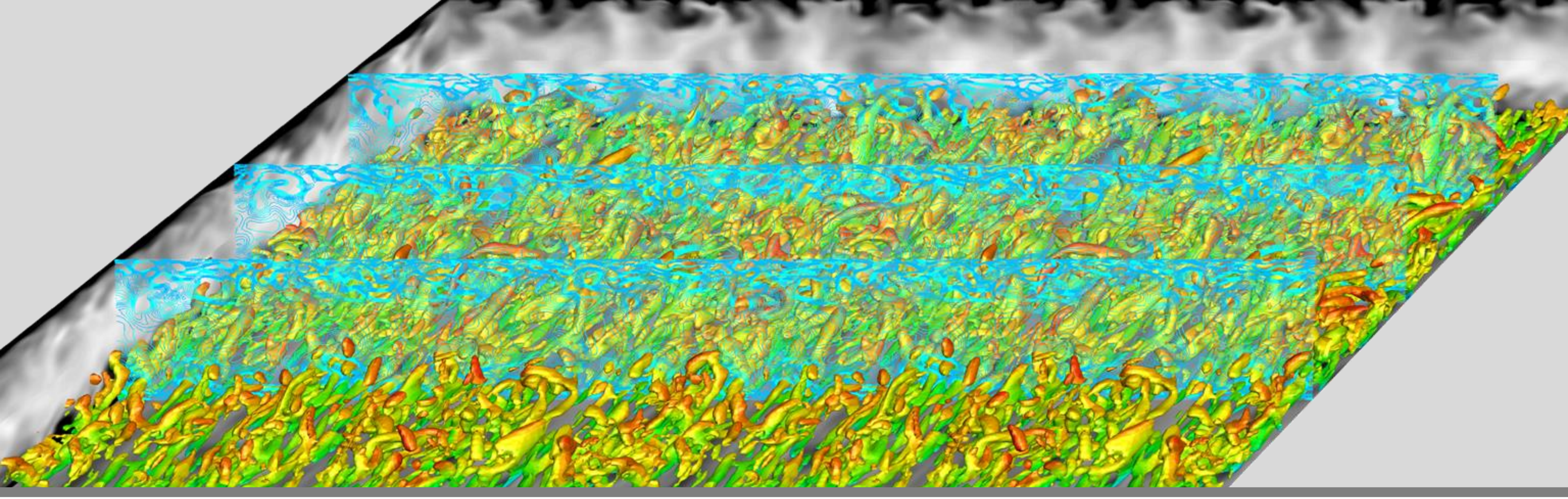
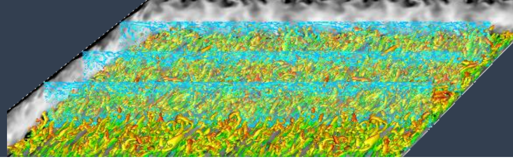


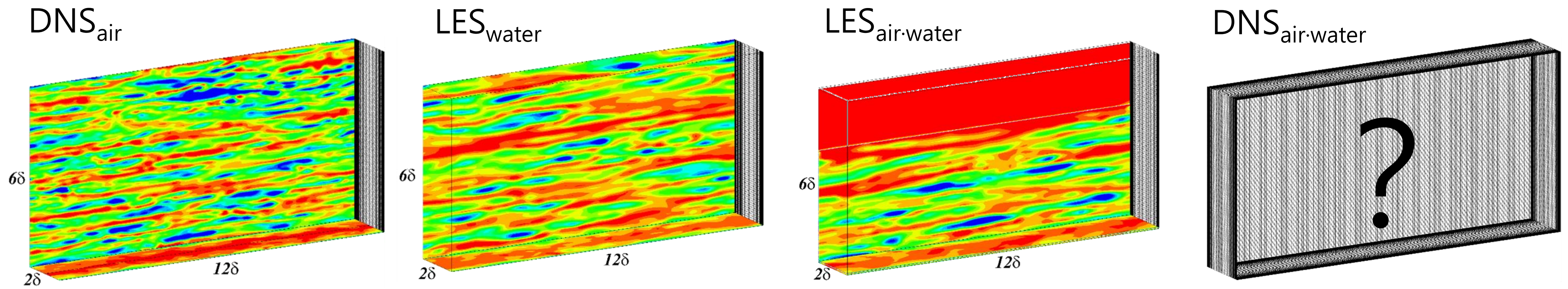
Influence of free surface on turbulent characteristics in an open-channel flow

