THE OCEAN CLEANUP

BASILISK & PLASTIC MARINE DEBRIS TRACKING

Basilisk (Gerris) Users' Meeting 2025, University of Oxford

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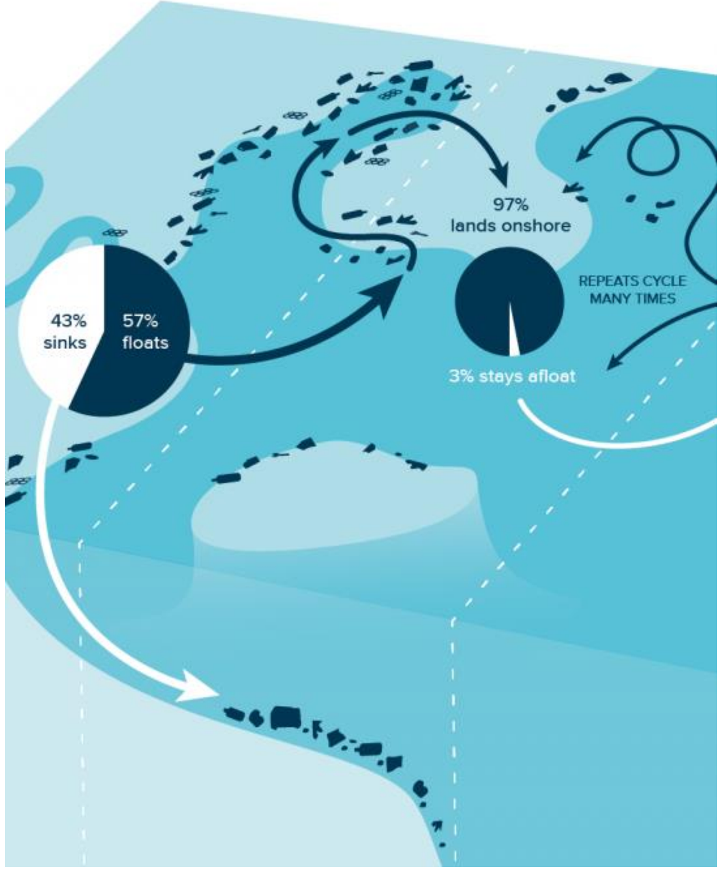
PROF. TON VAN DEN BREMER (TU DELFT)

MISSION

RID
THE OCEANS OF PLASTIC

Credit: Francis Perez

ARTERIES OF PLASTICS POLLUTION

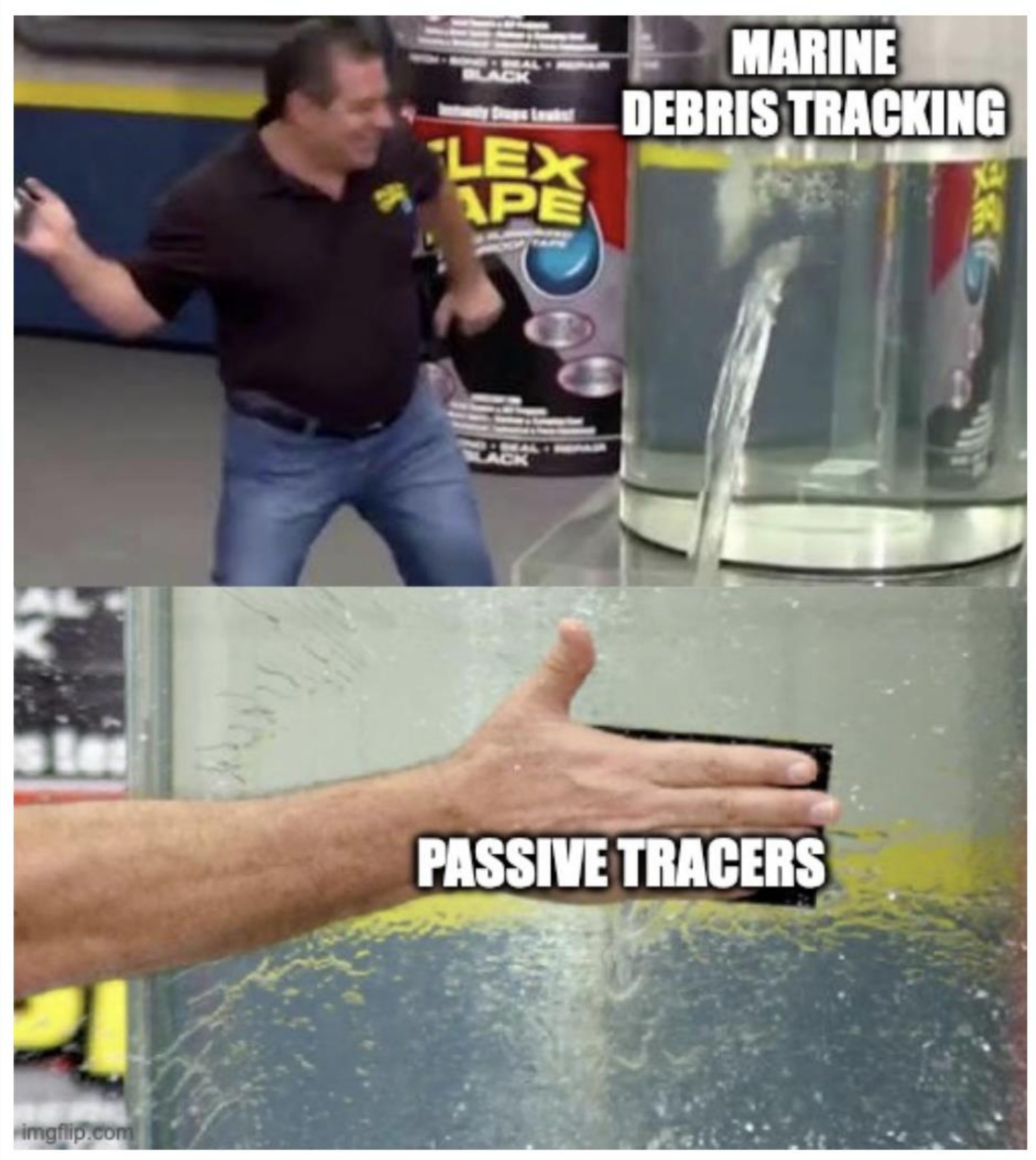


DUAL STRATEGY FOR PLASTIC-FREE OCEANS

Cleanup systems for **ocean plastic gyres**. In rivers, **Interceptors** capture plastics. We are **targeting the world's most polluting rivers.**

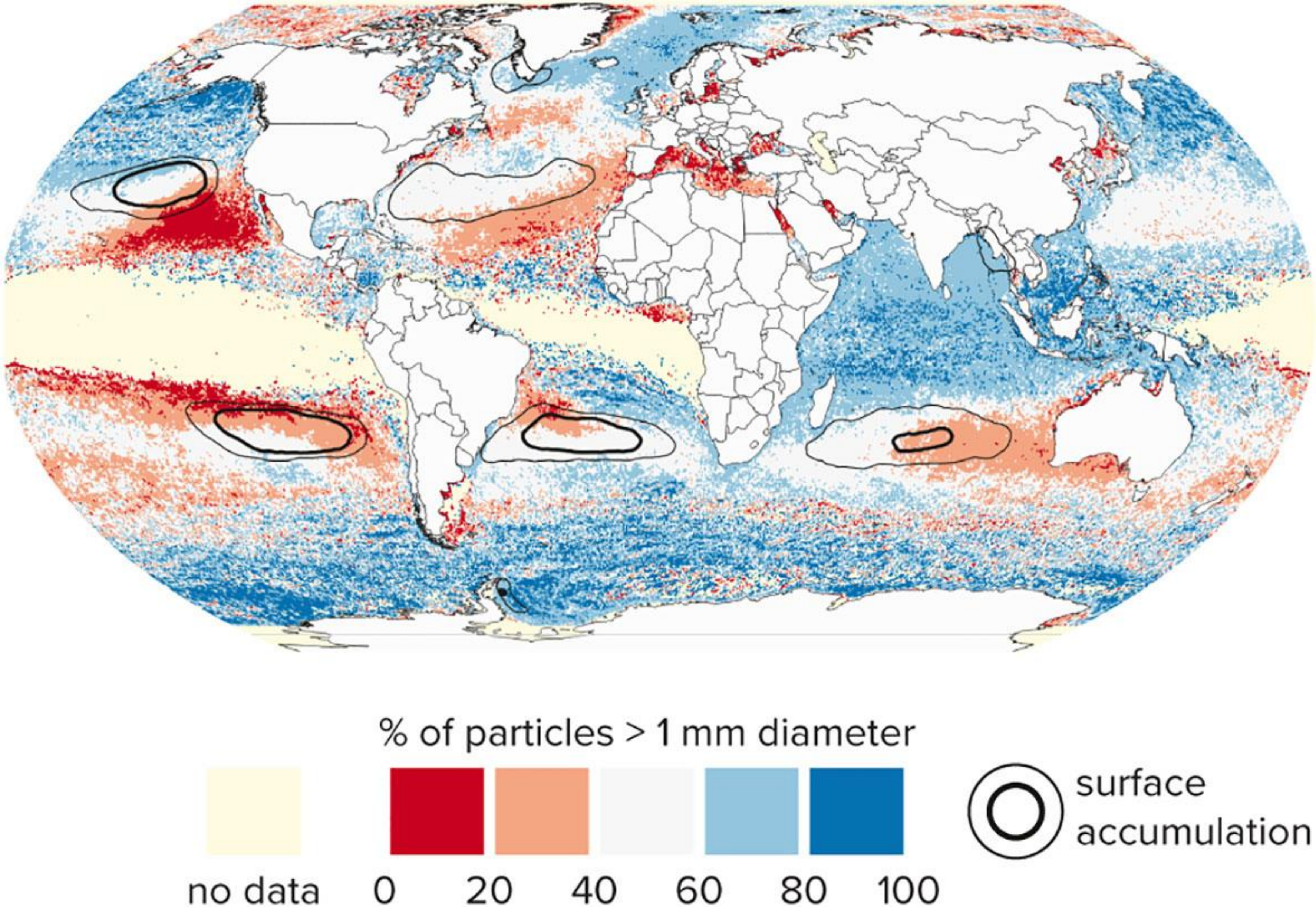
THE OCEAN CLEANUP

HOW TO MODEL THESE IN ALL SCALES OF THE OCEAN?


MARINE
DEBRIS TRACKING
PASSIVE TRACERS
imgflip.com

ADVECT[1]

- OGCM + Lagrangian Particles
- Lagrangian advection of marine debris by currents
- Buoyancy & drag driven[2]
- Terminal rising velocity (fluid and the particles properties)



[1]Klink, D., A. Peytavin, and L. Lebreton, 2022. Size Dependent Transport of Floating Plastics Modeled in the Global Ocean. Front. *Mar. Sci* 9.
[2]Dietrich, W.E., 1982. Settling velocity of natural particles. *Water resources research*, 18(6), pp.1615-1626.

