow rate	E
H	Head	E
ω	Rotation rate	

Laboratory of Hydraulic Engineering
Department of Civil Engineering
University of Patras

SEDIMARE

Sediment Transport and Morphodynamics in Marine and Coastal Waters with Engineering Solutions

Large-eddy simulations of turbulent oscillatory flow and sediment transport induced by waves

Ioannis Gerasimos Tsipas

Supervisor: Athanassios A. Dimas, Professor

Funded by the European Union

This project has received funding from the European Union's Horizon Europe research and innovation programme under the Marie Skłodowska-Curie grant agreement No 101072443.

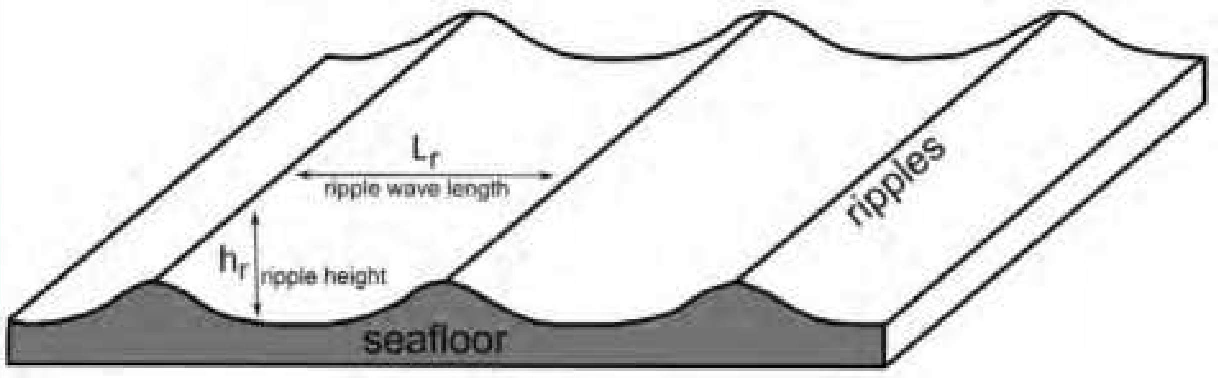
European Commission

Outline

- Introduction
- Objectives
- Methodology
- Simulation Set-up
- Results
- Conclusions/Future Work

- Surface waves induce oscillatory flow at seabed
- Generation of bed forms (ripples, dunes, bars)
- Significant impact on wave propagation and sediment transport by increasing bed roughness and promoting sediment suspension due to vortex shedding

The dynamics of turbulent oscillatory flow and sediment transport over sandy beds is critical for understanding various environmental and engineering processes, such as coastal erosion, sedimentation patterns, and habitat formation.



https://www.vhv.rs/viewpic/hbJbwRw_transparent-water-ripples-png-ripple-of-water-diagram/

Objectives

- Development of large-eddy simulation (LES) software to model turbulent oscillatory flow and mixed-grain sediment transport induced by waves.

- Methodology

Flow Equations (non-dimensional)

Continuity $equation$: $\frac{\partial u_i}{\partial x_i} = 0$

Navier-Stokes equations: $\frac{\partial u_i}{\partial t} + \frac{\partial}{\partial x_j}\left(u_i u_j\right) = -\frac{\partial p}{\partial x_i} - \frac{\partial \tau_{ij}}{\partial x_j} + \frac{1}{\text{Re}}\frac{\partial^2 u_i}{\partial x_j \partial x_j} + f_i$ $\quad Re = \frac{U_0 a_0}{\nu}$

u_i is the resolved velocity field according to LES .

Dynamic pressure: $p = P_o + P$ where P_o is the externally imposed pressure field.

$$u_o\left(t\right) = U_o\left(\cos\left(\omega t\right) + B\cos\left(2\omega t\right)\right)$$

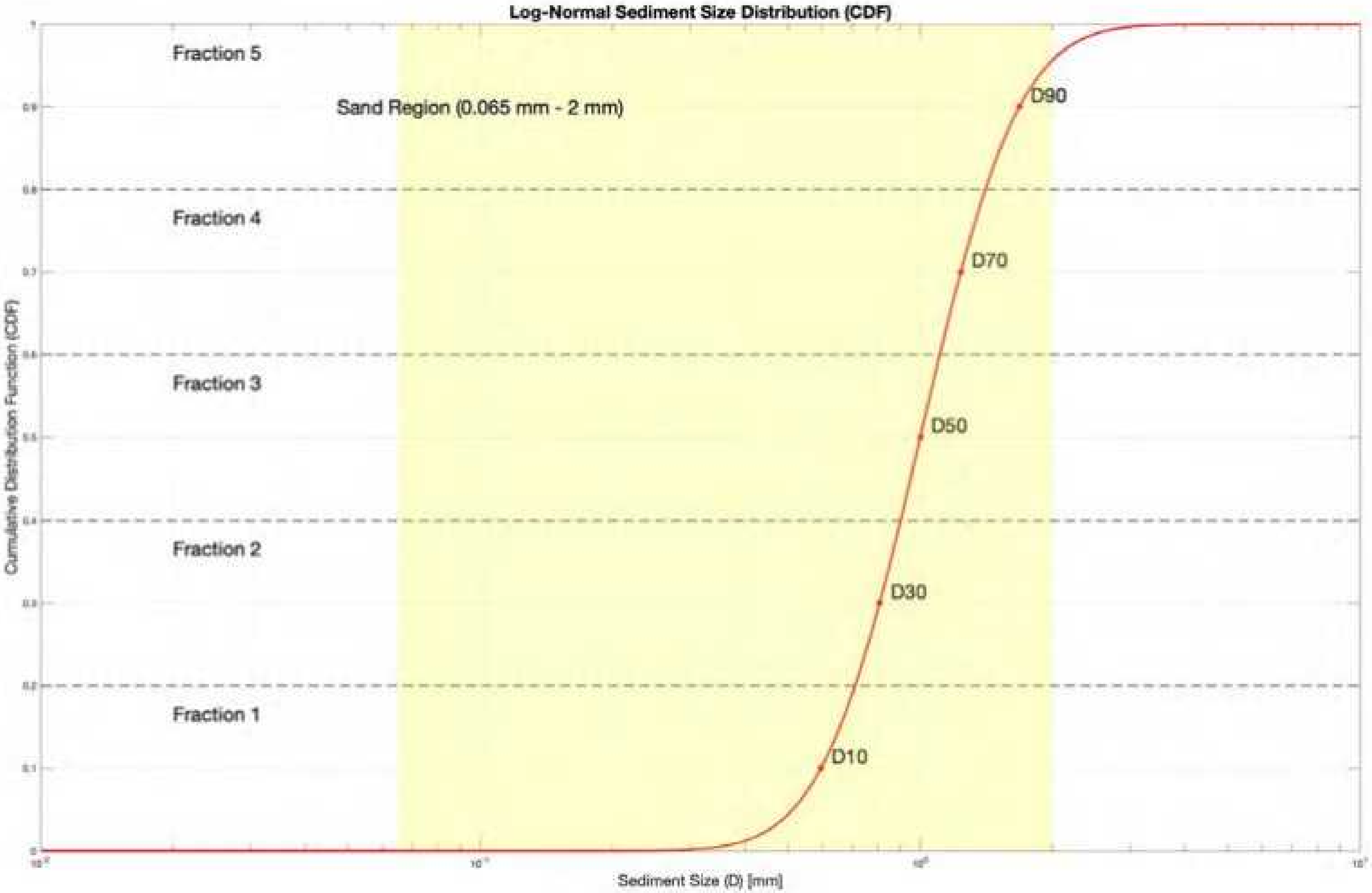
Subgrid-scale (SGS) stresses (Smagorinsky 1963) :

$$\tau_{ij} = -2D_{wall}\nu_{sgs}S_{ij} = -2D_{wall}\left(C_s\Delta\right)^2\left|S\right|S_{ij}$$

$$S_{i,j} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)$$

$$\left|S\right| = \left(2S_{ij}S_{ij}\right)^{1/2}$$

$$\Delta = \left(\Delta x_1 \Delta x_2 \Delta x_3\right)^{1/3}$$


Log-Normal Sediment Size Distribution (CDF)
Fraction 5
Sand Region (0.065 mm - 2 mm)
D90
Fraction 4
D70
Fraction 3
D50
Fraction 2
D30
Fraction 1
D10
Cumulative Distribution Function (CDF)
Sediment Size (D) [mm]

Sediment Transport Equations

Type equation here.Bed load transport rate (Engelund and Fredsøe, 1976):

$$\frac{q_{b(nd)}}{\sqrt{(S-1)gDg_{(nd)}^{3}}} = \begin{cases} \operatorname{sgn}(\theta)\frac{5\pi}{3}\left[1+\left(\frac{\pi}{6}\frac{\mu_d}{\left|\theta_{(nd)}\right|-\theta_{c(nd)}}\right)^{4}\right]^{-\frac{1}{4}}\left(\sqrt{\left|\theta_{(nd)}\right|}-0.7\sqrt{\left|\theta c_{(nd)}\right|}\right), & (\theta_{(nd)} > \theta c_{(nd)}) \\ 0 & ,(\theta_{(nd)} < \theta c_{(nd)}) \end{cases}$$

Shields number : $\theta = \frac{\tau_b}{\rho_w (S-1) g D g_{(nd)}^{3}}$

Critical Shields number: $\theta_c\left(D_{g(nd)}, S\right)$ → Hide/Exposure factor → $\theta_{c(nd)}\left(\frac{p_{ek}}{p_{hk}}\right)^{m}$

Grain diameters: $Dg_{(nd)}$

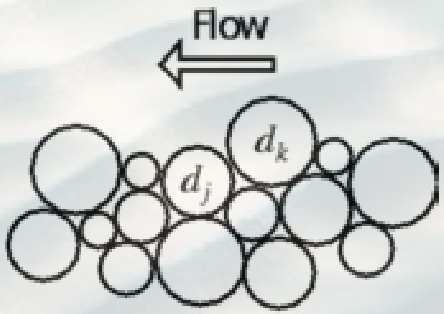
Sediment specific gravity: S

Dynamic friction coefficient: $\mu_d \approx 0.5\mu_s$

Hidden & Exposed probabilities of particles d_k

$$p_{hk} = \sum_{j=1}^{N}\left(p_{bj}\frac{d_j}{d_k + d_j}\right)$$

$$p_{ek} = \sum_{j=1}^{N}\left(p_{bj}\frac{d_k}{d_k + d_j}\right)$$



Advection-diffusion equation for the suspended sediment concentration:

$$\frac{\partial c_{(nd)}}{\partial t} + u_j \frac{\partial c_{(nd)}}{\partial x_j} - w_{s(nd)} \frac{\partial c_{(nd)}}{\partial x_3} = \frac{1}{\sigma Re} \frac{\partial^2 c_{(nd)}}{\partial x_j \partial x_j} - \frac{\partial \chi_j}{\partial x_i} + f_c$$

where $w_{s(nd)}$ is the sediment fall velocity (Hallermeier 1981) for each grain fraction:

$$\frac{w_{s(nd)} Dg_{(nd)}}{\nu} = \begin{cases} \mathrm{D}^3_{*(nd)}/18 & \mathrm{D}^3_{*(nd)} < 39 \\ \mathrm{D}^{2.1}_{*(nd)}/6 \quad for & 39 < \mathrm{D}^3_{*(nd)} < 10^4 \\ 1.05\mathrm{D}^{1.5}_{*(nd)} & 10^4 < \mathrm{D}^3_{*(nd)} \leq 3 \cdot 10^6 \end{cases} \quad .where. \quad D_{*(nd)} = Dg_{(nd)} \left(\frac{(S-1)g}{\nu^2} \right)^{1/3}$$

σ is the Schmidt number, χ_j is the SGS turbulent term (Zedler and Street 2001):

$$\chi_j = \frac{v_{sgs}}{\sigma_\iota} \frac{\partial c_{(nd)}}{\partial x_j}$$

and σ_t is the turbulent Schmidt number.

Suspended load transport rate: $q_{s1,2(nd)} = \int_{x_{3bed}}^{x_{3top}} u_{1,2} c_{(nd)} dx_3$

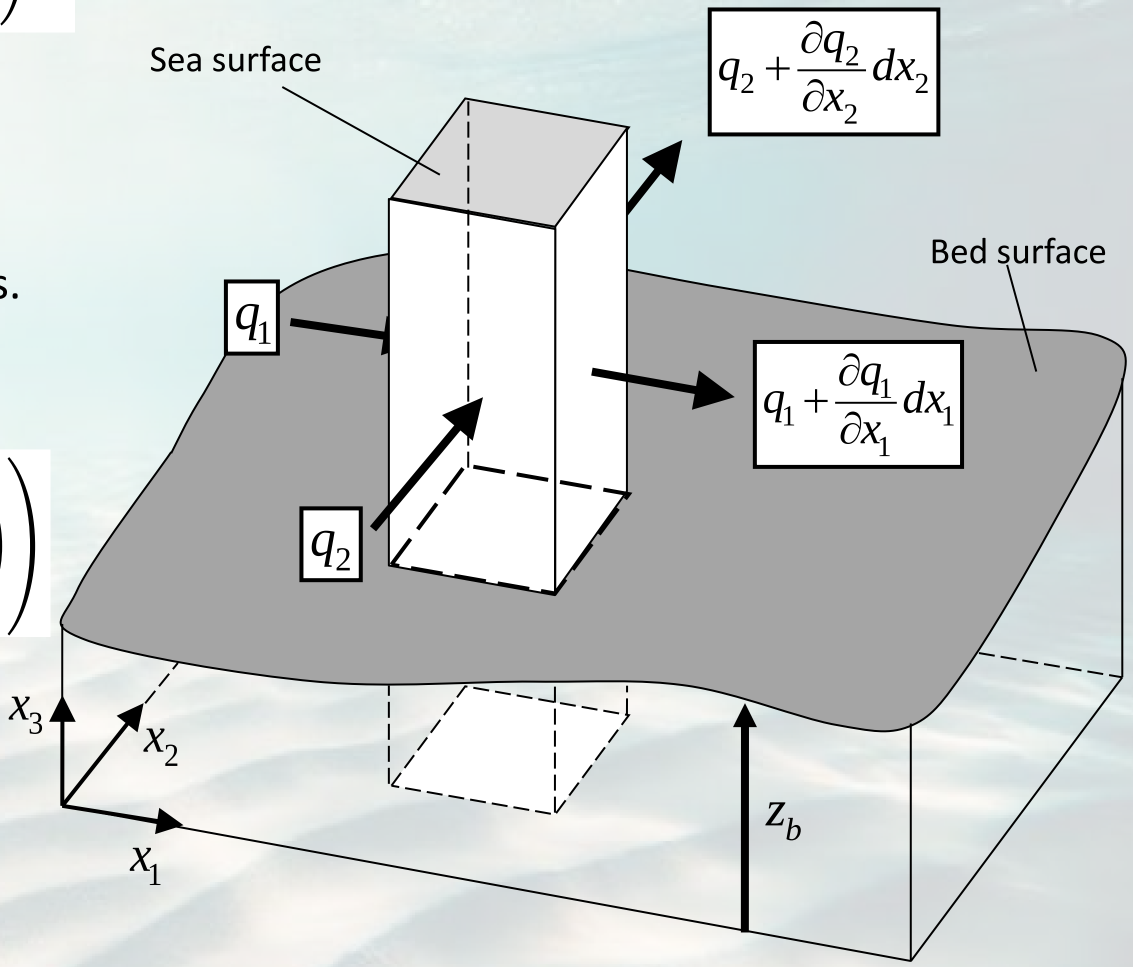
Bed Evolution modeling

Exner Equation: The bed elevation evolution follows the Exner Equation in two dimensions and expresses the coupling between the evolution of bed morphology and the sediment transport fluxes.

$$\frac{\partial z_b}{\partial t} + \frac{1}{1-n}\frac{\partial}{\partial t}\left(\int_{x_3 \geq z_b}^{h} c_{(nd)} dx_3\right) = -\frac{1}{1-n}\left(\frac{\partial q_{1(nd)}}{\partial x_1} + \frac{\partial q_{2(nd)}}{\partial x_2}\right)$$

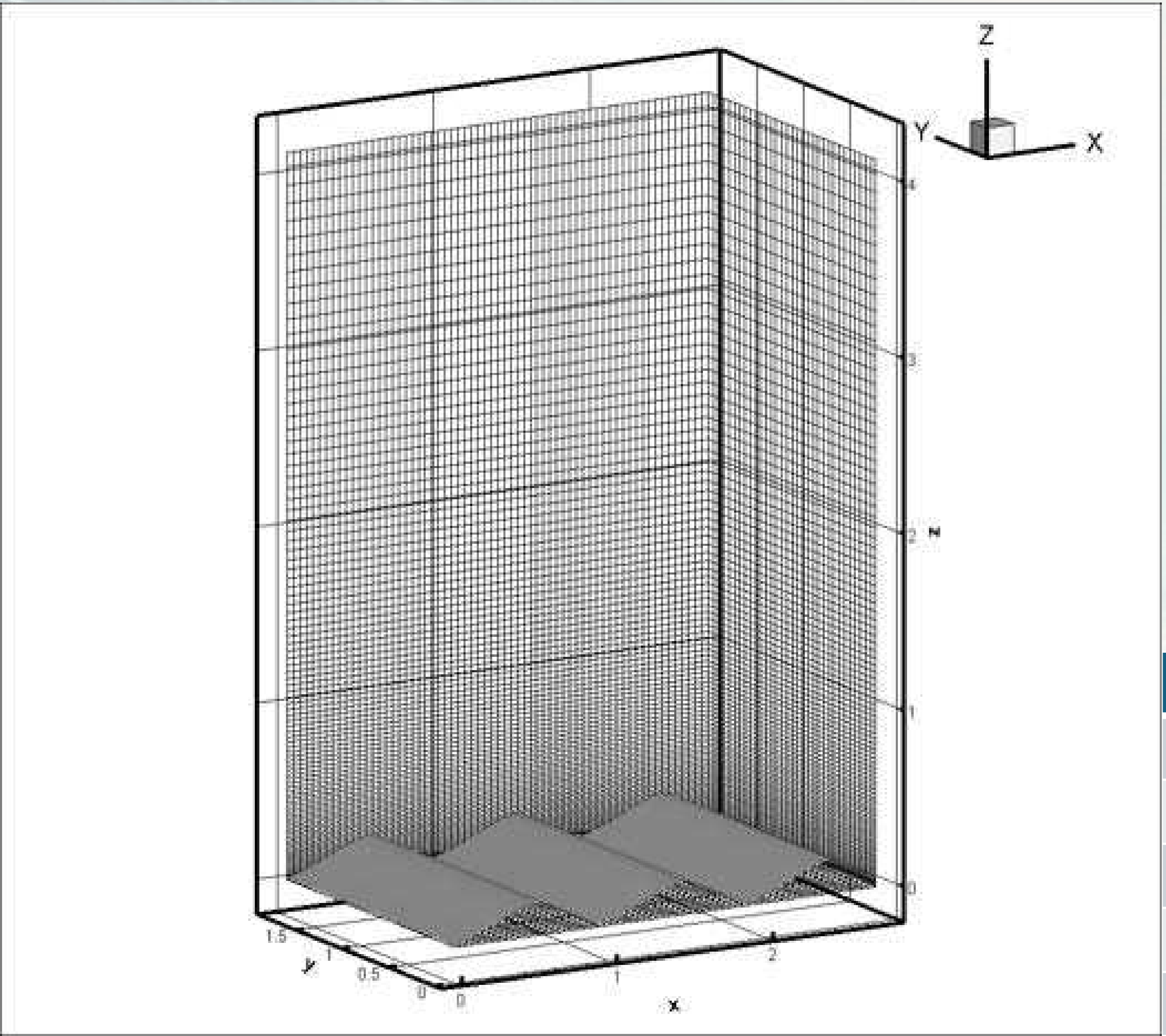
z_b is the bed level
n is the bed sediment porosity
$q_{1,2} = (q_b + q_s)_{1,2}$ is the total sediment flux in the horizontal directions.

$$\frac{\partial z_b}{\partial t} = -\frac{1}{1-n}\sum_{nd=1}^{N}\left(\frac{\partial}{\partial t}\left(\int_{x_3 \geq z_b}^{h} c_{(nd)} dx_3\right) + \left(\frac{\partial q_{1(nd)}}{\partial x_1} + \frac{\partial q_{2(nd)}}{\partial x_2}\right)\right)$$



