Ocean Waves: Insights from Particle Trajectories

Stokes drift: Modern challenges in mathematical theory and applications to marine sustainability

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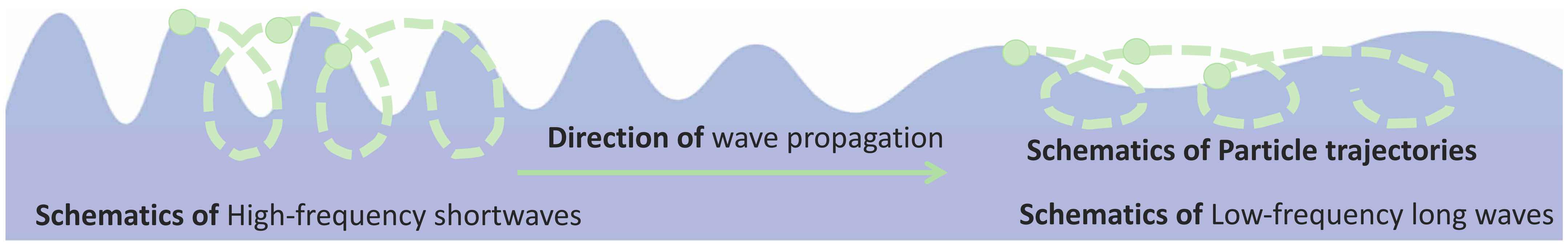
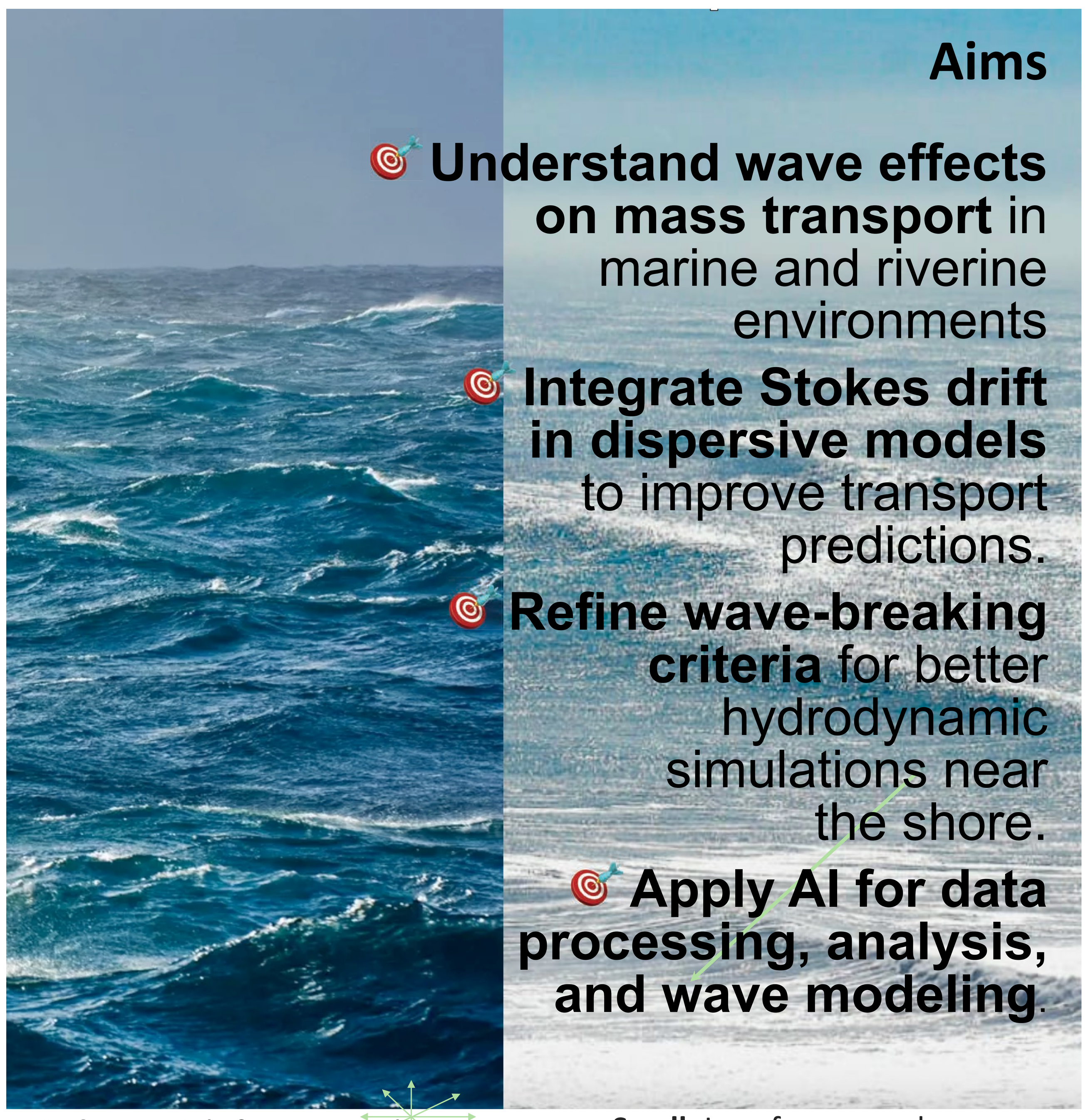
Background and motivation

