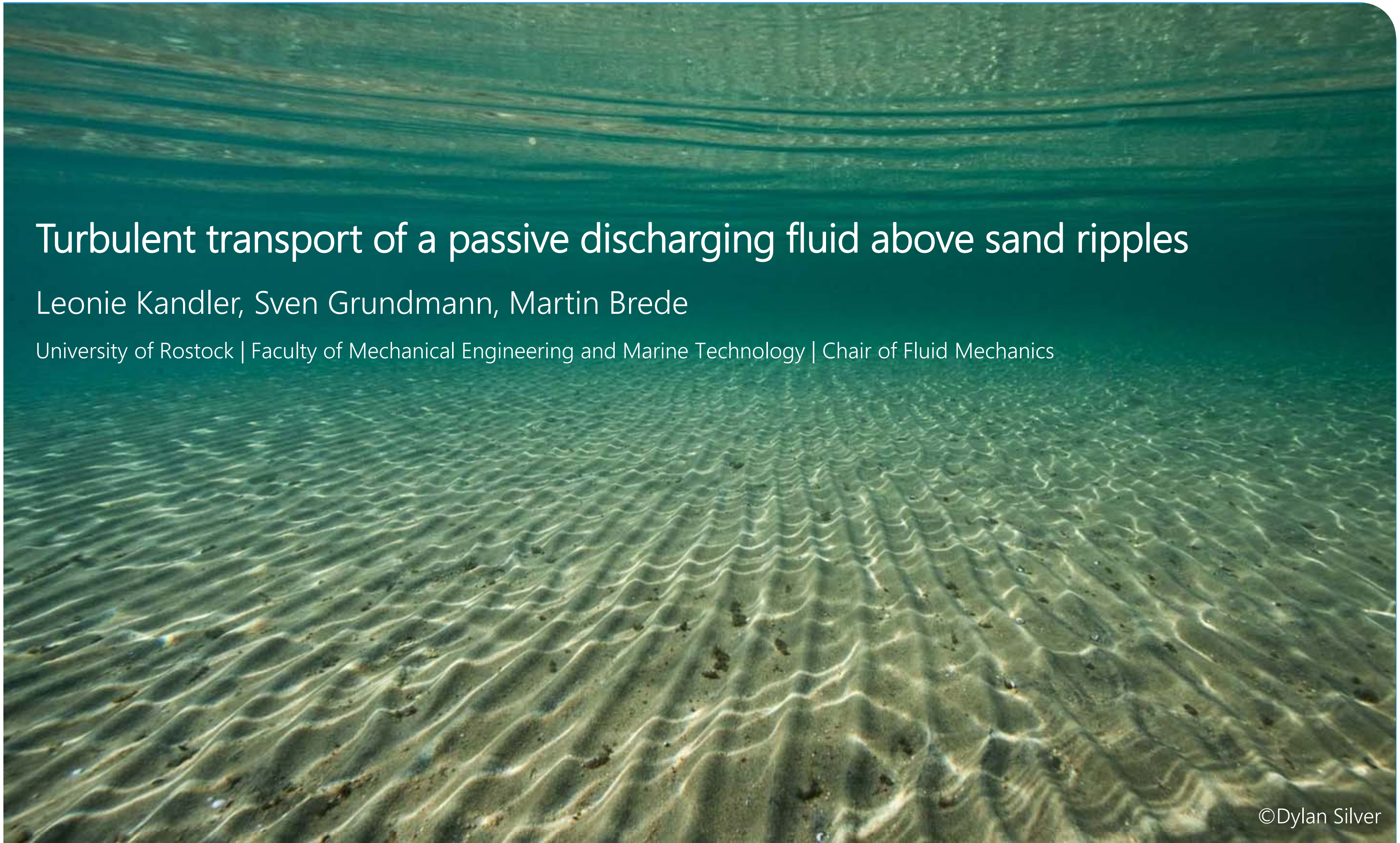
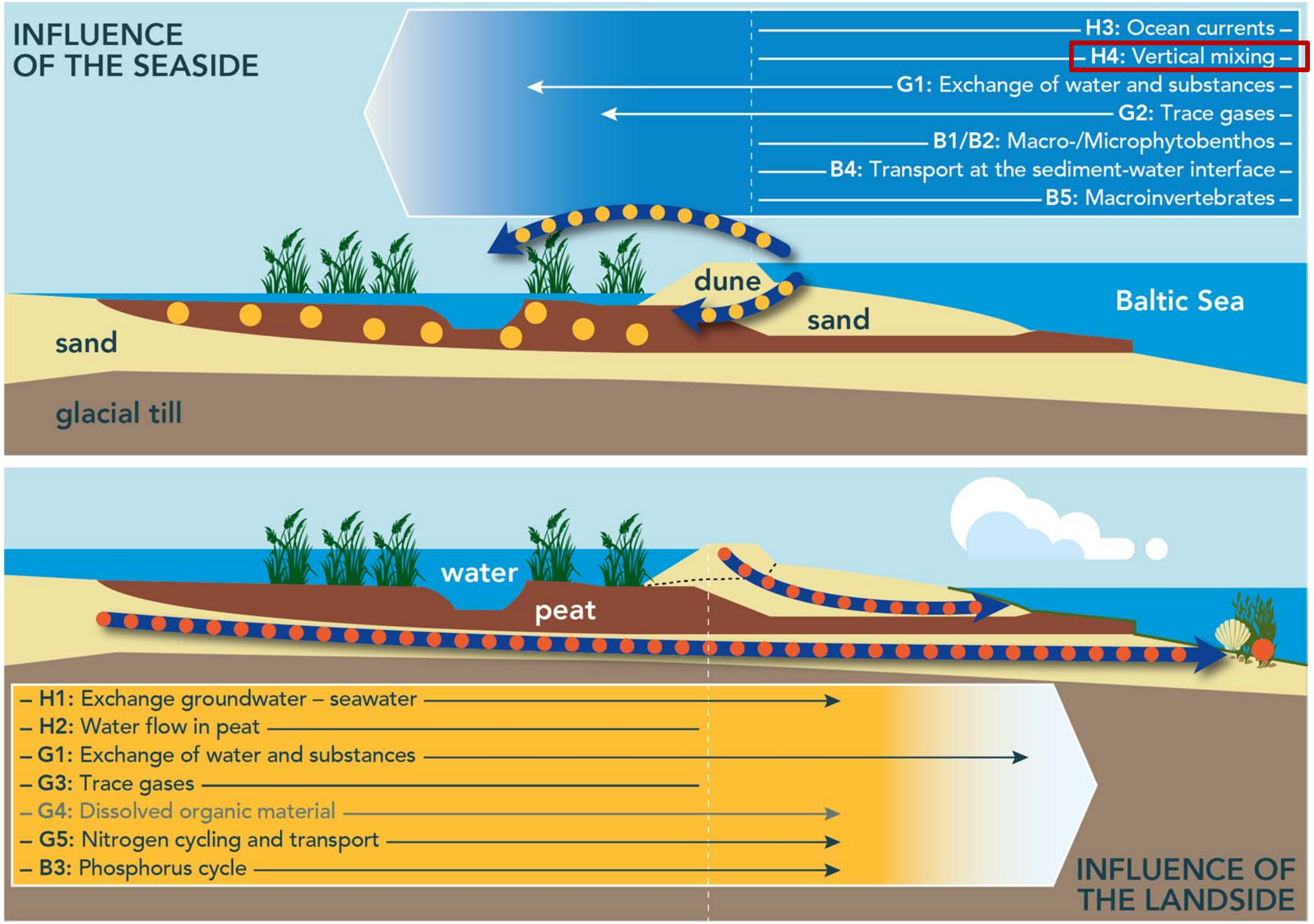
Turbulent transport of a passive discharging fluid above sand ripples