PUTTING THINGS ON PERSPECTIVE

1/12 DEGREE

OCEAN OFFSHORE PROCESSES AND PLASTIC PARTICLES

1. Large-Scale Circulation

- **Subtropical Gyres**: Accumulation zones
- **Geostrophic Currents**: Persistent circular motion
- **Ekman Transport**: Wind-driven motion of surface waters.

2. Wind and Wave-Induced

- **Stokes Drift**: Net motion of floating debris by wave
- **Windage**: Aerodynamic efforts on debris
- **Langmuir Circulation**: Wind-driven vortex pairs align floating debris into parallel windrows.

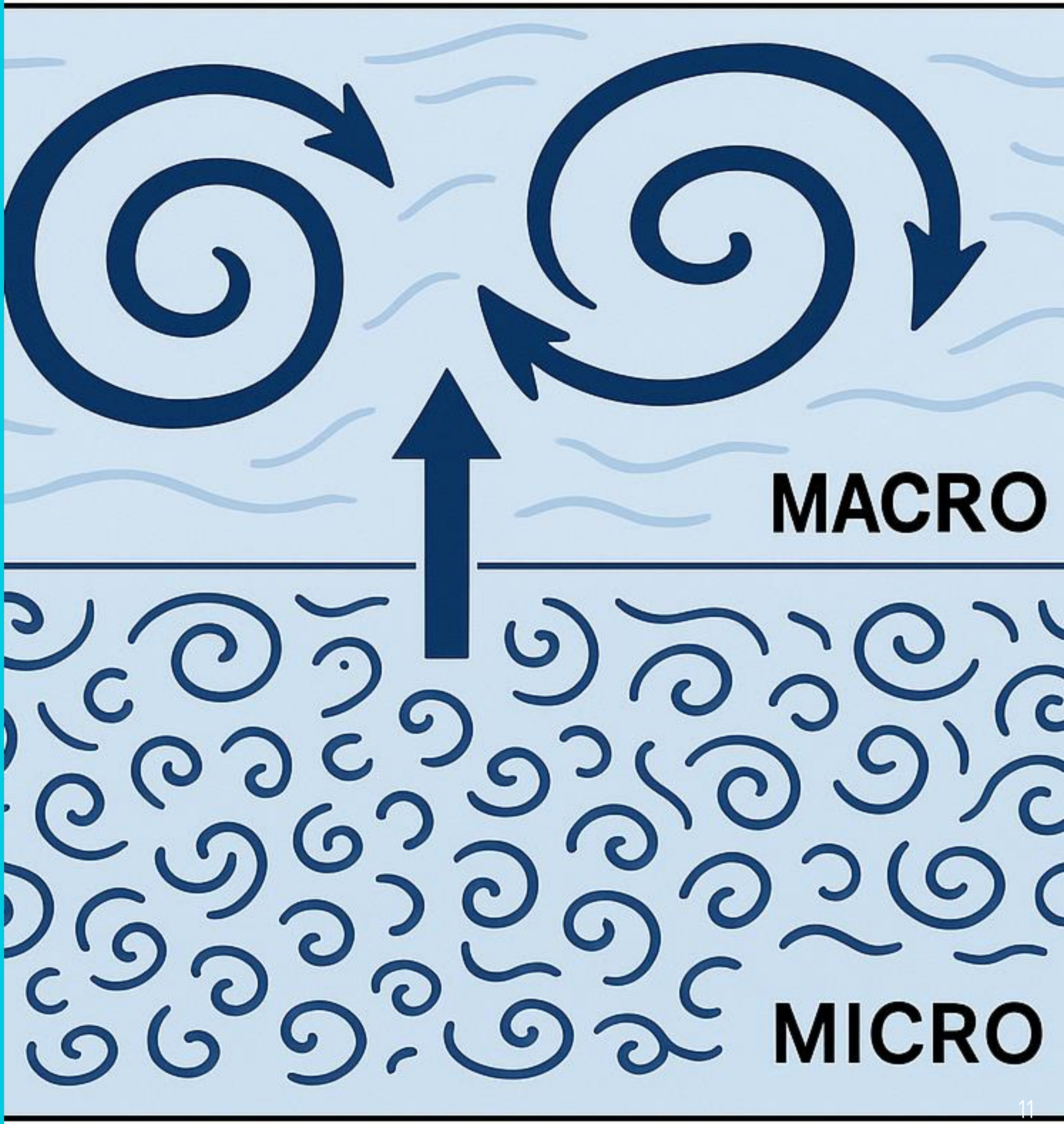
3. Mesoscale and Submesoscale

- **Eddies (Mesoscale)**: Large circular currents (~10–100 km) that trap or eject debris.
- **Frontal Zones**: Interfaces between water masses
- **Submesoscale Filaments**: Fast-moving features that can disperse debris over shorter timescales.

4. Vertical Transport & Mixing

- **Turbulent Mixing**: Surface turbulence (e.g., from storms) pushes debris down temporarily.
- **Eddy-Driven Subduction**: Downwelling zones of eddies
- **Diurnal Thermocline Variability**: Day-night heating cycles.

INFORMATION TRANSFER



EULER-LAGRANGE (EL)

FLUID

$$\rho_f\left(\frac{\partial \boldsymbol{u}}{\partial t}+\boldsymbol{u}\cdot\boldsymbol{\nabla}\boldsymbol{u}\right)=-\boldsymbol{\nabla}p+\boldsymbol{\nabla}\cdot(2\mu_f\mathbf{D})+\sigma\kappa\delta_s\boldsymbol{n}+\boldsymbol{g}+\cancel{\boldsymbol{f}_{p\to f}}$$

$$\frac{\partial \rho_f}{\partial t}+\boldsymbol{\nabla}\cdot(\rho_f\boldsymbol{u})=0$$

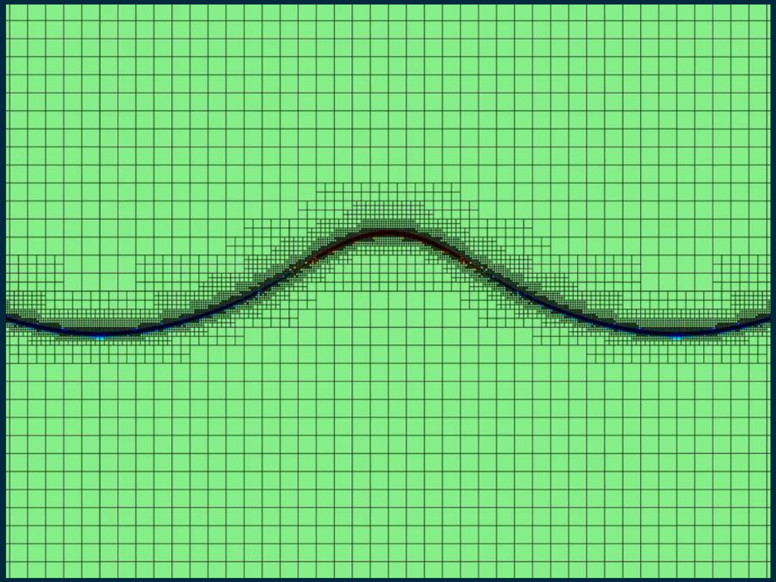
$$\boldsymbol{\nabla}\cdot\boldsymbol{u}=0$$

SOLID

$$M\frac{d\mathbf{V}}{dt}=(M-m_f)\mathbf{g}+m_f\frac{D\mathbf{u}}{Dt}+3\pi d_p\mu(\mathbf{u}-\mathbf{V})$$

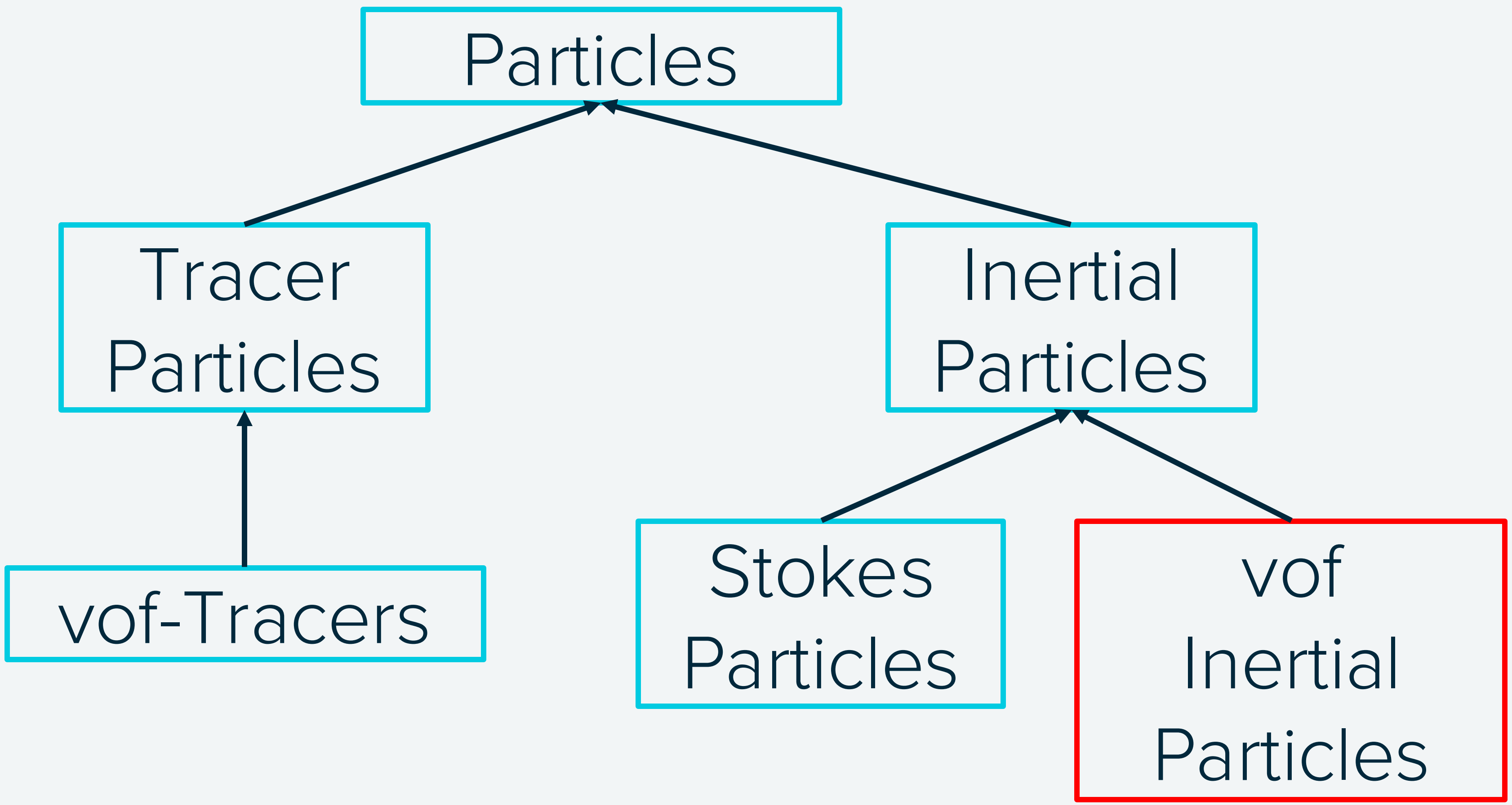
$$+\frac{1}{2}\rho_f m_f\frac{d(\mathbf{u}-\mathbf{V})}{dt}+\frac{3}{2}d_p^2(\pi\mu\rho)^{\frac{1}{2}}\left(\int_0^t\frac{\frac{d(\mathbf{u}-\mathbf{V})}{d\zeta}}{(t-\zeta)^{\frac{1}{2}}}d\zeta\right)$$

