HOKKAIDO UNIVERSITY

Sediment Advection and Diffusion by Obliquely Descending Eddies

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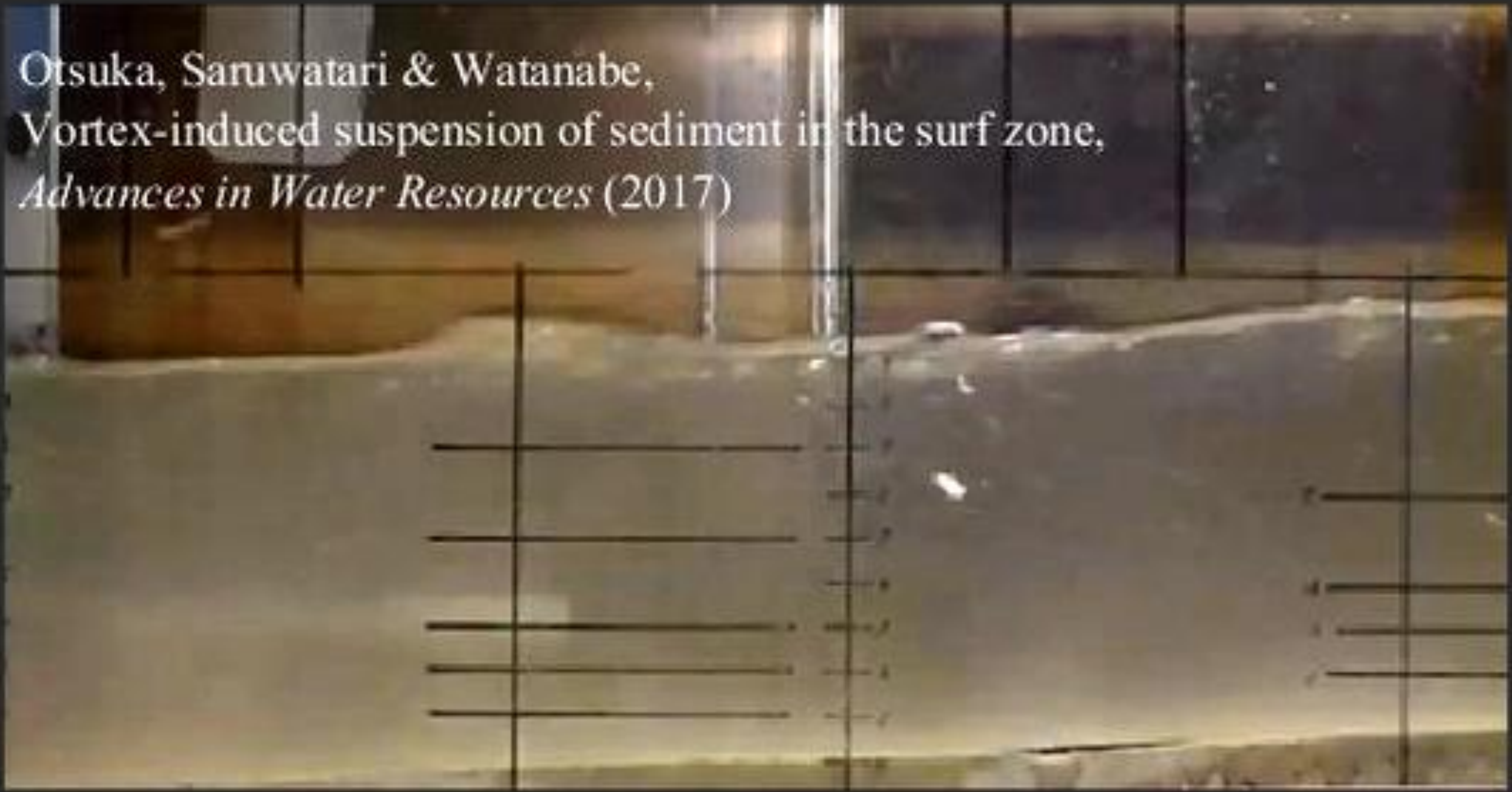
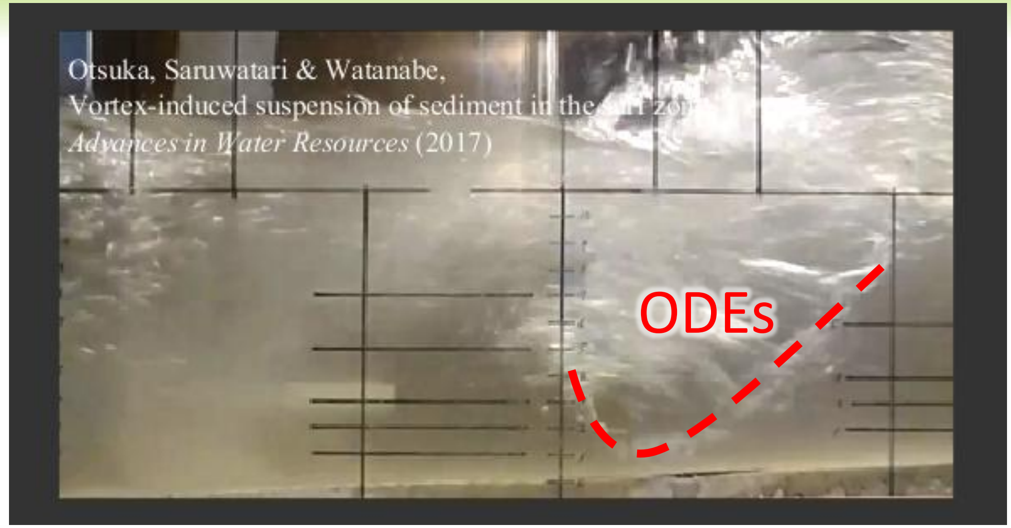
Sand picked-up and suspended

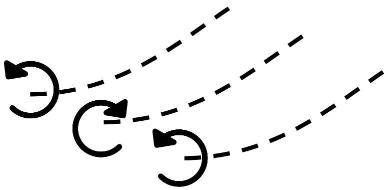


Background



Nadaoka et al. (1989, JFM):
Identification of ODEs

Watanabe et al. (2005, JFM):



Recent studies on ODEs contribution in dynamics of sediment-laden lows

LaClaire & Ting (2017, CE): High correlation between sediment population & vorticity

Zhou et al. (2017, JGR): Upward/downward flows by ODEs enhance sediment suspension