Leonie Kandler, Sven Grundmann, Martin Brede

University of Rostock | Faculty of Mechanical Engineering and Marine Technology | Chair of Fluid Mechanics

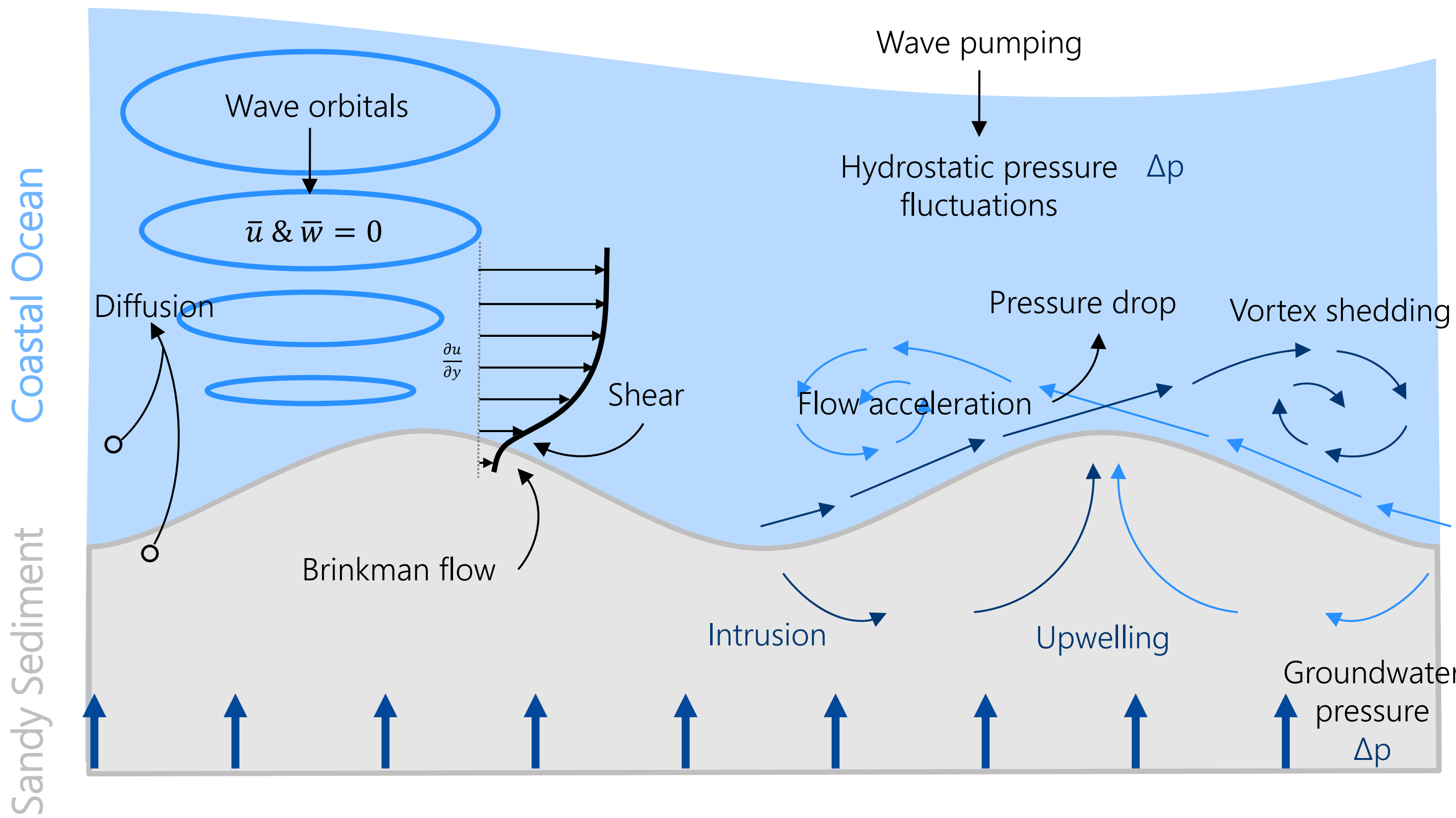


Turbulent transport of a passive discharging fluid above sand ripples



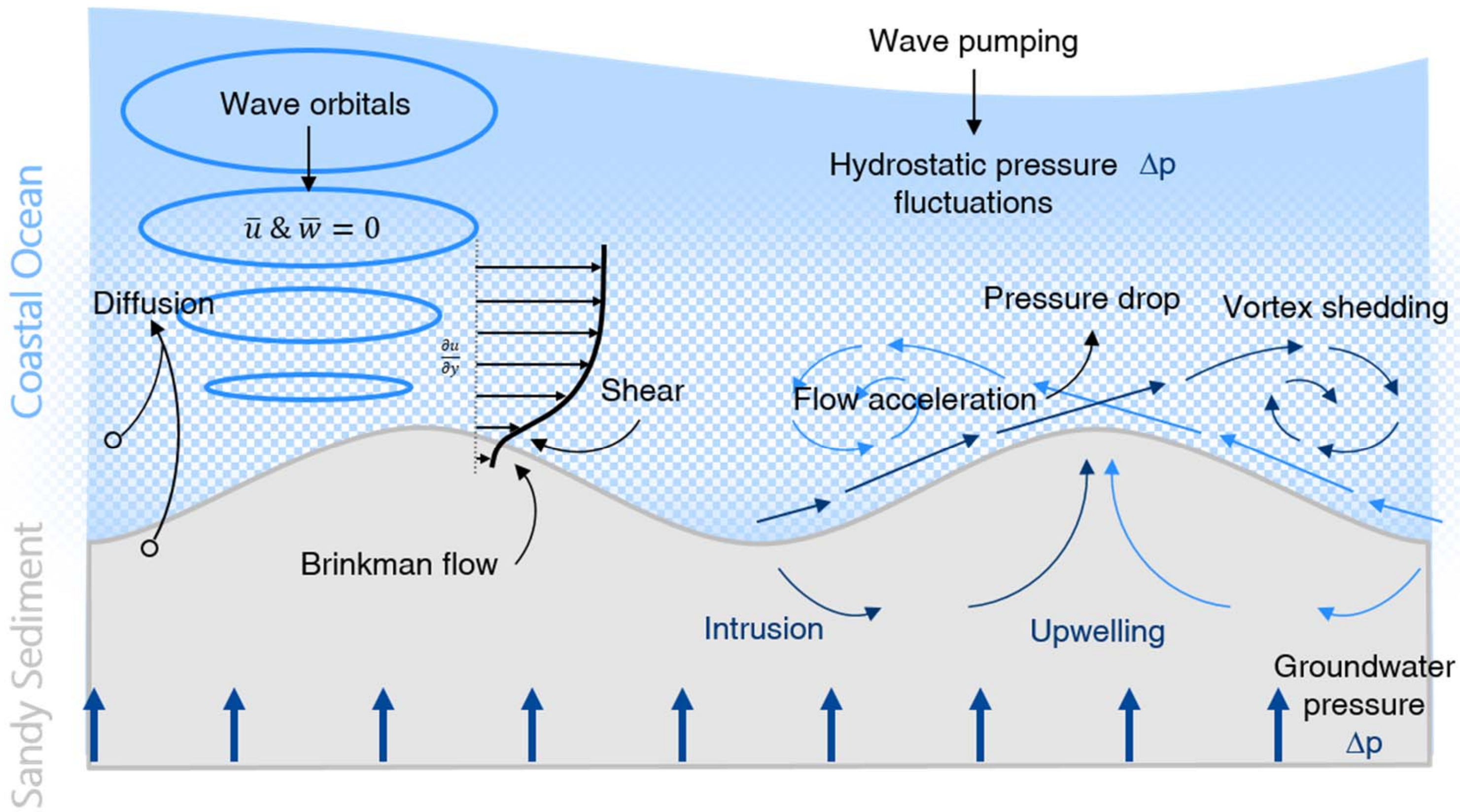
DFG Research Training Group

Complex fluid dynamical processes at the sediment-water-interface



Turbulent transport of a passive discharging fluid above sand ripples

How can mixing and transport within the benthic boundary layer be quantified?