- DNS of canonical waves with Basilisk[3]
- Navier-Stokes + interfacial flow solver + Geometrical VoF + Quad/Octrees data structure
- Maxey-Riley[4] Point-Particle



http://basilisk.fr/sandbox/popinet/wave.c

[3] S. Popinet. An accurate adaptive solver for surface-tension-driven interfacial flows. *Journal of Computational Physics*, 228, 16, 2009.
[4] M. R. Maxey and J. J. Riley. Equation of motion for a small rigid sphere in a nonuniform flow. *Physics of Fluids*, 26, 883-889, 1983.

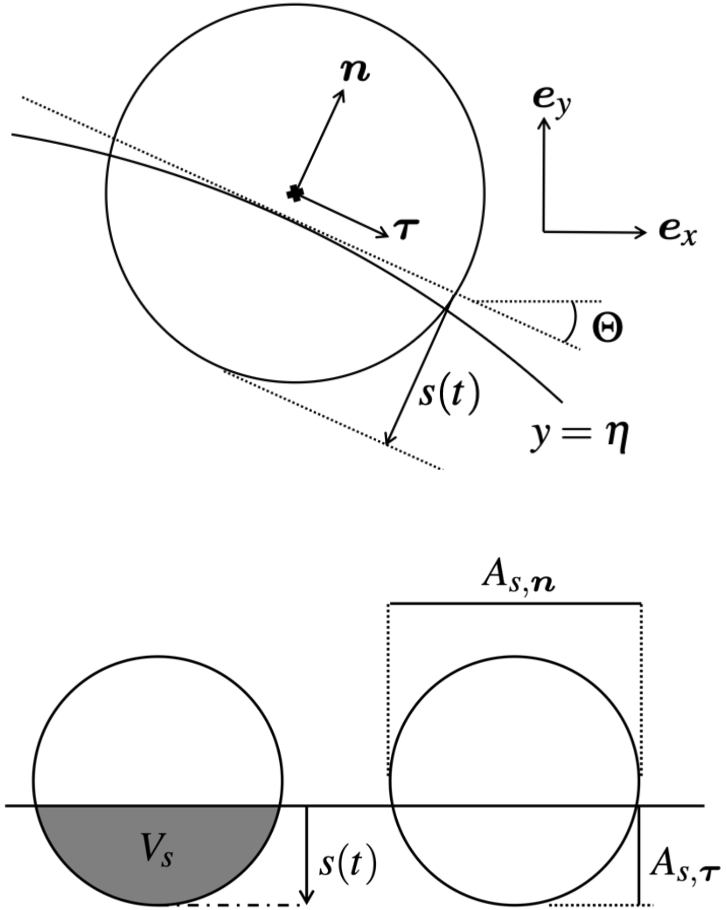


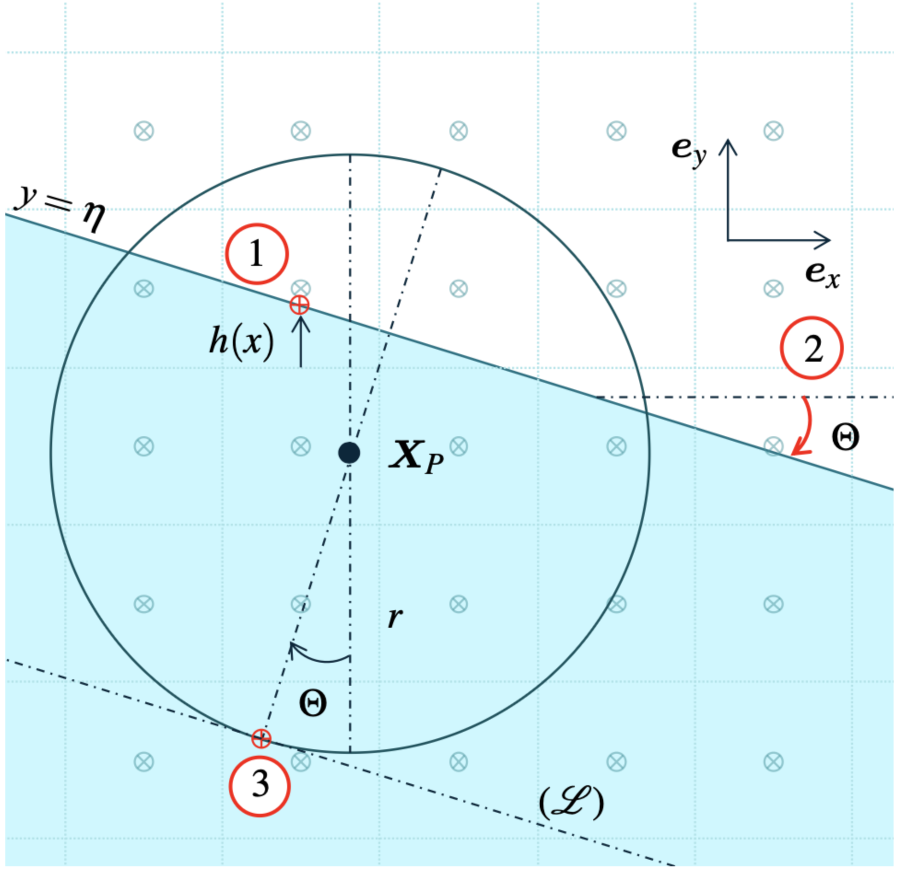
INHERITENCE FROM ANTOON'S SANDBOX

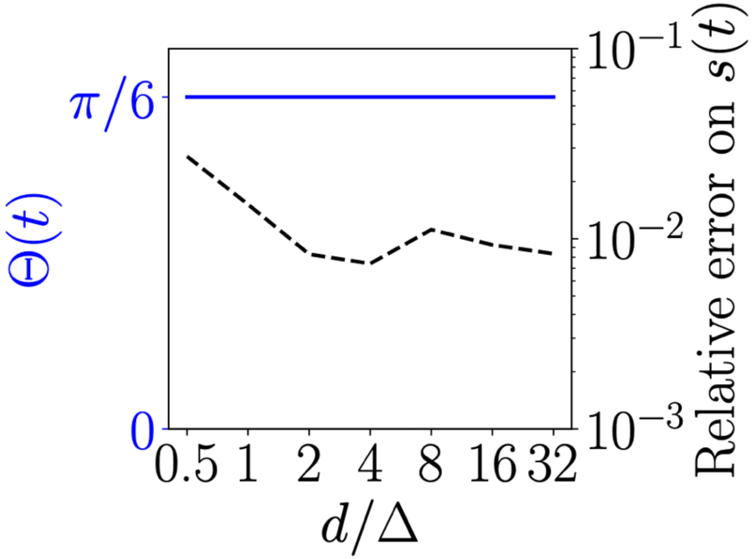
http://basilisk.fr/sandbox/Antoonvh/README

- Dilute regime (one-way coupled)
- Non Stokesian
- Macro plastics (> 2cm)
- Negligible effects of surface tension
- d << λ

HEIGTH-FUNCTION[5] FOR HYDRODYNAMIC FORCES

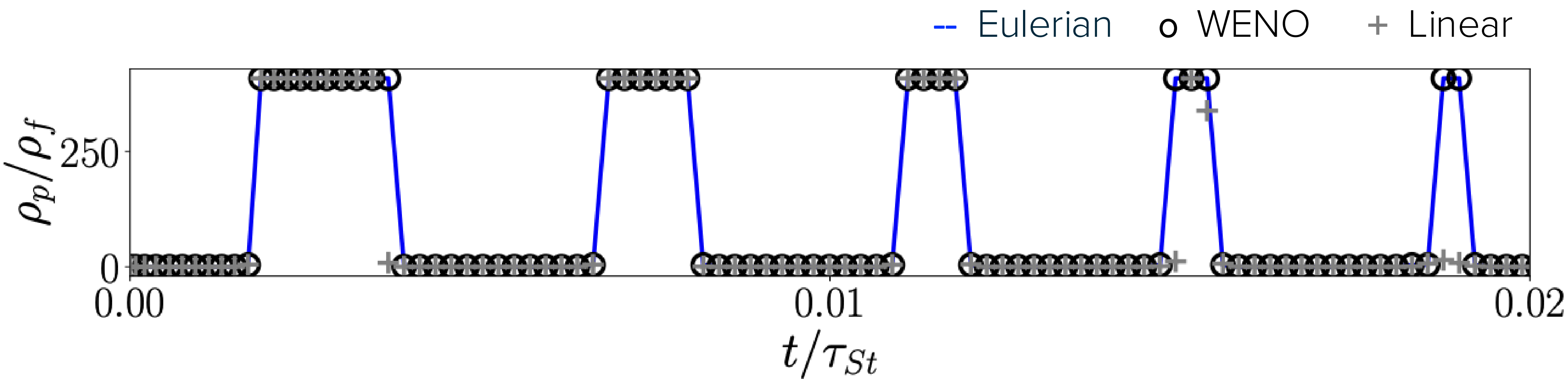


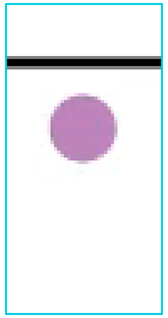




[5]Popinet, S. (2009). An accurate adaptive solver for surface-tension-driven interfacial flows. *Journal of Computational Physics*, 228.