Otsuka et al. (2017, AWR): Experimentally and numerically showed mechanical contribution of ODEs to sediment suspension

Objectives

Otsuka et al (2017)

To show the mechanism of sediment (dye) advection by the obliquely descending eddies

To discuss the diffusion effects of the concentration field to the sediment (dye) transport

Extension of Otsuka et al (2017)

Numerical Method

Large Eddy Simulation

(Watanabe et al., 2005 JFM., 2009 JCP)

Filtered Navier-Stokes eq. for incompressive flows

$$\frac{\mathrm{D}\bar{\boldsymbol{u}}}{\mathrm{D}t} = -\boldsymbol{\nabla}\bar{p} - \nu_T \boldsymbol{\nabla}^2 \bar{\boldsymbol{u}} + \nu_0 \boldsymbol{\nabla}^2 \bar{\boldsymbol{u}} + \boldsymbol{g}$$

Poisson eq. for pressure

$$\boldsymbol{\nabla}^2 \bar{p} = R$$

Advection eq. for Level-set func. (L-S method)

$$\frac{\mathrm{D}\phi}{\mathrm{D}t} = 0$$

Sc=inf: Passive tracer

Sc=1.0: mix coef. same with fluid

Sc=0.52: Hsu & Liu (2004)

Advection-diffusion eq. for dye concentration

$$\frac{\mathrm{D}\bar{c}}{\mathrm{D}t} = -\varepsilon_s \boldsymbol{\nabla}^2 \bar{c} \qquad \varepsilon_s = \frac{\nu_T}{Sc}$$

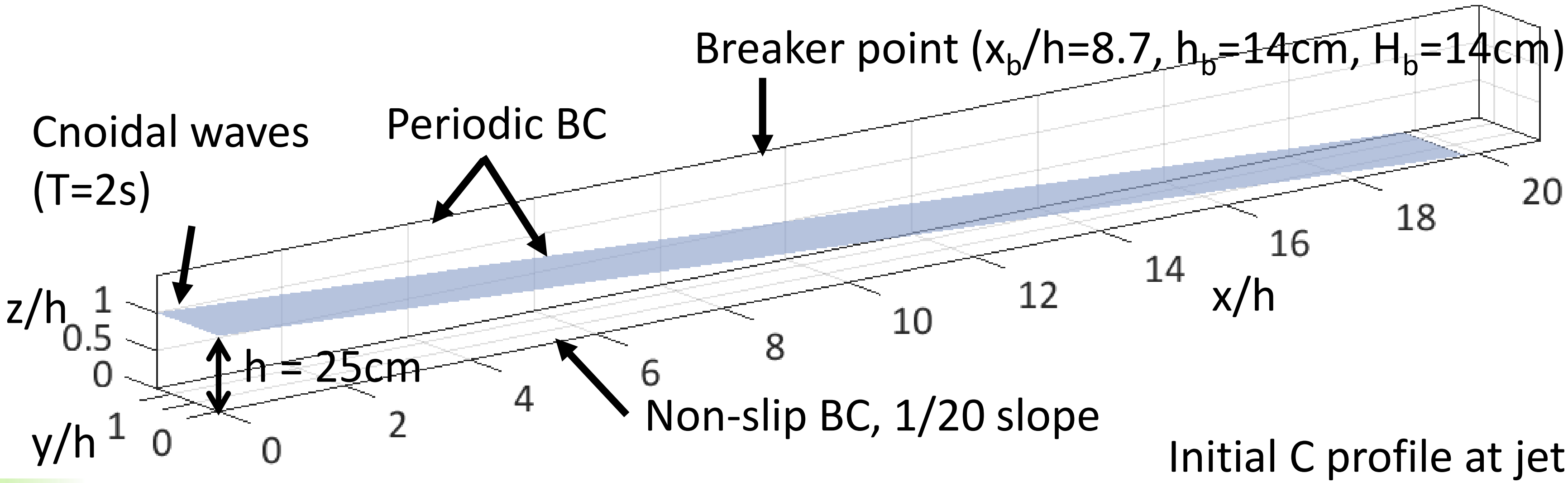
(c representing sediment distribution)

ε_s: Mixing coef.

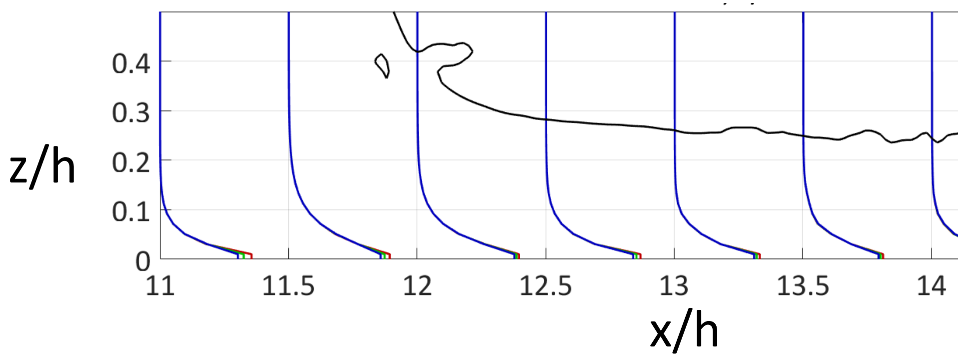
ν_T:Sub-grid viscosity

Sc: Schmidt num.