Universität Rostock Traditio et Innovatio

BALTIC TRANSCOAST

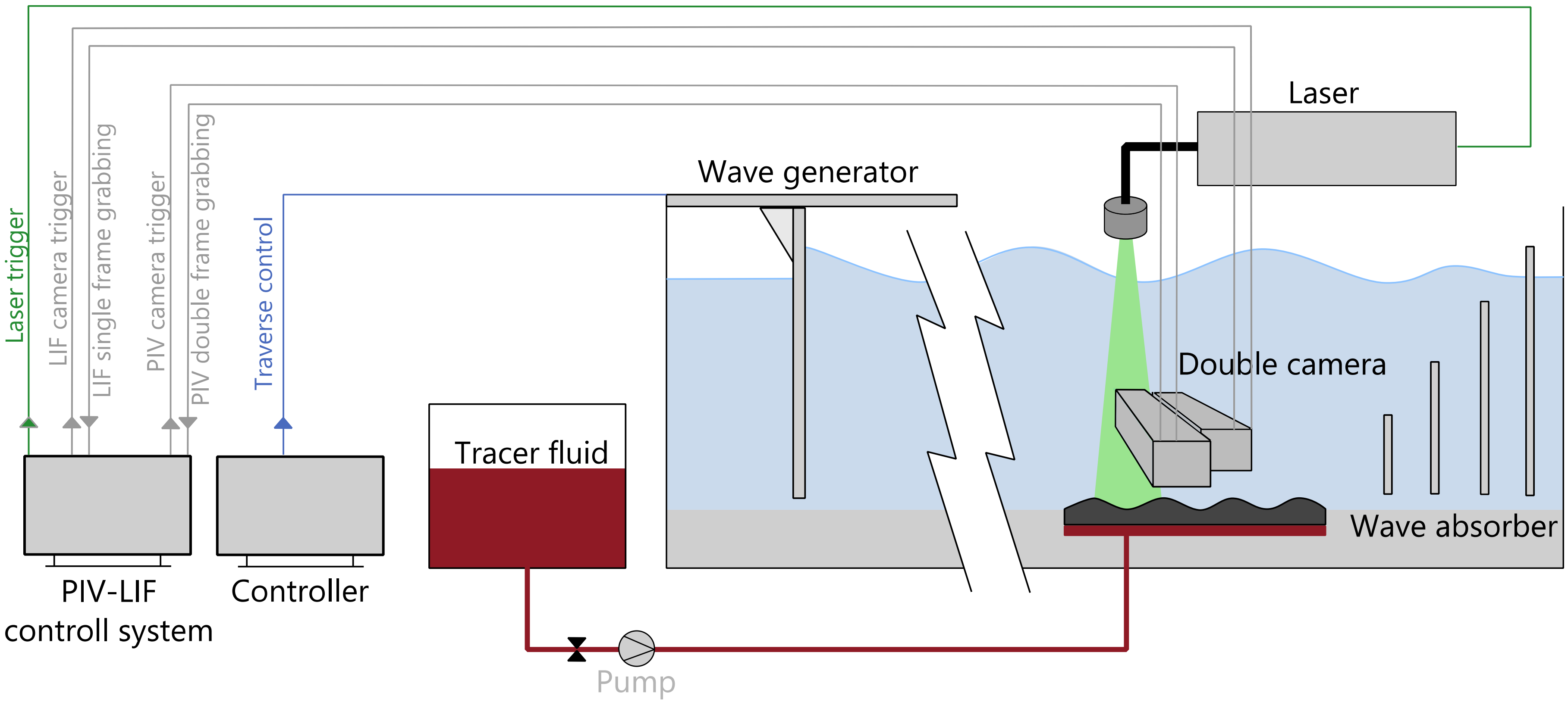
Ism UNIVERSITÄT ROSTOCK

Turbulent transport of a passive discharging fluid above sand ripples

PIV-LIF measurements in a wave tank experiment

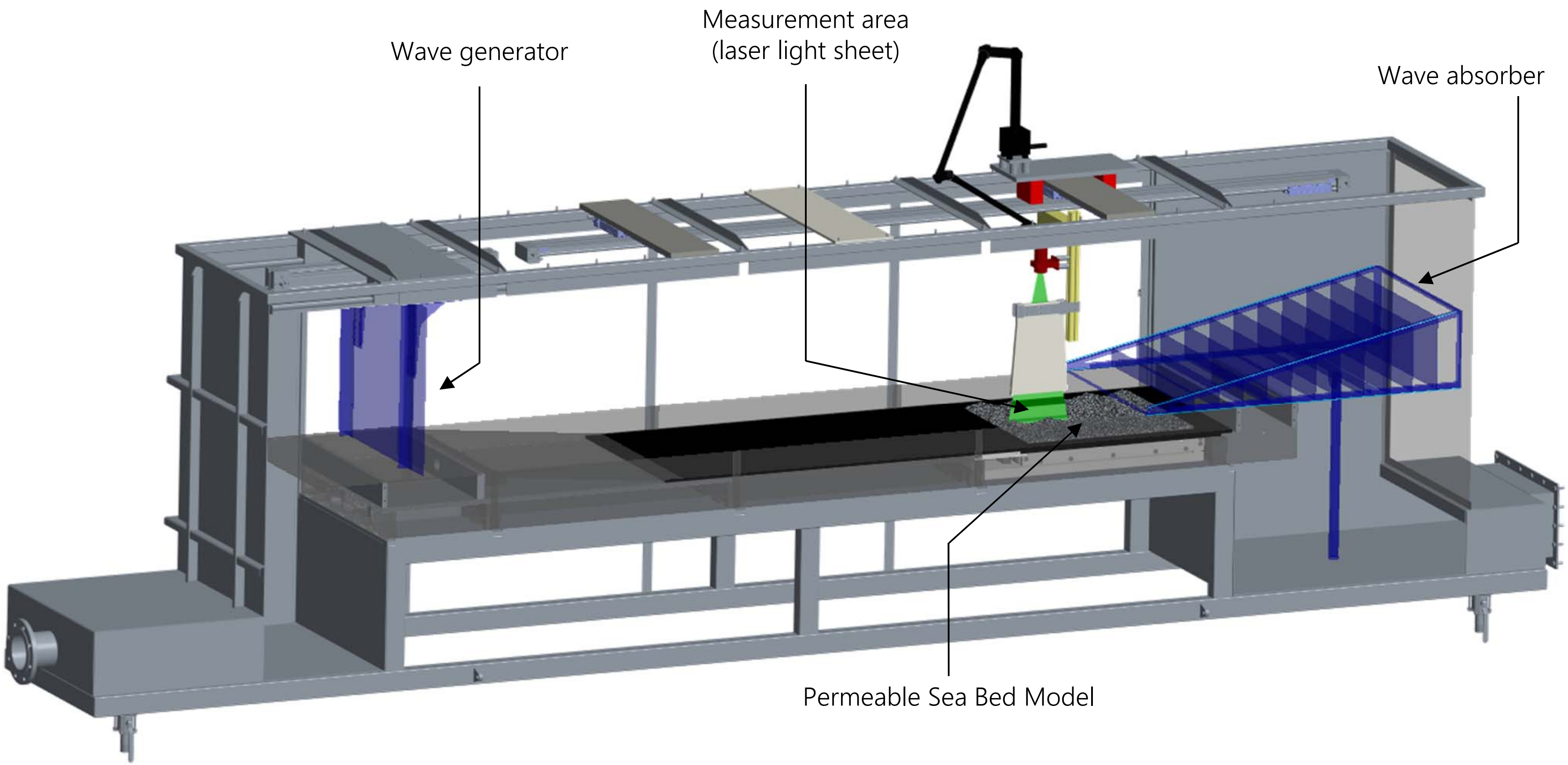