Simulation Set-up

Van Der Werf et al.(2007) , experiment Mr5b63

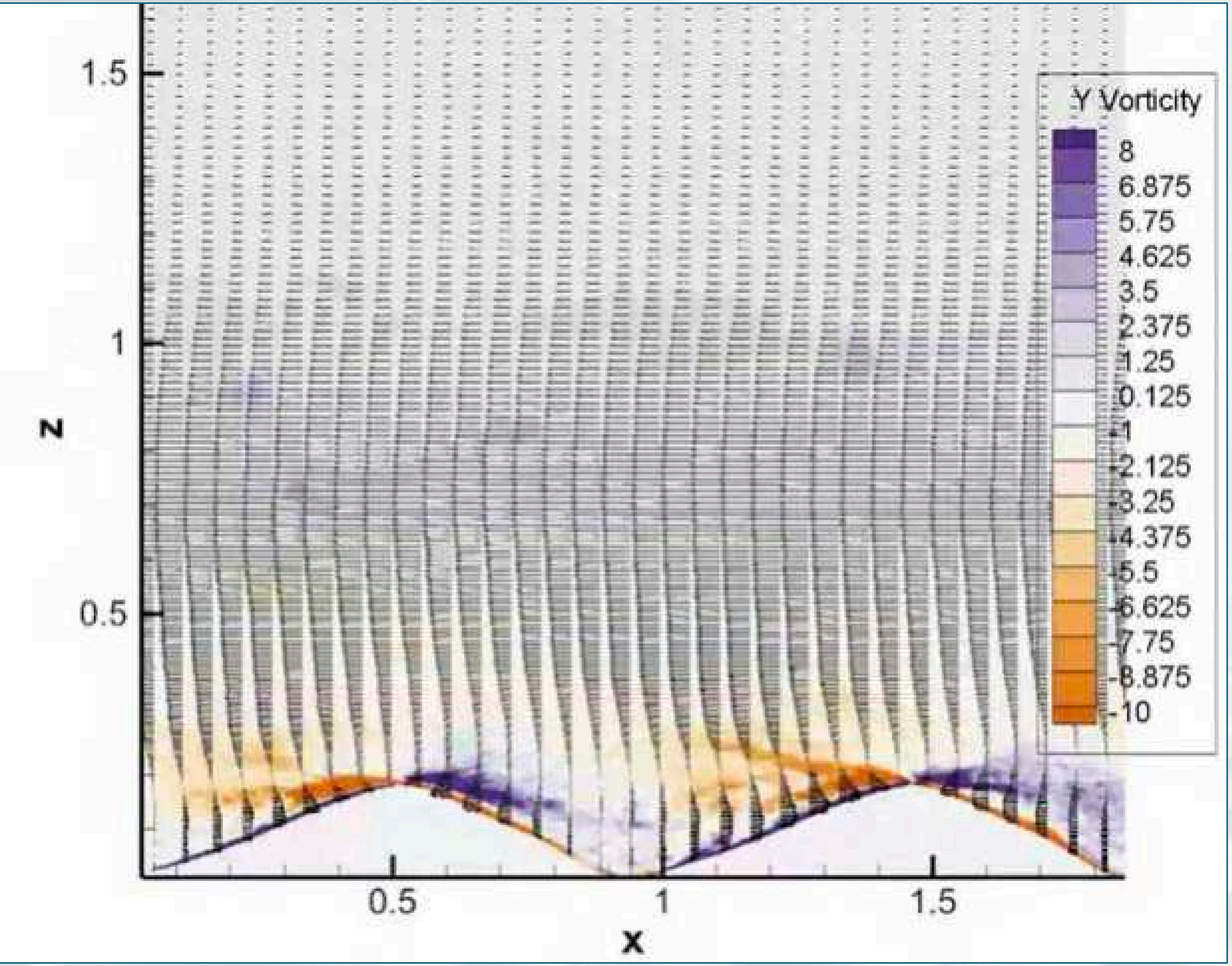


$$\mathrm{Re} = 23000$$

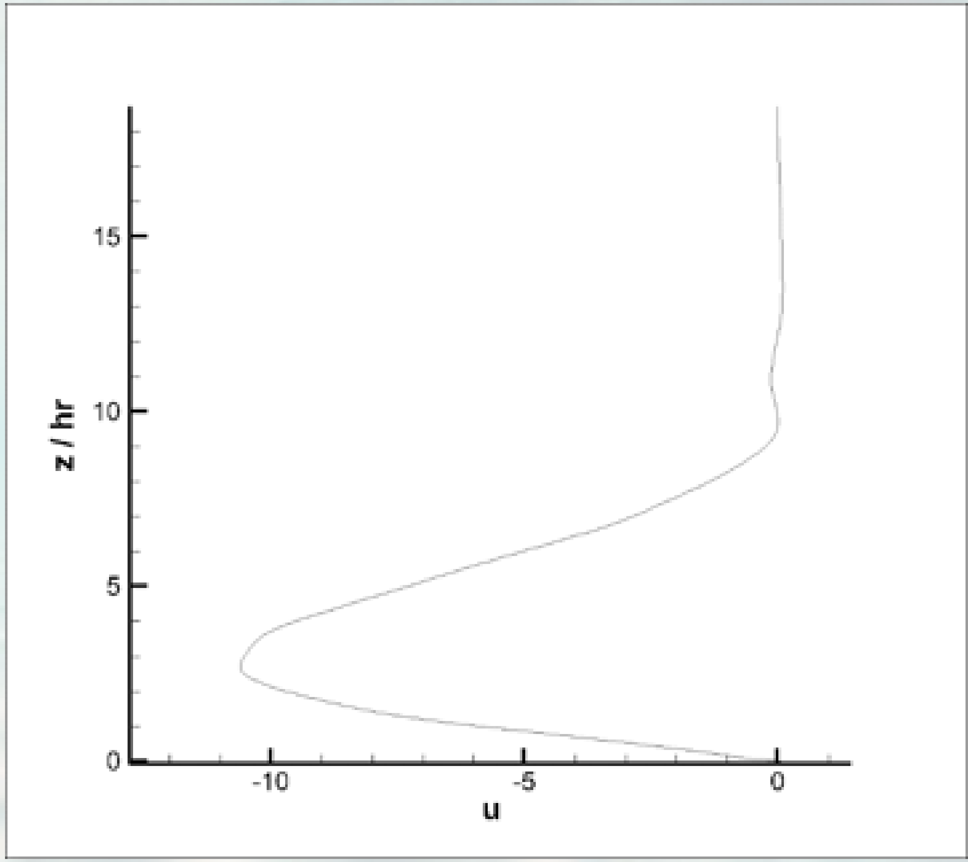
Lr = 0.9425
h_r = 0.18
Δx = 0.00368 m
Δy = 0.00368 m
Δz = 0.001 -> 0.04853 m
Grid = 513x33x650 = 11.003.850 cells

D_g(m)	Ψ	a_0/D_g
0.00025	104.4	2100
0.00035	74.5	1500
0.00044	59.3	1193
0.00053	49.2	990
0.00066	39.5	795

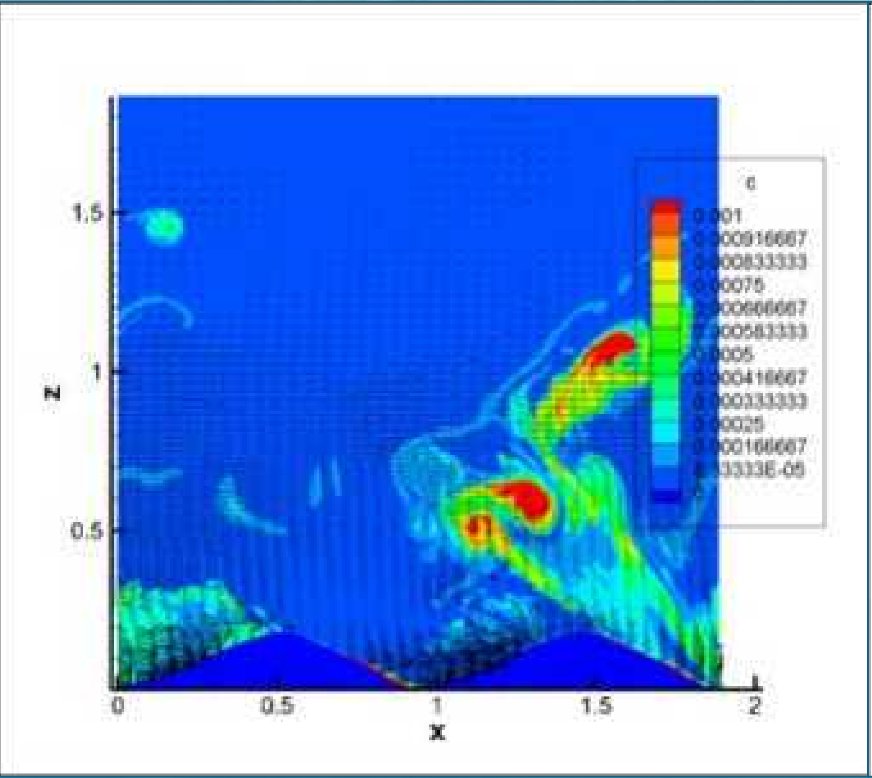
The period- and spanwise-averaged velocity field (vectors) and Y vorticity field



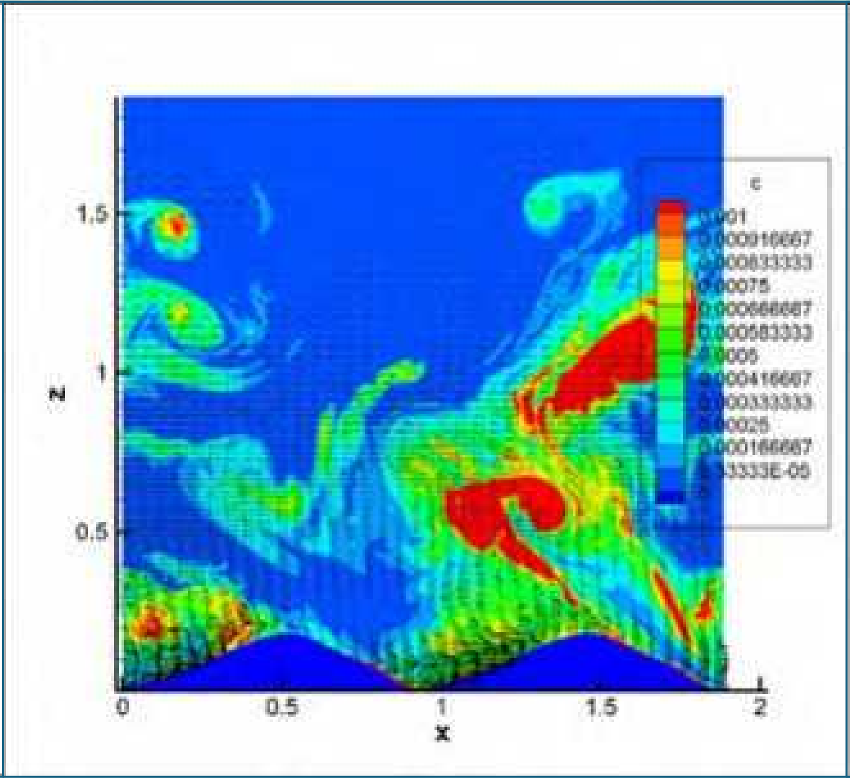
Profile of the mean streamwise velocity, u



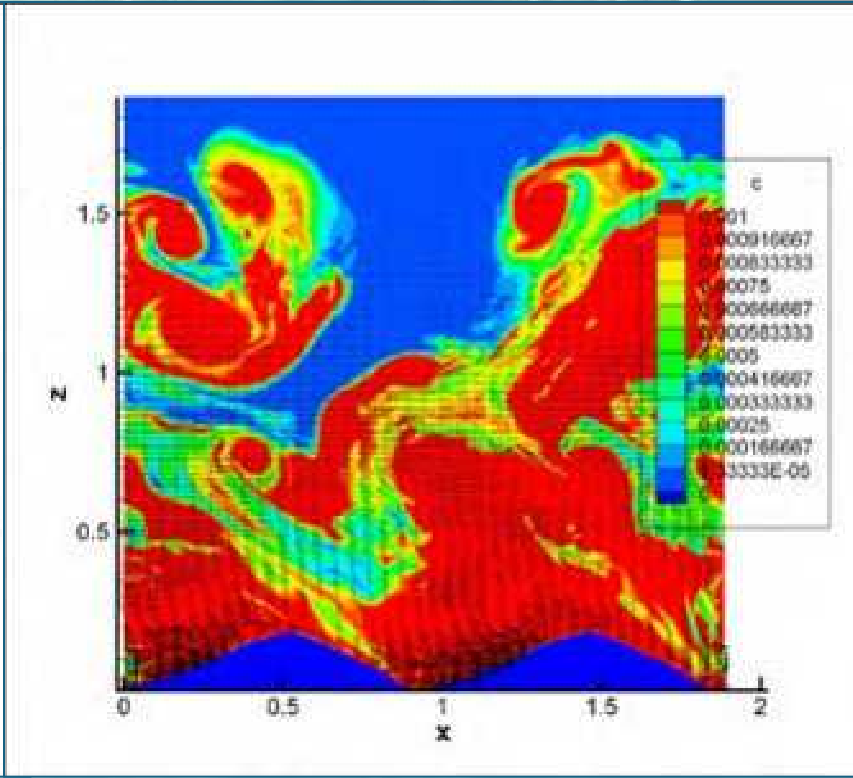
Instantaneous snapshots of the distribution of the suspended sediment on the 1T of the 12th Period



(a) 0.66mm dimension size fraction

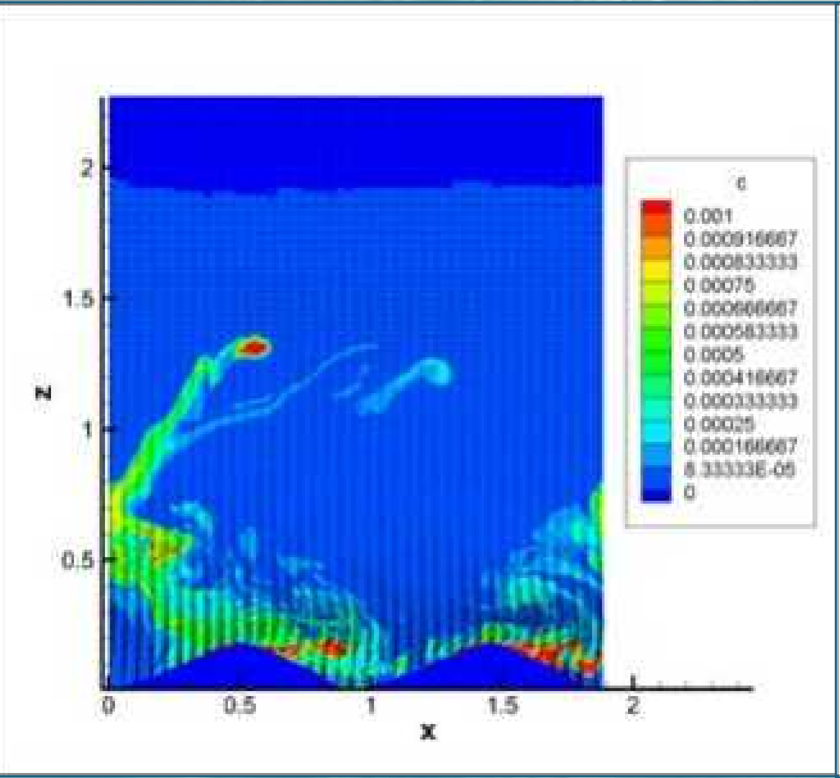


(b) 0.44mm dimension size fraction

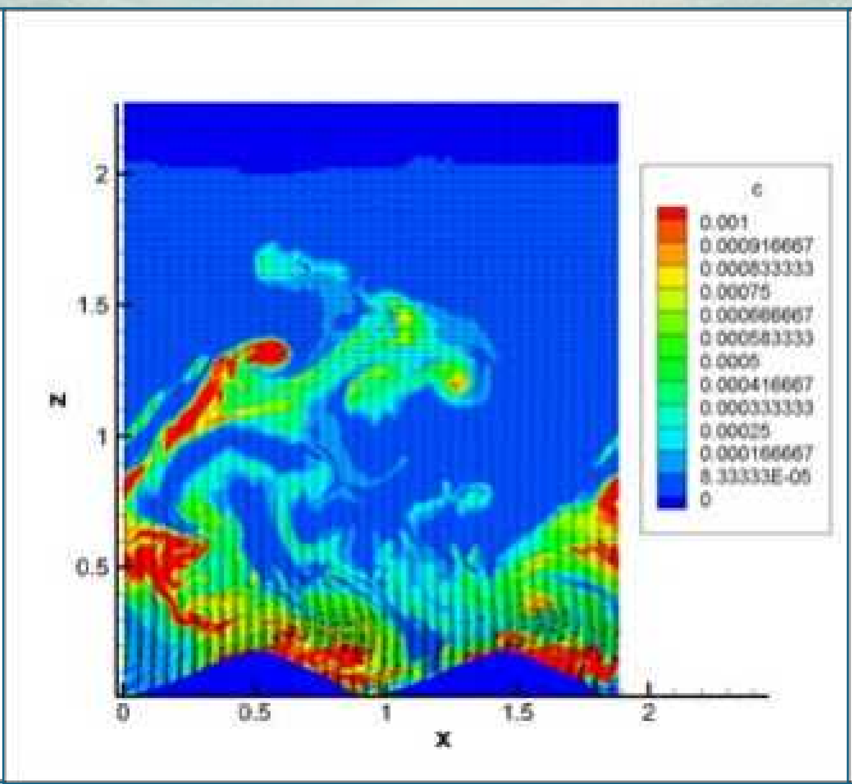


(c) 0.25mm dimension size fraction

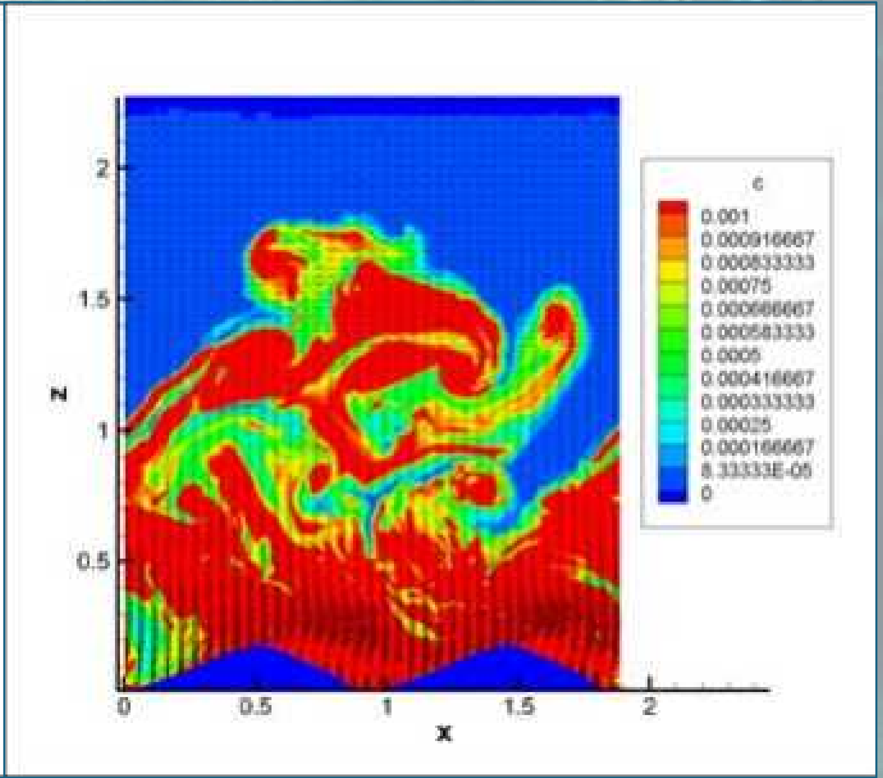
Instantaneous snapshots of the distribution of the suspended sediment on the T/4 12th Period