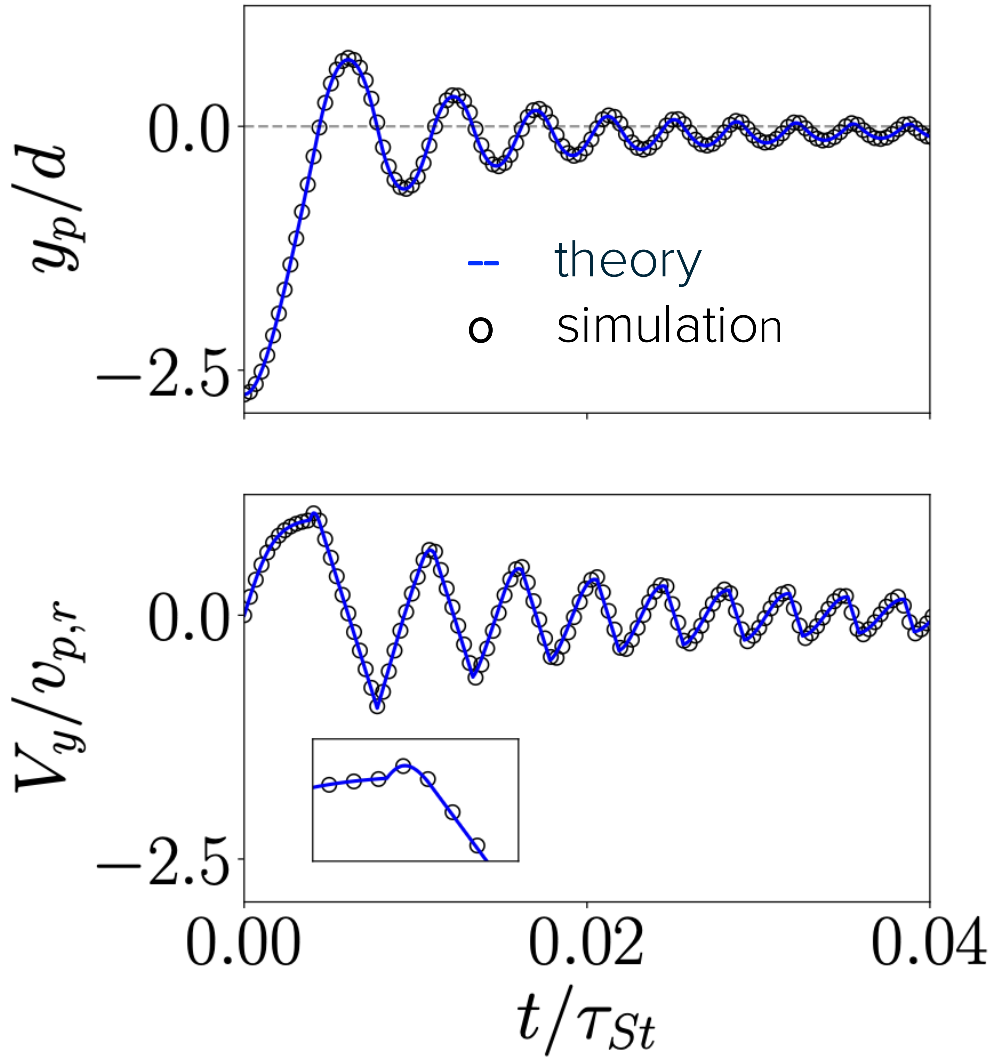
5TH ORDER WENO[7] INTERPOLATION



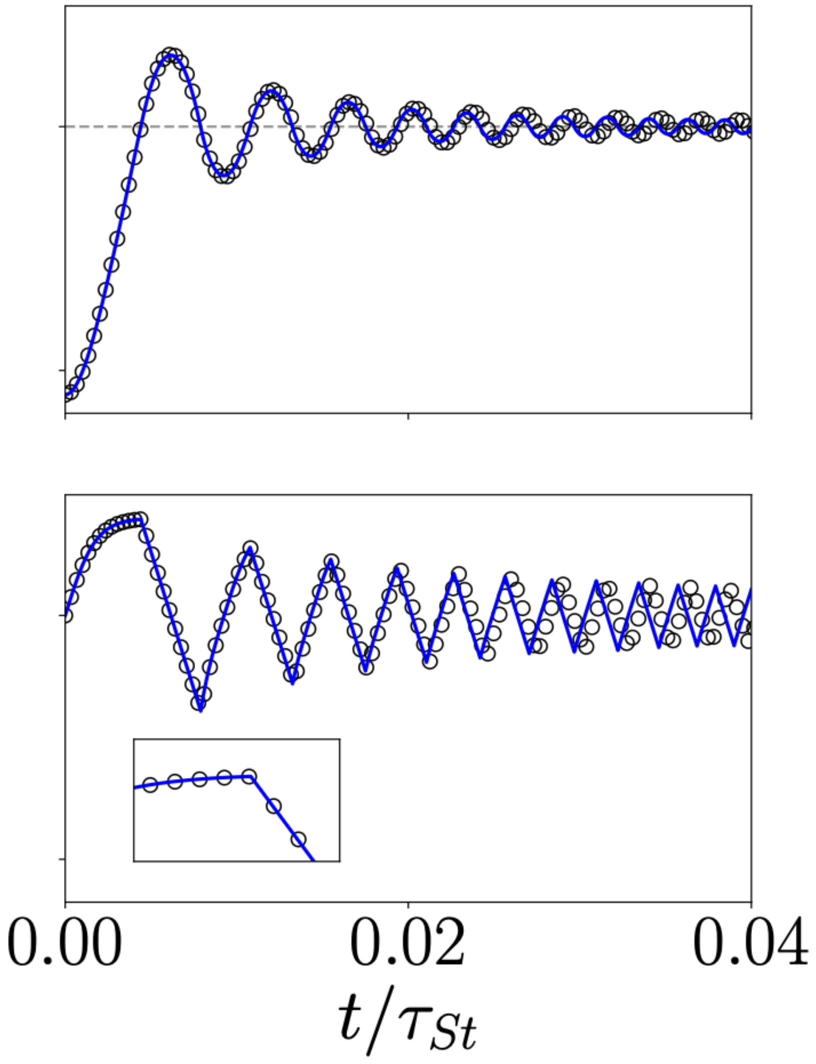


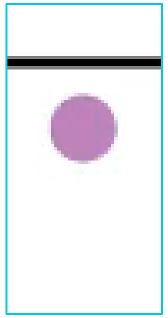
[7]Shu, C.-W. and Osher, S. (1988). Efficient implementation of essentially non-oscillatory shock-capturing schemes. *Journal of Computational Physics*, 77, 439–471.

5TH ORDER WENO[7]



