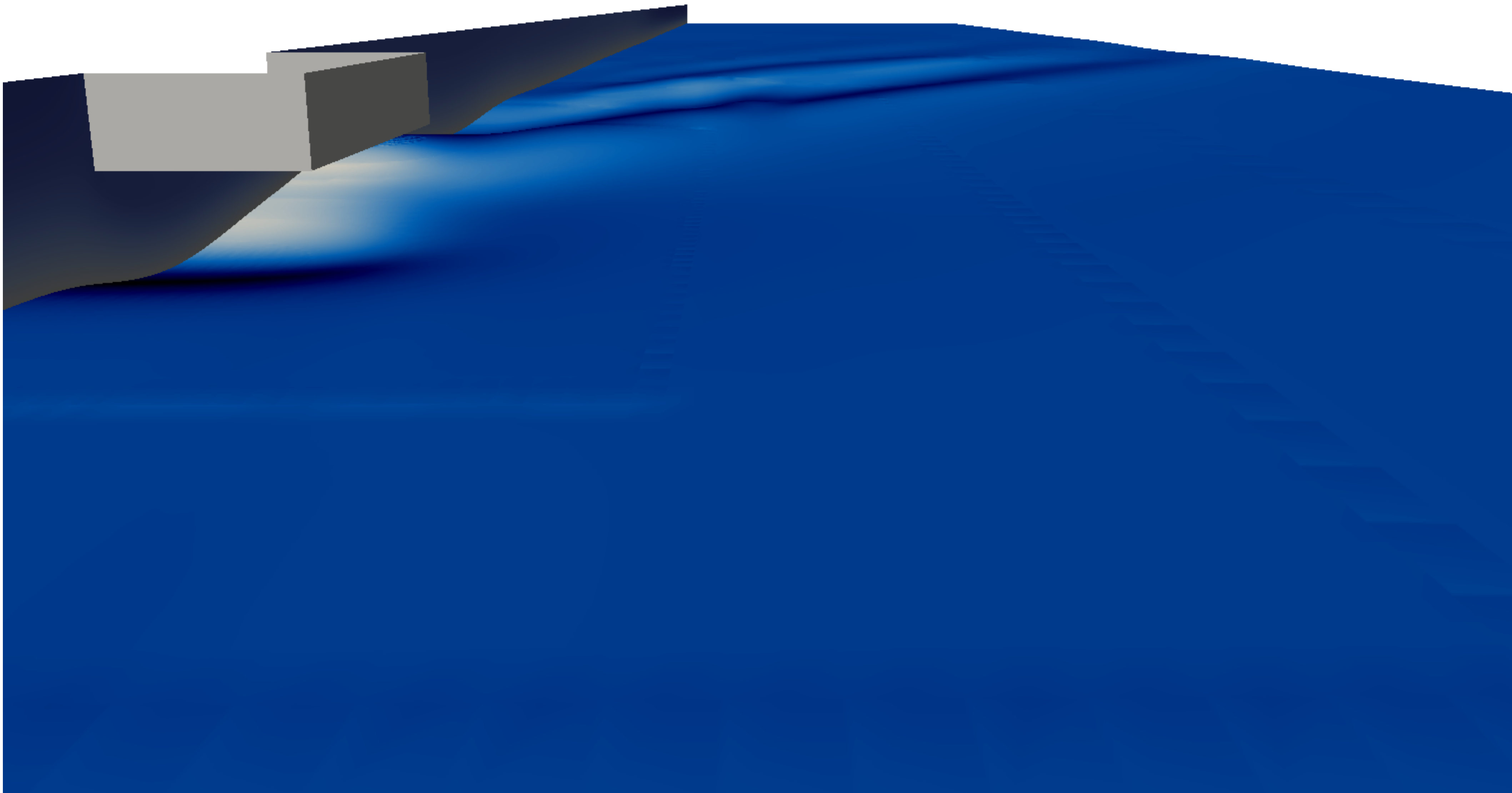
A study of dead water resistance

Reynolds Averaged Navier Stokes simulations of a barge moving in stratified water



Project description

- The objective of this project is to get qualitative understanding of the dead water phenomenon. Comparison of two RANS turbulence models is also conducted to find the most suitable model.

- To study the dead water phenomenon, a multiphase OpenFOAM solver has been used to caclulate drag on a barge moving in stratified water.

Numerical models

- The multiphase solver TwoLiquidMixingFoam

- The RANS turbulence models used for comparison is the k-Omega SST and the k-epsilon.