A Young Hwang

Motivation

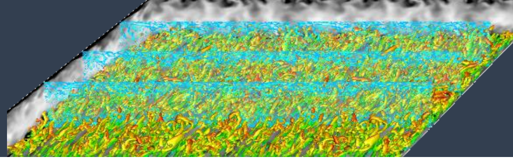


- **Comparison of open-channel LES and DNS**



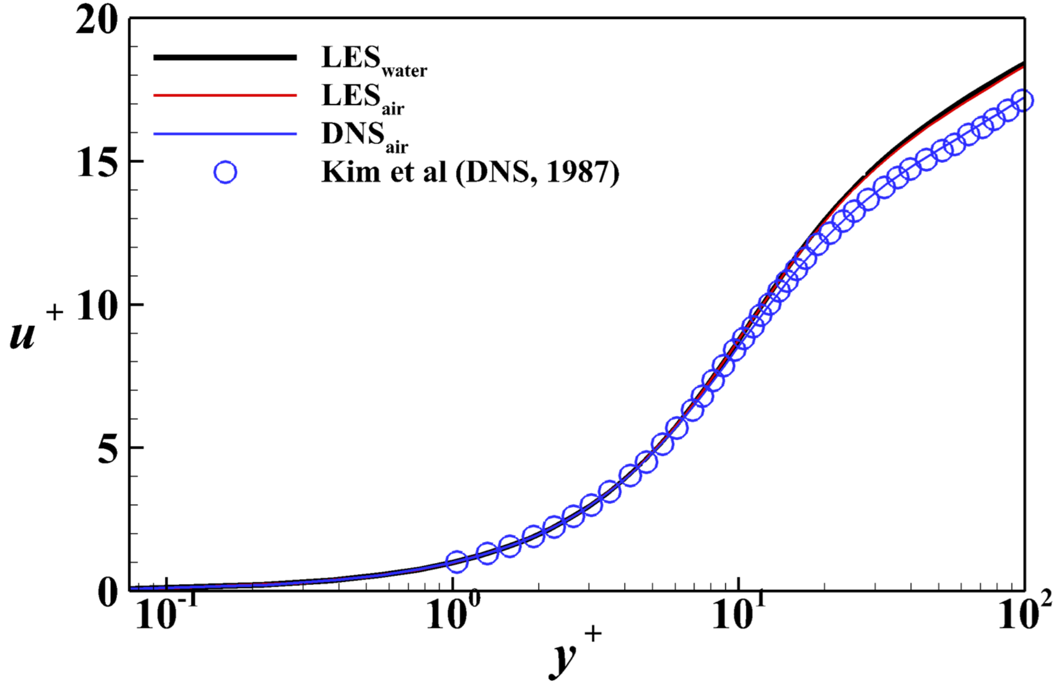
	DNS	LES	LES	LES	DNS
Fluid	air		water	air-water	
domain size	12δ × 2δ × 6δ				?
No. cell	192 × 128 × 160	96 × 96 × 80	96 × 96 × 80		
	3,932,160	737,280	737,280		
Δx^+	13	26	22		
Δz^+	8	16	13		
Δy^+_{min}, Δy^+_{max}	0.07, 14	0.09, 18	0.07, 13		