Computational Conditions



Initial C profile at jet splashing

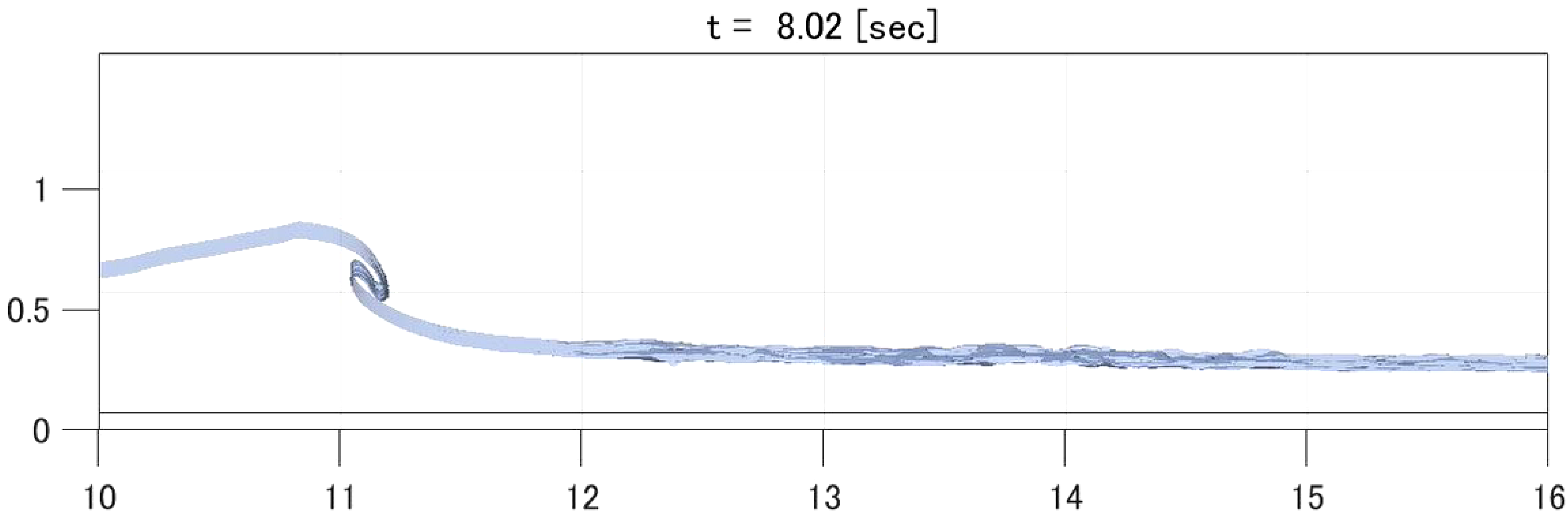


Domain size	630cm x 40cm x 44cm
Grid number	1050 x 66 x 74
Grid interval	6mm x 6mm x 6mm
Timestep interval	3.4 x 10^{-4} sec

	Case 1	Case 2	Case 3
Sc	Inf (Passive tracer)	1.0	0.52 (Hsu & Liu, 2004)

Free-surface evolution during wave breaking process

Case 1: Free-surface evolution

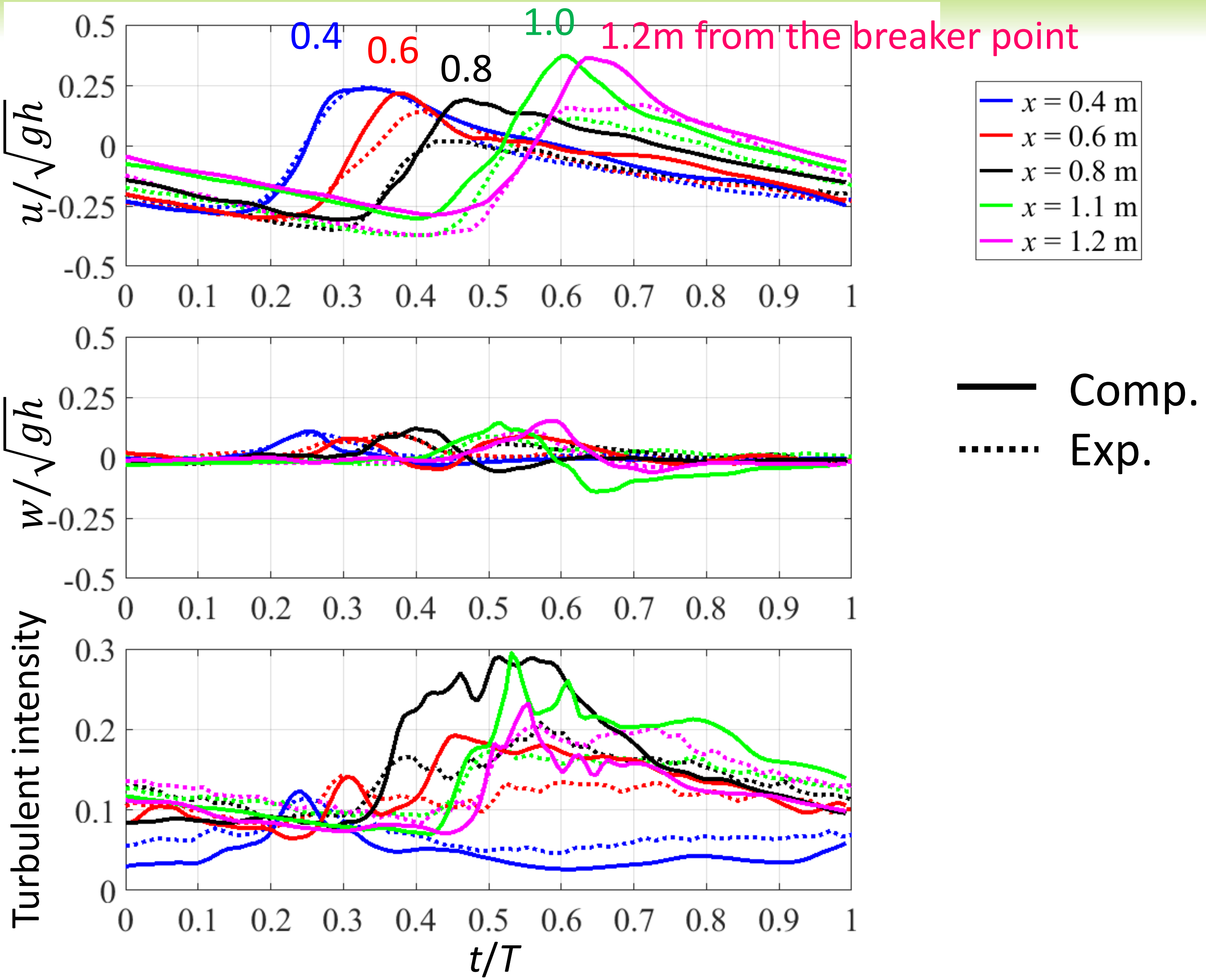


Splash-up cycle:

Jet splash → secondary jet splash up → second plunging → …

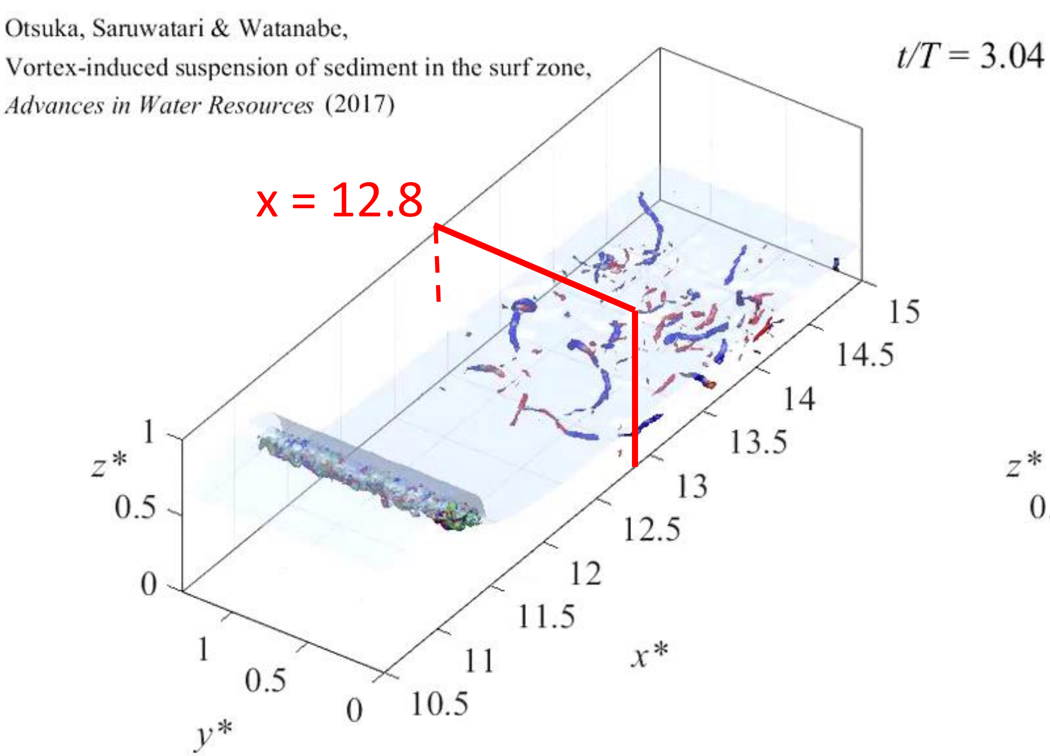
→ Vortices and turbulence

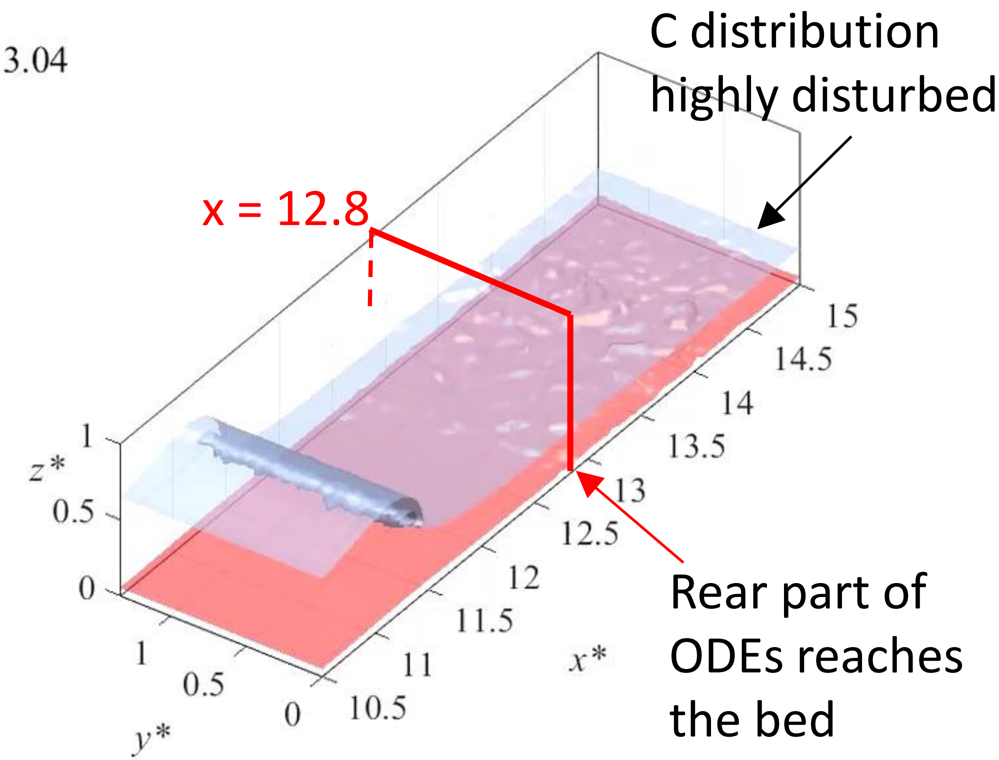
Validations



Flow under Breaking Wave

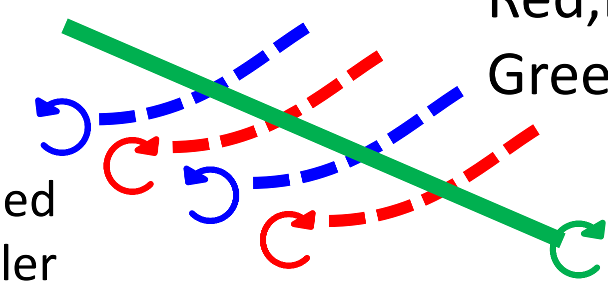
Iso-surfaces of vorticity (left) and numerical dye (right)