I am a **mathematician,** and **my research** focuses on **developing and applying** mathematical tools –such as analytical, asymptotic, and numerical methods– **to explore** the **quantitative and qualitative characteristics** of highly **nonlinear phenomena** particularly in **water waves**. The study of water waves is an interdisciplinary field that is essential for addressing **marine sustainability challenges**, including **pollution transport**, **maintaining the dynamic balance of coastal ecosystems**, and preventing **natural disasters in coastal environments. I joined the SEAS** Programme **to broaden my research goals and techniques** by collaborating with experts from diverse fields. So far, **I have incorporated** experimental approaches, including **real-data analysis, participation in field campaigns, and the adaptation of artificial intelligence techniques**, to enhance **data processing, pattern recognition, and predictive modeling**. This has added **new perspectives** to my work and opened up **exciting new possibilities of knowledge.**

Project description

When waves move through water, **small buoyant particles follow an orbital motion**, resulting in **a net forward movement after each cycle.** This phenomenon is known as Stokes drift. **Stokes drift** is **strongest near the surface** and decreases with depth. The amount of Stokes drift **depends on the wave's amplitude (height) and wavelength,** and it **occurs** in the **direction of wave propagation**. This project investigates the **impact of Stokes drift on the horizontal and vertical transport of particles beneath waves** under different **sea state conditions**, such as swell and for various types of fluid and inertial particles. **Swell waves** are characterized by **longer wavelengths, lower frequencies, and smoother, more uniform crests.** Once formed, swells **can propagate across entire ocean basins**, often traveling thousands of kilometers from their point of origin. Because they are less dependent on local wind conditions**, swells maintain their energy and shape over long distances, eventually reaching distant coastlines**. This project explores **how waves influence the pathways and stagnation zones of impurities in the ocean by integrating Stokes drift in dispersive water wave models.**





Aims

- **Understand wave effects on mass transport** in marine and riverine environments
- **Integrate Stokes drift in dispersive models** to improve transport predictions.
- **Refine wave-breaking criteria** for better hydrodynamic simulations near the shore.
- **Apply AI for data processing, analysis, and wave modeling.**