(a) 0.66mm dimension size fraction

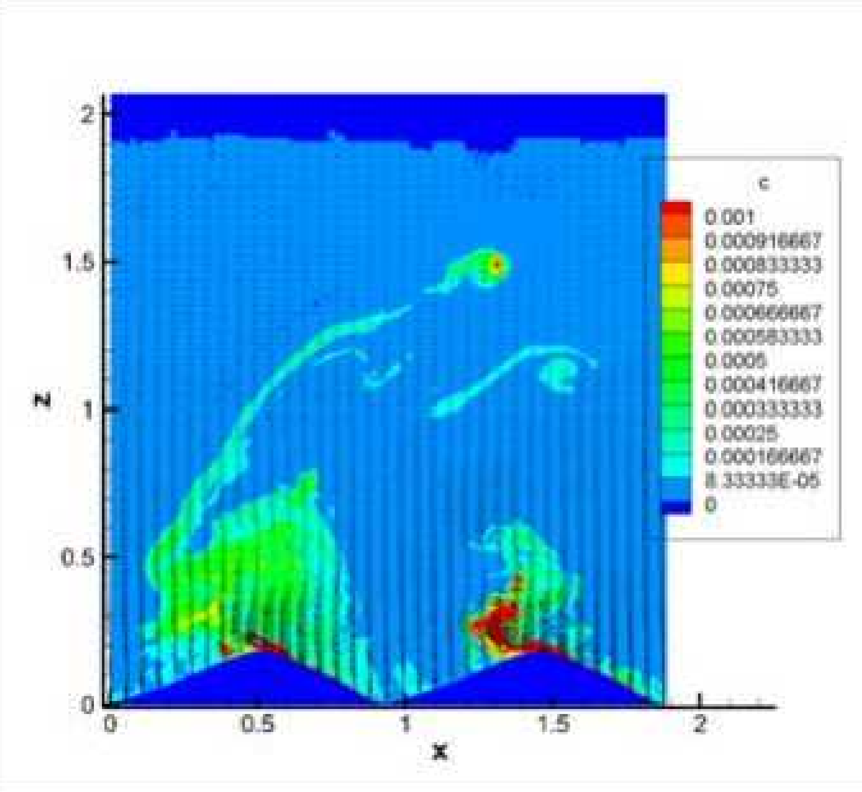


(b) 0.44mm dimension size fraction

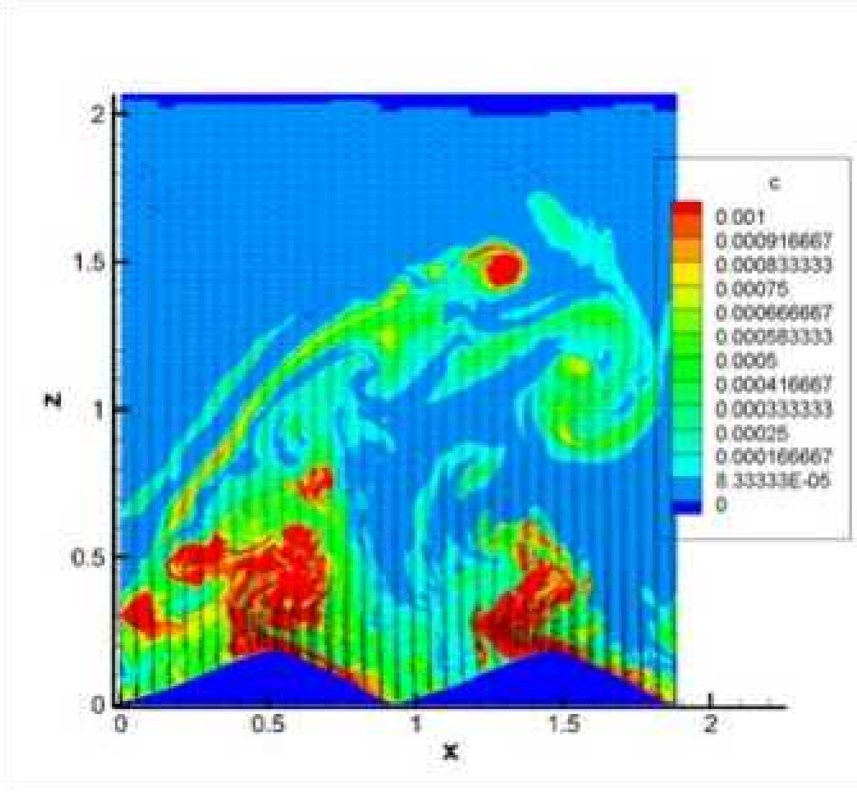


(c) 0.25mm dimension size fraction

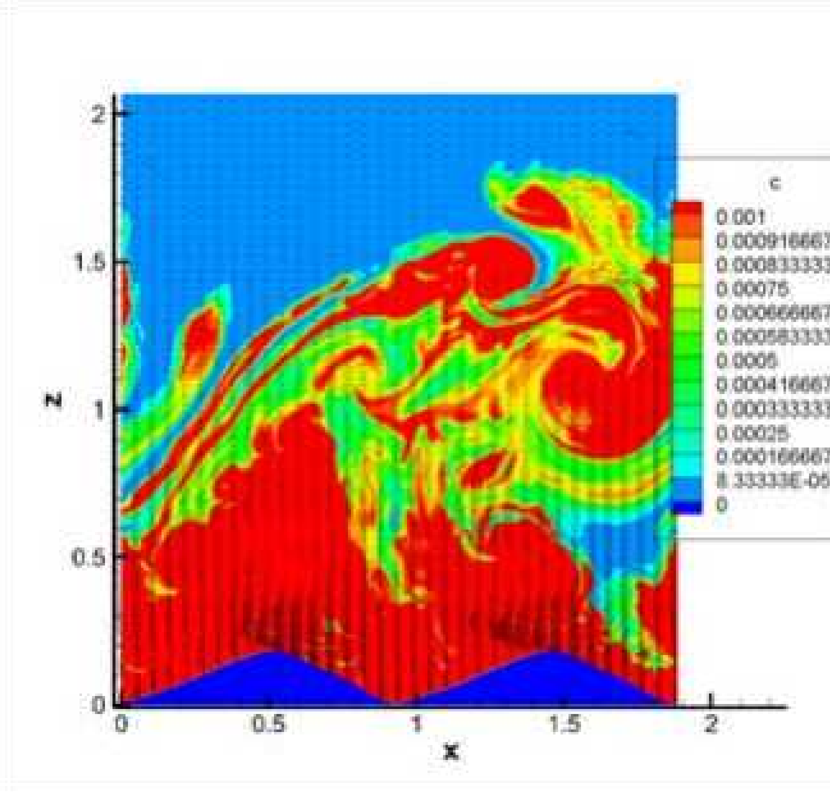
Instantaneous snapshots of the distribution of the suspended sediment on the T/2 12th Period



(a) 0.66mm dimension size fraction

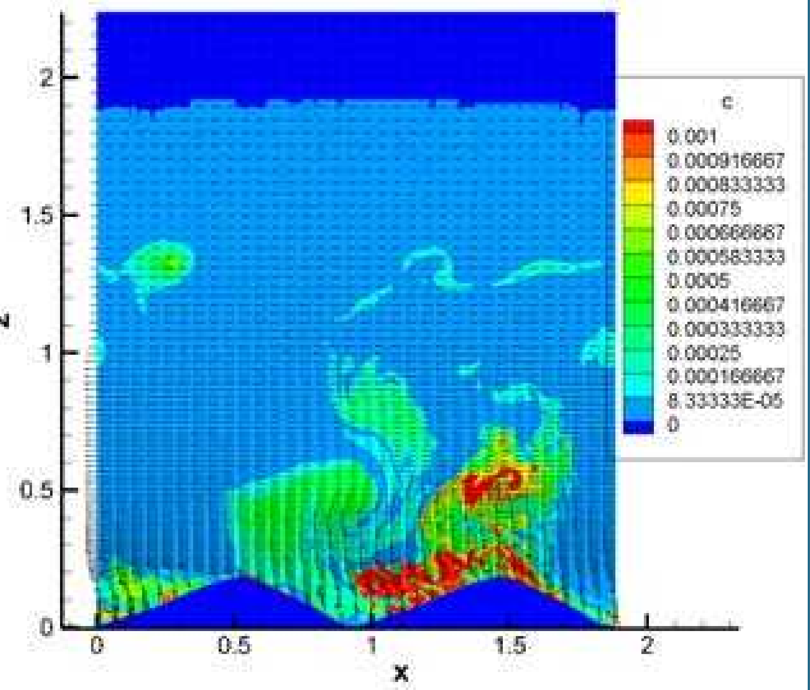


(b) 0.44mm dimension size fraction

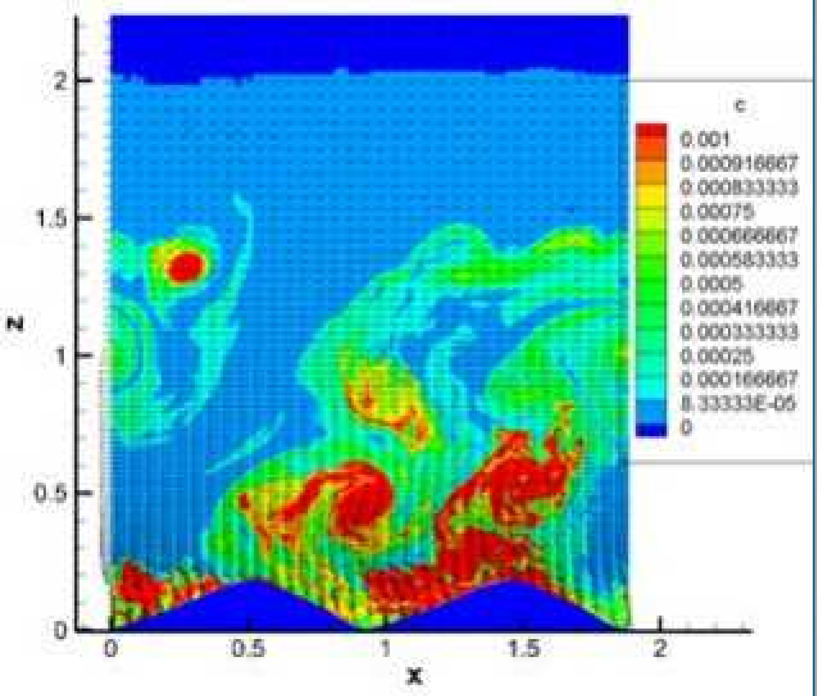


(c) 0.25mm dimension size fraction

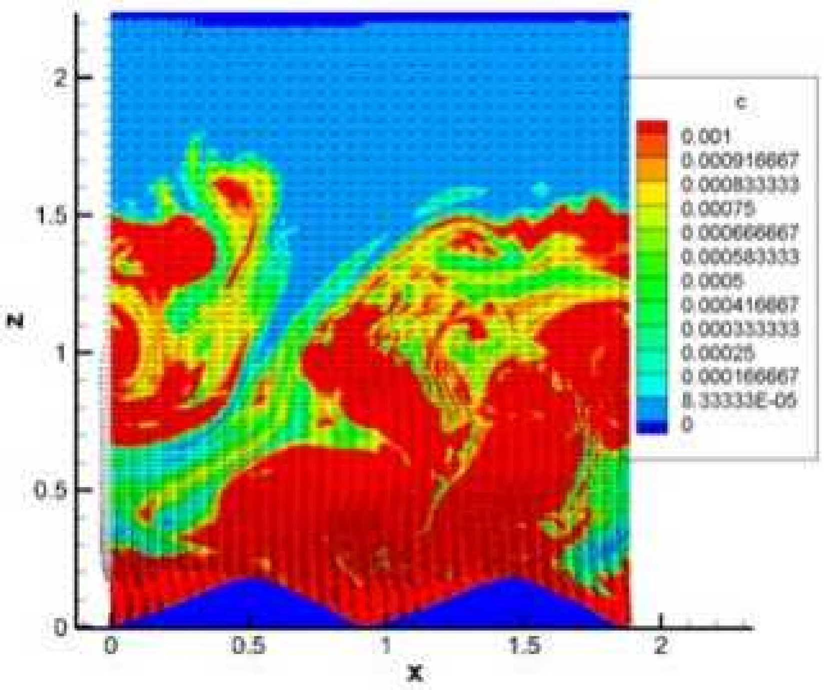
Instantaneous snapshots of the distribution of the suspended sediment on the 3T/4 12th Period



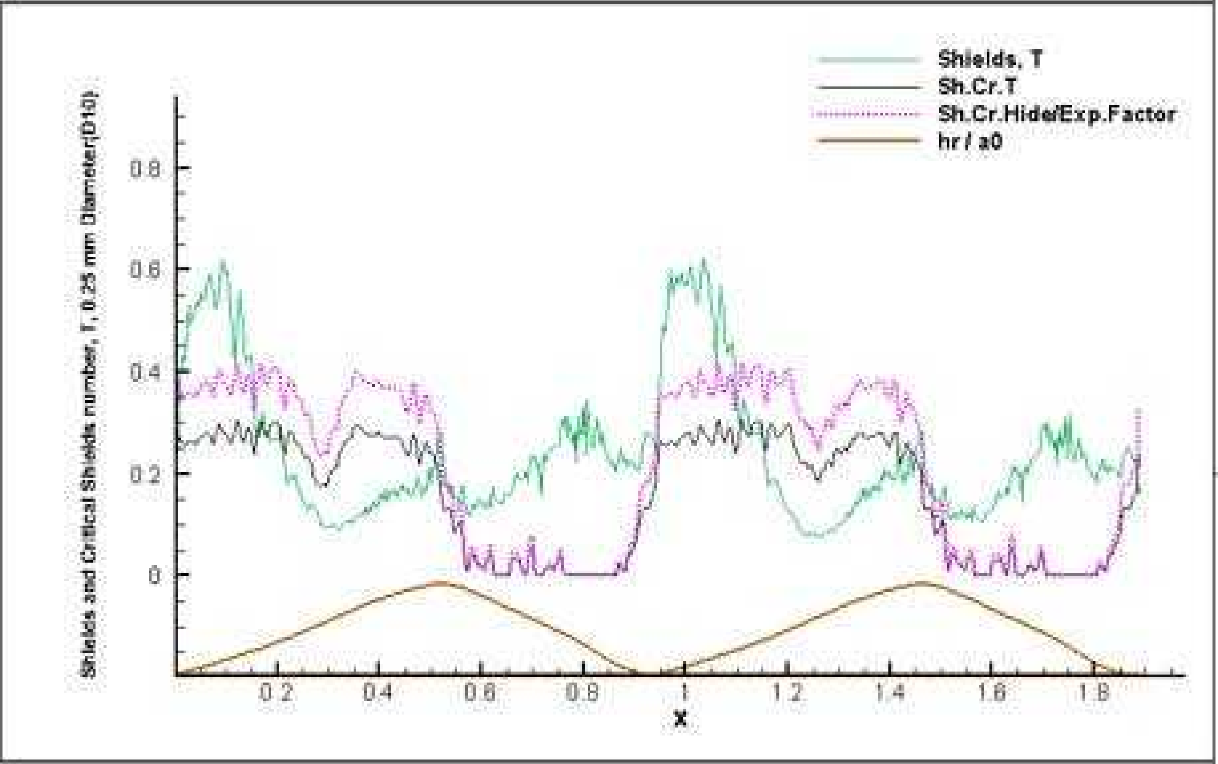
(a) 0.66mm dimension size fraction

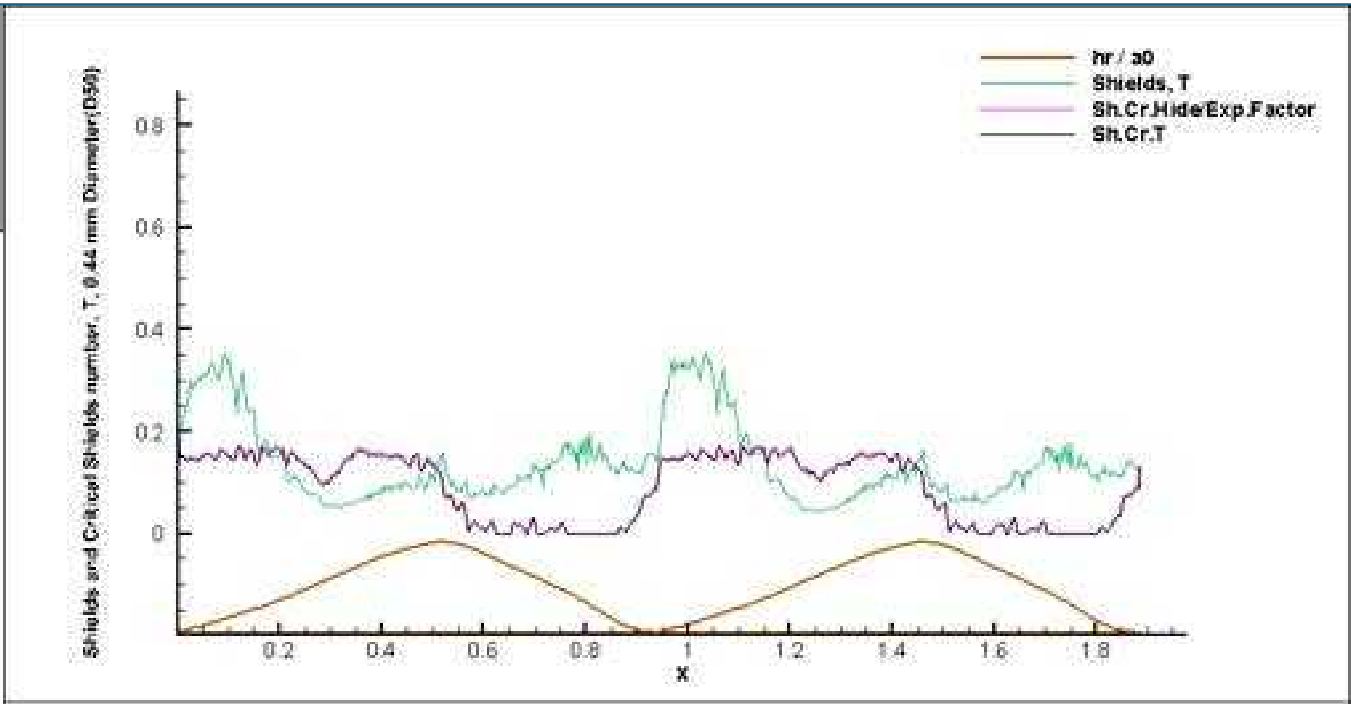


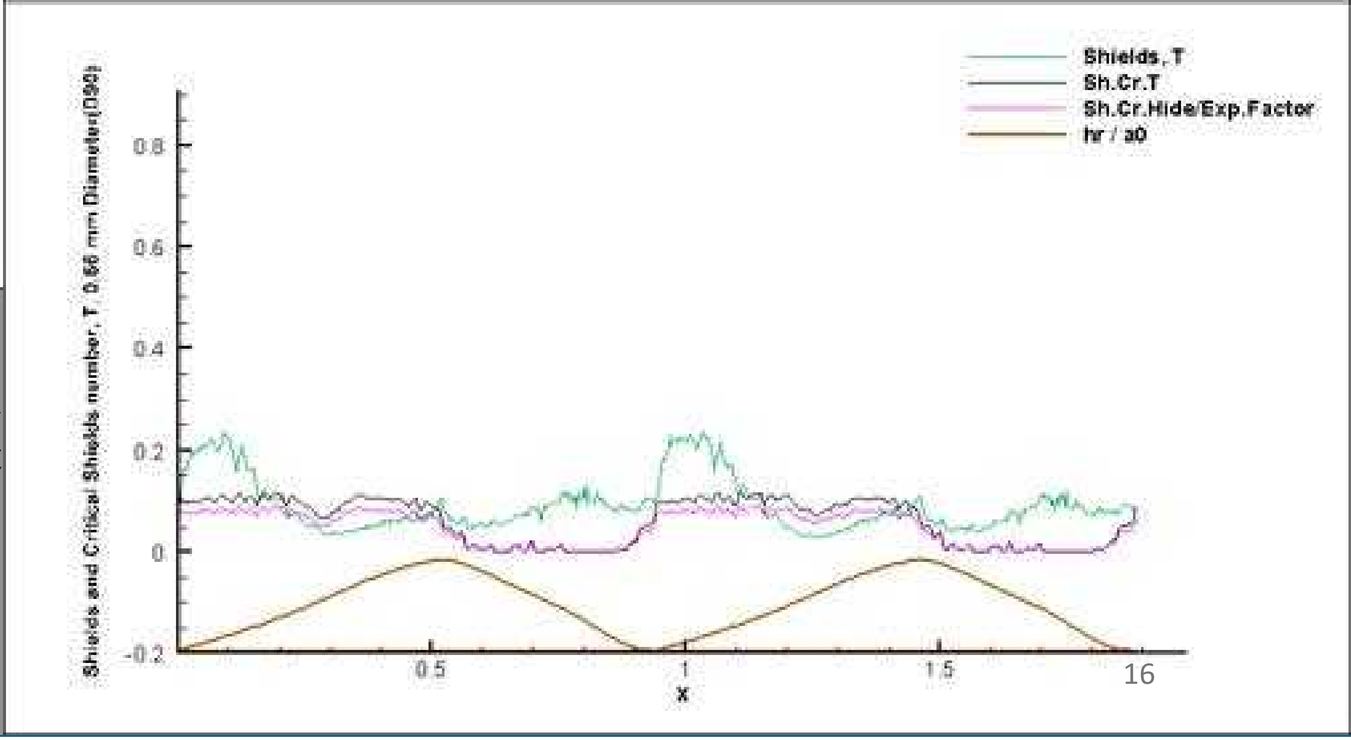
(b) 0.44mm dimension size fraction.