PIV – Particle Image Velocimetry (2D velocity fields)

LIF – Laser Induced Fluoreszenz (2D concentration fields)



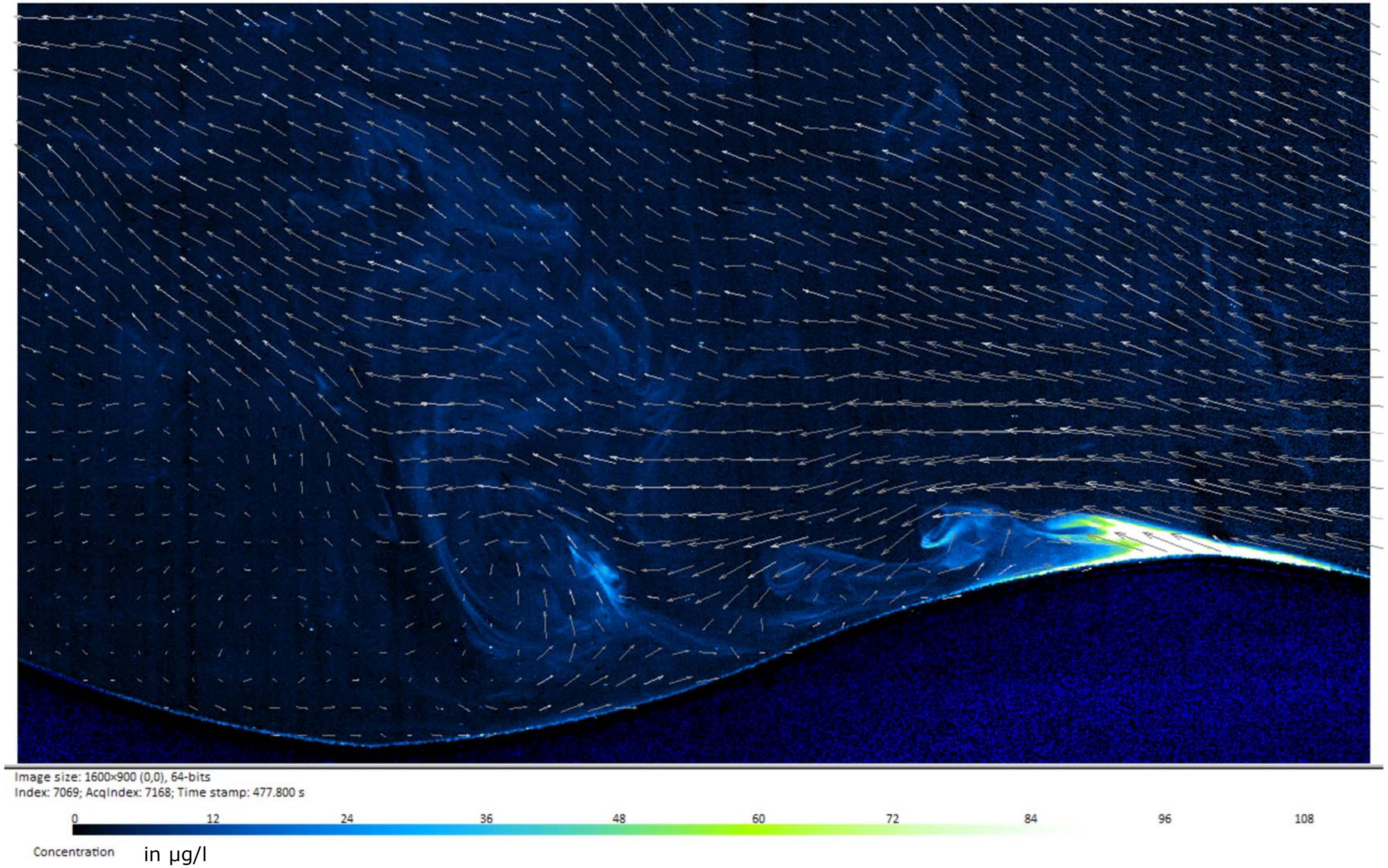
Turbulent transport of a passive discharging fluid above sand ripples

CAD Model of wave tank setup (4.0 x 0.8 x 1.0 m)