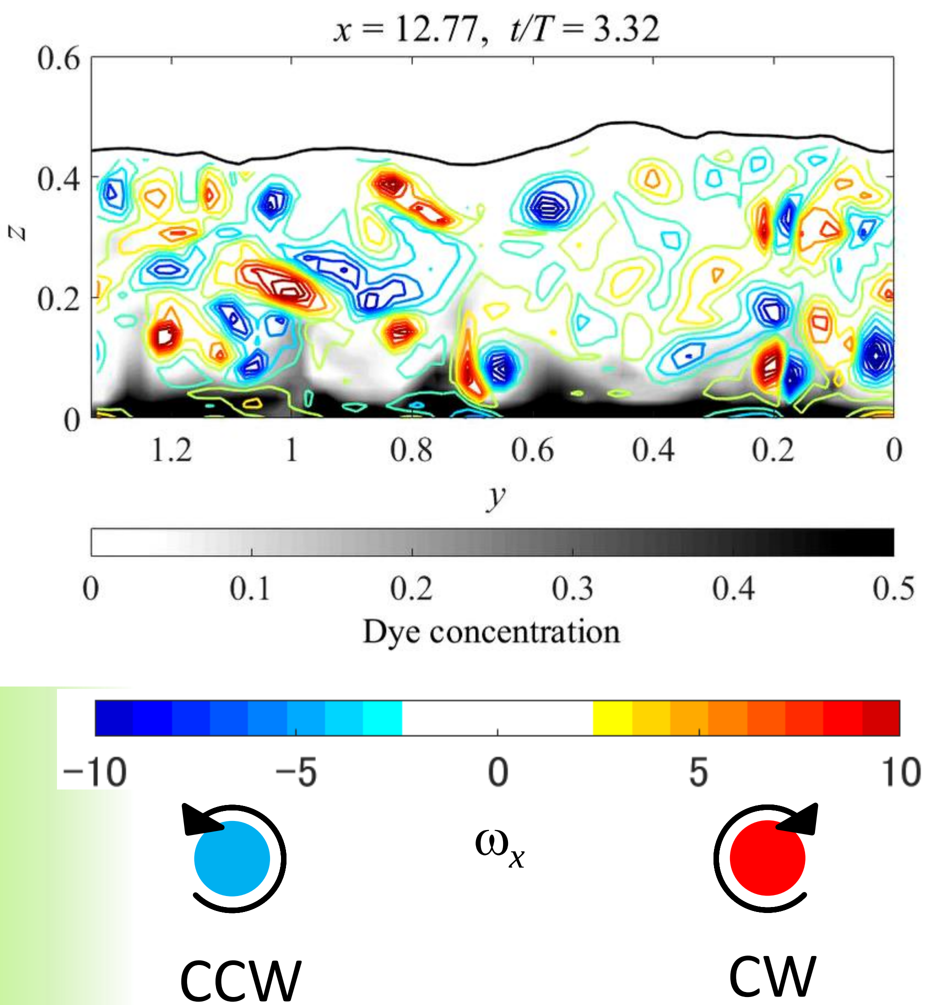
Red,Blue: ωx (ODEs)

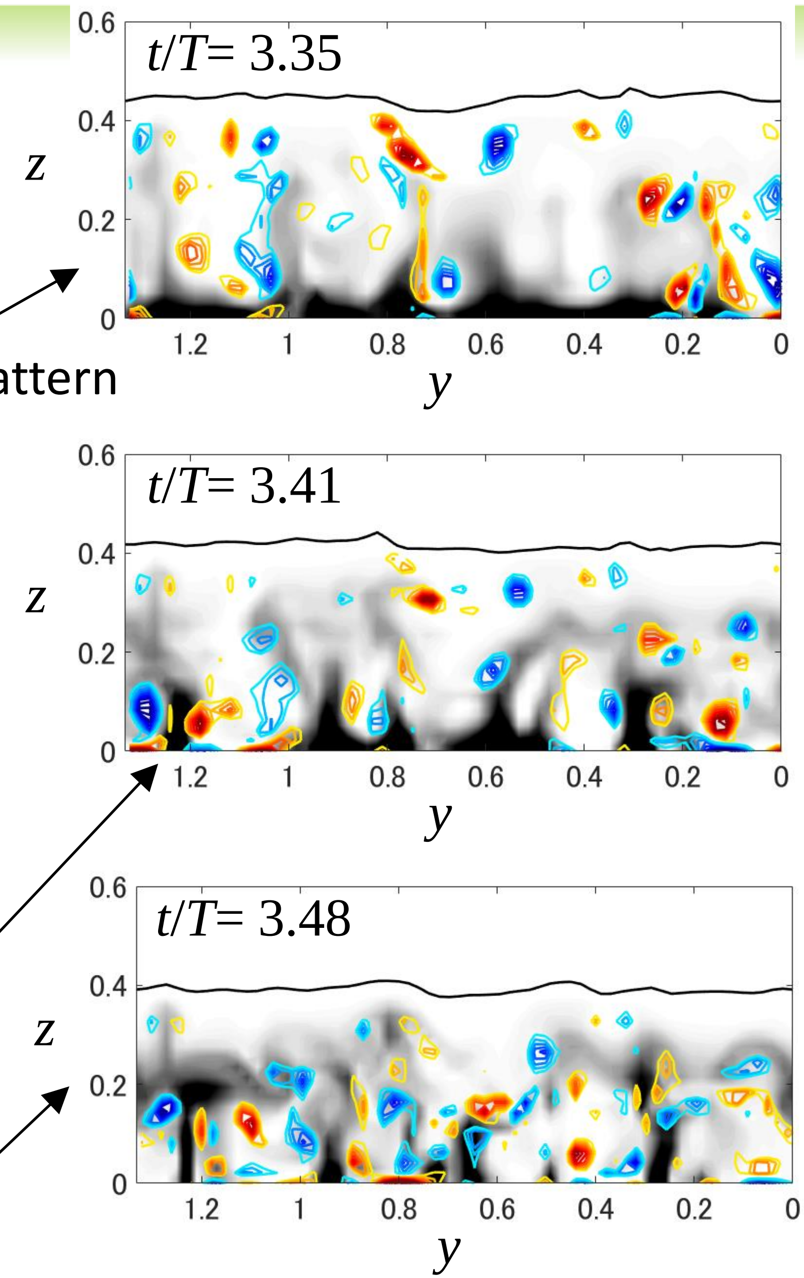
Green: ωy (Roller vortex)