(c) 0.25mm dimension size fraction

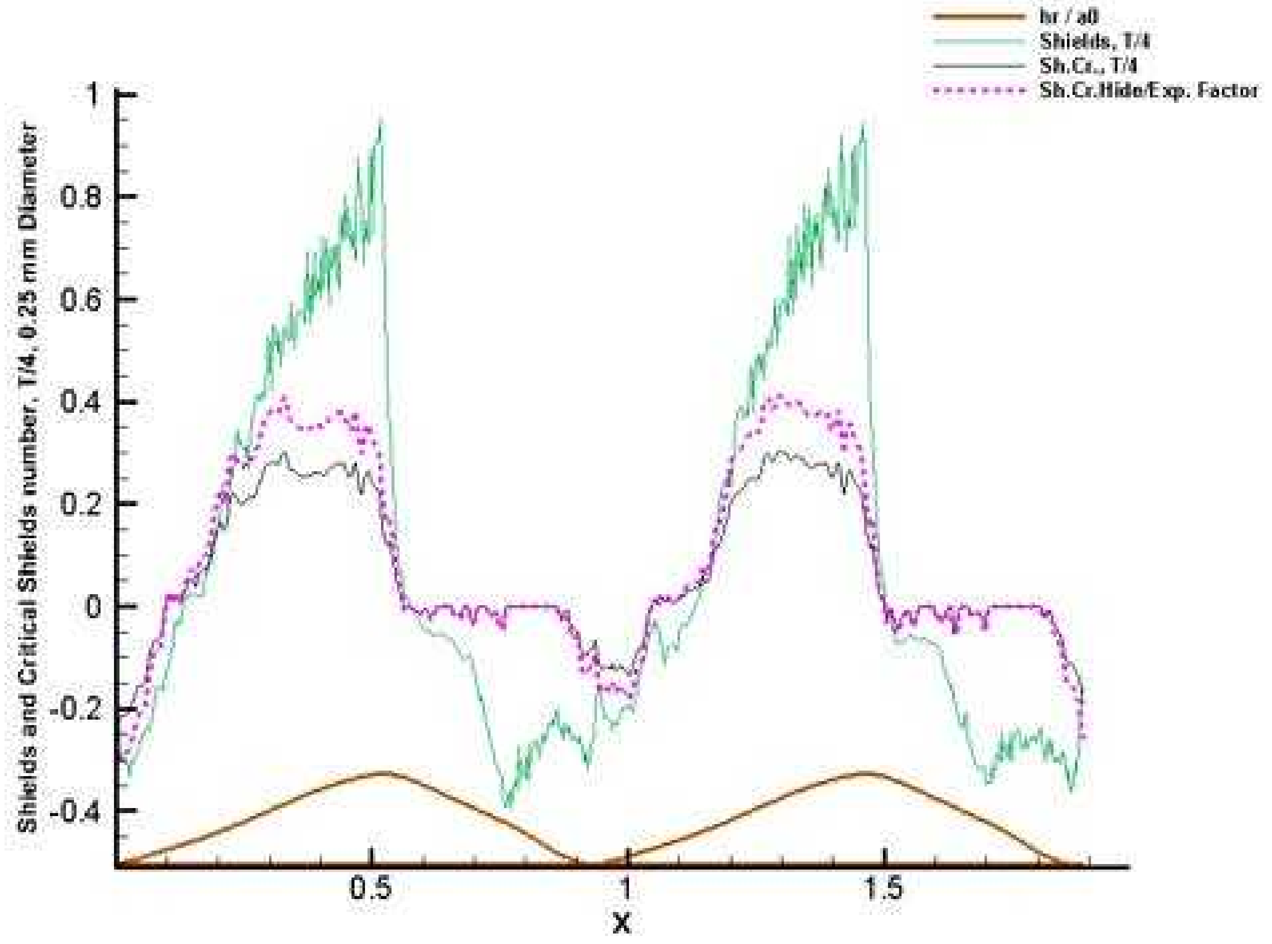


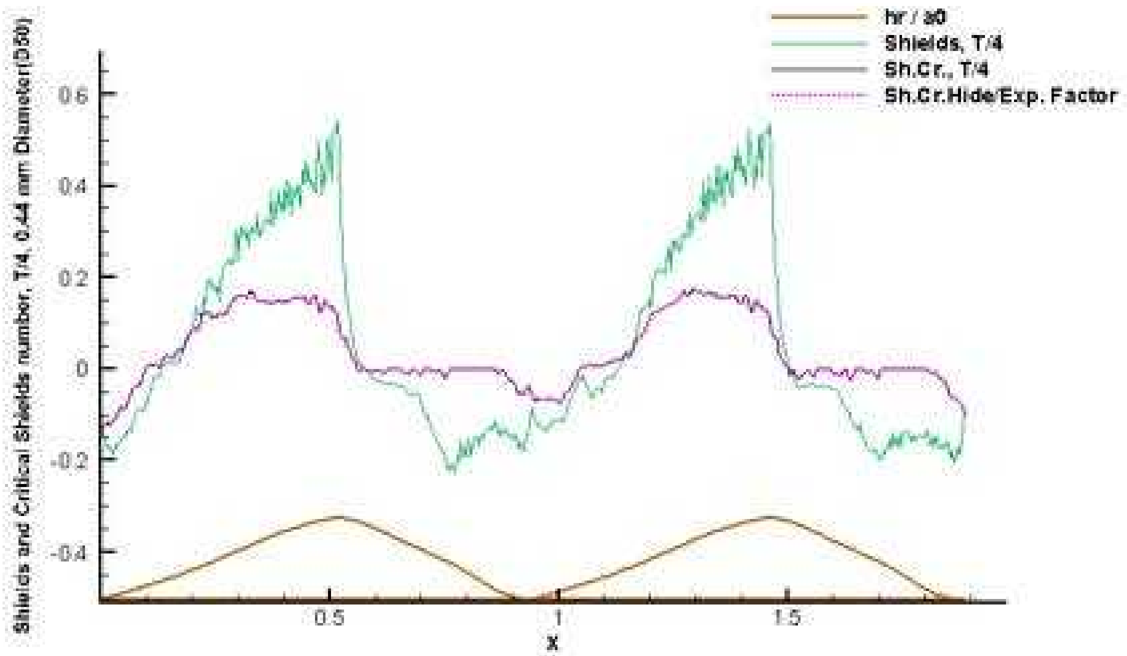


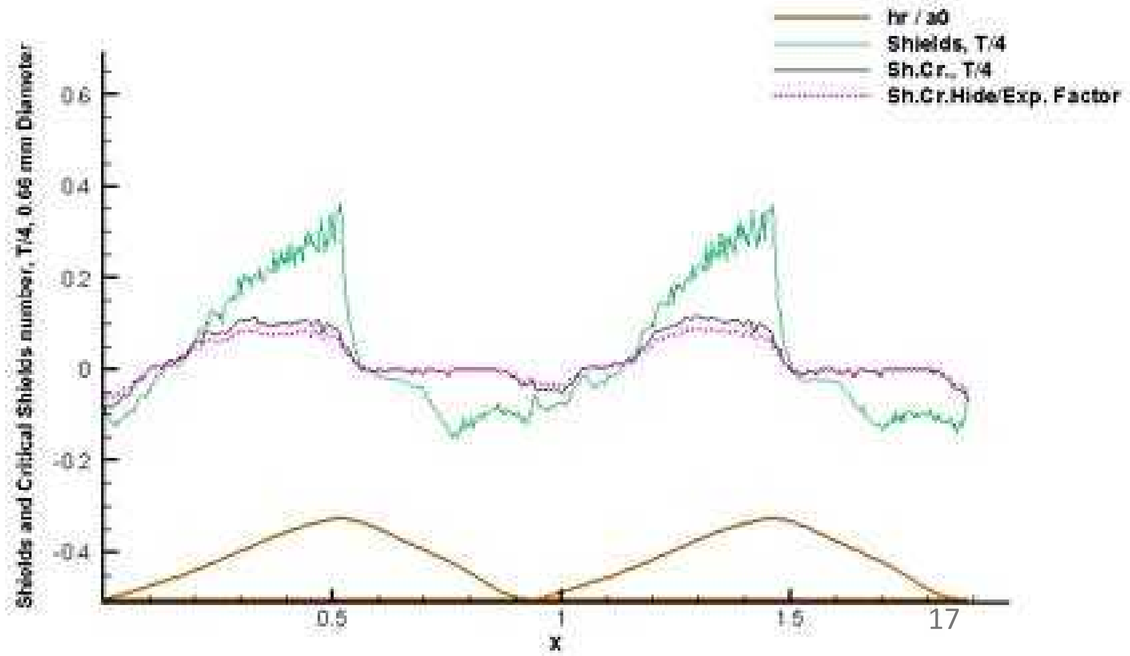


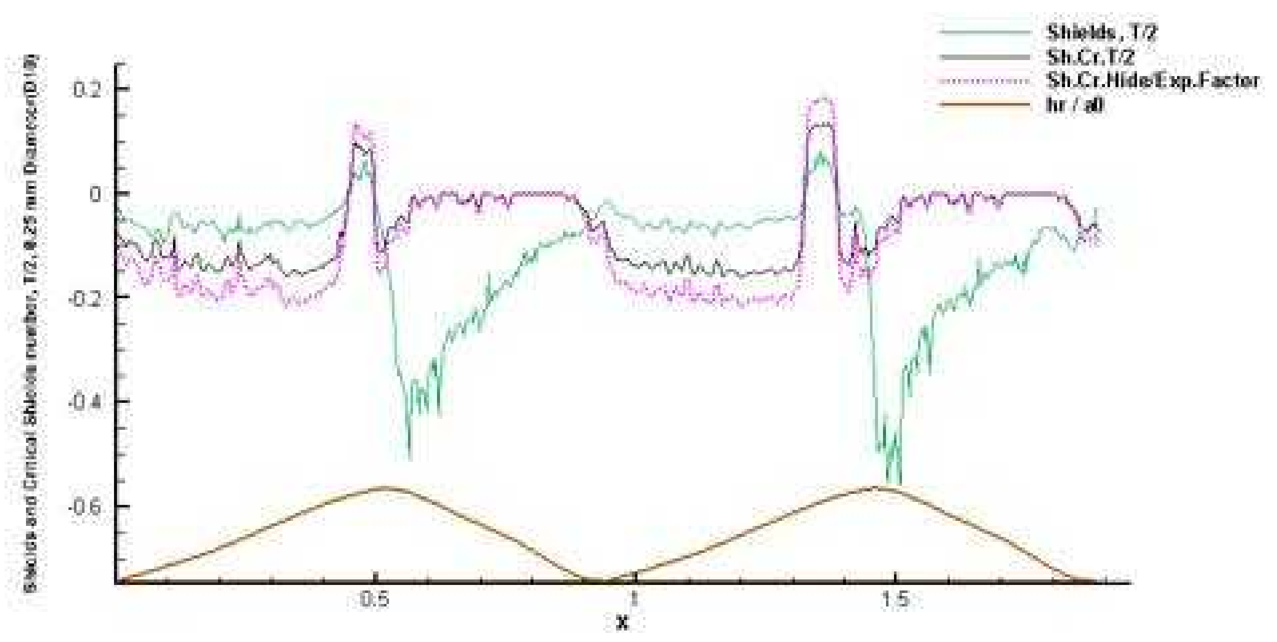
Profiles of Phase and Spanwise average Shields number & comparison between critical Shields number with and without the hide/exposure factor for the smallest, the median and the biggest fraction of sediment in 1T of 13 periods.

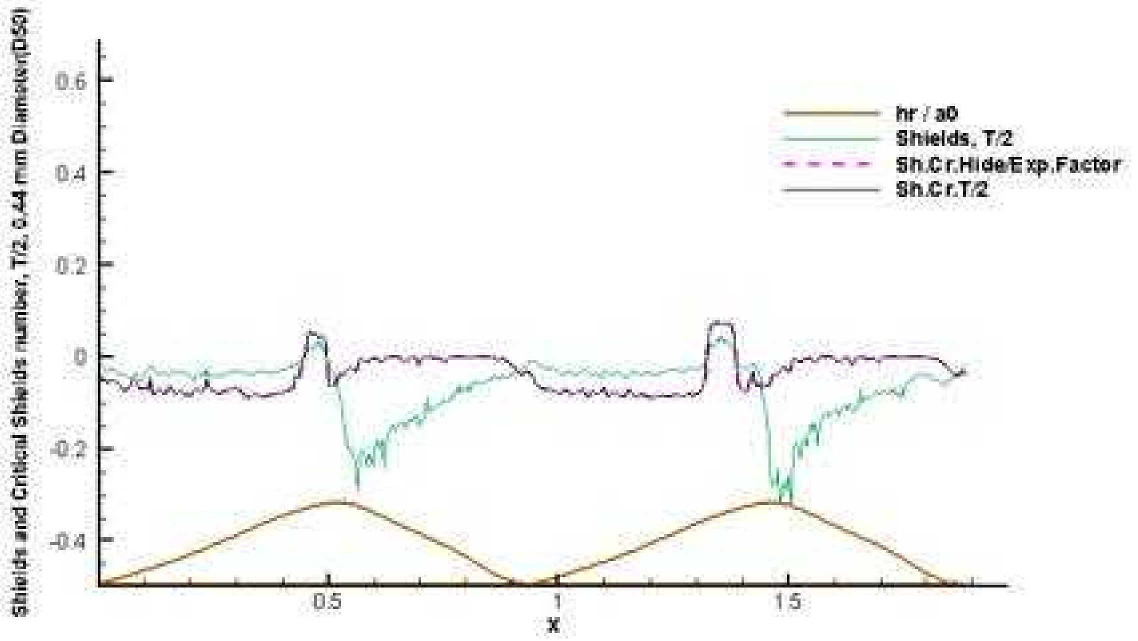
Profiles of Phase and Spanwise average Shields number & comparison between the critical Shields number with and without the hide/exposure factor for the smallest, the median and the biggest fraction of sediment in T/4 of 13 periods.

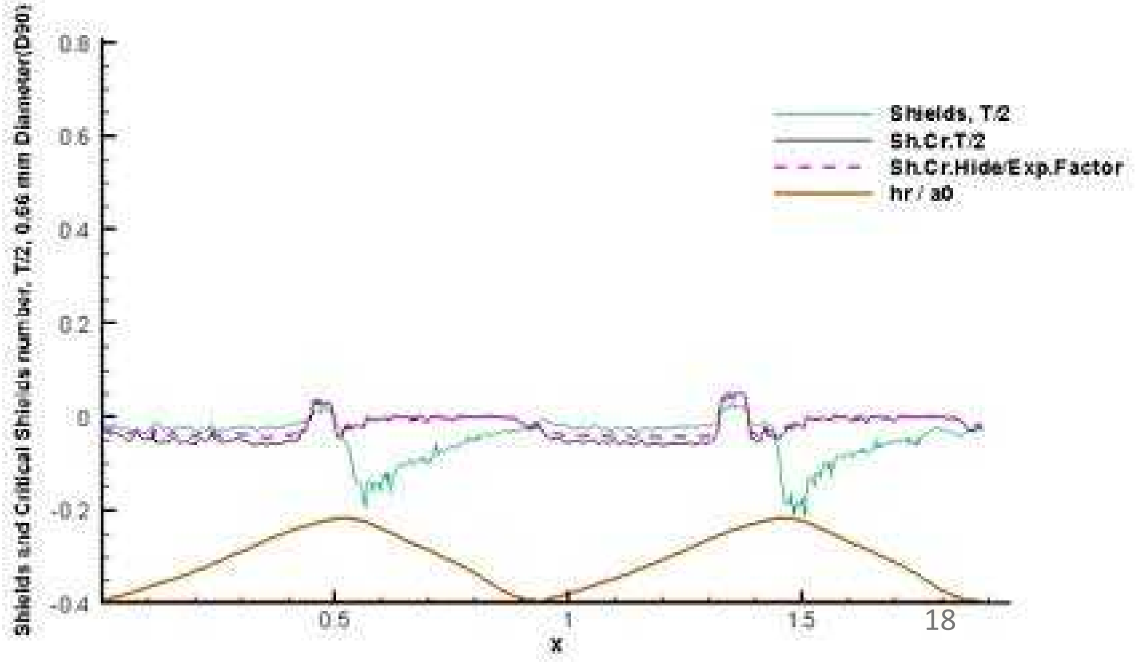




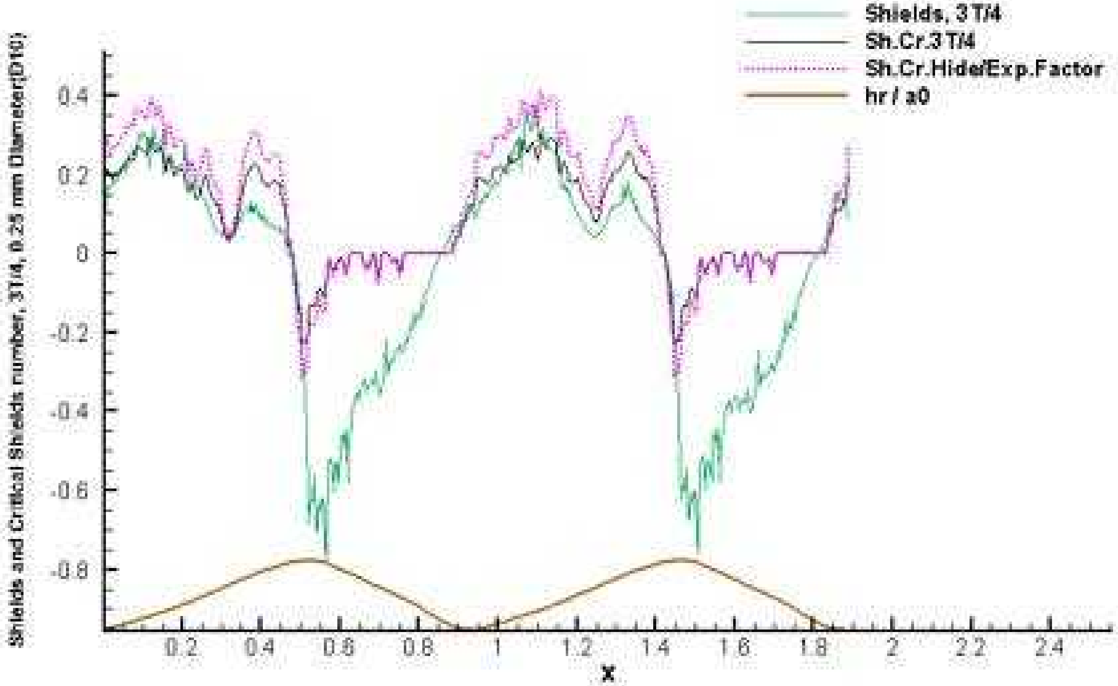


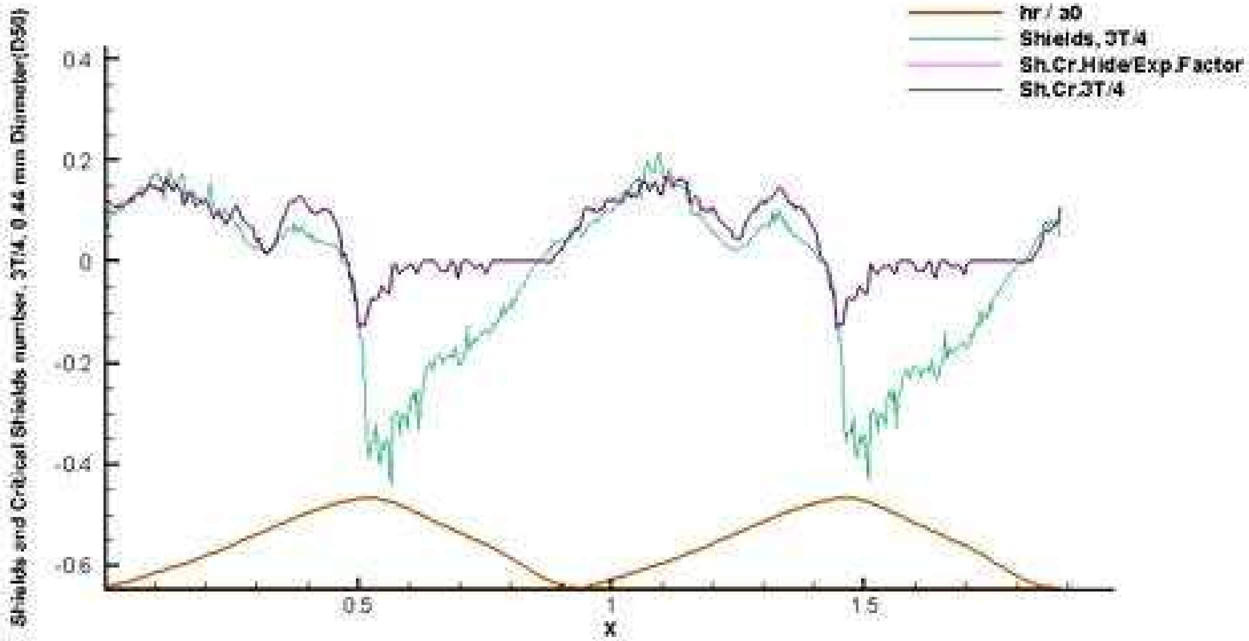


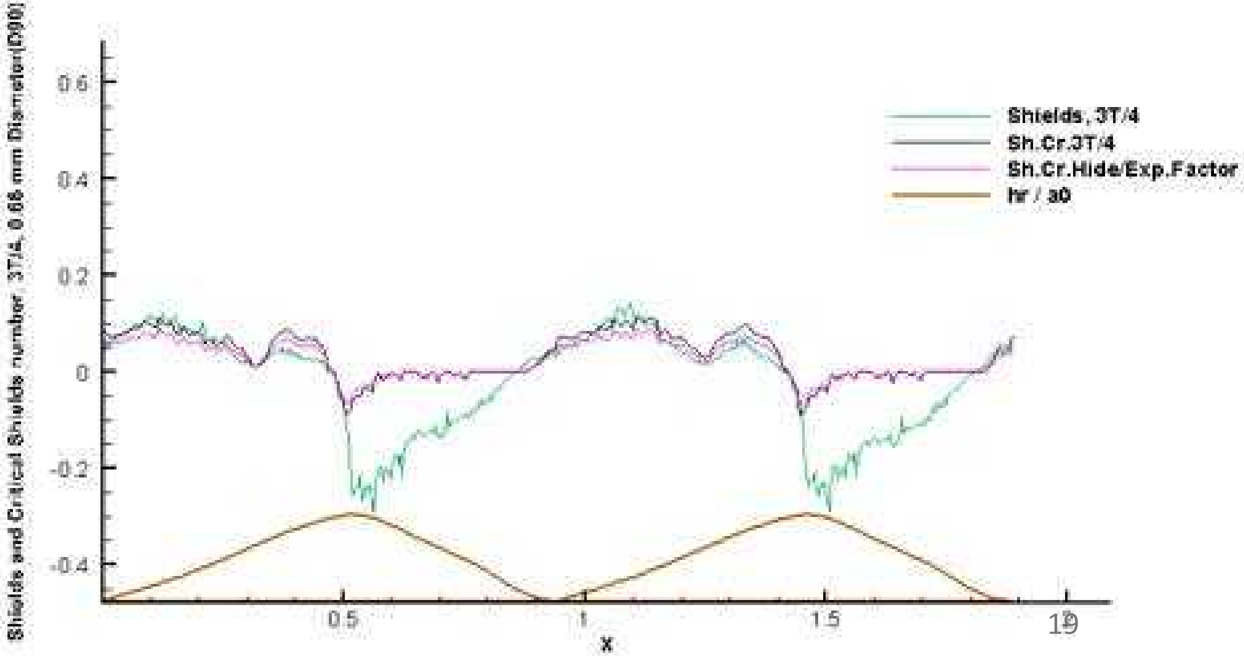




Profiles of the Phase and Spanwise average Shields number and comparison between the critical Shields number with and without the hide/exposure factor for the smallest, the median and the biggest fraction of sediment in T/2 of 13 periods.