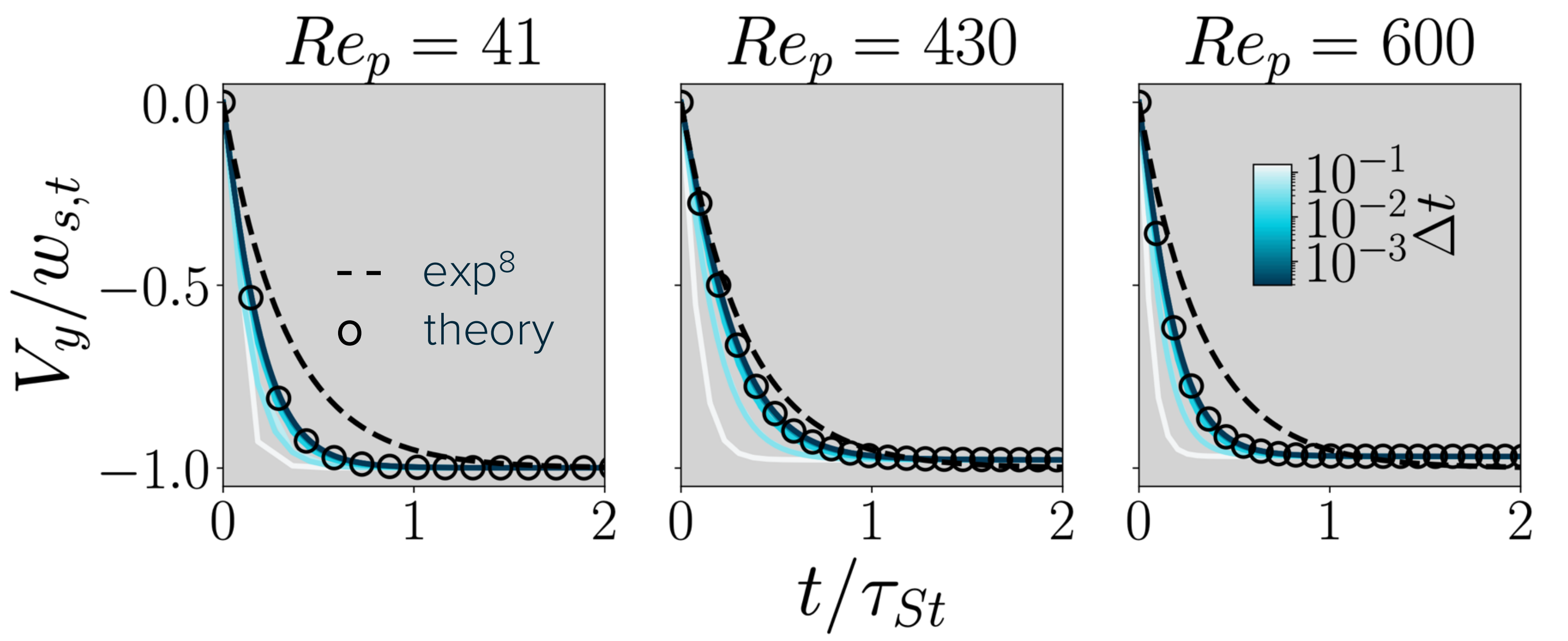
LINEAR



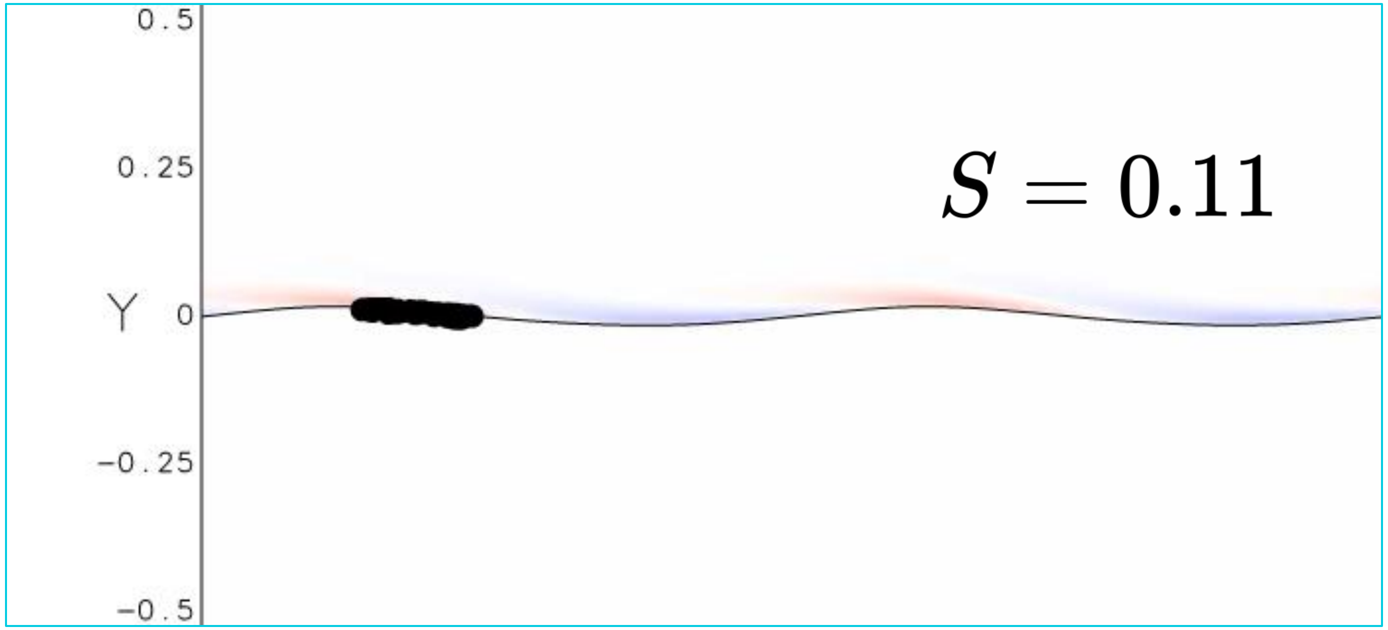


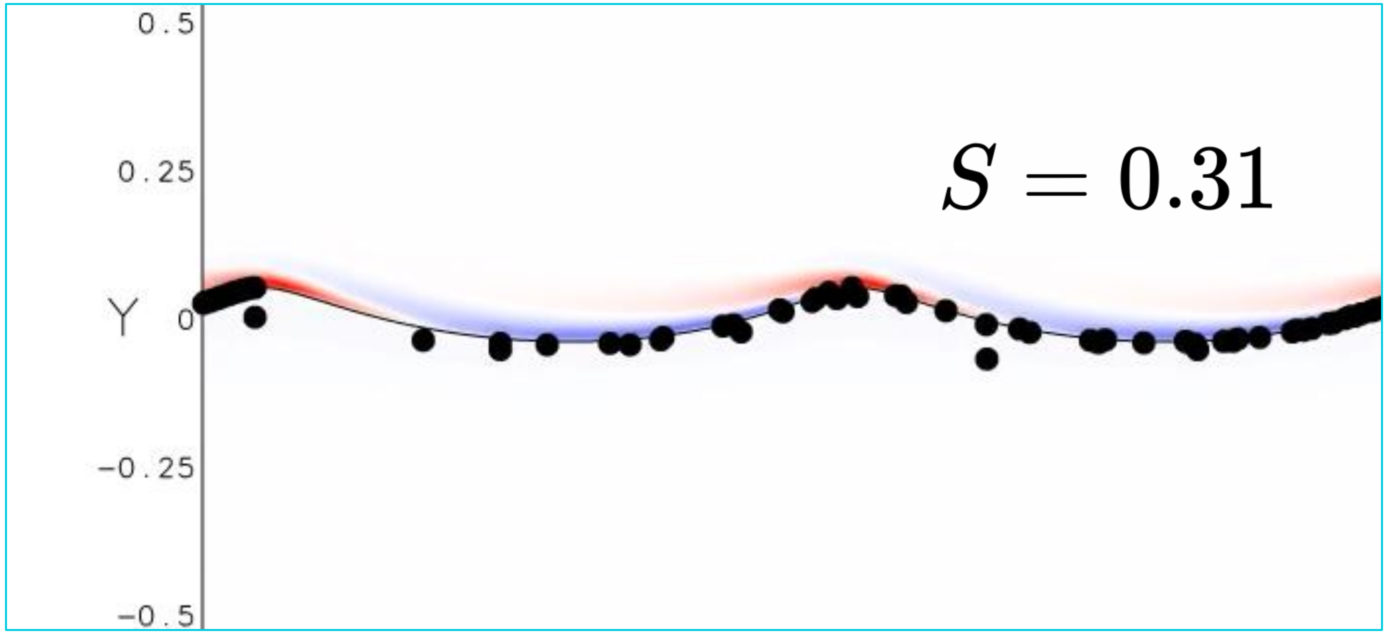
[7]Shu, C.-W. and Osher, S. (1988). Efficient implementation of essentially non-oscillatory shock-capturing schemes. *Journal of Computational Physics*, 77, 439–471.

SETTLING VELOCITY TEST



[8] Mordant, N., & Pinton, J.-F. (2000). Velocity measurement of a settling sphere. *The European Physical Journal B-Condensed Matter and Complex Systems, 18*, 343–352.





PARAMETERS

WAVE-INDUCED MOTION OF RELATIVELY SMALL PLASTICS

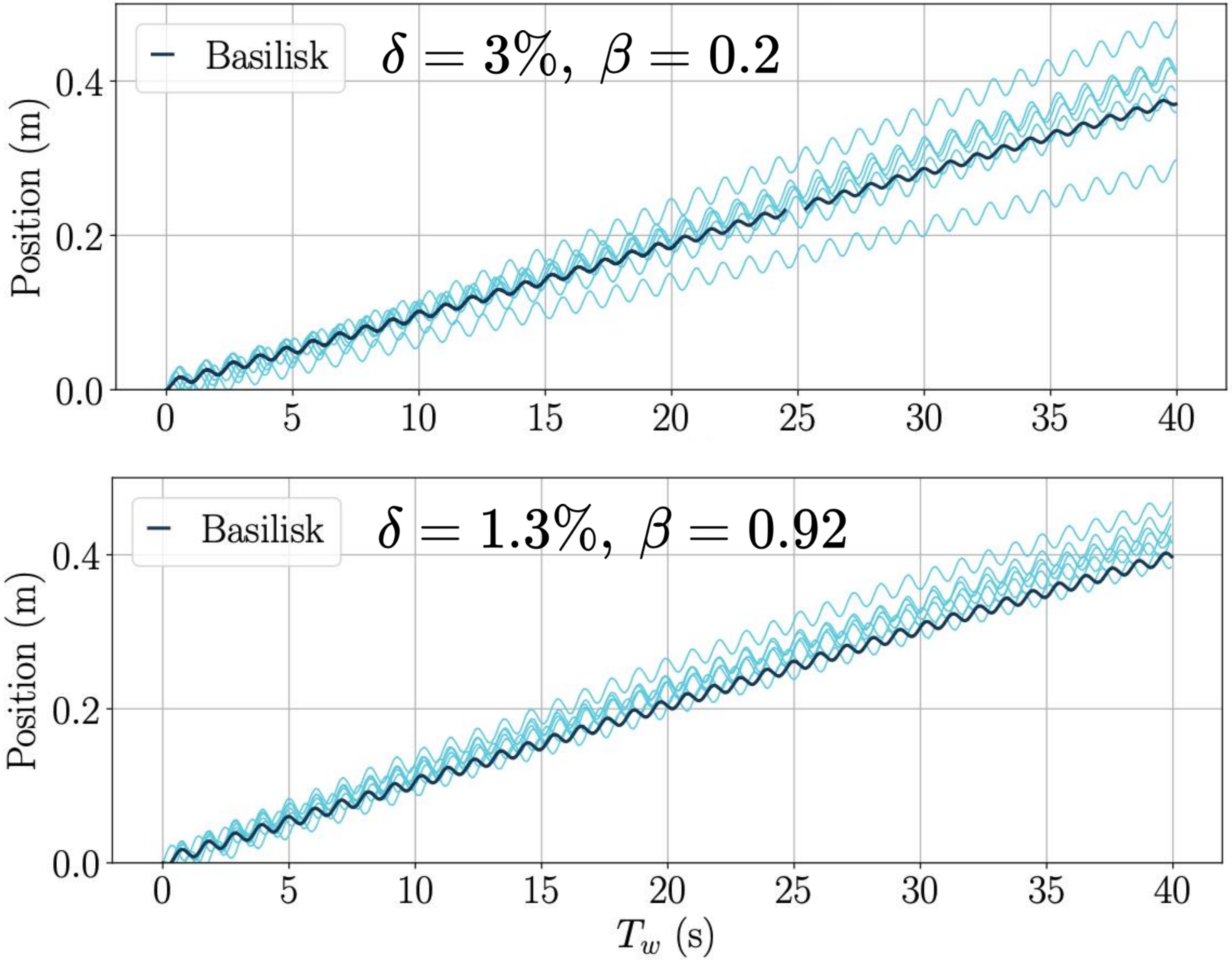
$$\delta = \frac{d}{\lambda} \leq 3\%$$

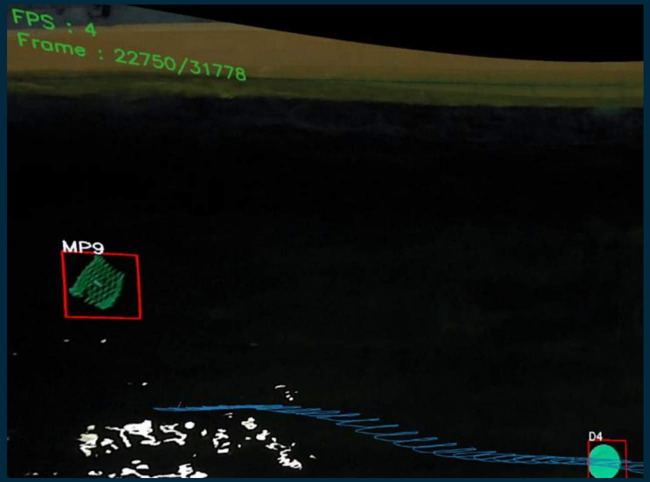
$$\beta = \frac{\rho_p}{\rho_w}$$

$$0.2 \leq \beta \leq 0.9$$

EXPERIMENTS[9] (BLUE) VS SIMULATION (BLACK)