Rear part wrapped
around the roller

Vorticity and dye concentration at x = 12.8



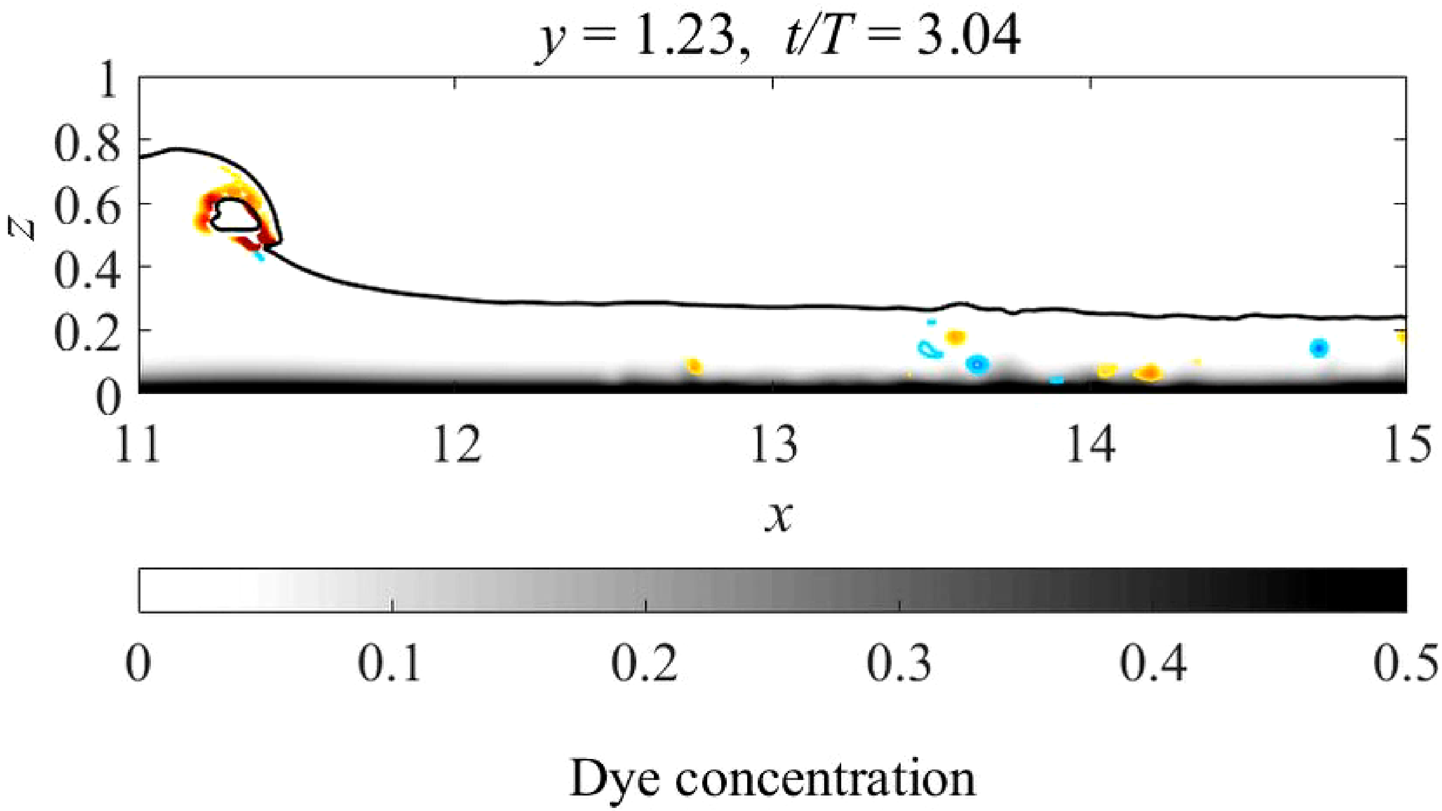


Stripe pattern

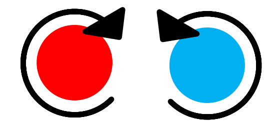
Dye trapped by counter-rotating motion and transported upward