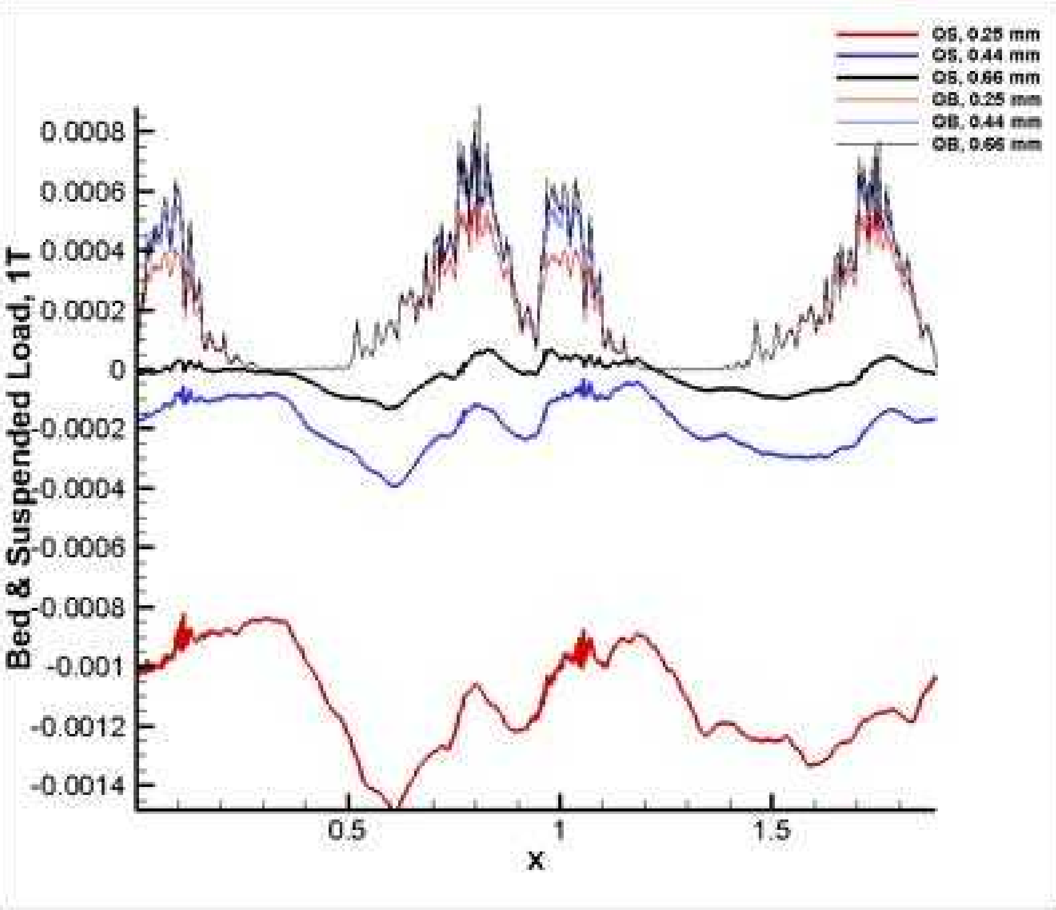


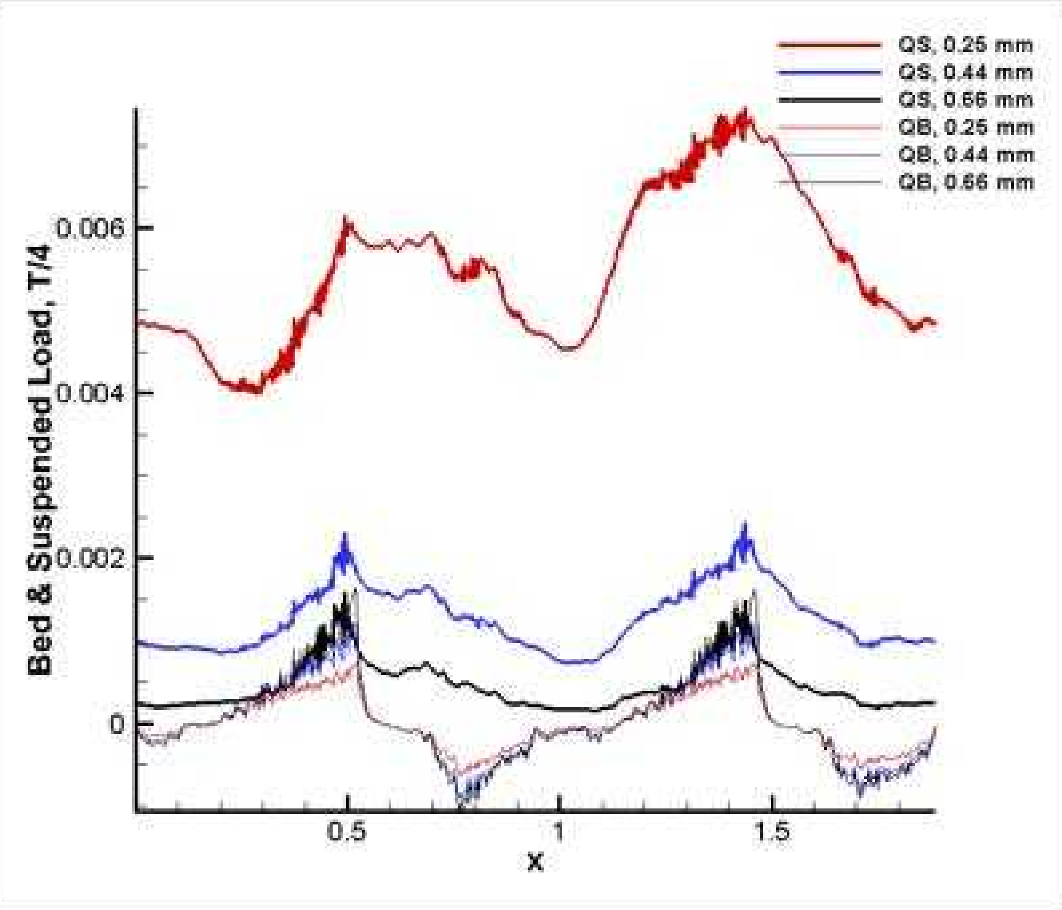


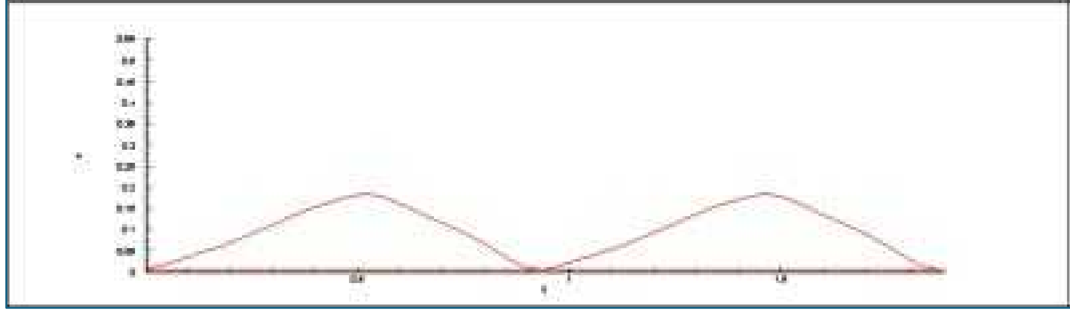


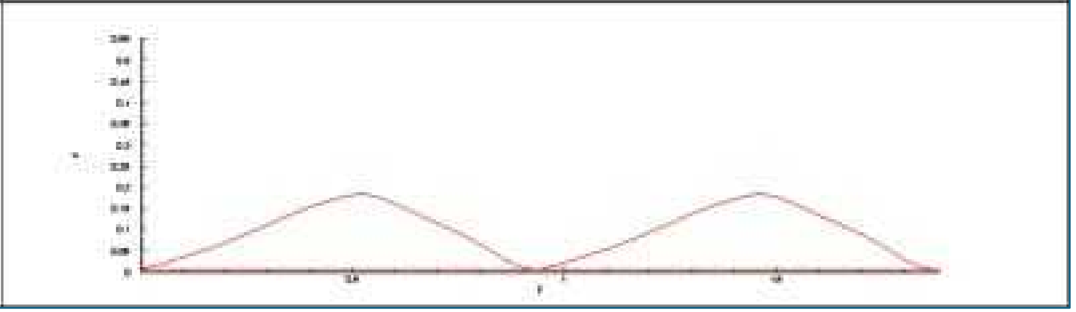
Profiles of the Phase and Spanwise average Shields number & comparison between the critical Shields number with and without the hide/exposure factor for the smallest, the median and the biggest fraction of sediment in 3T/4 of 13 periods.

Period and spanwise averaged Bed(qb) and Suspended(qs) Load for 1T and T/4 of 13 periods for the smallest, median and largest sediment fraction.

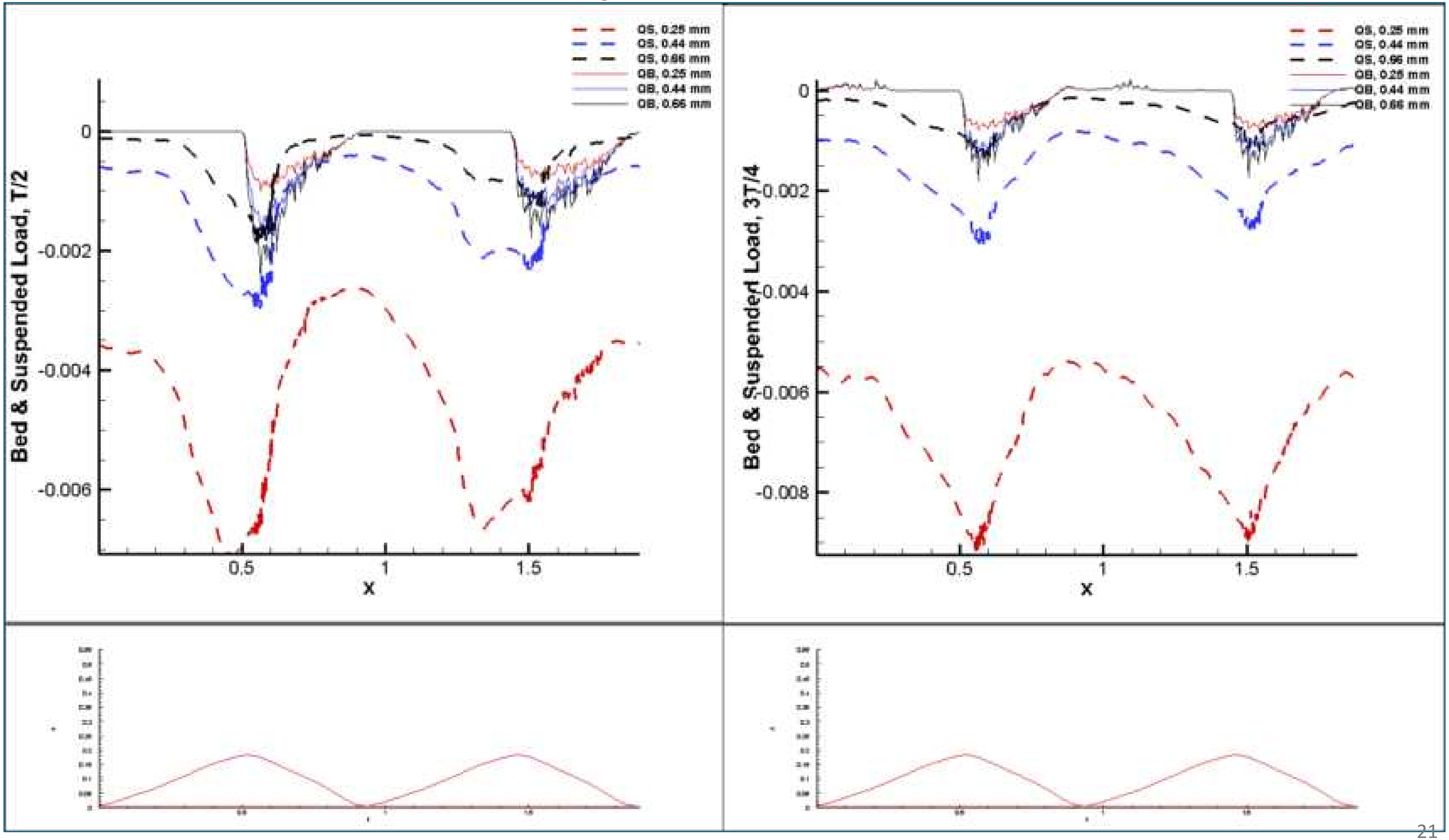




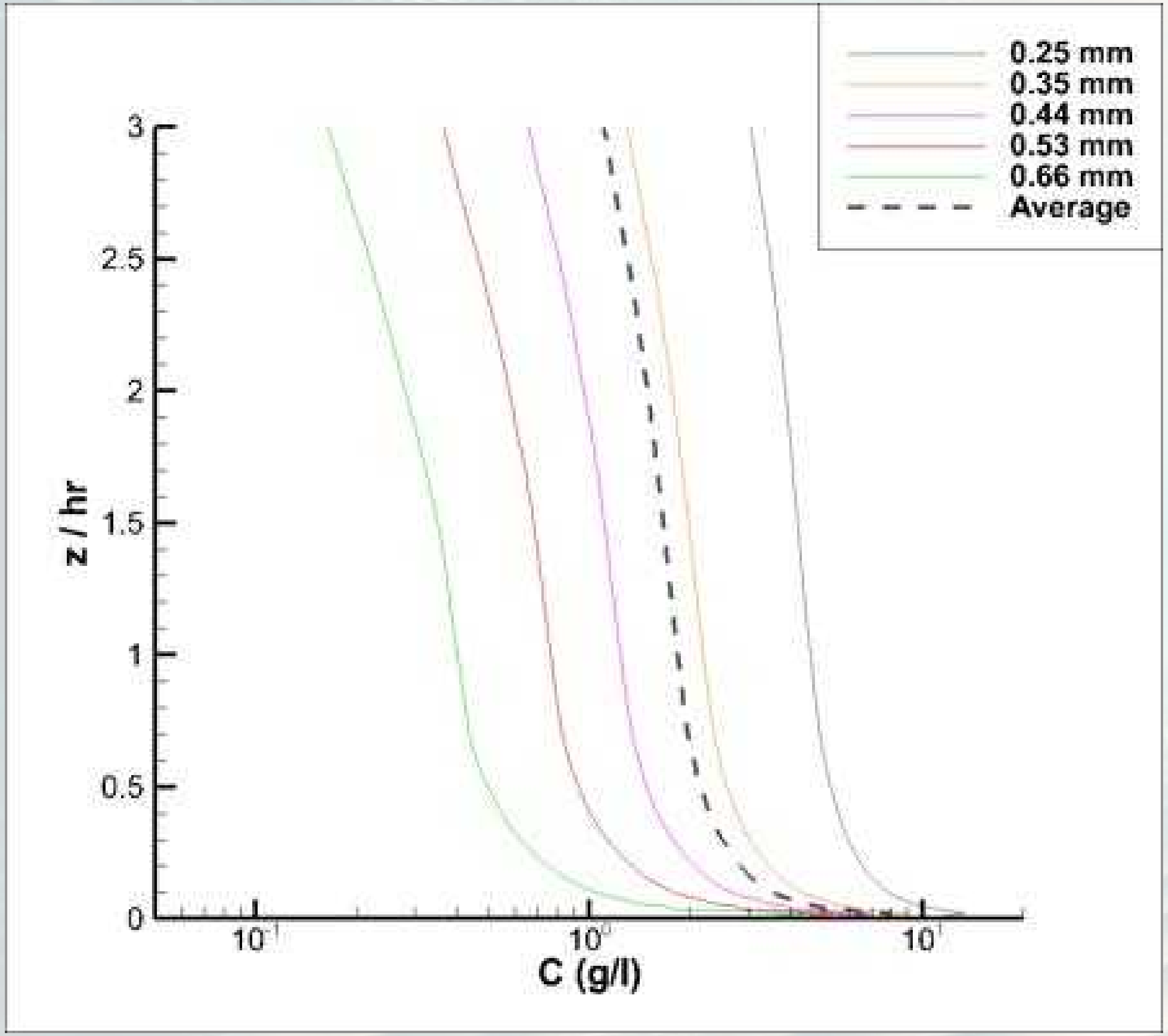




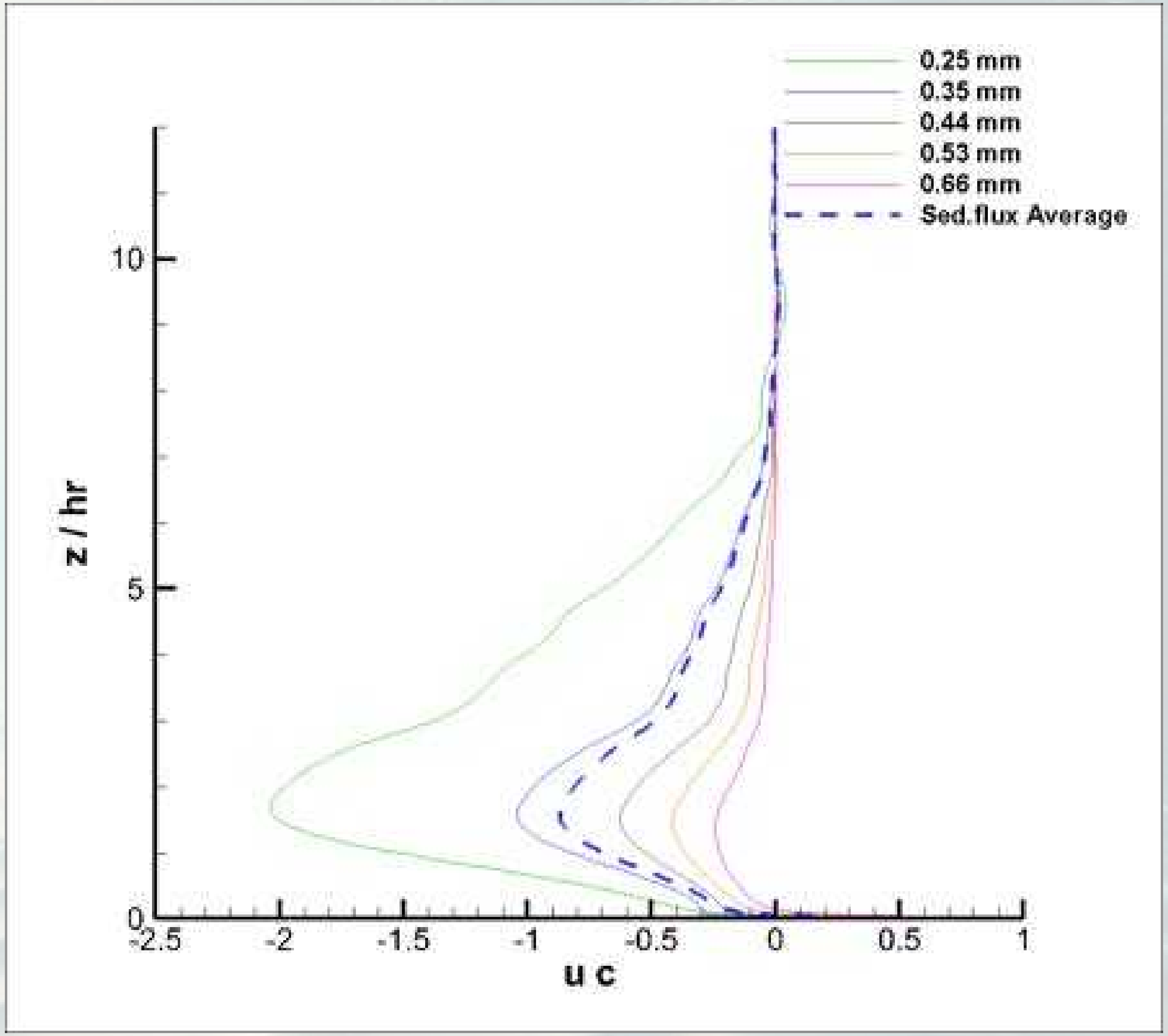
Period and spanwise averaged Bed(qb) and Suspended(qs) Load for T/2 and 3T/4 of 13 periods for the smallest, median and largest sediment fraction.