Turbulent transport of a passive discharging fluid above sand ripples

Raw Image



in µg/l

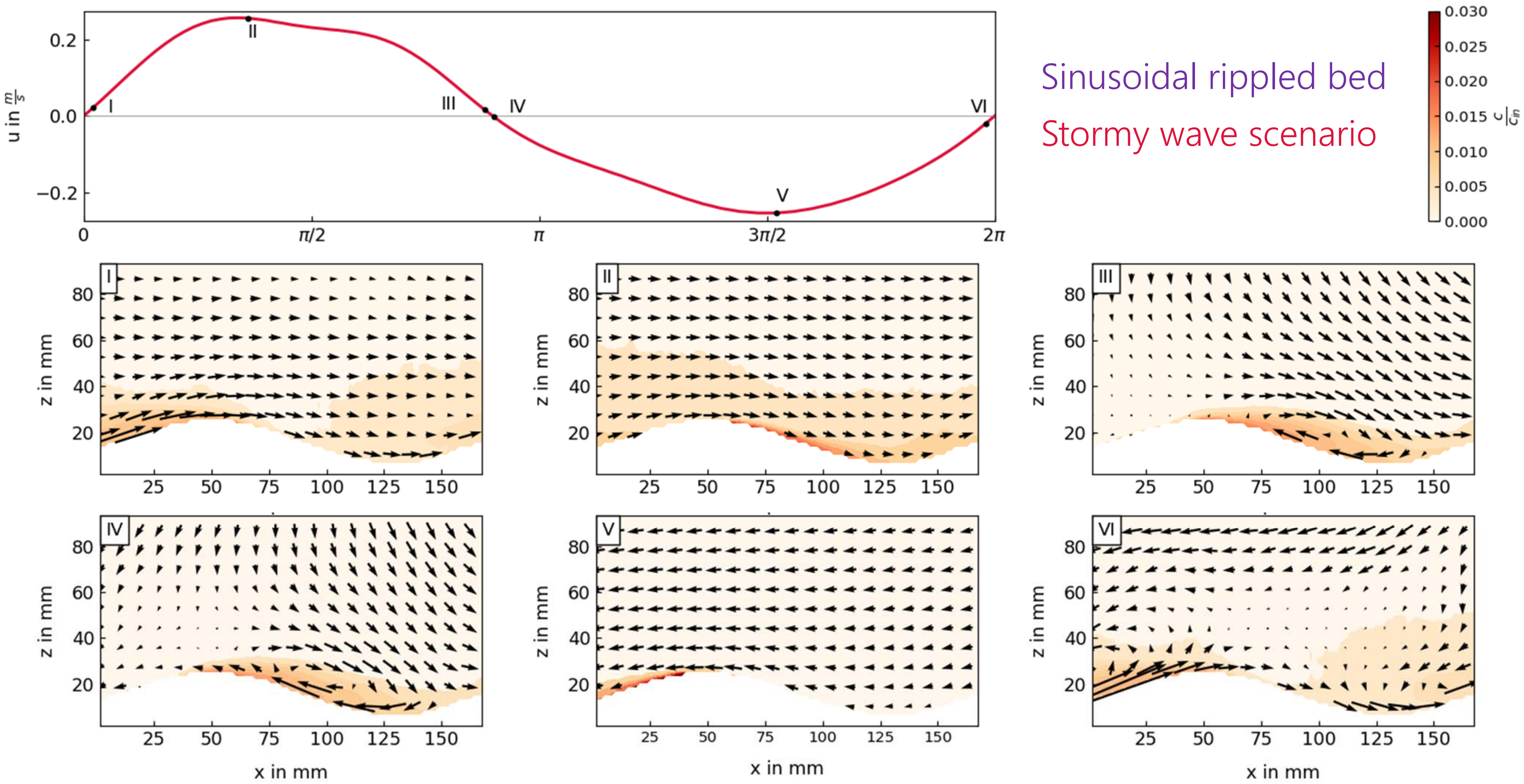
Technical details

- Experimental details:
  - 2D-PIV-LIF
  - Camera system: 2 Dantec Flow-sense 2M cameras, resolution = 1600 x 1200 pix, pixel size 7.4 µm, double frame rate =15 Hz
  - Li-tron Nd:YAG Laser λ = 532nm
  - Measurement frequency: 15 Hz
  - ca. 10.000 time steps
  - $\dot{V}_{dicharge} \approx 0{,}96\,\frac{l}{min} = 57{,}6\,\frac{l}{h}$
  - $A_{dicharge} \approx 0.16\ \mathrm{m}^2$
  - $c_{Tracer} = 200 - 1200\,\frac{\mu g}{l}$, $c_{ref} = 200\ \frac{\mu g}{l}$
  - Rhodamin 6G (Sigma-Aldrich®) $\lambda_{absorption}$ = 525-530 nm $\lambda_{emission}$ = wavelength 590 nm

- Post Processing details:
  - Dantec DynamicStudio 6.10
  - PIV-Preparation: Image Mean Substraction, Image Balancing, Image Masking*
  - Adaptive PIV - Grid Step Size: 16 x 16 pix, min IA: 32 x 32 pix, max IA: 64 x 64 pix, *„Wall windowing“ at sea bed surface
  - LIF-Processing …
  - Image Resampling
  - Export of numerical PIV and LIF data
  - Further evaluation using own Python code

Turbulent transport of a passive discharging fluid above sand ripples

Results – Phase averaged velocity (u, w) and concentration fields (c)



Sinusoidal rippled bed

Stormy wave scenario

Universität Rostock Traditio et Innovatio

BALTIC TRANSCOAST

Ism UNIVERSITÄT ROSTOCK

Turbulent transport of a passive discharging fluid above sand ripples

„Vertical transport dominated by turbulent motion“ [Berg et al. 2003]

Reynolds averaged Navier-Stokes-equation:

Symmetrically periodic flow!

$$\underbrace{\rho\frac{\partial\bar{u}_i}{\partial t}}_{\text{Variation}}+\underbrace{\rho\bar{u}_j\frac{\partial\bar{u}_i}{\partial x_j}}_{\text{Convection}}=\underbrace{\rho k_i}_{\text{Body force therm}}-\underbrace{\frac{\partial\bar{p}}{\partial x_i}}_{\text{Forces due to pressure gradients}}+\eta\underbrace{\frac{\partial^2\bar{u}_i}{\partial x_j{}^2}}_{\text{Diffusion (Transport on molecuar scale)}}-\boxed{\rho\frac{\partial\overline{(u_i'u_j')}}{\partial x_j}}$$

Additional momentum transport due to turbulence

„Vertical transport dominated by turbulent motion“

Conservation equation also valid for a **passive scalar**

$\overline{\vec{u}'\phi'}$ → scalar flux, that results from a fluctuating velocity field

Universität Rostock Traditio et Innovatio

BALTIC TRANSCOAST

Turbulent transport of a passive discharging fluid above sand ripples

„Vertical transport dominated by turbulent motion“ [Berg et al. 2003]