Validation

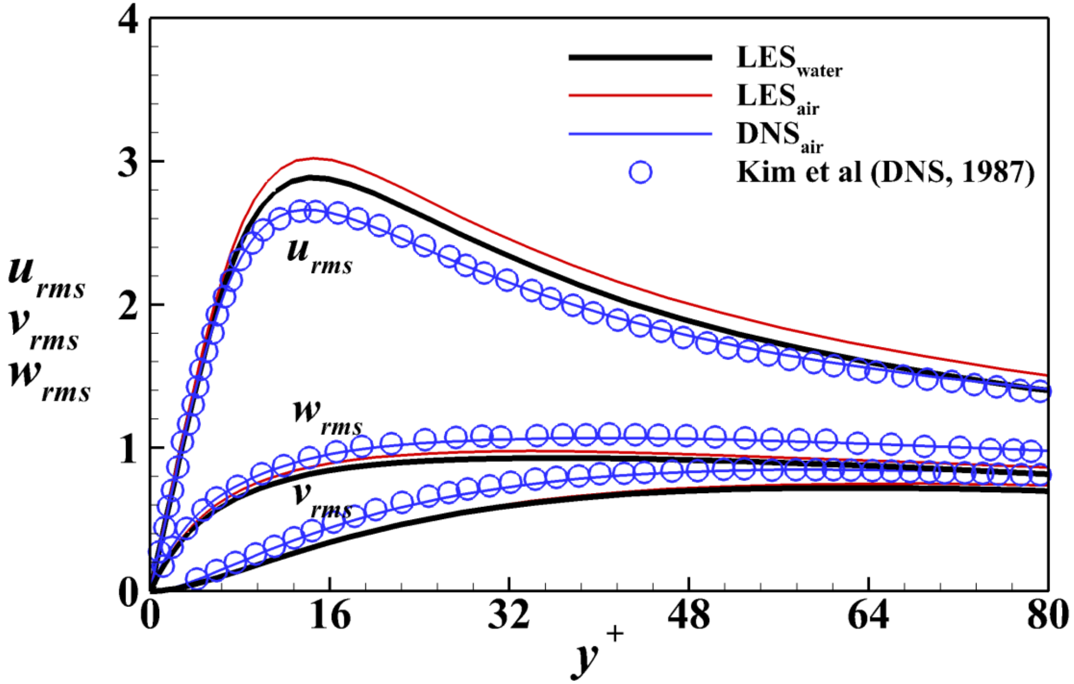


▪ Turbulence statistics

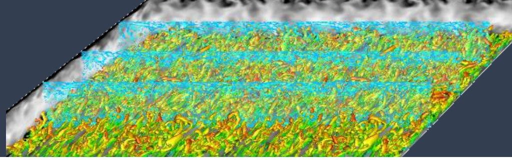
Mean velocity profile



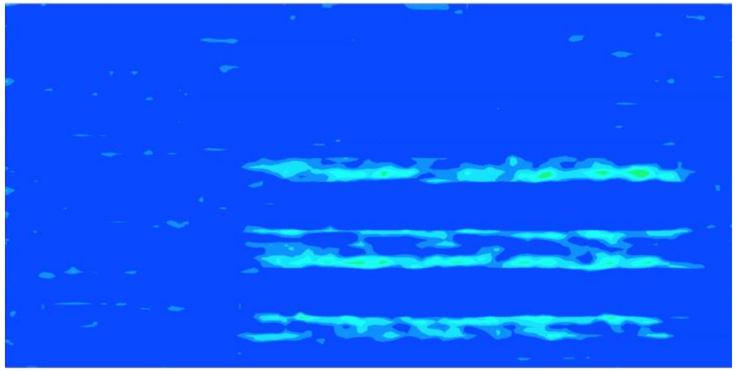
Root-mean-square velocity fluctuation



✓ LES_{water} in good agreement with LES_{air}

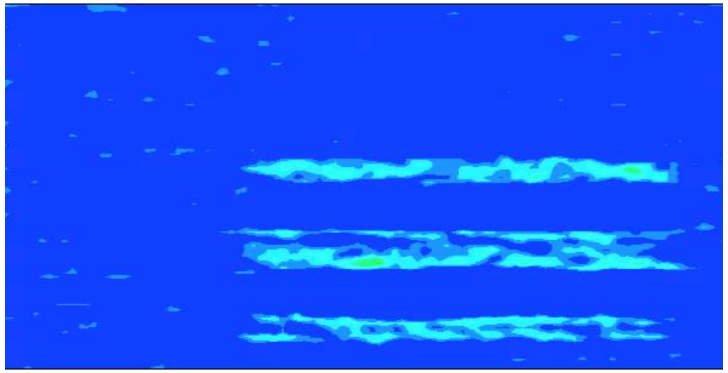


▪ Gradient & divergence scheme



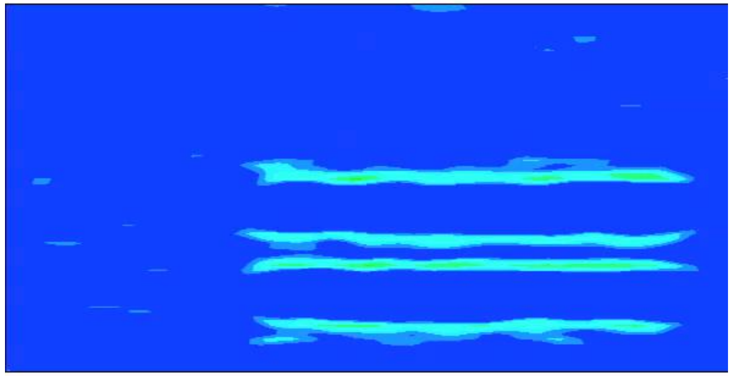
gradient scheme
Gauss linear

divergence scheme
Gauss linear



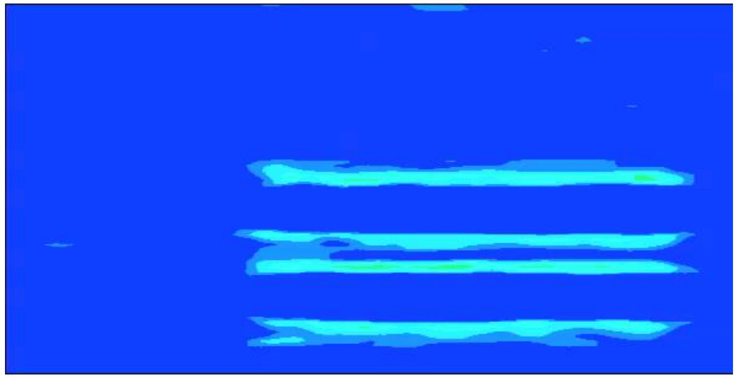
gradient scheme
cellLimited Gauss linear 1.0