Transported near the surface

Longitudinal cross-section of dye concentration



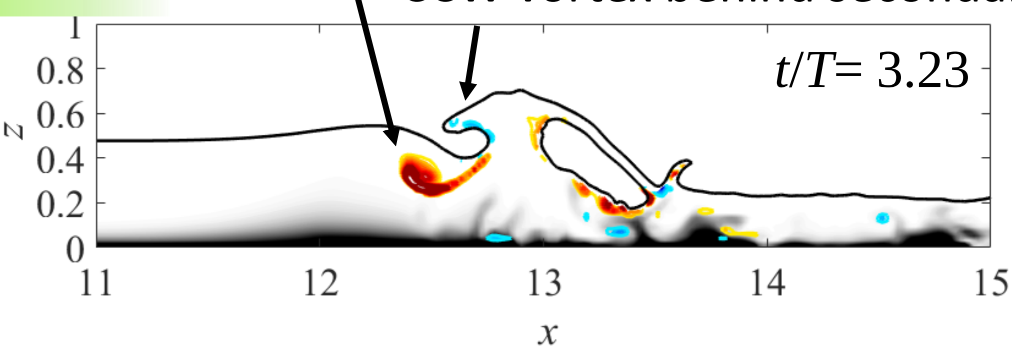
Red: CW
Blue: CCW

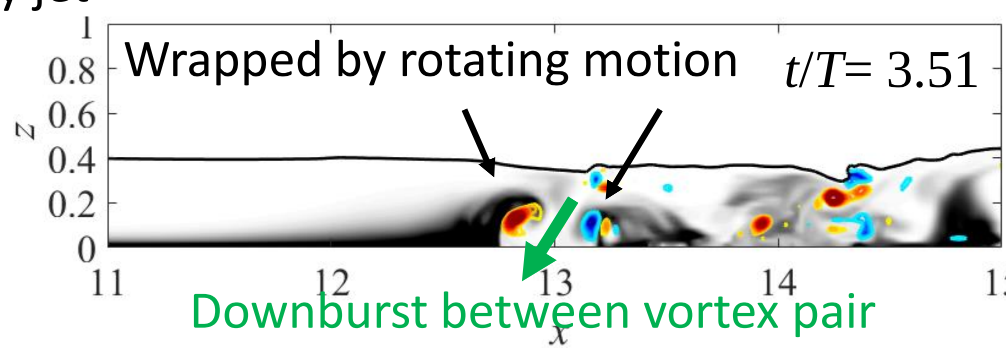


ωy by horizontal rollers

CW vortex around the tube

CCW vortex behind secondary jet

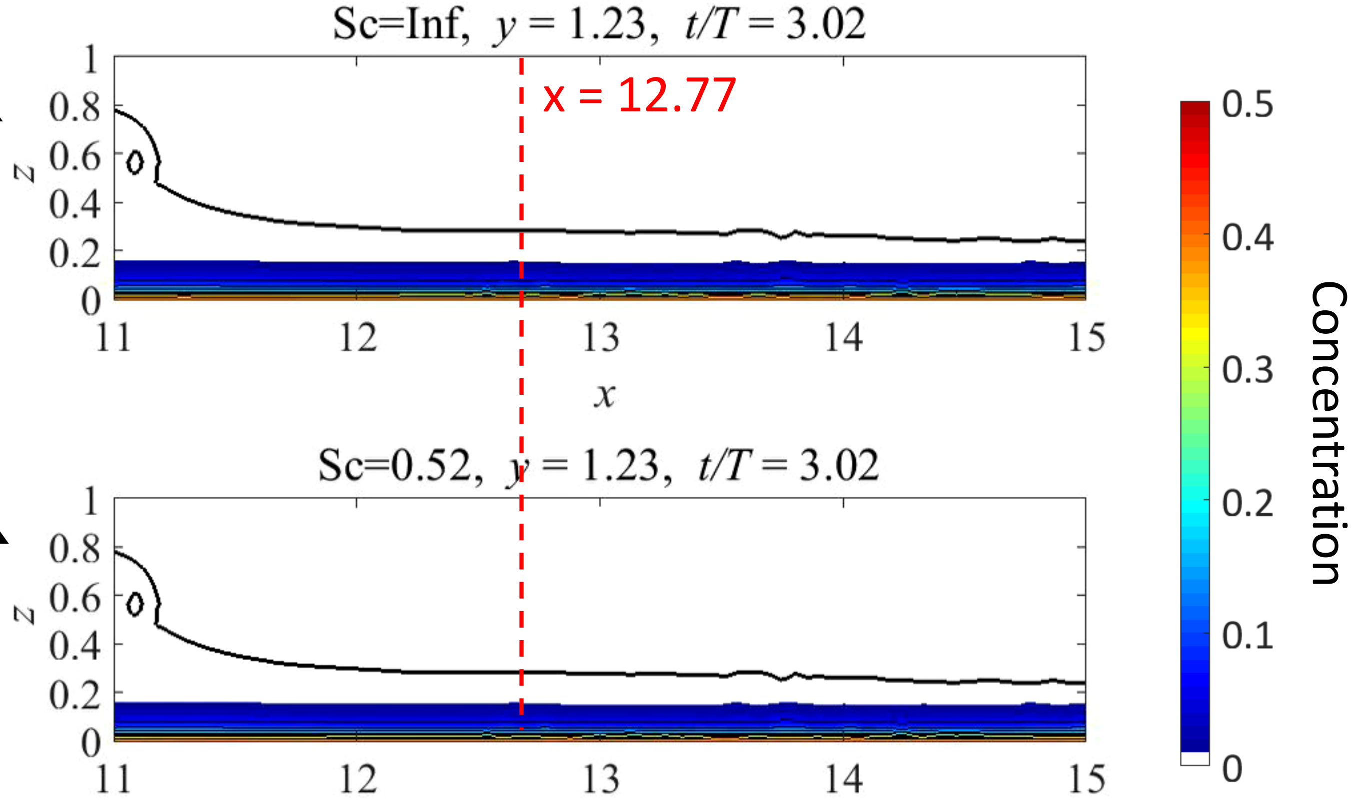




Case 1
(Sc=inf)

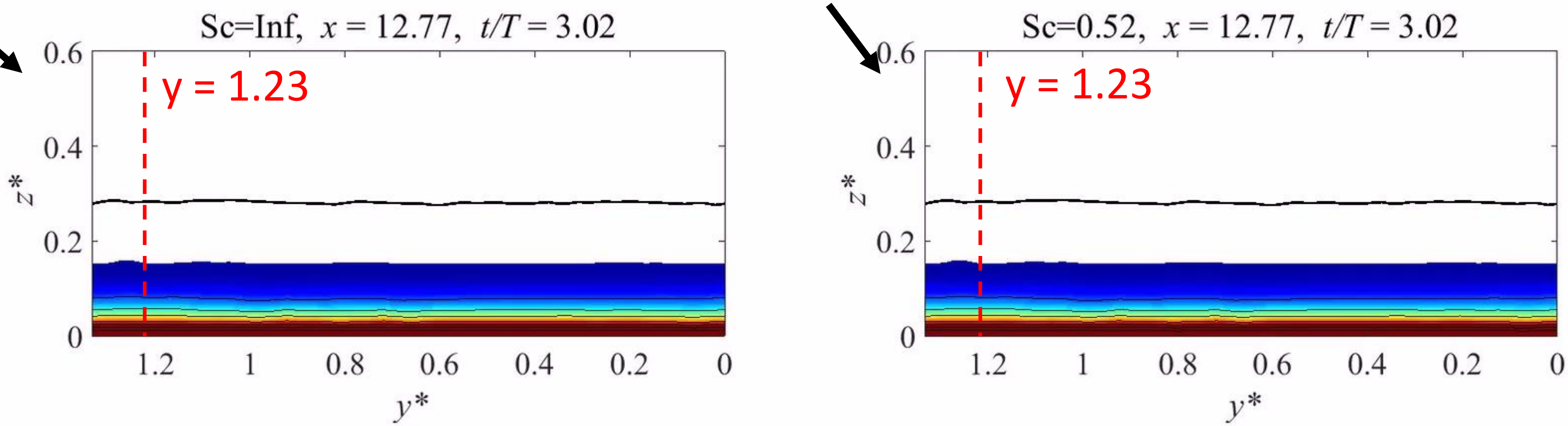
Case 3
(Sc=0.52)