Profiles of the mean suspended sediment concentration of each sediment size fraction up to 3 h_r



Profiles of the mean suspended sediment flux, uc, for all the sediment size fractions and the average of the sediment fluxes of the fractions.



Conclusions

In this Configuration :

- Shields Critical with Hide & Exposure factor is larger than normal Shields Critical for the fractions with diameter size smaller than D_{50}, it is smaller for the ones with diameter size larger than D_{50}, they are almost equal to each other for D_{50}.
- The fractions with diameters larger than D_{50} contribute more to the bed load.
- Suspended Load : Diameter Size Decreases -> Suspended Load Increases
- Concentration : Diameter Size Decreases -> Concentration Increases

3rd Network Training School:
Advanced Integrated Coastal Zone Monitoring and Management
IH Cantabria, Spain
Santander, 11 – 13 March 2025

Numerical investigations of bottom boundary layer hydrodynamics under a dam-break-driven swash event

Doctoral Candidate: Quan NGUYEN

Supervising Scientists: Nicholas DODD and Riccardo BRIGANTI

Overview of the project

Overview of the project

The swash zone

- Difficulty in adequately represent the wave boundary layer in the swash zones.
- Difficulty in directly measure the bed shear stress within the bottom boundary layer (BBL)
- An existing BBL sub-model for a **fixed bed** in the swash zone

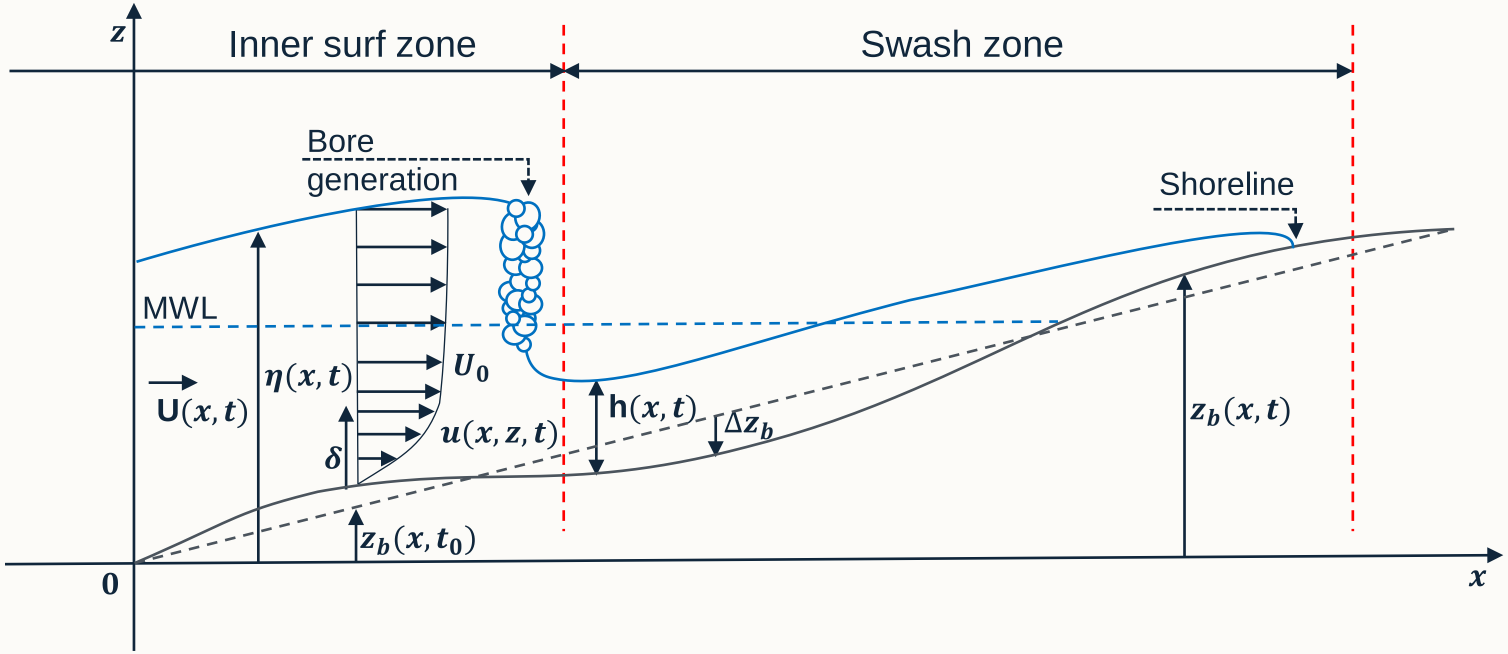


Figure 1. Schematic of general swash geometry.

➢ To develop an **improved** boundary layer description (sub-model) for a **mobile bed** that is suitable for incorporation into a Nonlinear Shallow Water Wave Equation (NLSWE) morphodynamic solver.

Research methodology

Numerical model

❖ Depth-averaged, phase-resolving, fully-coupled model

Hydrodynamics	**1D nonlinear shallow water equations (NLSWEs)**
Morphodynamics	Coupled with **Exner equation**
Sediment transport	Coupled with **Meyer-Peter and Müller equation**
Bottom boundary layer model	**Momentum integral method**

Research methodology

Numerical model calibration and validation

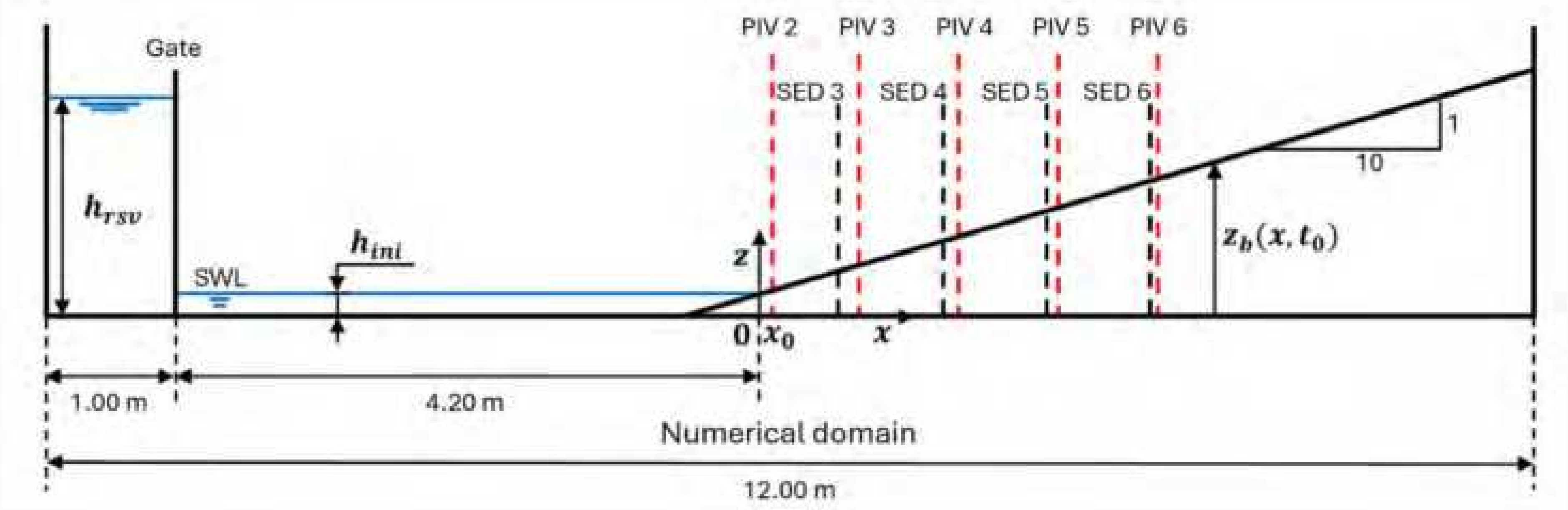


Figure 2. Schematic of the numerical setup based on the Aberdeen Swash facility.

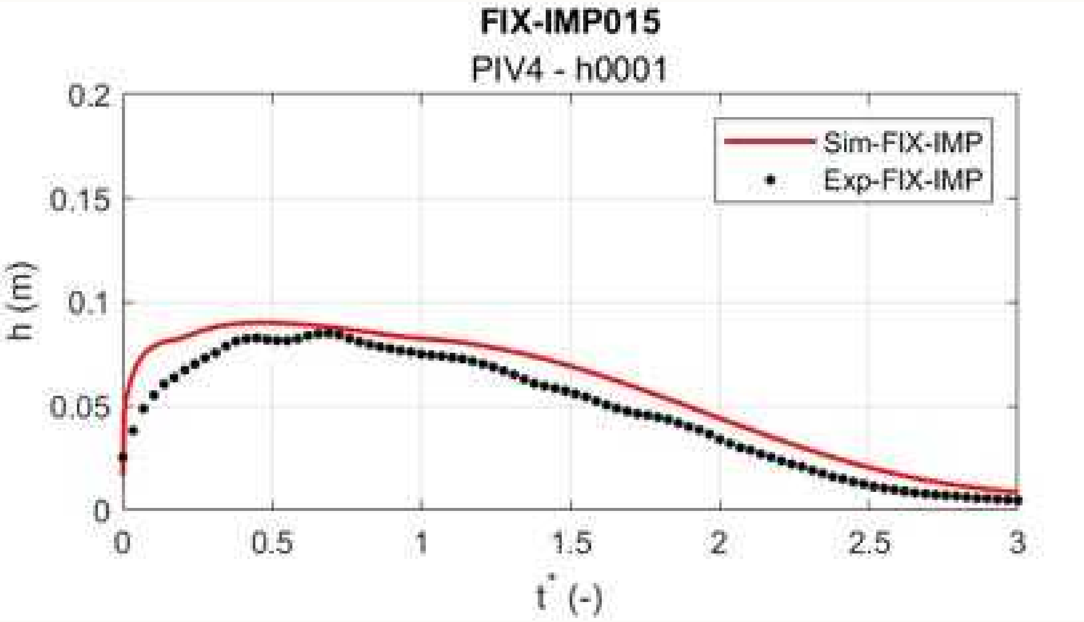
Laboratory-based datasets

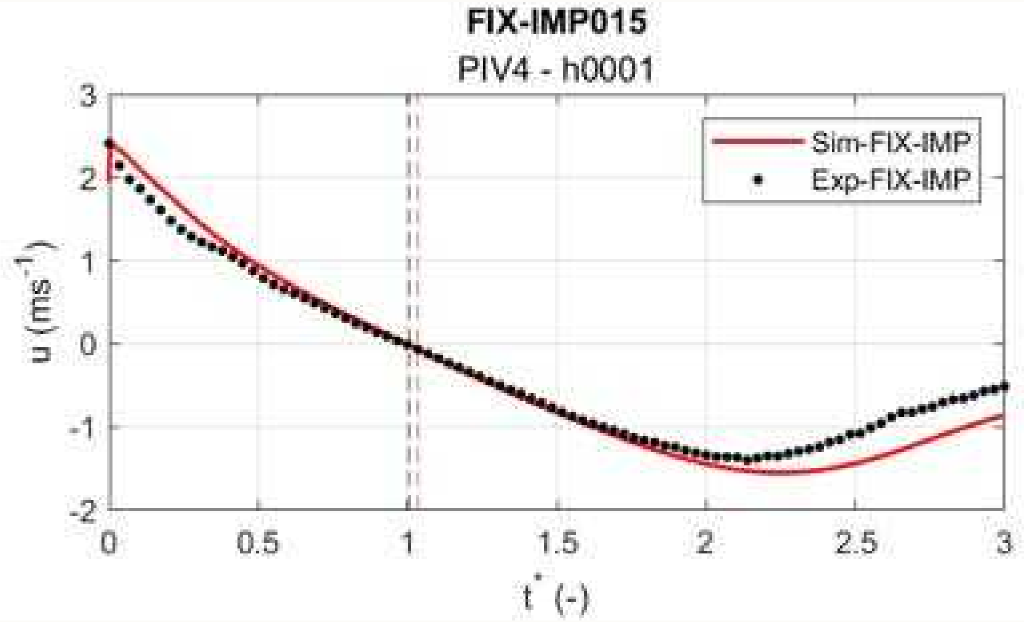
- Experimental study of bore-driven swash hydrodynamics on impermeable rough slopes (Kikkert et al., 2012).
- Intra-swash hydrodynamics and sediment flux for dam-break swash on coarse-grained beaches (O'Donoghue et al., 2016).

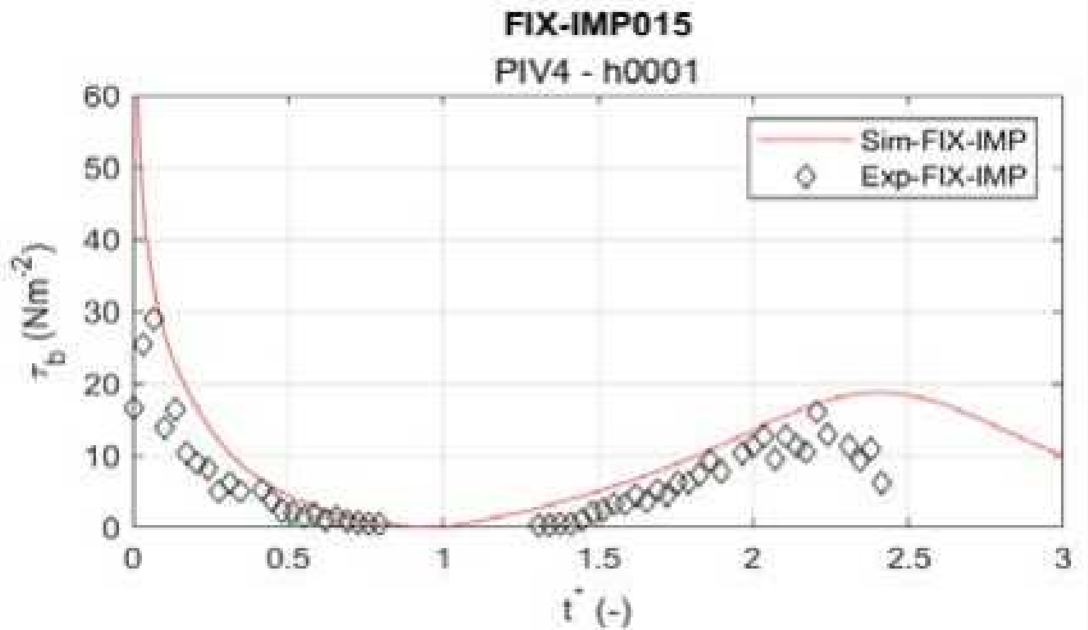
Previous results

Simulation of single swash events on impermeable fixed beds

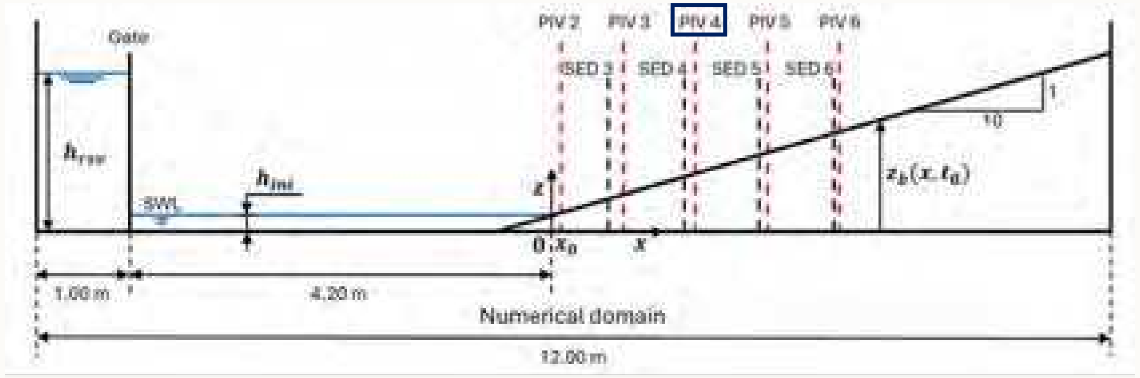
Water depth - Depth-averaged velocity – Bed shear stress







$$t^* = \frac{t - t_{bore\ arrival}}{t_{flow\ reversal} - t_{bore\ arrival}}$$



Model advancements and Limitations

- ➢ The model accurately predicts the depth-averaged horizontal velocity in the run-up phase
  - X **Overestimation of boundary layer thickness and underestimation of velocity profile**

- ➢ The modelled bed shear stress is well predicted when compared with the log-law-derived shear stress
  - X **Uncertainties in bed shear stress modelling**

- ➢ Numerical results of the flow variables for the validation tests are close to the experimental results
  - X **Overestimation of Flow Variables**

On-going work and research results

The calculation of w-component of the velocity

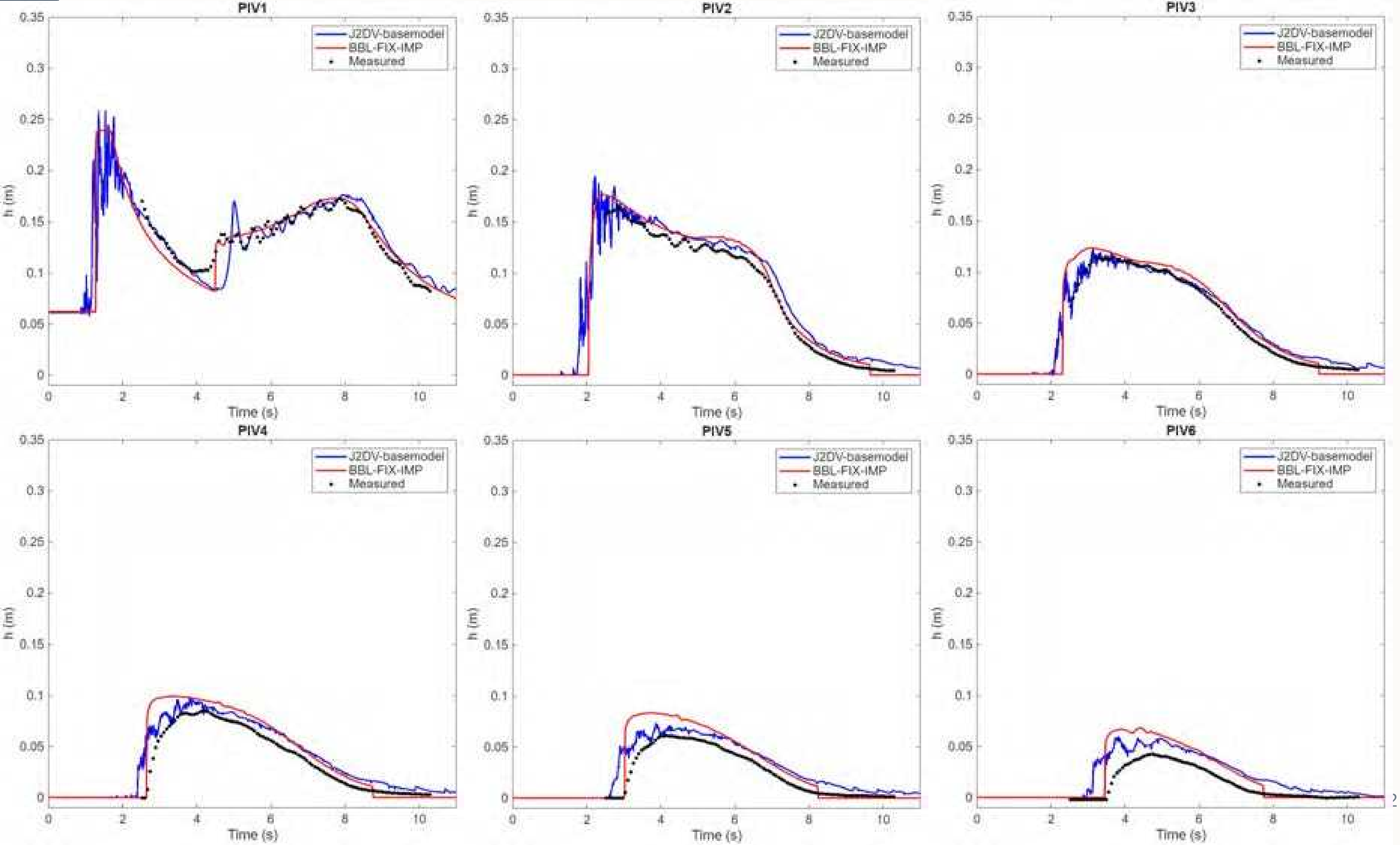
Comparing with 2DV RANS (VOF) equation solver

Compared against corresponding simulation data for the same event, generated from a 2DV RANS (VOF) equation solver (Kranenborg et al., 2022).