divergence scheme
Gauss linear



gradient scheme
Gauss linear

divergence scheme
Gauss linearUpwind

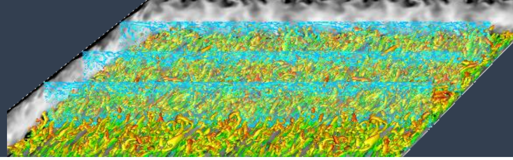


gradient scheme
Gauss linear

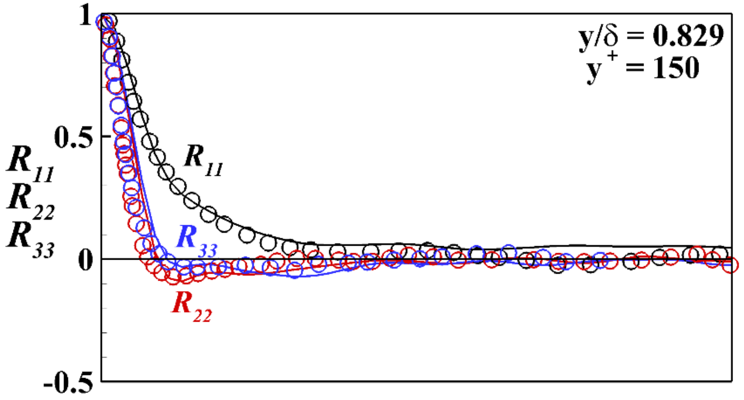
divergence scheme
Gauss vanLeer

✓ transition from laminar to turbulence

Numerical Conditions

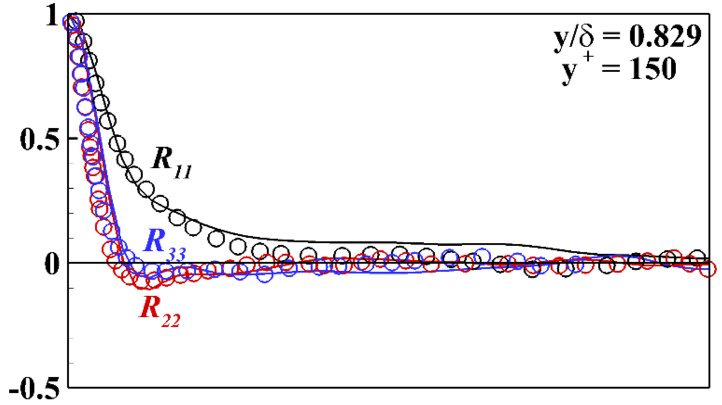


- **Gradient & divergence scheme**



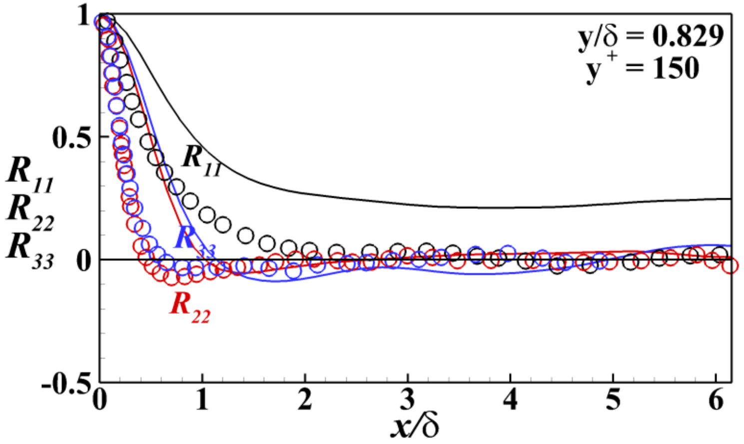
gradient scheme
Gauss linear

divergence scheme
Gauss linear



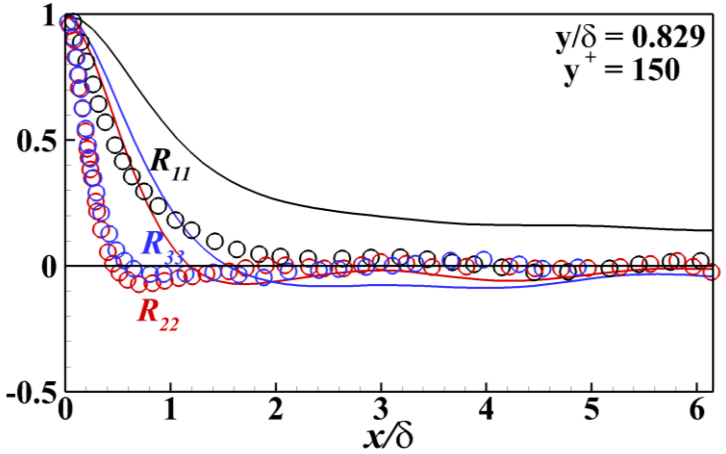
gradient scheme
cellLimited Gauss linear 1.0