A little lower C by
diffusion effect

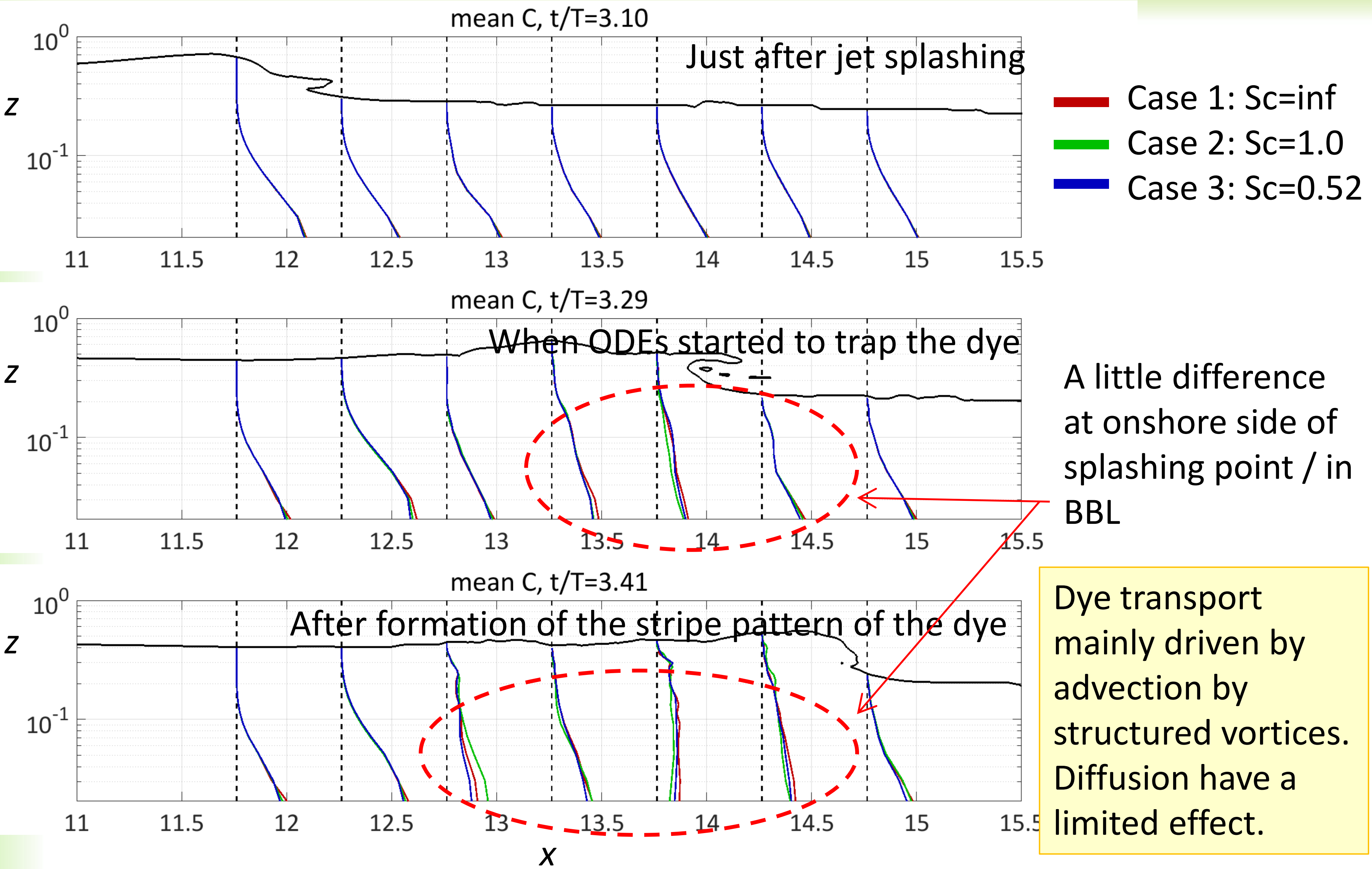


Case 1 (Sc=inf)

Case 3 (Sc=0.52)



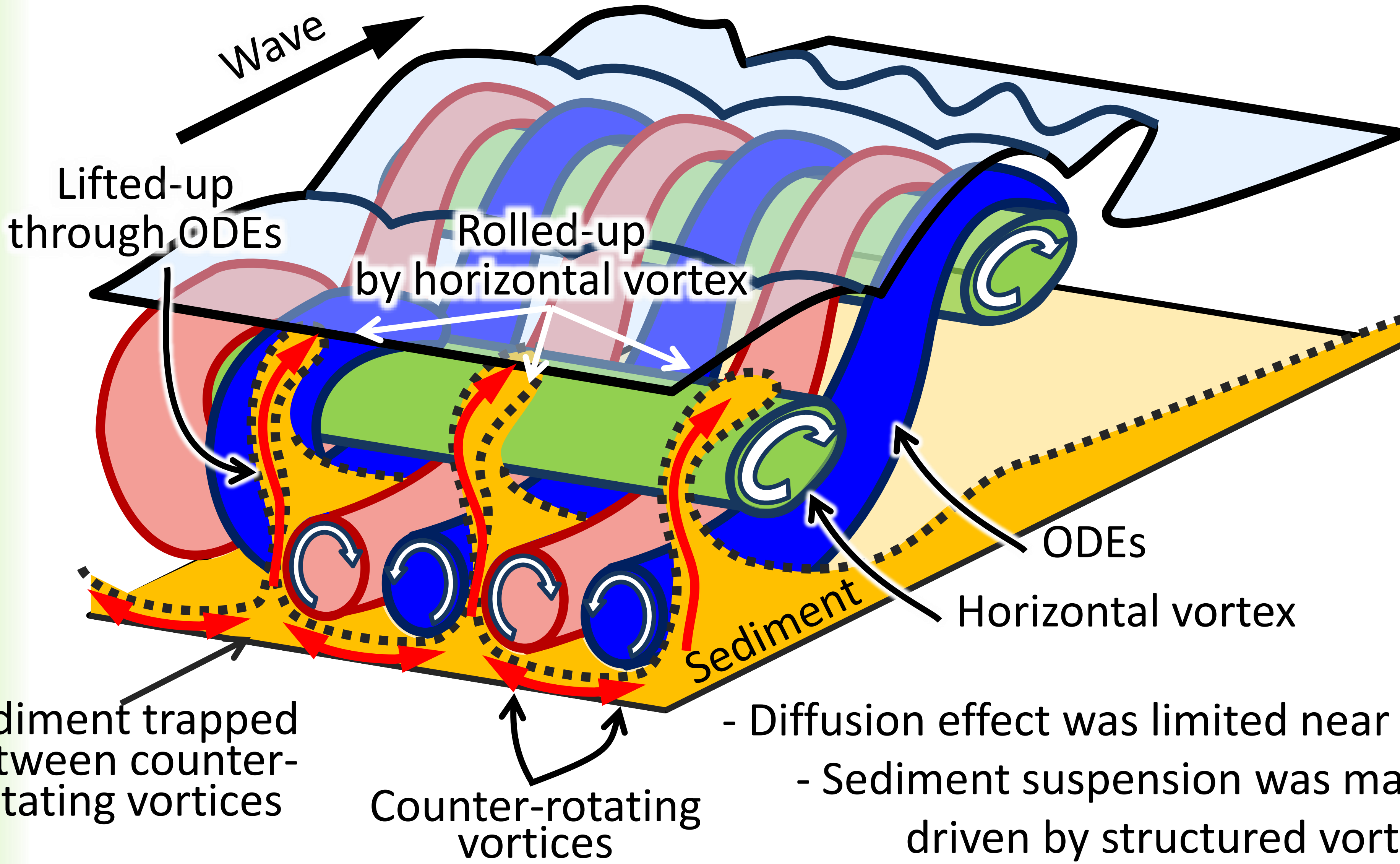
Concentration Profiles by Line Plots



Dye transport mainly driven by advection by structured vortices. Diffusion have a limited effect.

Summary

Vortex structure and dye/sediment transport



- Diffusion effect was limited near BBL
- Sediment suspension was mainly driven by structured vortices