- Water depth
- Depth-averaged velocity
- Velocity profile

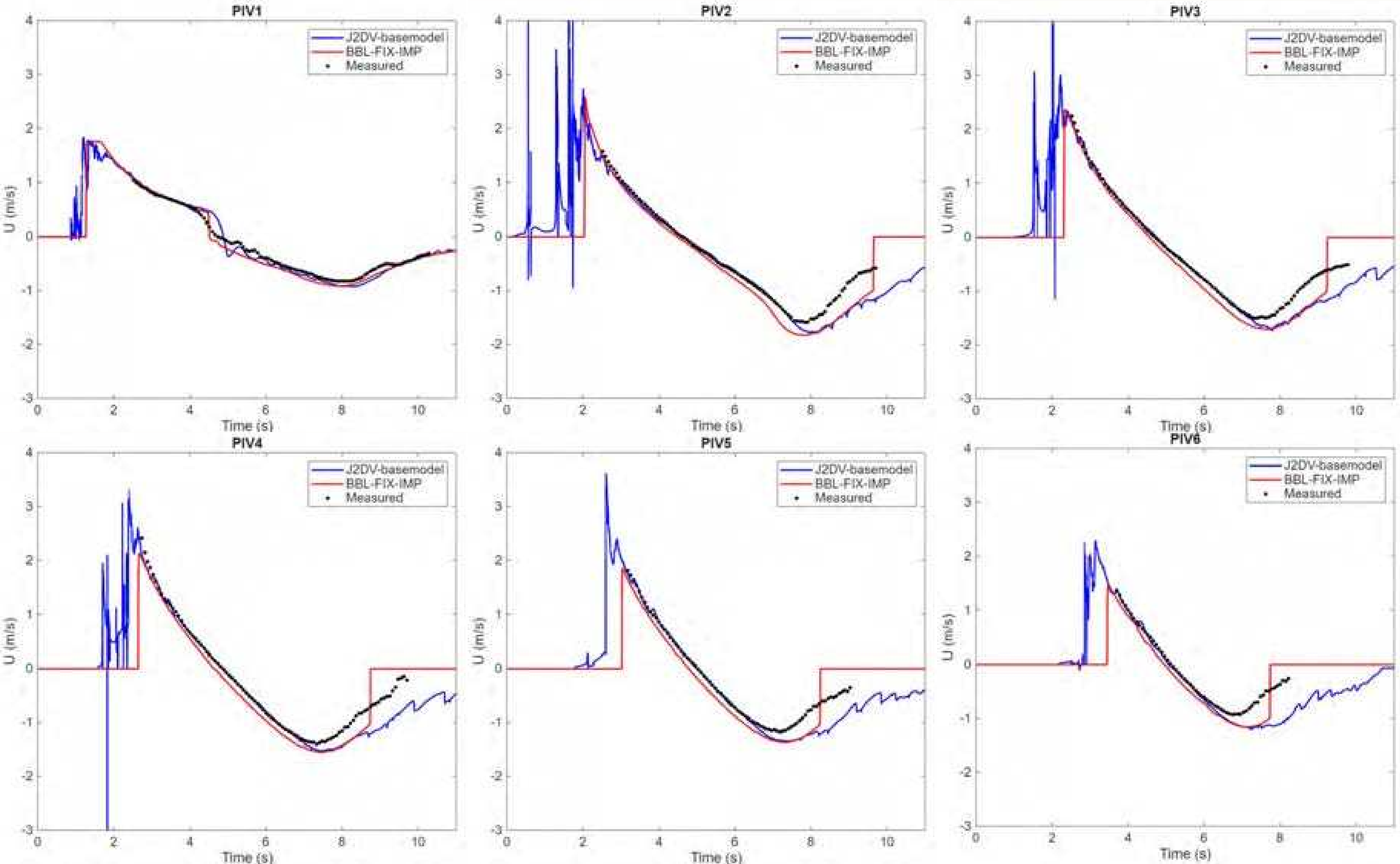
Comparing with 2DV RANS (VOF) equation solver

- Water depth


PIV1
PIV2
PIV3
PIV4
PIV5
PIV6
J2DV-basemodel
BBL-FIX-IMP
Measured
h (m)
Time (s)

Comparing with 2DV RANS (VOF) equation solver

- Depth-averaged velocity


PIV1
PIV2
PIV3
PIV4
PIV5
PIV6
J2DV-basemodel
BBL-FIX-IMP
Measured
U (m/s)
Time (s)

Re-construct of vertical velocity

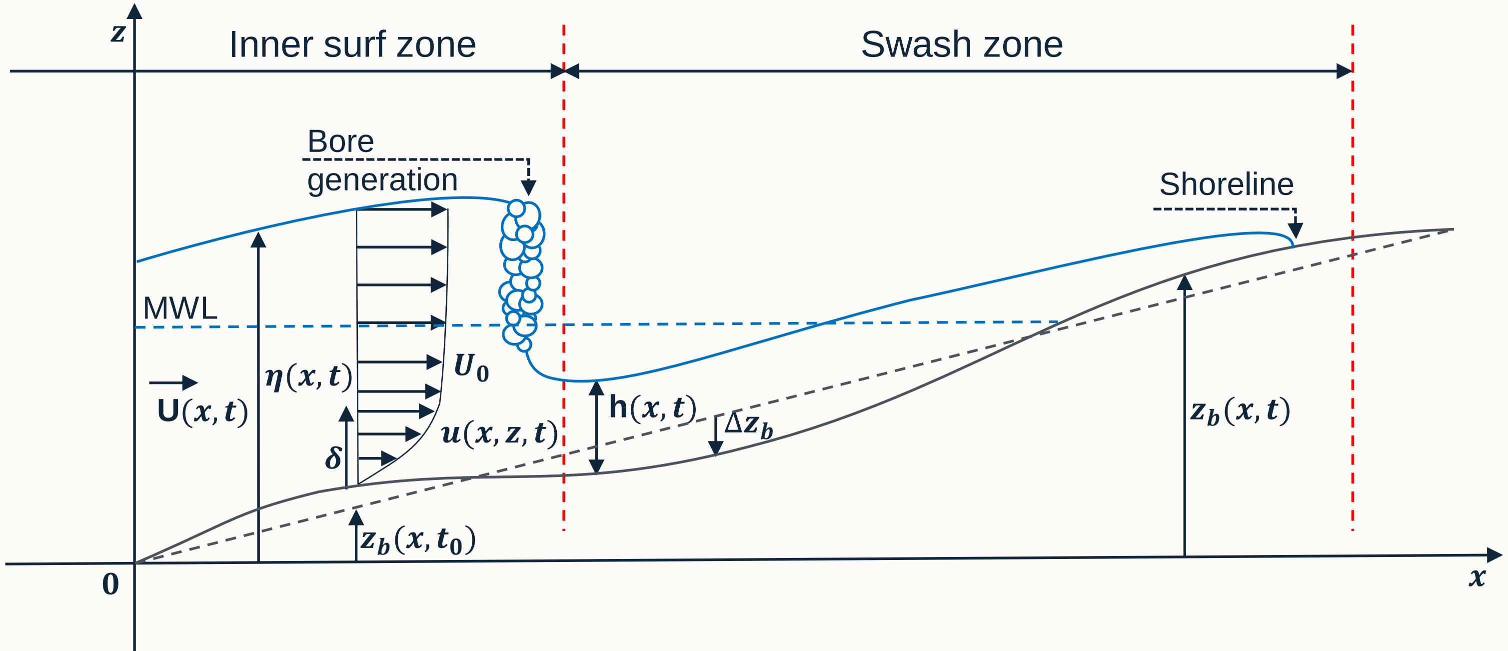
- In the bottom boundary layer, $u(x,z,t)$ increases with z, starting from zero at $z = z_0$ reaching a maximum at the top of the boundary layer, i.e., $z = z_0 + \delta(x,t)$.

z_0 is the bed roughness length, which is defined as the height at which the velocity is assumed to be zero.

- The horizontal velocity at the top of the boundary layer is called the free stream velocity, denoted as U_0.
- Inside the BBL, $u(x,z,t)$ can be approximated using the logarithmic law:

$$u(x,z,t) = \frac{U_f}{\kappa} ln\left(\frac{z}{z_0}\right)$$

U_f is the friction velocity, κ is von Karman's constant ($\kappa = 0.4$).



- Integrate the Continuity Equation

The 2D continuity equation is:

$$\frac{\partial u}{\partial x} + \frac{\partial w}{\partial z} = 0$$

Integrate the continuity equation from z_0 to z:

$$\int_{z_0}^{z} \frac{\partial w}{\partial z}\, dz = -\int_{z_0}^{z} \frac{\partial u}{\partial x}\, dz$$

$$w(x,z) - w(x,z_0) = -\int_{z_0}^{z} \frac{\partial u}{\partial x}\, dz$$

At the lower limit of the BBL ($z = z_0$), assuming an impermeable bed, the normal velocity is zero. Then, $w(x, z_0) = 0$ and the w-component of the velocity is expressed as:

$$w(x,z) = -\int_{z_0}^{z} \frac{\partial u}{\partial x}\, dz$$

In which, the horizontal velocity $u(x, z)$ is expressed as follows:

For z within the bottom boundary layer ($z_0 \le z \le z_0 + \delta(x)$), the logarithmic law is typically expressed as:

$$u(x,z) = \frac{u_*(x)}{\kappa} \ln\left(\frac{z}{z_0}\right)$$

For z within the free-stream region ($z_0 + \delta(x) < z \le h(x)$):

$$u(x,z) = U_0(x)$$

Leibniz Rule

$$\frac{\partial}{\partial x}\int_{z_0}^{z} u(x,z)\, dz = u(x,z)\frac{\partial z}{\partial x} - u(x,z_0)\frac{\partial z_0}{\partial x} + \int_{z_0}^{z} \frac{\partial u(x,z)}{\partial x}\, dz$$

$$\frac{\partial}{\partial x}\int_{z_0}^{z} u(x,z)\, dz = u(x,z)\frac{\partial z}{\partial x} + \int_{z_0}^{z} \frac{\partial u(x,z)}{\partial x}\, dz$$

$$-\int_{z_0}^{z} \frac{\partial u(x,z)}{\partial x}\, dz = u(x,z)\frac{\partial z}{\partial x} - \frac{\partial}{\partial x}\int_{z_0}^{z} u(x,z)\, dz$$

$$w(x,z) = u(x,z)\frac{\partial z}{\partial x} - \frac{\partial}{\partial x}\int_{z_0}^{z} u(x,z)\, dz$$

The term

$$\int_{z_0}^{z} u(x,z)\, dz$$

is expressed as:

$$\int_{z_0}^{z} u(x,z)\, dz = \int_{z_0}^{z} \frac{u_f(x,z)}{\kappa} \ln\left(\frac{z}{z_0}\right) dz$$

$$\int_{z_0}^{z} u(x,z)\, dz = \frac{u_f(x,z)}{\kappa} \int_{z_0}^{z} \ln\left(\frac{z}{z_0}\right) dz$$

$$\int_{z_0}^{z} u(x,z)\, dz = \frac{u_f(x,z)}{\kappa} \left[z \ln\left(\frac{z}{z_0}\right) - (z - z_0)\right]$$

Then:

$$\frac{\partial}{\partial x}\int_{z_0}^{z} u(x,z)\, dz = \frac{\partial}{\partial x}\left(\frac{u_f(x,z)}{\kappa}\left[z \ln\left(\frac{z}{z_0}\right) - (z - z_0)\right]\right)$$

$$\frac{\partial}{\partial x}\int_{z_0}^{z} u(x,z)\, dz = \left(\frac{1}{\kappa}\left[z \ln\left(\frac{z}{z_0}\right) - (z - z_0)\right]\right)\frac{\partial u_f(x,z)}{\partial x}$$

So, inside the BBL, the w(x,z) is expressed as:

$$w(x,z) = \frac{u_f}{\kappa} \ln\left(\frac{z}{z_0}\right)\frac{1}{10} - \left(\frac{1}{\kappa}\left[z \ln\left(\frac{z}{z_0}\right) - (z - z_0)\right]\right)\frac{\partial u_f(x,z)}{\partial x}$$

In which, $\frac{\partial z}{\partial x}$ is the slope of the bed $\frac{\partial z}{\partial x} = \frac{1}{10}$.

Outside the BBL, the w(x,z) is expressed as:

$$w(x,z) = w(x, z_0 + \delta) - \frac{dU_0}{dx}[z - (z_0 + \delta)]$$

Re-construct of vertical velocity

- Inside the bottom boundary layer:

$$w(x,z) = \frac{u_f}{\kappa} ln\left(\frac{z}{z_0}\right)\frac{1}{10} - \left(\frac{1}{\kappa}\left[z ln\left(\frac{z}{z_0}\right) - (z - z_0)\right]\right)\frac{\partial u_f(x,z)}{\partial x}$$

- Outside the bottom boundary layer:

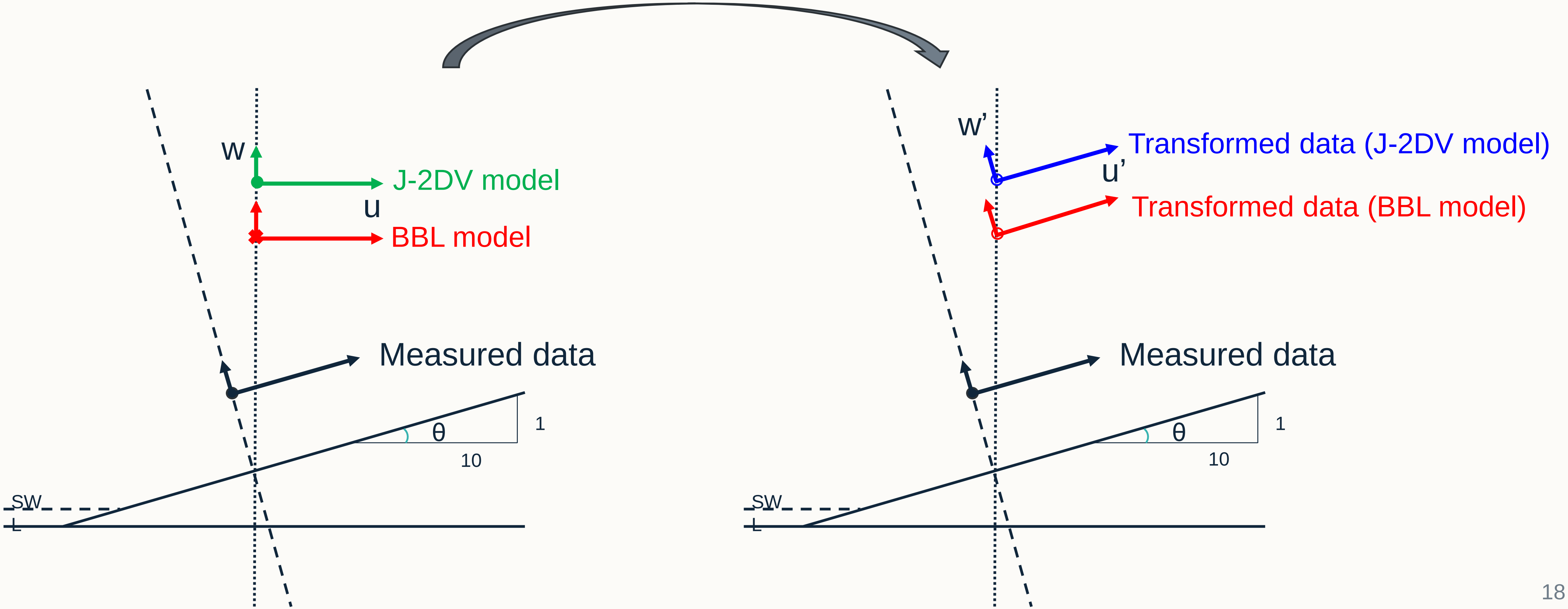
$$w(x,z) = w(x, z_0 + \delta(x)\ ) - \frac{\partial U_0(x)}{\partial x}\left[z - \left(z_0 + \delta(x)\right)\right]$$

U_0 is free stream velocity;
U_f is the friction velocity;
δ is the bottom boundary layer thickness;
z_0 is the bed roughness length;
κ is von Karman's constant ($\kappa = 0.4$).

Comparing with 2DV RANS (VOF) equation solver

- Data pre-processing

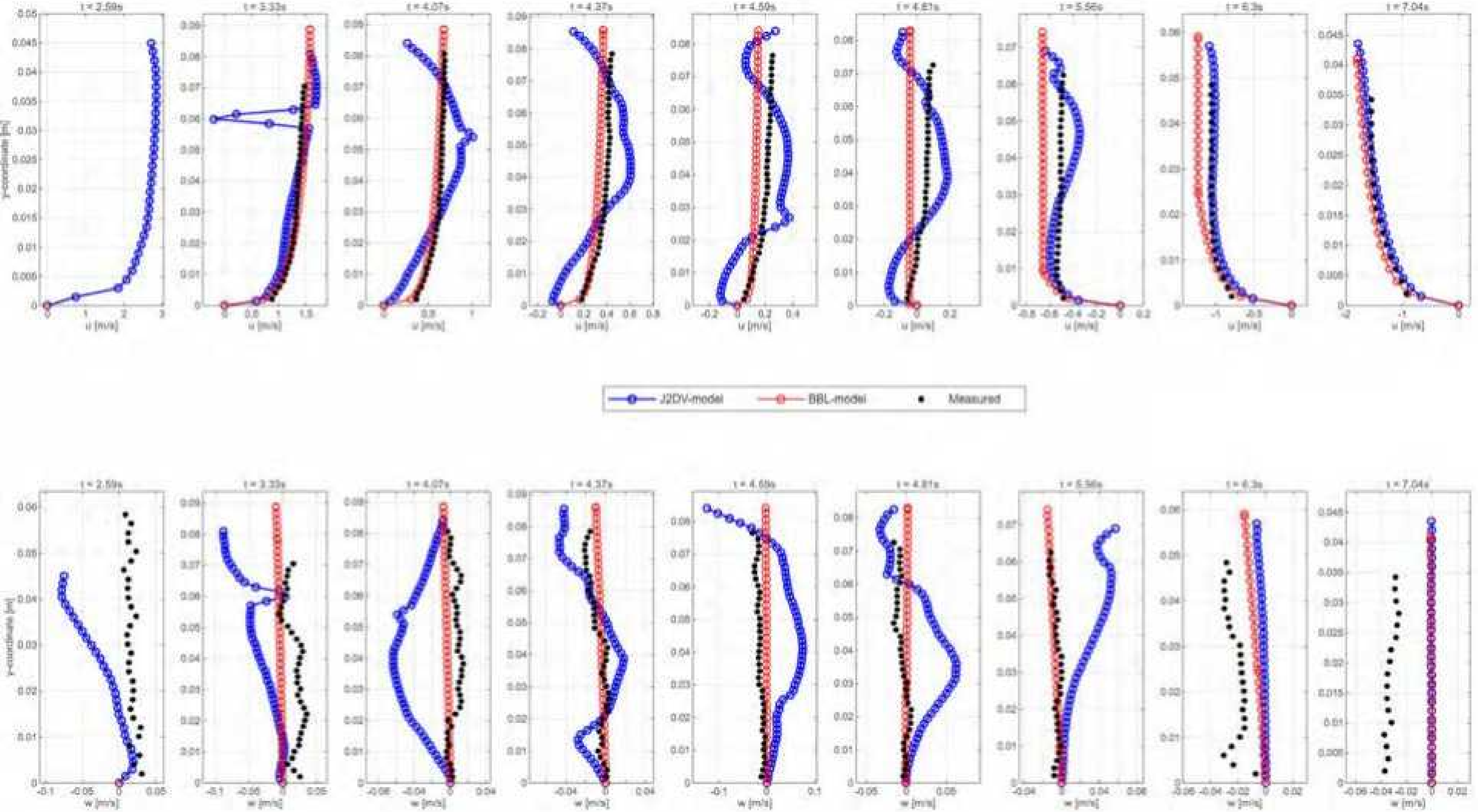
$$\begin{bmatrix} u' \\ w' \end{bmatrix} = \begin{bmatrix} \cos(\theta) & \sin(\theta) \\ -\sin(\theta) & \cos(\theta) \end{bmatrix} \times \begin{bmatrix} u \\ w \end{bmatrix}$$