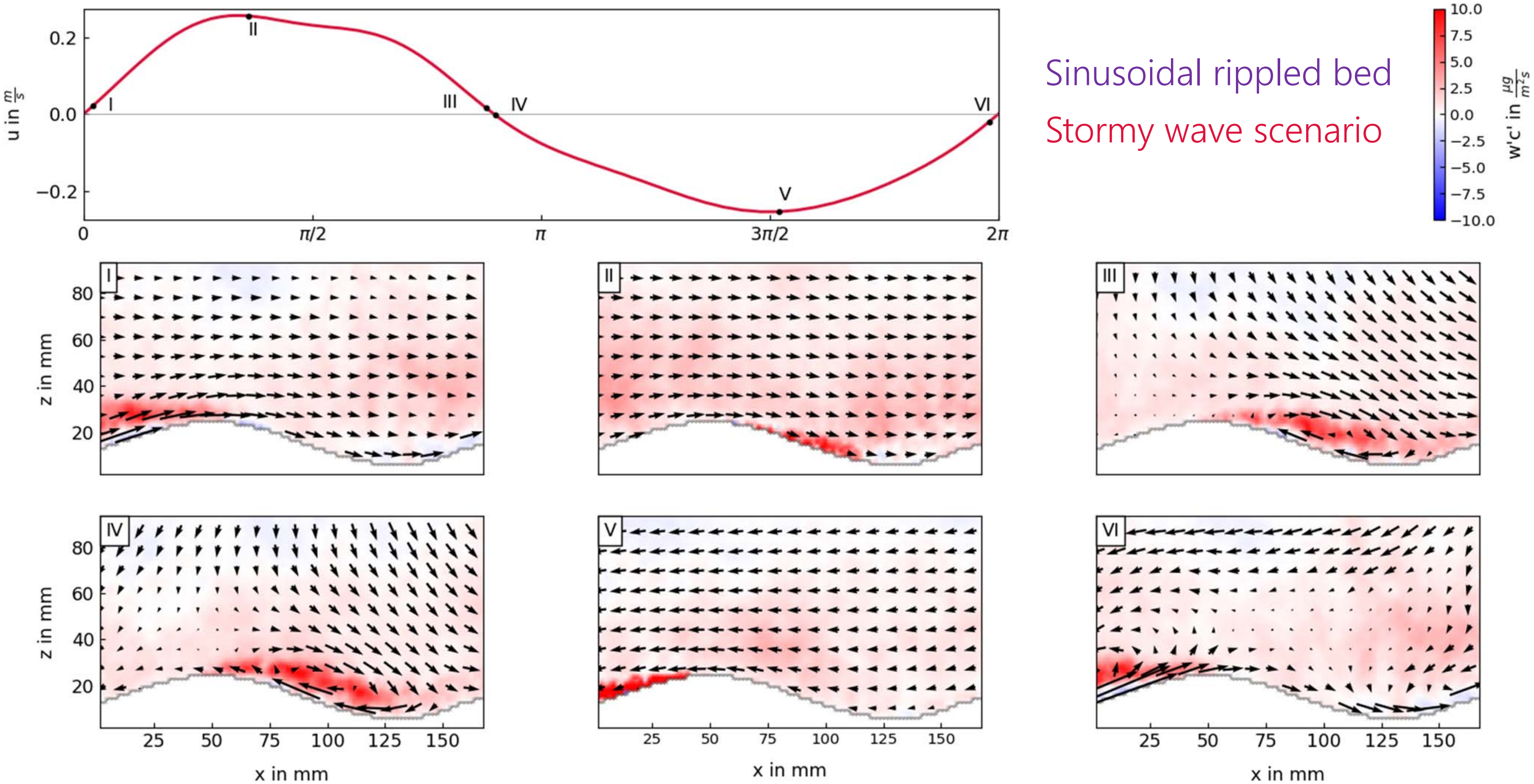
RANS → Additional momentum transport due to turbulence → Berg et al. 2003: Vertical transport dominated by turbulent motion

Conservation equation also valid for a **passive scalar,** as e.g. concentration

$\overline{w'c'}$ → vertical concentration flux, that results from a fluctuating velocity field

Turbulent transport of a passive discharging fluid above sand ripples

Results – Phase averaged vertical turbulent (Reynolds) fluxes $\langle w'c' \rangle_{ph}$



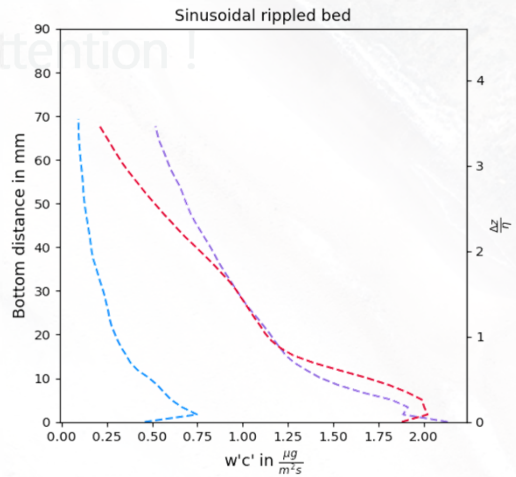
12 different experimental configurations:

Variation of **bottom topography** and **wave scenario**

→ Influence of these variables on **vertical turbulent transport:**

- **Reynolds flux profiles**
- **Prandtl mixing length**

→ Boundary conditions for numerical simulations



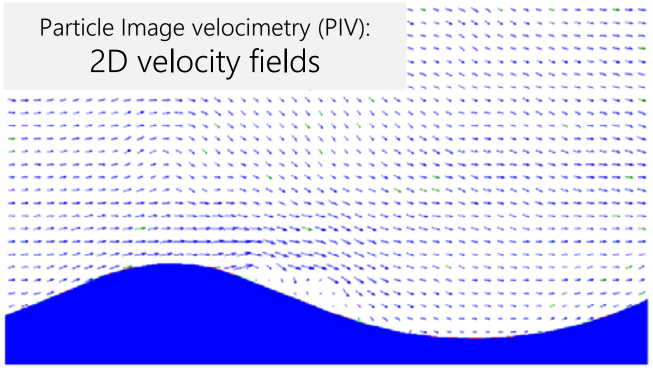
Project Website:

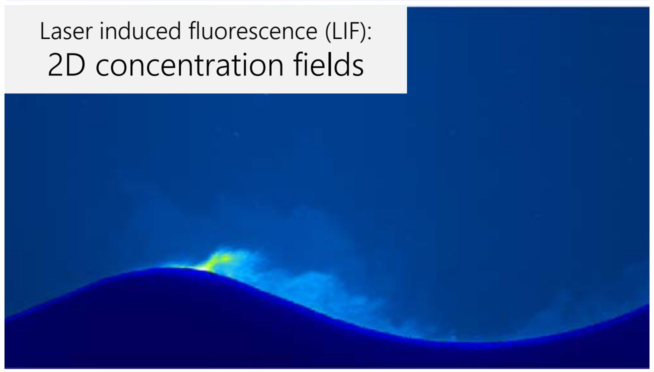
Turbulent transport of a passive discharging fluid above sand ripples

Experimental data from wave tank experiments

Temporal resolution: 15 Hz, 10.000 time steps
Spatial resolution: 1600 x 900 px → 169.1 x 95.98 mm (scale factor: 14.3)

Variables measured → Raw data





Settings of final measurement campaign
→ 12 configurations

Wave scenario	Orbital velocity [m/s]	Wave period [s]
Calm	0.06	1.99
Intermediate	0.22	2.52
Stormy	0.26	3.28