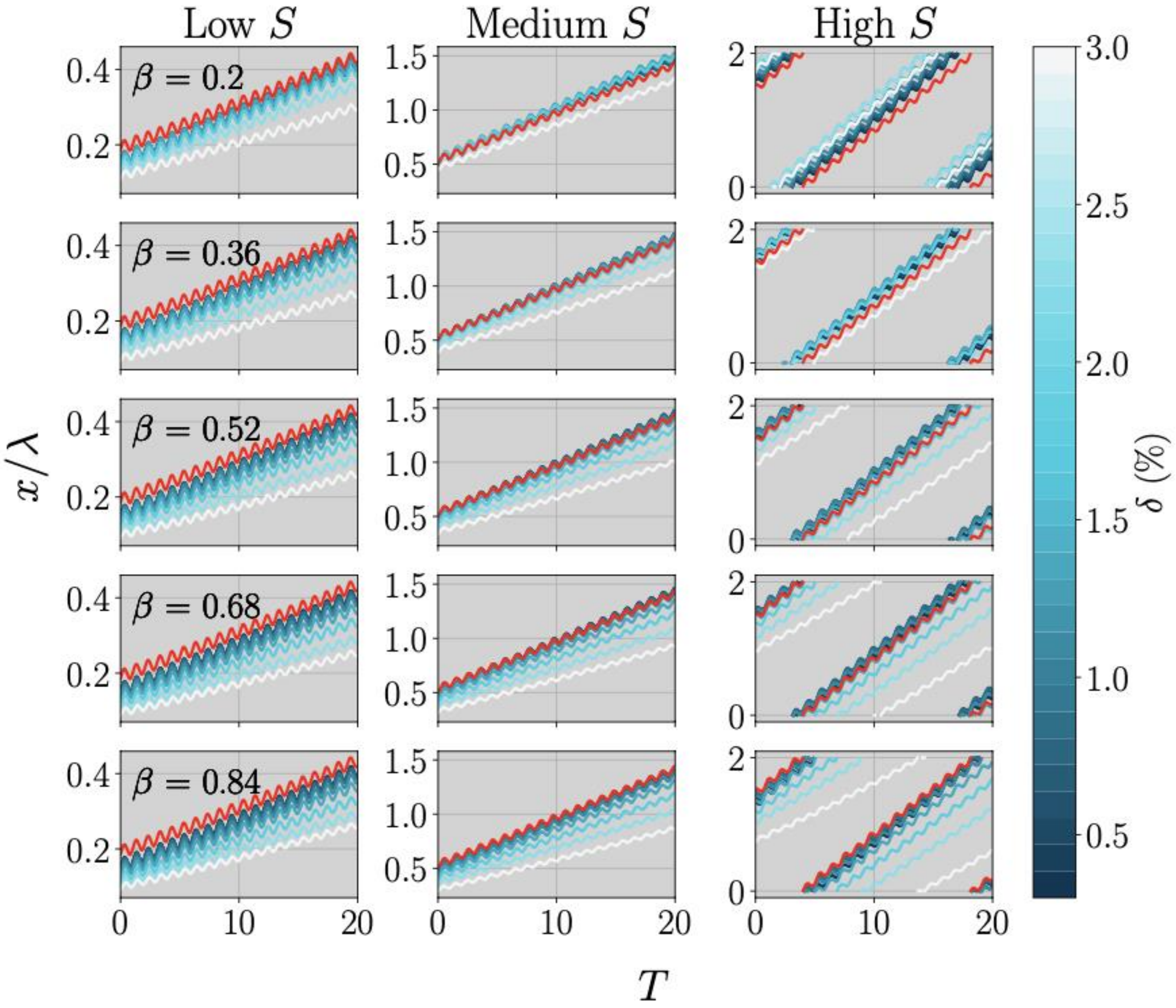
$$S = 0.16$$





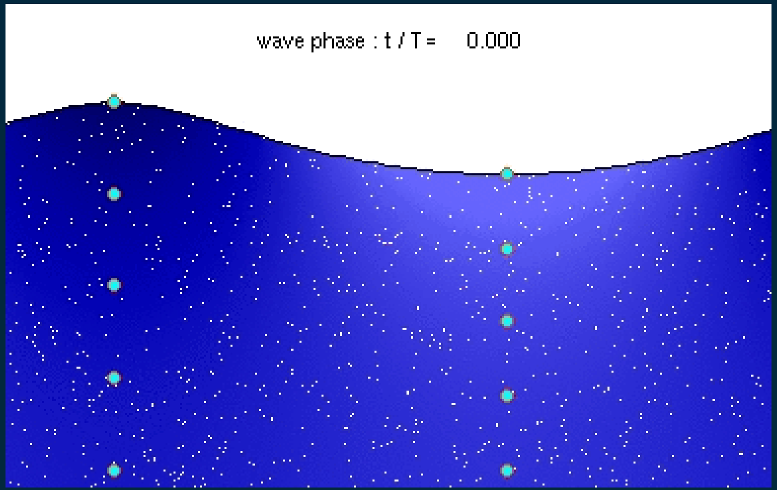
MARIN

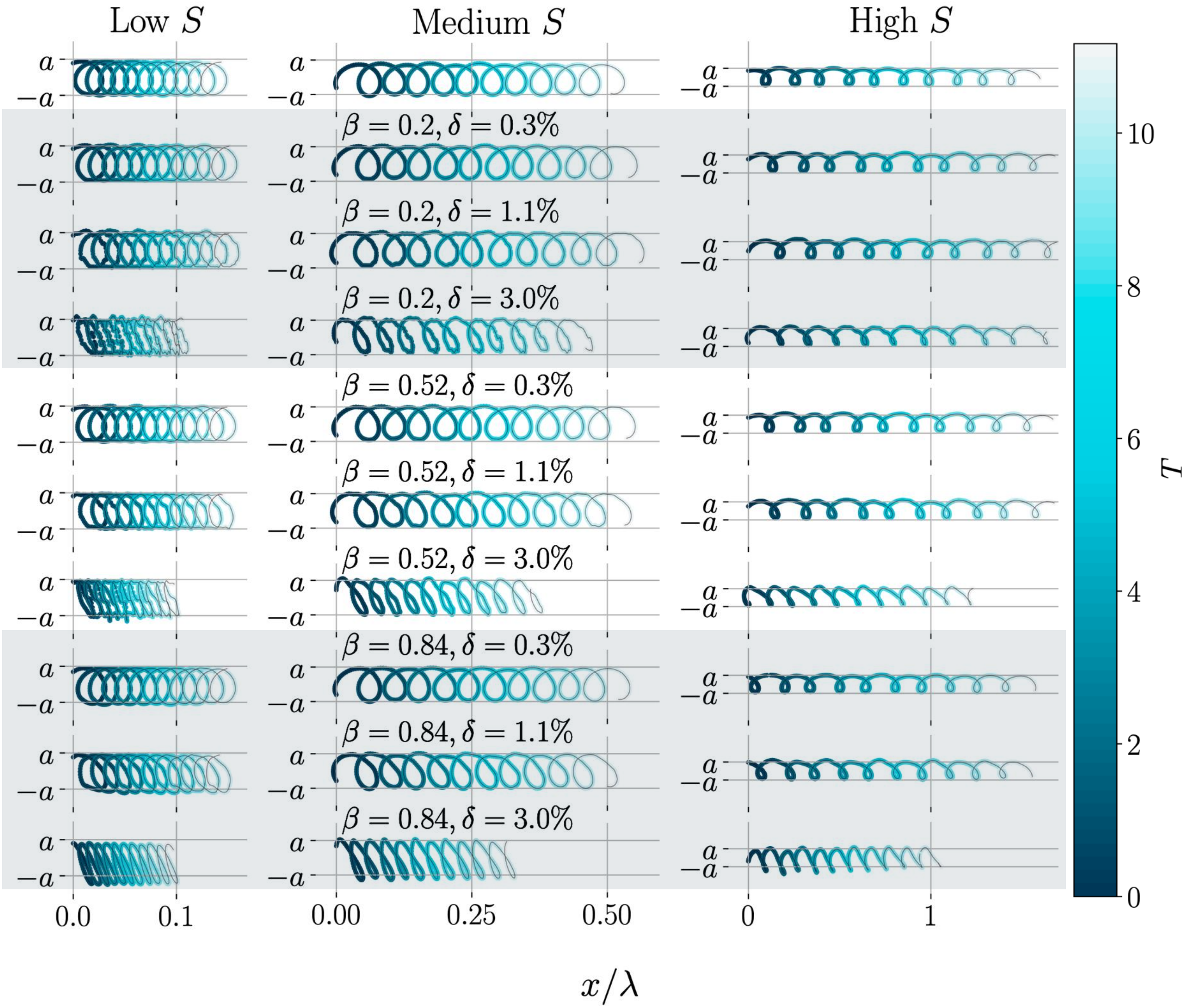
[9]Calvert, R. *et al.* (2024). A laboratory study of the effects of size, density, and shape on the wave-induced transport of floating marine litter. Journal of Geophysical Research: Oceans 129.