divergence scheme
Gauss linear



gradient scheme
Gauss linear

divergence scheme
Gauss linearUpwind

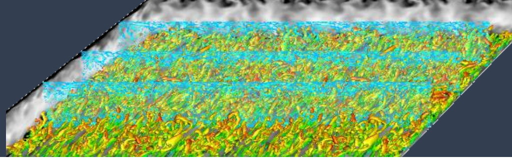


gradient scheme
Gauss linear

divergence scheme
Gauss vanLeer

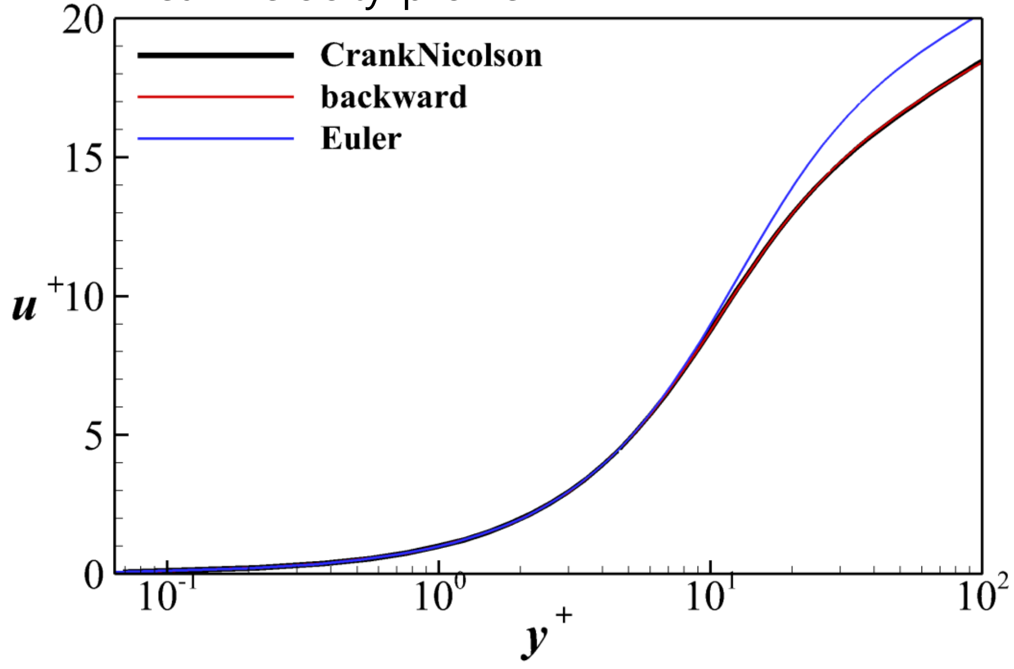
✓ Gauss linear for divergence scheme