Sea bed model	Bed shape	Ripple wavel. [mm]	Ripple height [mm]	Ripple asymmetry factor	Radius crest [mm]	Radius trough [mm]
REF	Flat			1	-	
SIN	Sinusoidal			1	53.78	53.78
NAT	„Naturally“ shaped	159.22	19.56	1	47.81	109.74
ASYM	Asymmetri-cally shaped			1.5	-	

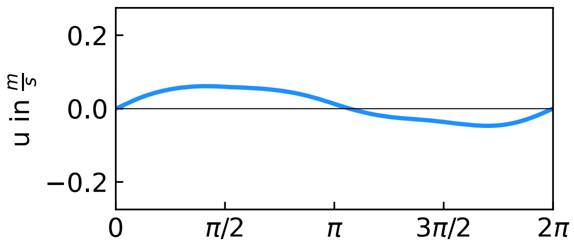
Universität Rostock Traditio et Innovatio

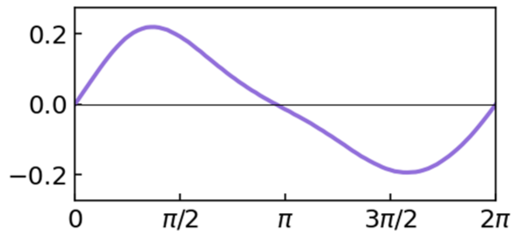
BALTIC TRANSCOAST — Ism UNIVERSITÄT ROSTOCK

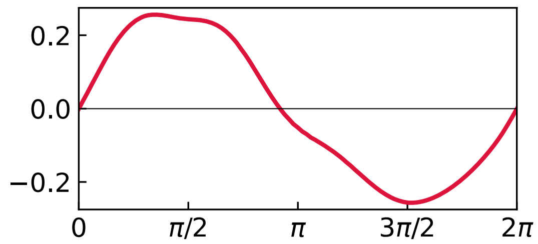
Turbulent transport of a passive discharging fluid above sand ripples

Experimental Setup

1) **Wave scenario** (based on in-situ measurements of coastal near bed orbital velocities)







Calm wave scenario

T ≈ 1.99 s, $u_{top,max}$ ≈ 0.06 m/s

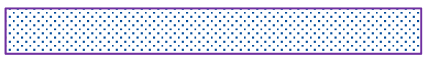
Intermediate wave scenario

T ≈ 2.52 s, $u_{top,max}$ ≈ 0.22 m/s

Stormy wave scenario

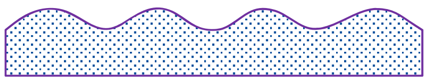
T ≈ 3.28 s, $u_{top,max}$ ≈ 0.26 m/s

2) **Sea bed** (based on in-situ measurements of coastal sand ripples)



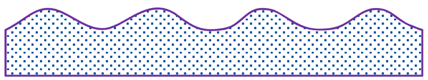
Flat bed

η = 0 mm, λ = 0 mm, β/λ = 0



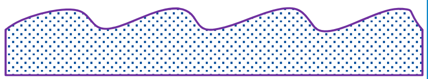
Sinusoidal rippled bed

η = 18.8 mm, λ = 147 mm, β/λ = 0



„Naturally“ rippled bed

η = 18.8 mm, λ = 147 mm, β/λ = 0



Asymmetric rippled bed

η = 18.8 mm, λ = 147 mm, β/λ = 0

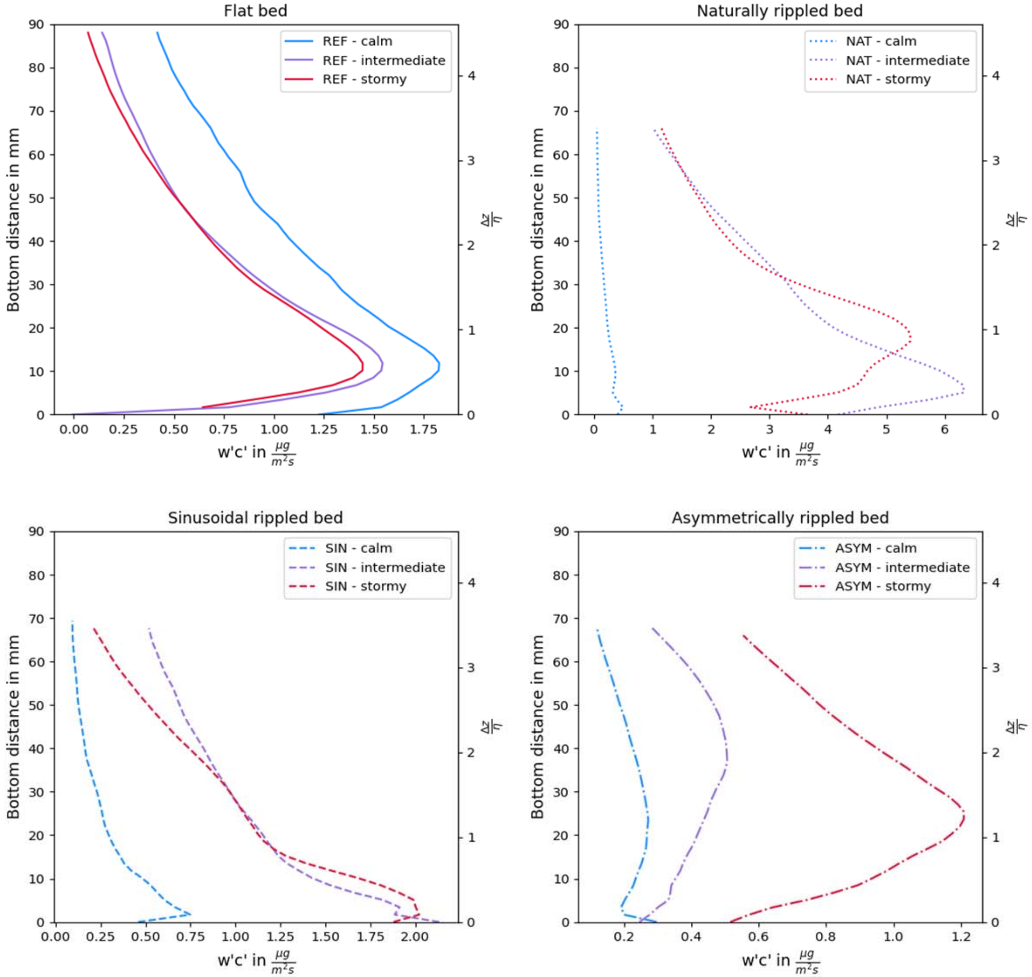
Universität Rostock Traditio et Innovatio

BALTIC TRANSCOAST

Ism UNIVERSITÄT ROSTOCK

Turbulent transport of a passive discharging fluid above sand ripples

Results – Mean phase averaged vertical Reynolds flux profiles $\langle w'c' \rangle$