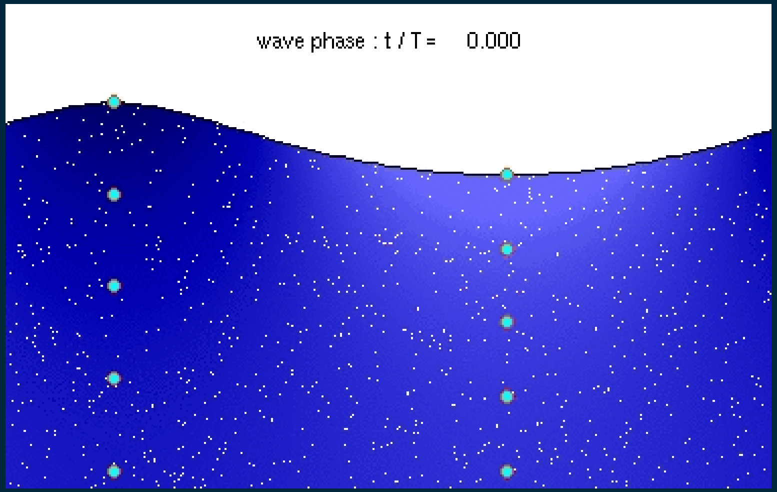
PASSIVE TRACERS
VS
INERTIAL PARTICLES

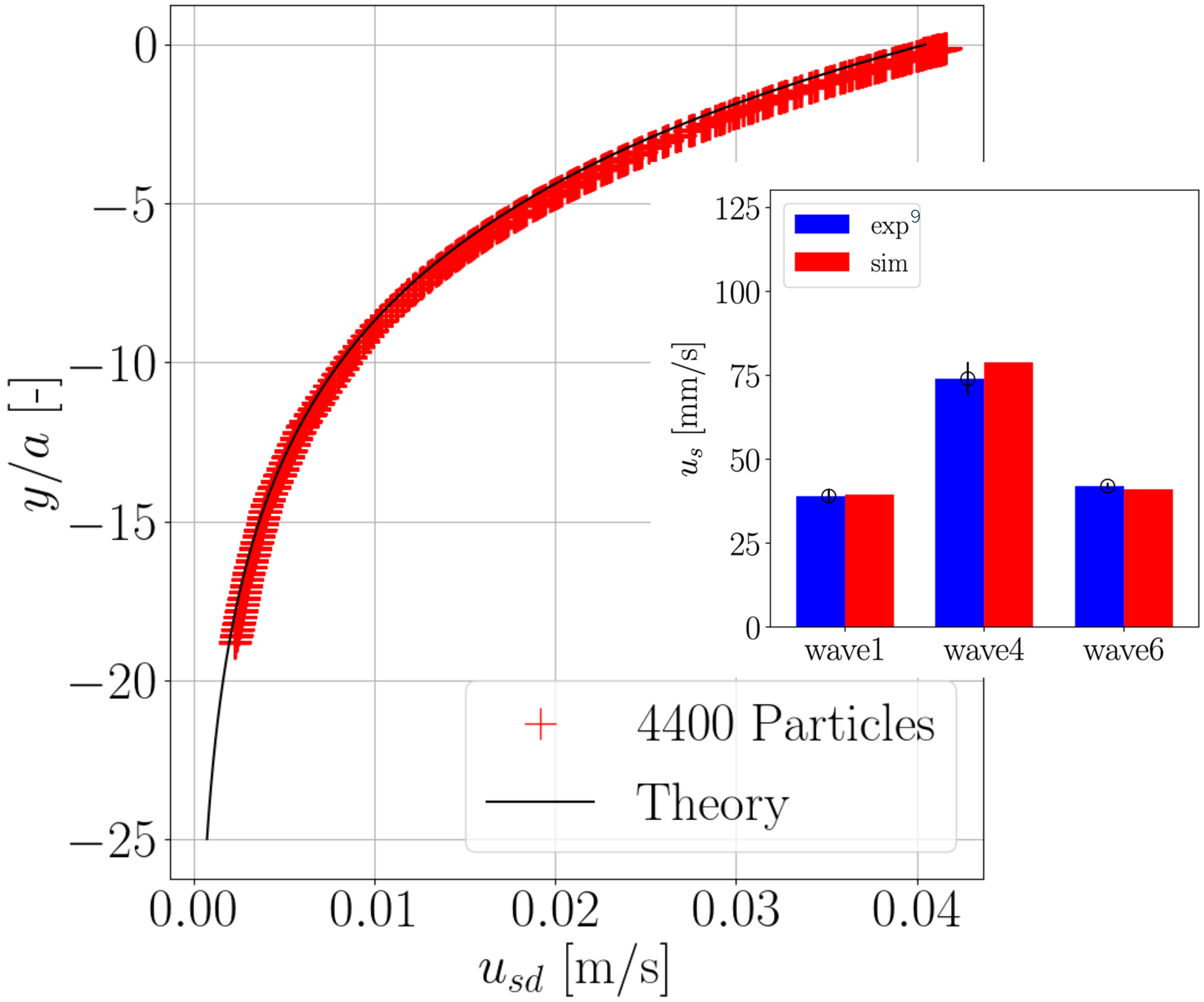
WAVE-INDUCED MOTION





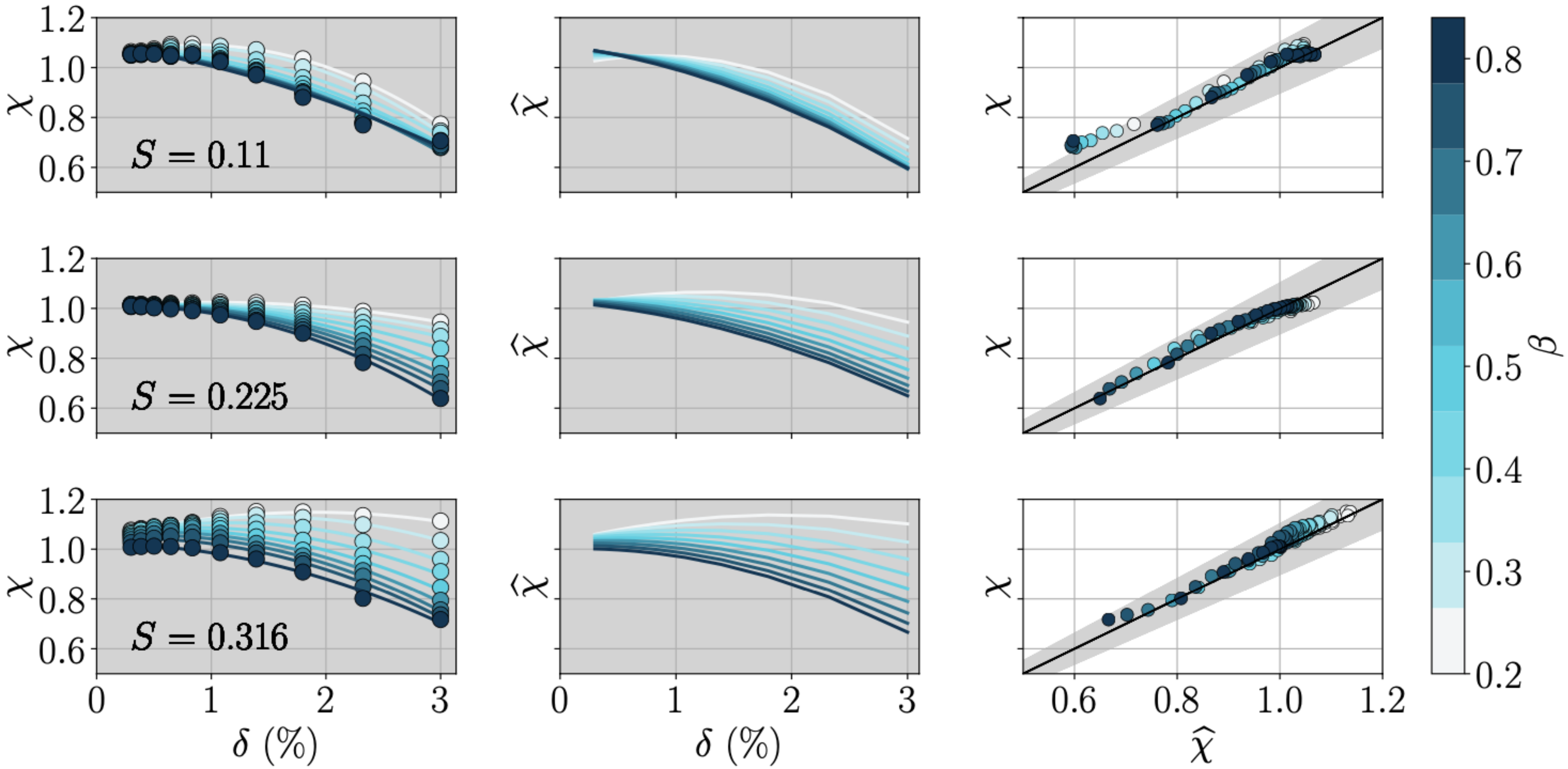
STOKES DRIFT
(PASSIVE TRACERS)





[9]Calvert, R. *et al.* (2024). A laboratory study of the effects of size, density, and shape on the wave-induced transport of floating marine litter. Journal of Geophysical Research: Oceans 129.

DRIFT AMPLIFICATION FACTOR

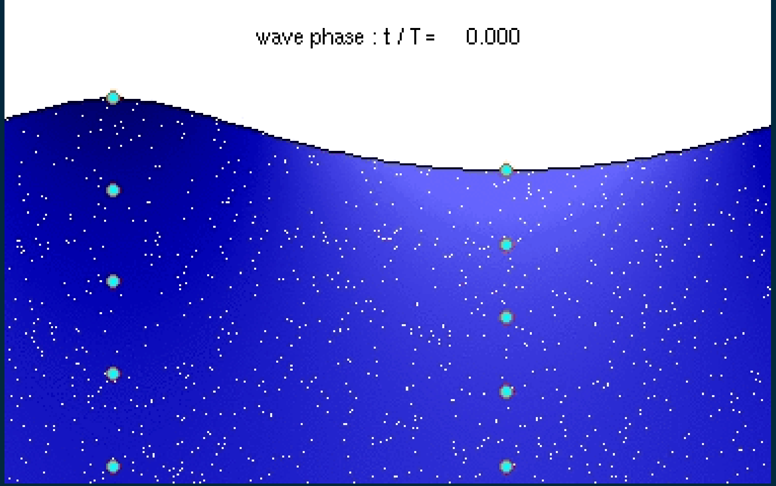


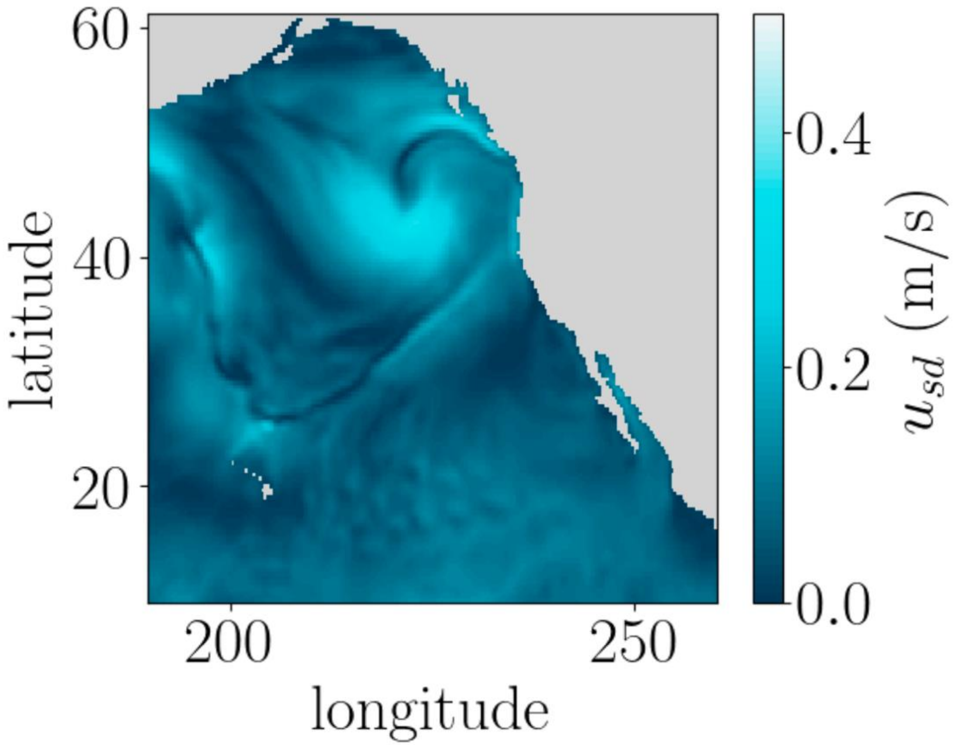
$$\widehat{\chi}(\delta; S, \beta) = \widehat{a}(S, \beta)\delta^2 + \hat{b}(S, \beta)\delta + \hat{c}(S, \beta)$$