Numerical Conditions

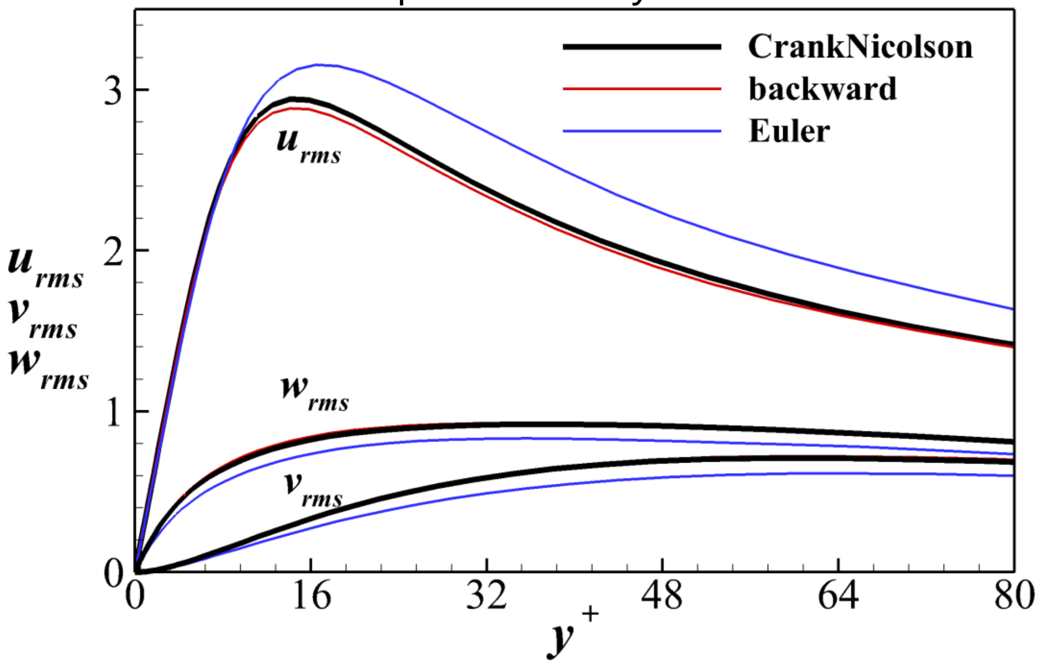


- **Temporal discretization schemes**

Mean velocity profile



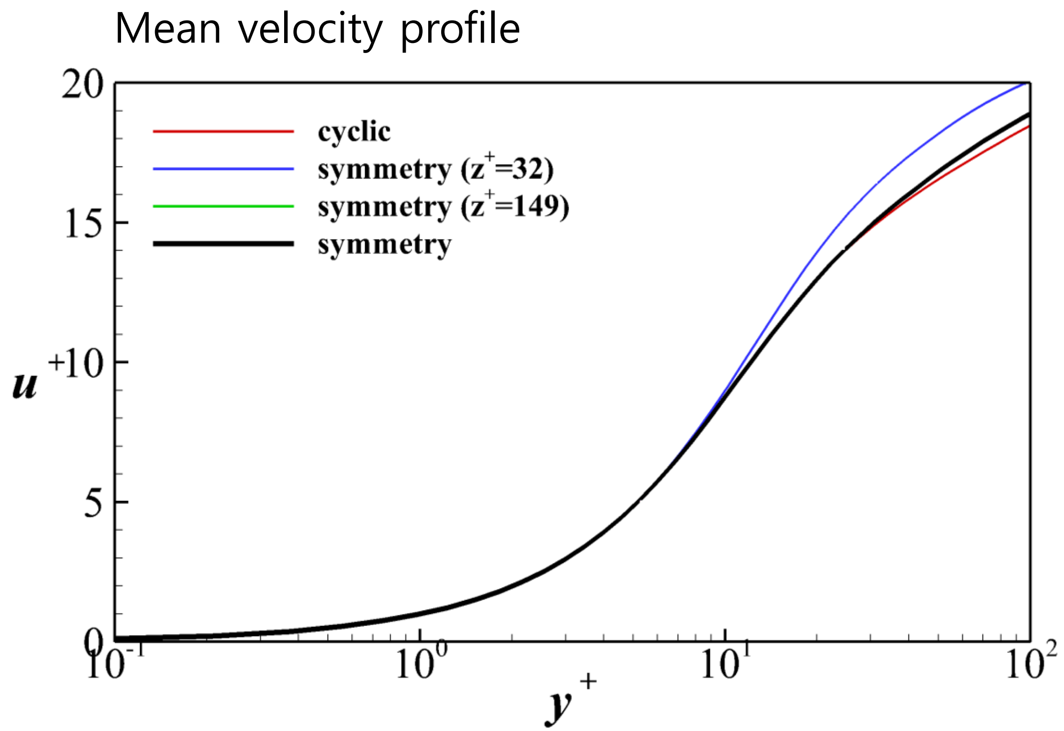
Root-mean-square velocity fluctuation

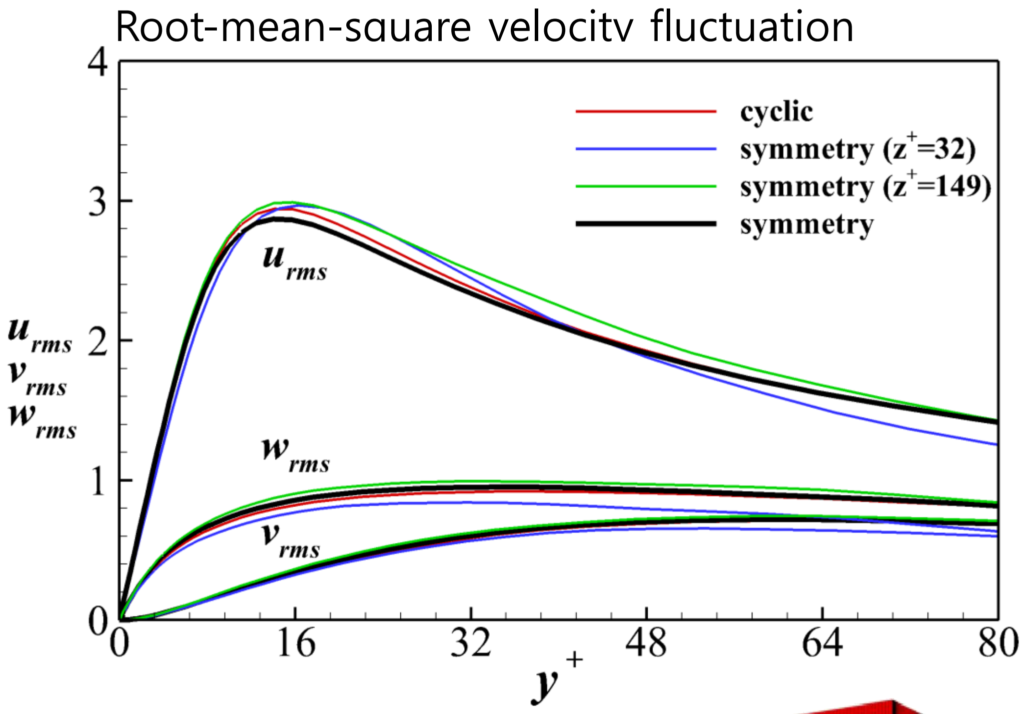


✓ comparison of ddt schemes

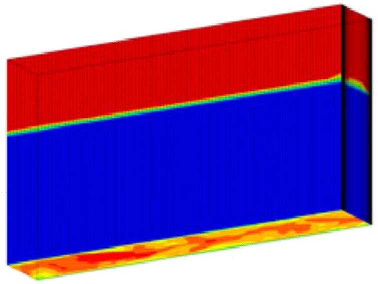