  - k-omega SST is known for good preformance calculating drag

  - k-epsilon has good preformance in multiphase fluid flow

Schemes

- **ddtSchemes**

  - Euler

  $$Co = \frac{u\Delta t}{\Delta \mathbf{x}}$$

- **gradSchemes**

  - Gauss linear

schemes

- **divSchemes**

  - div(rhoPhi,U) Gauss linearUpwind grad(U)

  - div(phi,alpha) Gauss vanLeer

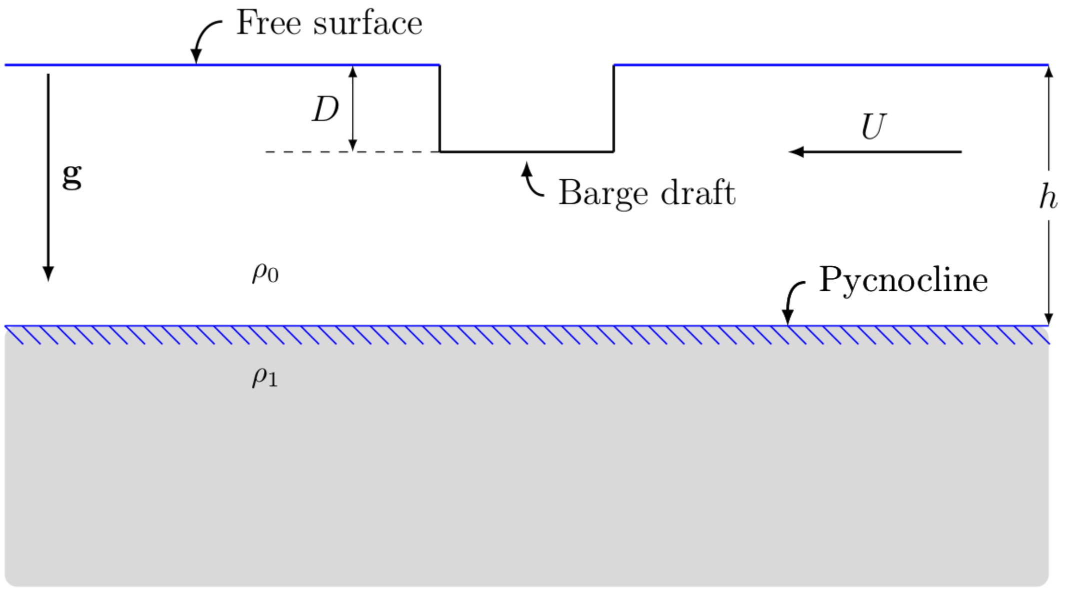
  - div(phirb,alpha) Gauss linear

  - div(phi,k) Gauss upwind

  - div(phi,omega) Gauss upwind

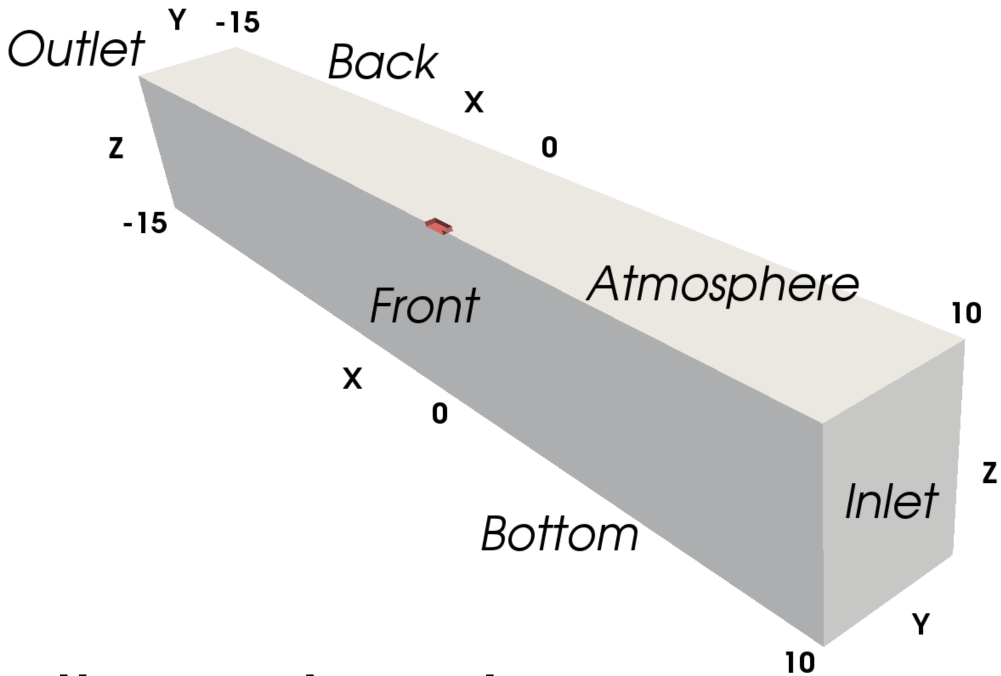
  - div(((rho*nuEff)*dev2(T(grad(U))))) Gauss linear