Wind sea: High-frequency shortwaves **Swell:** Low-frequency long waves

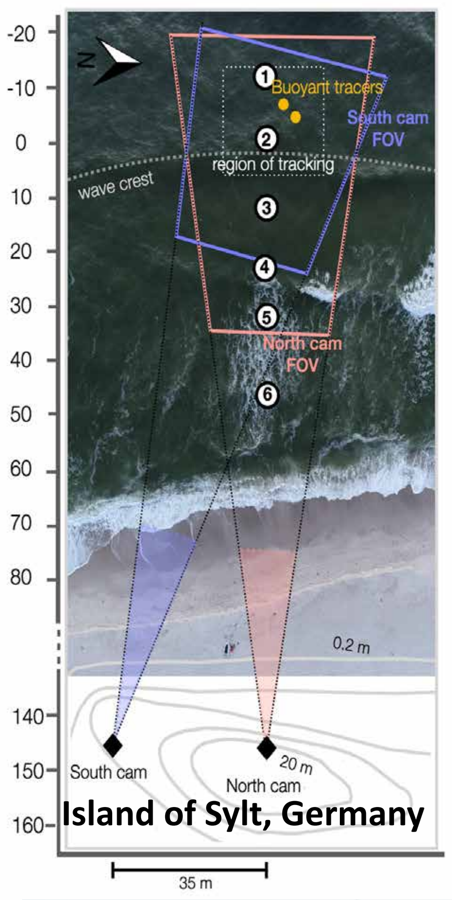
Marine sustainability

Talking about marine sustainability **embodies interdisciplinary and complex approaches** needed to manage with **responsibility and effectiveness a broad spectrum of issues** related to the **resources and services provided by the ocean** and to **mitigate human print on the marine ecosystems. The transport and** accumulation of floating objects and impurities in the ocean represent urgent problems and are demanding a better **understanding of the physical processes behind the transport** that can effectively guide policies toward its **estimation, monitoring, prevention and removal.** The common challenge they pose is the **inclusion of wave-induced effects in surface drift for an accurate forecast of the dynamics in the upper and intermediate layers of the ocean**. In this study we aim to contribute to their understanding looking for novel **interdisciplinary techniques**.

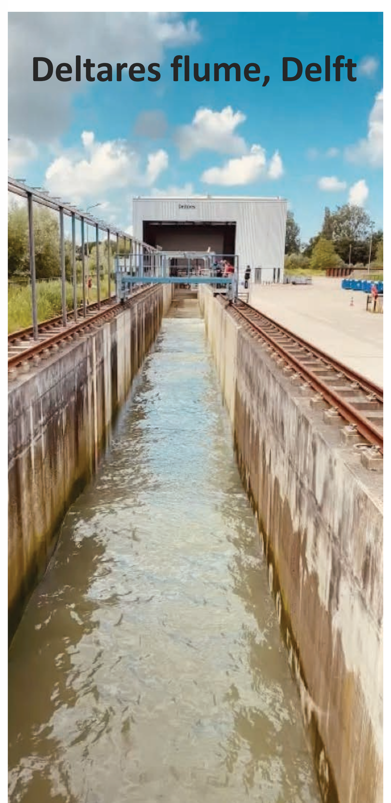
Main questions

How waves influence the pathways and stagnation zones of impurities in the ocean, such as microplastics and salmon lice?
Is there a measurable vertical distribution of buoyant microplastics in certain oceanic regions/riverine settings under key marine/hydraulic conditions?
How can AI enhance the estimation, monitoring, and cleaning policies of impurities in marine environments?

Field experiences



Island of Sylt, Germany


Deltares flume, Delft


Swell somewhere in the Ocean

Highlighted results/activities of 2024

- **Involved in three field campaigns:**
  Island of Sylt, Germany – Data analysis of reconstructed trajectories of surface tracers to validate a wave-breaking criterion near the shore zone.
  Deltares Flume, Delft – Participated in experiments and data collection to investigate Stokes drift under simulated sea-state conditions in the flume.
  Coming soon – Data analysis from a **cruise in the Atlantic Ocean**, focusing on measuring Stokes drift in the open sea.
- Research on ***Modified Rouse model to predict the vertical distribution of positively buoyant microplastics in rivering Enviroments.*** Joint work with M. Franco (KIT), D. Valero (Imperial College London), and H. Kalisch (UiB).
- **Co-author of four submitted papers in nonlinear phenomena:**
  1. ***Lagrangian acceleration as a diagnostic for wave breaking in the nearshore zone*** *Geophysical Research Letters*
  2. ***Solitary wave collisions for Whitham-Boussinesq systems*** *Partial Differential Equations in Applied Mathematics*
  3 ***Low mode interactions in water wave model in triangular domain*** *Wave Motion*
  4. ***Two color soliton interactions in nematic liquid crystals with temperature-dependent reorentational response***. *NooEl especial edition*
- **Presented a talk at ICCE 2024 and Invited to BIRS-Banff Canada Workshop** on Nonlinear Water Waves: Rigorous Analysis and Scientific Computing
- **Project Manager (Since March 2024) of RESCUER** *(Resilient Solutions for Coastal, Urban, Estuarine, and Riverine Environments).*A Doctoral Network.

Supervisory team

Supervisor: Professor Guttorm Alendal a visionary researcher in the Department of Mathematics at UiB, , applies data-driven models to nonlinear problems, focusing on mathematics for sustainable development and bridging industry and academia.

Co-supervisor: Professor Henrik Kalisch, an esteemed researcher in the Department of Mathematics at UiB, is known for his innovative work in the mathematical modeling of nearshore processes, making him a leading figure in the field.

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