✓ CrankNicolson or backward available

- **Boundary condition**





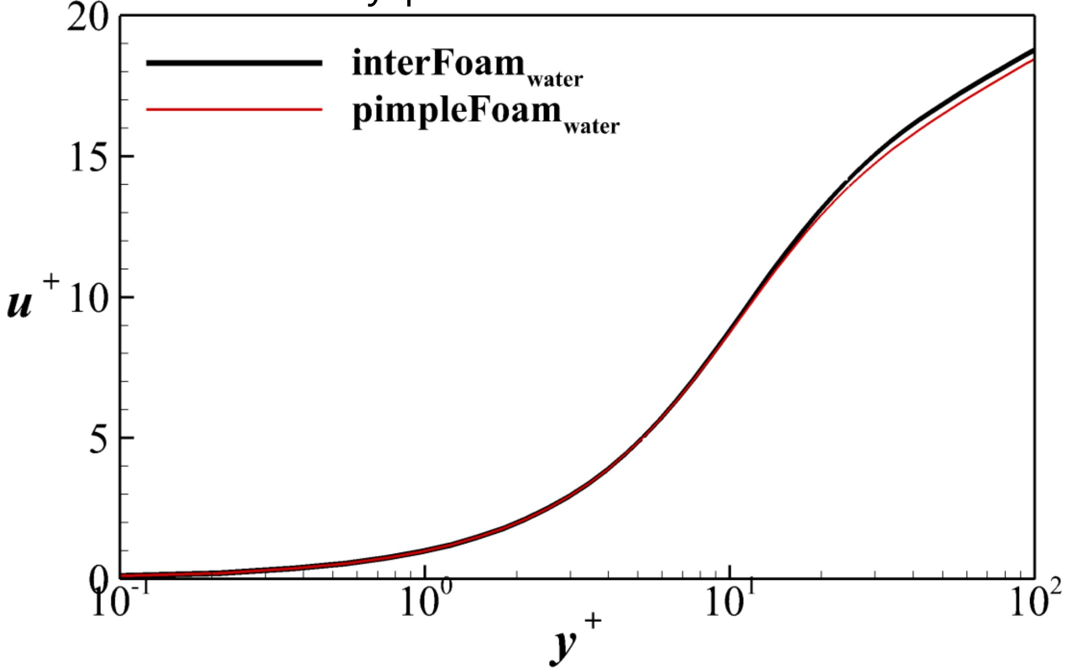
- ✓ comparison of turbulence characteristics for boundary condition
- ✓ influence of symmetry boundary condition is weak
- ✓ number of averaging points in symmetry : 30