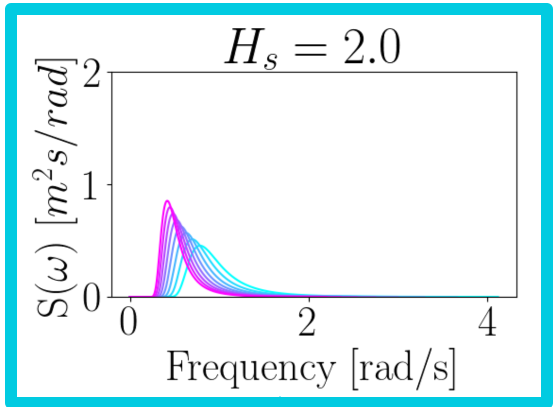
$$\chi = \frac{\widetilde{V_{p,x}}}{u_s(y=0)}$$

$$\chi = f(\delta; S, \beta)$$

STOKES DRIFT & WAVEWATCH III





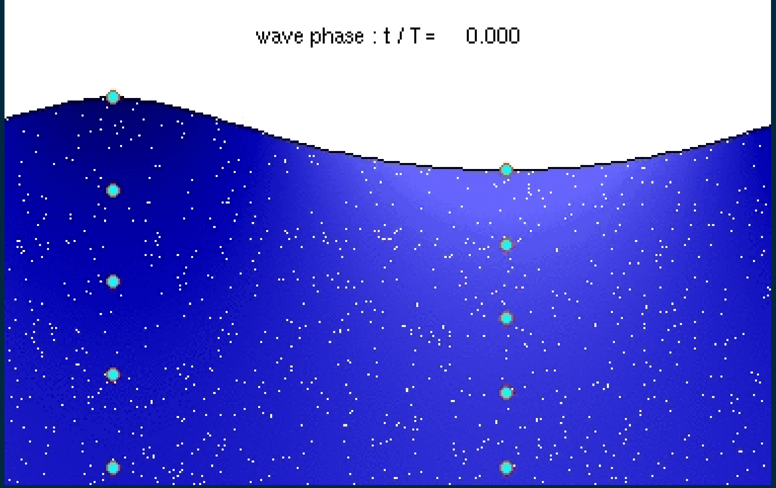


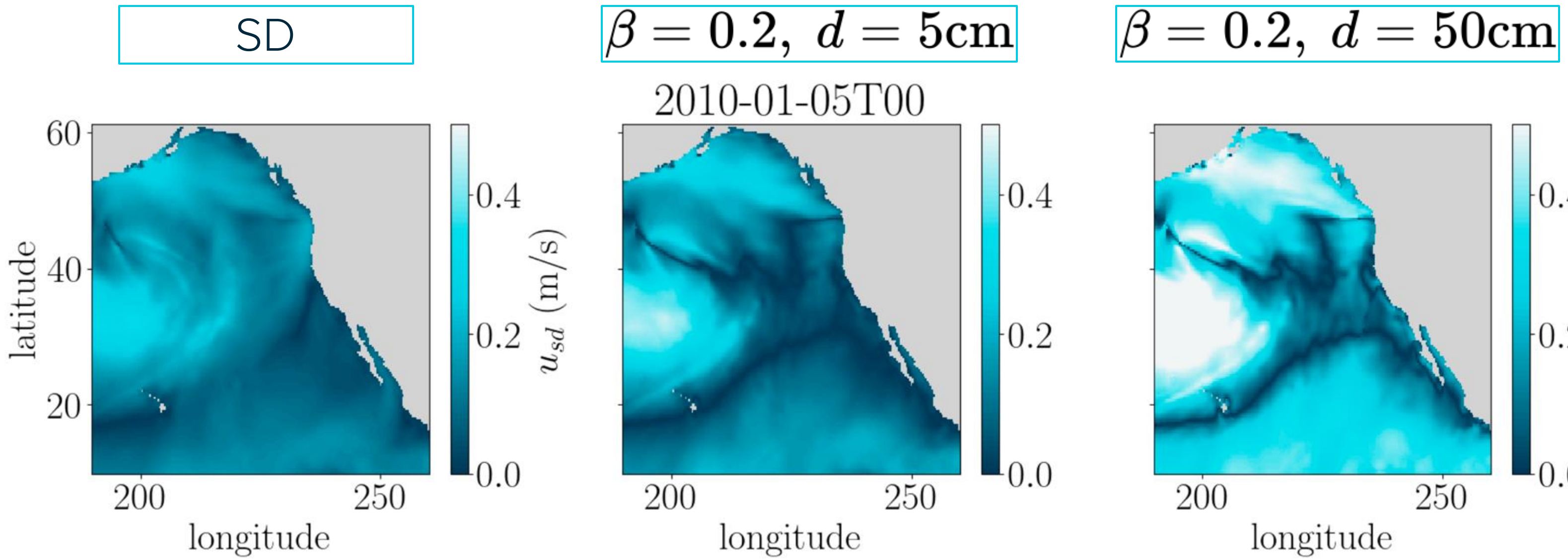
- **Spectral integration** over all resolved wavenumbers and directions,
- **Finite-depth correction** for finite depth effects.

$$U_{ssx} = g \iint \sigma \frac{\cosh(2kd_w)}{\sinh^2(kd_w)} k\cos(\theta) F(k,\theta)\, dk\, d\theta$$

$$U_{ssy} = g \iint \sigma \frac{\cosh(2kd_w)}{\sinh^2(kd_w)} k\sin(\theta) F(k,\theta)\, dk\, d\theta$$

MODIFIED STOKES DRIFT & WAVEWATCH III

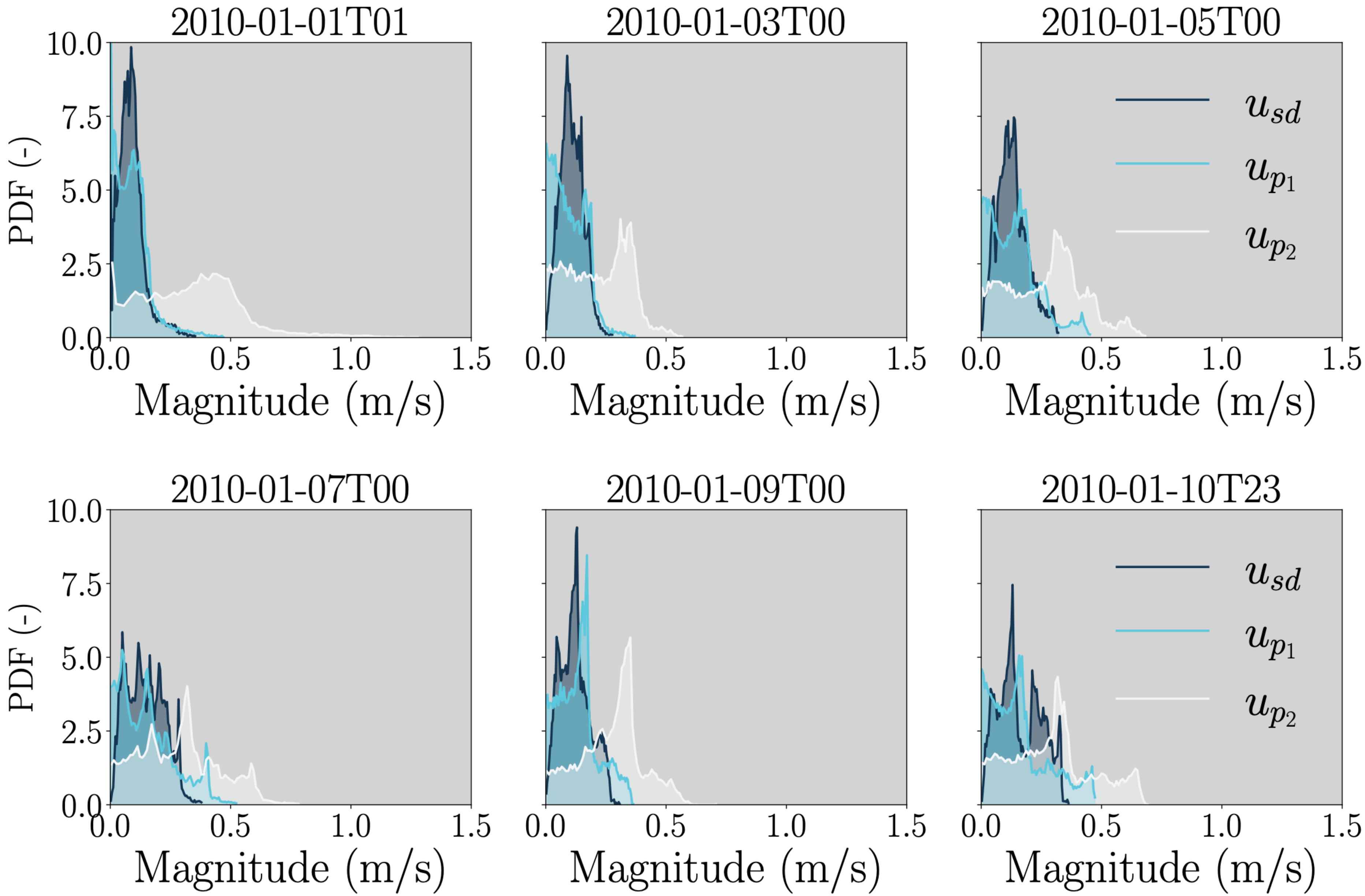




- **Spectral integration** over all resolved wavenumbers and directions,
- **Finite-depth correction** for finite depth effects.

$$U_{ssx} = \quad g \iint \sigma \frac{\cosh(2kd_w)}{\sinh^2(kd_w)} k\cos(\theta)\,\widehat{\chi}(k,\theta)\,F(k,\theta)\,dk\,d\theta$$

$$U_{ssy} = \quad g \iint \sigma \frac{\cosh(2kd_w)}{\sinh^2(kd_w)} k\sin(\theta)\,\widehat{\chi}(k,\theta)\,F(k,\theta)\,dk\,d\theta$$


2010-01-01T01
2010-01-03T00
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2010-01-10T23
PDF (-)
10.0
7.5
5.0
2.5
0.0
0.0
0.5
1.0
1.5
Magnitude (m/s)
u_{sd}
u_{p_1}
u_{p_2}

CONCLUSION

- We combined DNS with experimental data to study wave-induced drift of plastics
- By computing the ratio $\widehat{\chi}(\delta; S, \beta)$ we quantify inertia influence on the modified Stokes drift field.
- This enables evaluation of plastic transport and accumulation driven by wave dynamics.
- Our approach reveals how spectral and directional wave properties affect the convergence of inertial plastics.

A Volume of Fluid / Point-Particle approach for the simulation of the wave-induced drift of plastic marine debris

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(Dated: 7 July 2025)

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