Comparing with 2DV RANS (VOF) equation solver

- Velocity profile

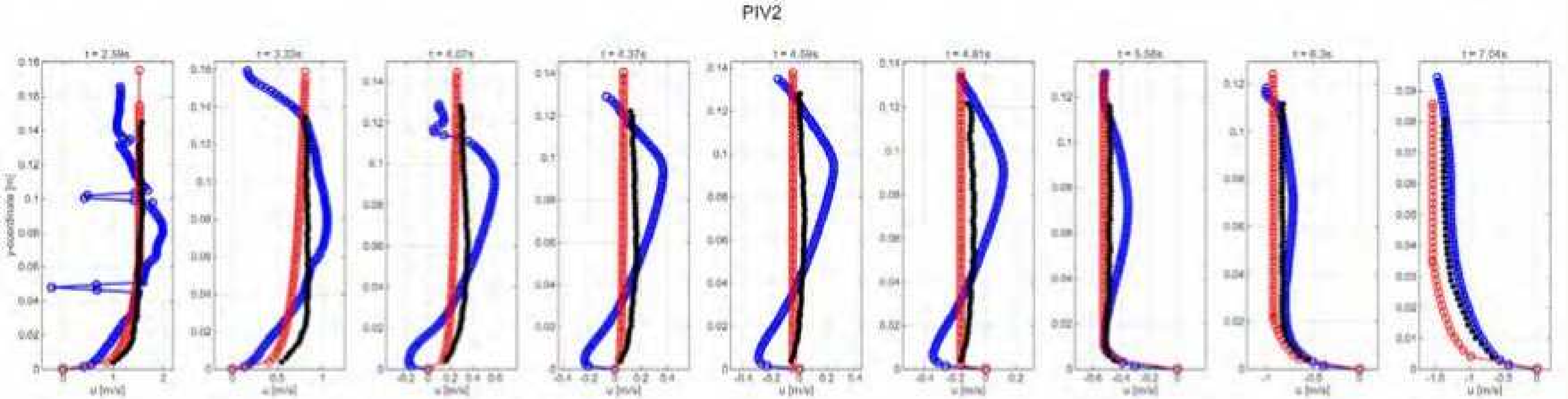
PIV4



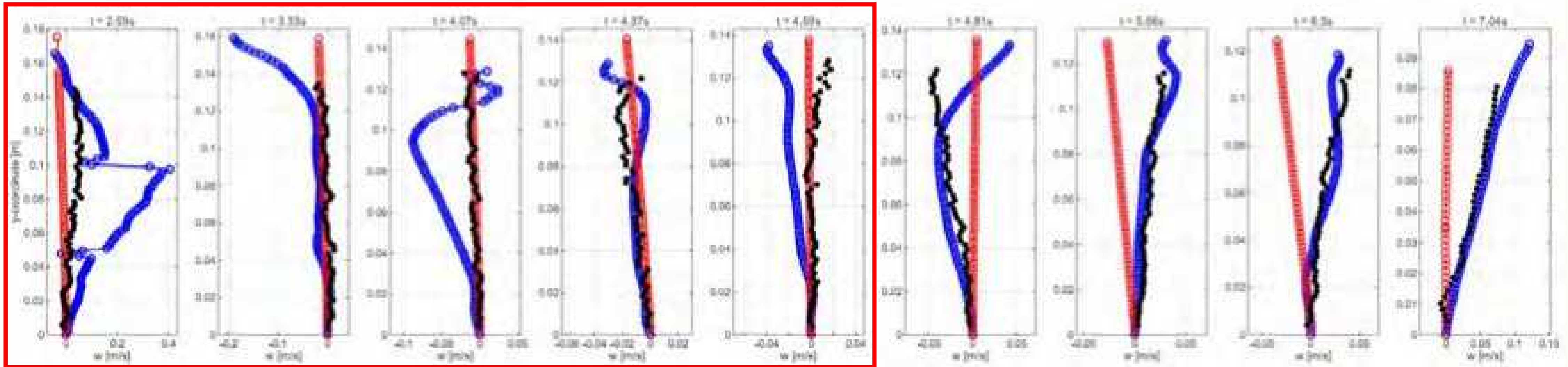
t = 2.59s
t = 3.33s
t = 4.07s
t = 4.37s
t = 4.59s
t = 4.81s
t = 5.56s
t = 6.3s
t = 7.04s
y-coordinate [m]
u [m/s]
J2DV-model
BBL-model
Measured
w [m/s]

Conclusion

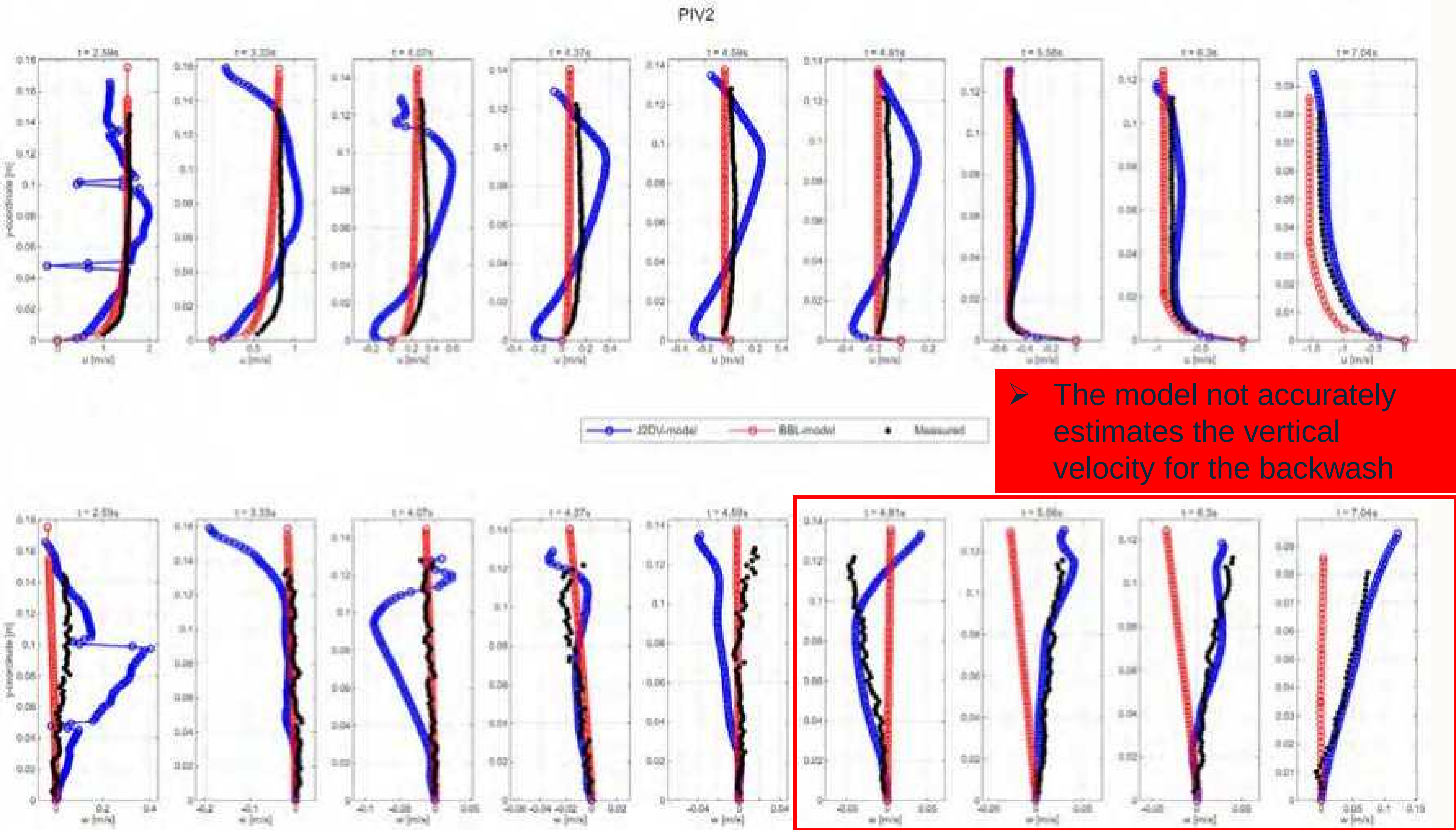
Model advancements



- The model accurately estimates the vertical velocity in the run-up phase

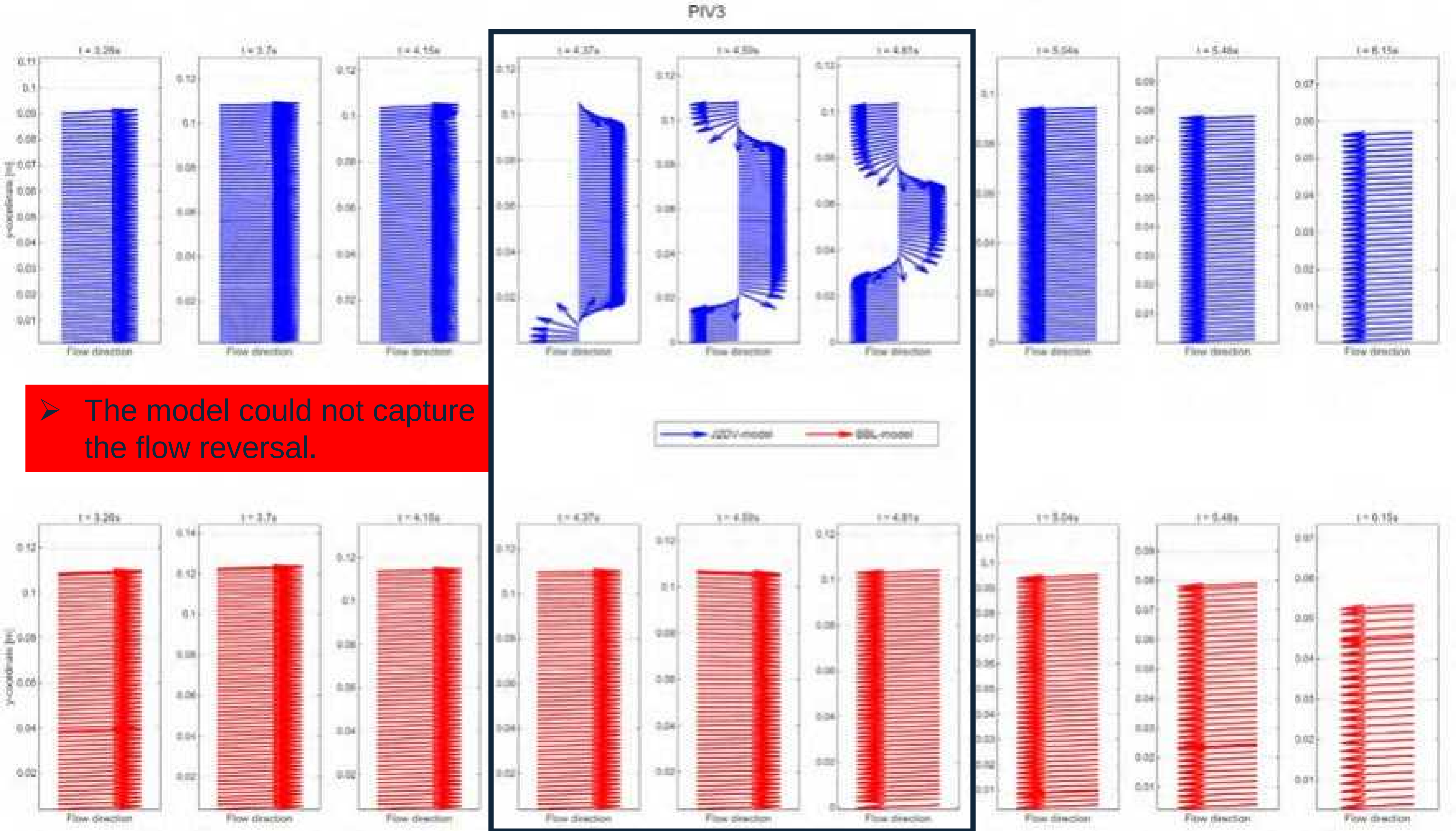


Model Limitations



- The model not accurately estimates the vertical velocity for the backwash

Model Limitations



- The model could not capture the flow reversal.

Future works

- Improving the simulation of the velocity profile, with a focus on the velocity profile at the **flow reversal**.
- Re-construct the vertical velocity for the **mobile** bed.

SEDIMARE 2023-2027

Sediment Transport and Morphodynamics in Marine and Coastal Waters with Engineering Solutions

3rd Network Training School

IH Cantabria, Spain

Santander, 11 – 13 Mar 2025

Numerical investigations of bottom boundary layer hydrodynamics under a dam-break-driven swash event

[1]*Quan T. Nguyen, [3]Joost W.M. Kranenborg,

[1]Nicholas Dodd, [1]Riccardo Briganti, [2]Fangfang Zhu, [3,4]Jebbe J. van der Werf, [4]Pieter C. Roos

*lead presenter

[1]University of Nottingham, UK

[2]University of Nottingham Ningbo Campus, China

[3]Deltares, Delft, The Netherlands

[4]University of Twente, Enschede, The Netherlands

Mathematical modeling and numerical simulations of water-saturated granular materials with emphasis to sediment transport

Evangelos Petridis

UCLouvain
Institute of Mechanics, Materials and Civil Engineering

Funded by the European Union

Introduction

Payne and Straughan (1999) established continuous dependence in the Brinkman-Forchheimer equations with constant porosity . When the porosity is space dependent :

- Velocity is not divergence free.

- The term describing viscous shear stresses is not the Laplacian .

- We have normal viscous stresses (bulk viscosity ζ) .

- The shear viscosity μ enters the expression for the interfacial drag (Darcy coefficient a) .

- We are working in the weighted L^2 space with the porosity $\phi(\mathbf{x})$ being the weight .

$$\|\mathbf{u}\| = \left(\int_\Omega \phi |\mathbf{u}|^2 d\mathbf{x} \right)^{1/2}$$

Model

The Brinkman–Forchheimer equations for flow in porous media with variable porosity are

$$\phi \frac{\partial \mathbf{u}}{\partial t} + \phi \boldsymbol{\nabla} p$$

$$= \boldsymbol{\nabla} \cdot (\phi \zeta (\boldsymbol{\nabla} \cdot \mathbf{u}) I) + \boldsymbol{\nabla} \cdot \left(\phi \mu \mathbf{V}^d \right) - a^\star(\phi)\mathbf{u} - b^\star(\phi)|\mathbf{u}|\mathbf{u} + \phi \mathbf{f} \quad , \quad \zeta, \mu > 0$$

$$\boldsymbol{\nabla} \cdot (\phi \mathbf{u}) = 0$$

$$\mathbf{V}^d(\mathbf{u}) = \frac{1}{2}(\boldsymbol{\nabla}\mathbf{u} + (\boldsymbol{\nabla}\mathbf{u})^T) - \frac{1}{3}\boldsymbol{\nabla} \cdot \mathbf{u} \ I$$

$$b^\star(\phi) = b(1-\phi) + d(1-\phi)^2 \ , \ a^\star(\phi) = a\mu(1-\phi) \ , \ a, b, d > 0$$

$$0 < \phi_{\text{min}} \leq \phi \leq \phi_{\text{max}} < 1$$

where **u** is the average fluid velocity in the porous medium, a is the Darcy coefficient, b is the Forchheimer coefficient, ζ is the bulk viscosity , μ is the shear viscosity, p is the pressure , **f** is the gravity and ϕ is the variable porosity.

Conclusions

• Established continuous dependence of solutions on the parameters of the problem, namely, the Darcy and Forchheimer coefficients of interphasial drag and the shear and bulk viscosities of the fluid.

• The solution difference for different parameter values decays always with time.

• Derived lower and upper bounds for the kinetic energy of the fluid. The kinetic energy decays exponentially but faster than in pure-fluid domains because of the interphasial drag.

Introduction

• Underwater landslides are often hard to observe but their consequences can be dramatic. At short term, the sudden fall of an important column of sand under its own weight disturbs the surrounding fluid and might initiate strong waves. At long term, it might change completely the shape of the river or ocean floor, thus changing the conditions of flow. This has an impact on the ecosystem and the management of river flooding

• Here, the granular column collapse is modelled using a 2-pressure, 2-velocity flow model for fluid-solid mixtures

Fluid phase

Governing equations

$$\frac{\partial \phi_{\mathrm{f}}}{\partial t} + \nabla \cdot (\phi_{\mathrm{f}} u_{\mathrm{f}}) \ = \ 0\,,$$

$$\rho_{\mathrm{f}} \frac{\partial \phi_{\mathrm{f}} u_{\mathrm{f}}}{\partial t} + \rho_{\mathrm{f}} \nabla \cdot (\phi_{\mathrm{f}} u_{\mathrm{f}} \otimes u_{\mathrm{f}}) \ = \ \nabla \cdot \sigma_{\mathrm{f}} - f + \rho_{\mathrm{f}} \phi_{\mathrm{f}} g$$

Interphasial momentum exchange

$$f \ = \ p_{\mathrm{f}} \nabla \phi_{\mathrm{s}} + \delta (u_{\mathrm{f}} - u_{\mathrm{s}})$$

Stress tensor - Newtonian viscous stresses

$$\sigma_{\mathrm{f}} \ = \ -p_{\mathrm{f}} \phi_{\mathrm{f}} I + \tau_{\mathrm{f}}\,,$$

For simple isotropic fluids, τ_{s} is further decomposed as the sum of a diagonal and a deviatoric component,

$$\tau_{\mathrm{f}} \ = \ \phi_{\mathrm{f}}\, \zeta_{\mathrm{f}}\, (\nabla \cdot u_{\mathrm{f}}) I + 2 \phi_{\mathrm{f}}\, \mu_{\mathrm{f}}\, D_{\mathrm{f}}^{\mathrm{d}}\,,$$

Solid phase

Governing equations

$$\frac{\partial \phi_\mathrm{s}}{\partial t} + \nabla \cdot (\phi_\mathrm{s} u_\mathrm{s}) = 0\,,$$

$$\rho_\mathrm{s} \frac{\partial \phi_\mathrm{s} u_\mathrm{s}}{\partial t} + \rho_\mathrm{s} \nabla \cdot (\phi_\mathrm{s} u_\mathrm{s} \otimes u_\mathrm{s}) = \nabla \cdot \sigma_\mathrm{s} + f + \rho_\mathrm{s} \phi_\mathrm{s} g$$

Interphasial momentum exchange

$$f = p_\mathrm{f} \nabla \phi_\mathrm{s} + \delta (u_\mathrm{f} - u_\mathrm{s})$$

Stress tensor - Non - Newtonian viscous stresses

$$\sigma_\mathrm{s} = -\phi_\mathrm{s} p_\mathrm{s} I + C_\mathrm{s} + \tau_\mathrm{s}\,.$$

Solid phase - Stress tensor

$$\sigma_s = -\phi_s p_s I + C_s + \tau_s \,.$$

$$C_s = \gamma_s \nabla\phi_s \otimes \nabla\phi_s \,,$$

where the coefficient γ_s accounts for the spatial distribution of the grains

$$\tau_s = ((\zeta_s + \zeta_{s'})\,\nabla\cdot u_s + \chi_1)\,\phi_s I + 2\,(\mu_s + \mu_{s'})\,\phi_s D_s^d + \chi_2 \phi_s D_s \cdot D_s$$

where

$$\mu_s = \mu_f \left[\left(2.5 - \frac{2}{\phi_m}\right) + \left(5.2 - \frac{3}{\phi_m^2}\right)\phi_s + \frac{\phi_m^2}{\phi_s\,(\phi_m - \phi_s)^2} - \frac{1}{\phi_s} \right]$$

Solid phase - Stress tensor

In particular, all these parameters are nonlinear functions of the strain-rate tensor and read as follows,

$$\mu_{s'} = \frac{\mu_n}{\sqrt{2}} \frac{\det D_s}{(D_s : D_s)^{\frac{3}{2}}}, \qquad \zeta_{s'} = \frac{\mu_n \sqrt{2}}{3} \frac{\det D_s}{(D_s : D_s)^{\frac{3}{2}}},$$

$$\chi_1 = -\sqrt{2}\mu_n \left(2\sqrt{D_s^d : D_s^d} - \frac{3}{2} \frac{D_s^d : D_s^d}{\sqrt{D_s : D_s}} \right), \qquad \chi_2 = -\frac{\sqrt{2}\mu_n}{\sqrt{D_s : D_s}},$$

Where

$$\mu_n = 0.75\, \mu_f \frac{\phi_s}{(\phi_m - \phi_s)^2}.$$

Compaction equation

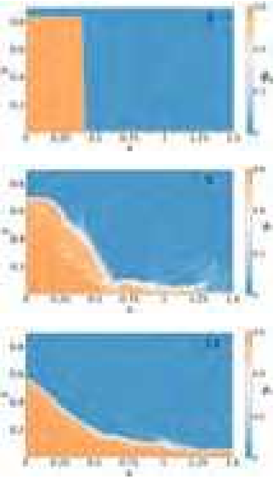
The above system of balance laws is closed with an evolution equation for the volume fraction ϕ_{s}. This equation is referred to as *compaction equation*

$$\frac{\partial \phi_{\mathrm{s}}}{\partial t} + u_{\mathrm{s}} \cdot \nabla \phi_{\mathrm{s}} \;=\; Re \frac{\phi_{\mathrm{s}}\, \phi_{\mathrm{f}}}{\mu_{\mathrm{c}}} \left(p_{\mathrm{s}} - p_{\mathrm{f}} - \beta_{\mathrm{s}} + \nabla \cdot (\gamma_{\mathrm{s}} \nabla \phi_{\mathrm{s}}) \right)$$

β_{s} is the configuration pressure which is a logarithmic function of ϕ_{s} and ϕ_{max}. γ_{s} is related to the microstructure - power law function of ϕ_{s} .

Simulations

The algorithm to solve the aforementioned equations is based on a predictor-corrector time-integration scheme with a generalised projection method for the phasial pressures



Future work

We will work on a problem include the flow of currents over deformable dunes in a channel.
Detailed numerical simulations of shear-driven (Couette) of water-sand mixtures. (Emphasis on sediment mobilization and resuspension)