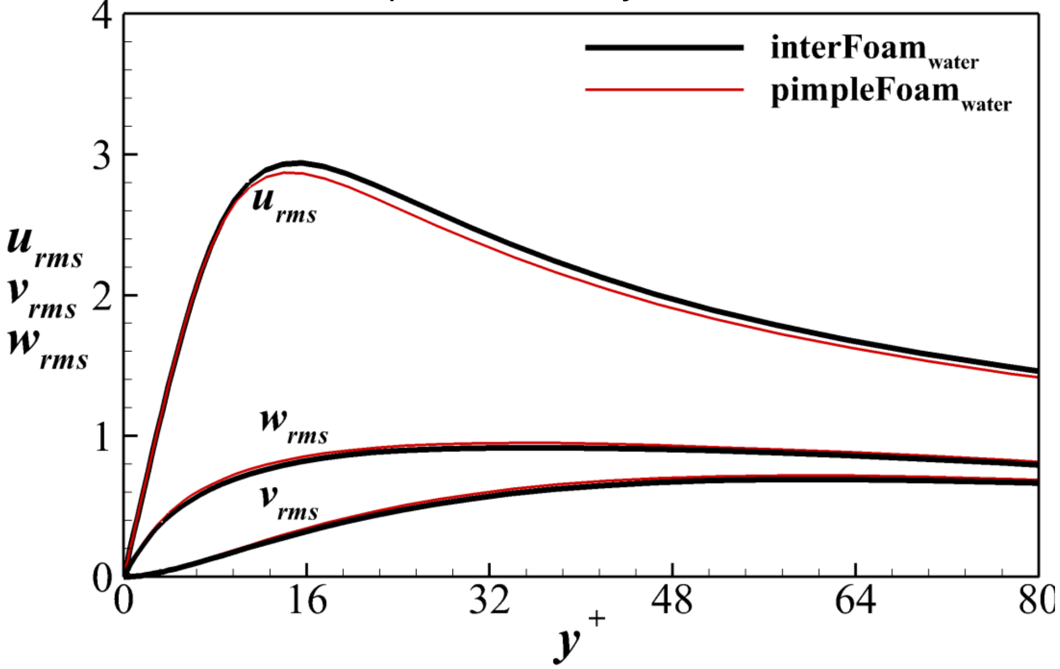
Numerical Solver

- **interFoam & pimpleFoam**

Mean velocity profile



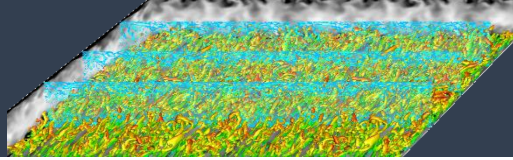
Root-mean-square velocity fluctuation



✓ comparison of turbulence characteristics for pimpleFoam and interFoam solver

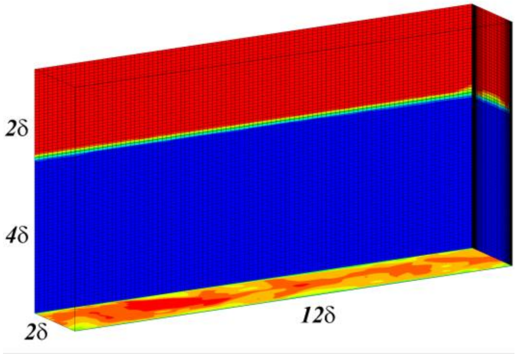
✓ $\text{interFoam}_{\text{water}}$ result is reasonable

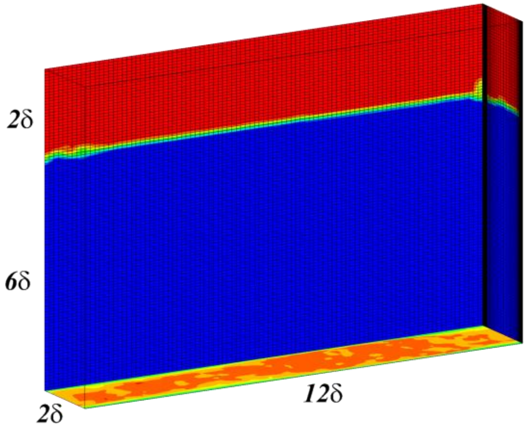
LES of Open Channel

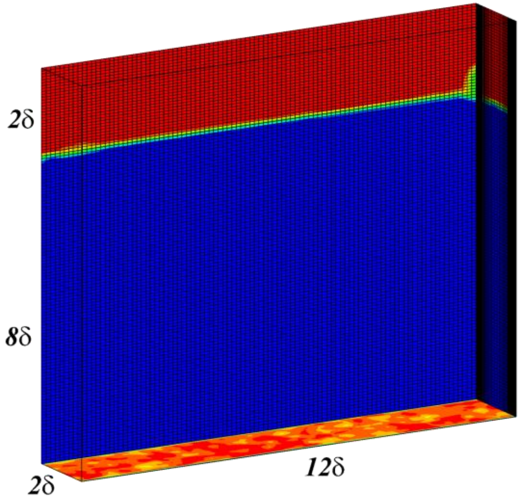


- **Comparison of domain size**

  - temporal discretization : 2^{nd} order CrankNicolson scheme
  - spatial discretization : Gauss linear scheme for gradient operator
    linear scheme for interpolation
    Gauss linear scheme for Laplacian operator (w/o correction)
  - solver : interFoam
    GAMG for pressure
    smoothSolver for velocity
  - sub-grid scale model for LES : WALE

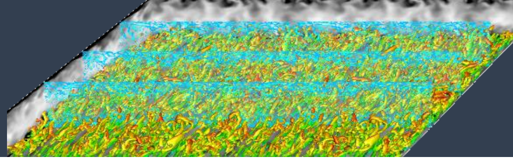






✓ influences of free surface and symmetry boundary condition at bottom

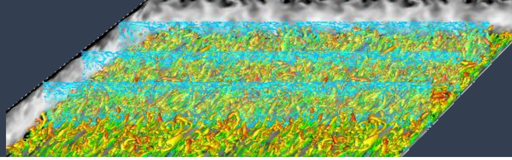
Conclusion



- **Numerical condition**

solver	B/C	ddt scheme	grad scheme	div scheme	result
pimpleFoam	cyclic	backward	Gauss linear	Gauss linear	O
			cellLimited Gauss linear 1.0	Gauss linear	O
			Gauss linear	Gauss linearUpwind	X
			Gauss linear	Gauss vanLeer	X
		Euler	Gauss linear	Gauss linear	X
		CrankNicolson			O
	symmetry				O
interFoam$_{water}$	symmetry	CrankNicolson	Gauss linear	Gauss linear	O
interFoam$_{air \cdot water}$					O

Conclusion



- **Current progress & future work**

solver	air depth	water depth	on-going	future work
$\text{interFoam}_{\text{air·water}}$	2δ	4δ	done	DNS
		6δ	averaging	
		8δ	averaging	

✓ DNS/LES of curved wall in an open channel

✓ validation of Reynolds-averaged N-S model near free surface

✓ anisotropic characteristics near free surface

✓ budget analysis of turbulent kinetic energy and dissipation rate