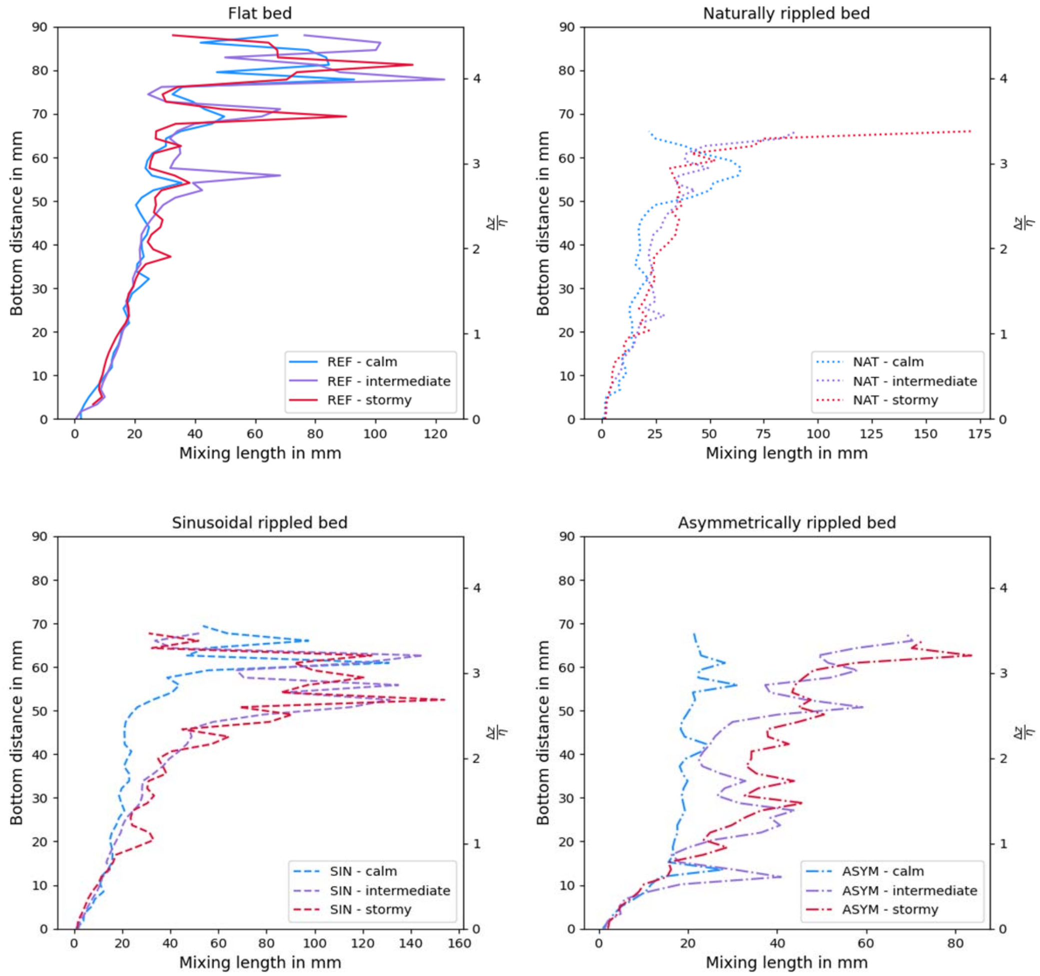
Universität Rostock Traditio et Innovatio

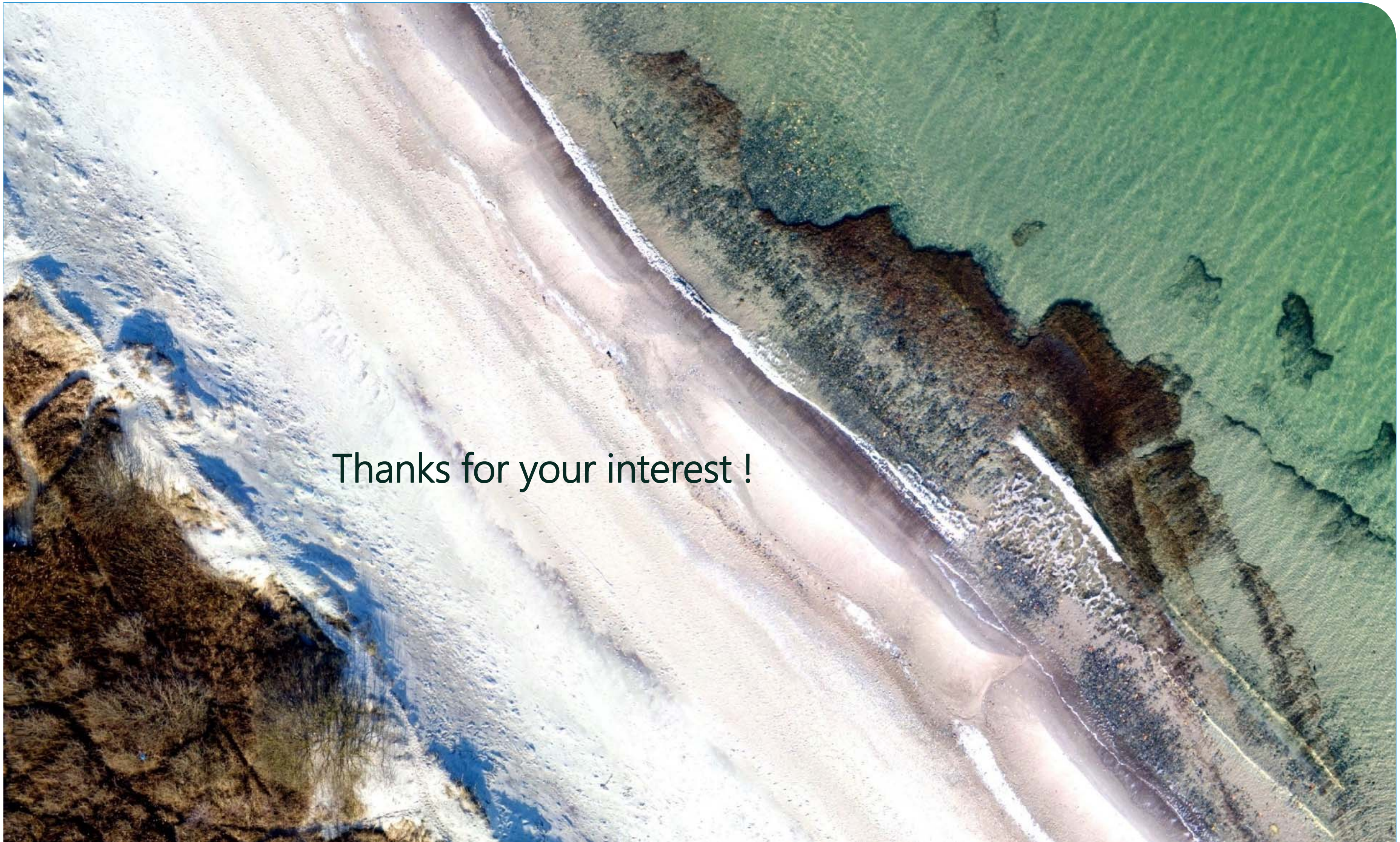
BALTIC TRANSCOAST

lsm UNIVERSITÄT ROSTOCK

Turbulent transport of a passive discharging fluid above sand ripples

Results – Mean phase averaged Prandtl mixing length profiles l_m





Thanks for your interest !