Simulation set up



- Constant draft
- Speed varies from $0.06 \leq U \leq 0.22$
- Three pycnocline depths $\frac{D}{h} = 0.5, 1.0 \ and \ 1.5$
- $0.35 \leq Fr_h \leq 1.35$
- $26815 \leq Re \leq 73743$

Simulation geometry



- Domain dimensions is:

  - 4 m in z-direction

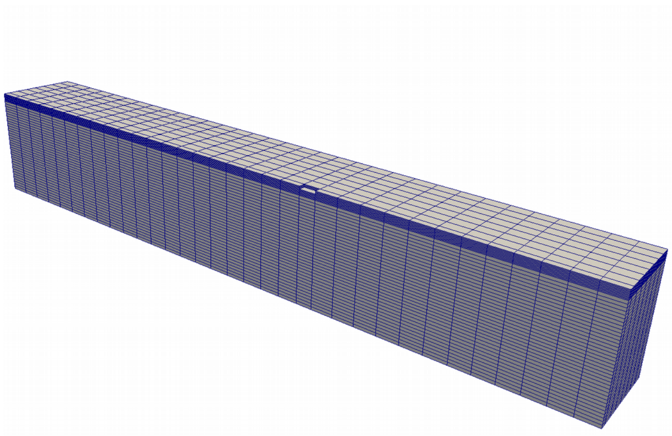
  - 3 m in y-direction

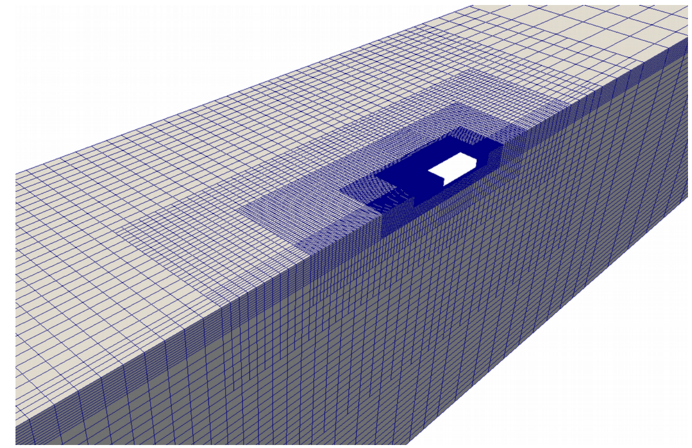
  - 25 m in x-direction

Boundary conditions

Boundary \ Variable		U	p_rgh	alpha.saltWater	k	omega	nut
Inlet	Type	fixedValue	fixedFluxPressure	fixedValue	fixedValue	fixedValue	fixedValue
	Value	internalField	internalField	internalField	internalField	internalField	internalField
Outlet	Type	O.P.M.V.	zeroGradient	V.H.F.R.	inletOutlet	inletOutlet	zeroGradient
	Value	internalField	-	internalField	internalField	internalField	-
Barge	Type	M.W.V.	F.F.P.	zeroGradient	kqrW.F.	omegaW.F.	nutUSpaldinW.F
	Value	(0 0 0)	internalField	-	internalField	internalField	internalField
atmosphere	Type	slip	fixedValue	zeroGradient	zeroGradient	zeroGradient	zeroGradient
	Value	-	internalField	-	-	-	-
atmosphereFrontOfBarge	Type	inletOutlet	fixedValue	zeroGradient	zeroGradient	zeroGradient	zeroGradient
	Value	internalField	internalField	-	-	-	-
Front	Type	symmetryPlane	symmetryPlane	symmetryPlane	symmetryPlane	symmetryPlane	symmetryPlane
	Value	-	-	-	-	-	-
Back	Type	symmetryPlane	symmetryPlane	symmetryPlane	symmetryPlane	symmetryPlane	symmetryPlane
	Value	-	-	-	-	-	-
Bottom	Type	symmetryPlane	symmetryPlane	symmetryPlane	symmetryPlane	symmetryPlane	symmetryPlane
	Value	-	-	-	-	-	-

Mesh generation





- Using a base mesh with 12668 cells.
- Using topoSetDicts in order to refine mesh around barge and pycnocline locations.

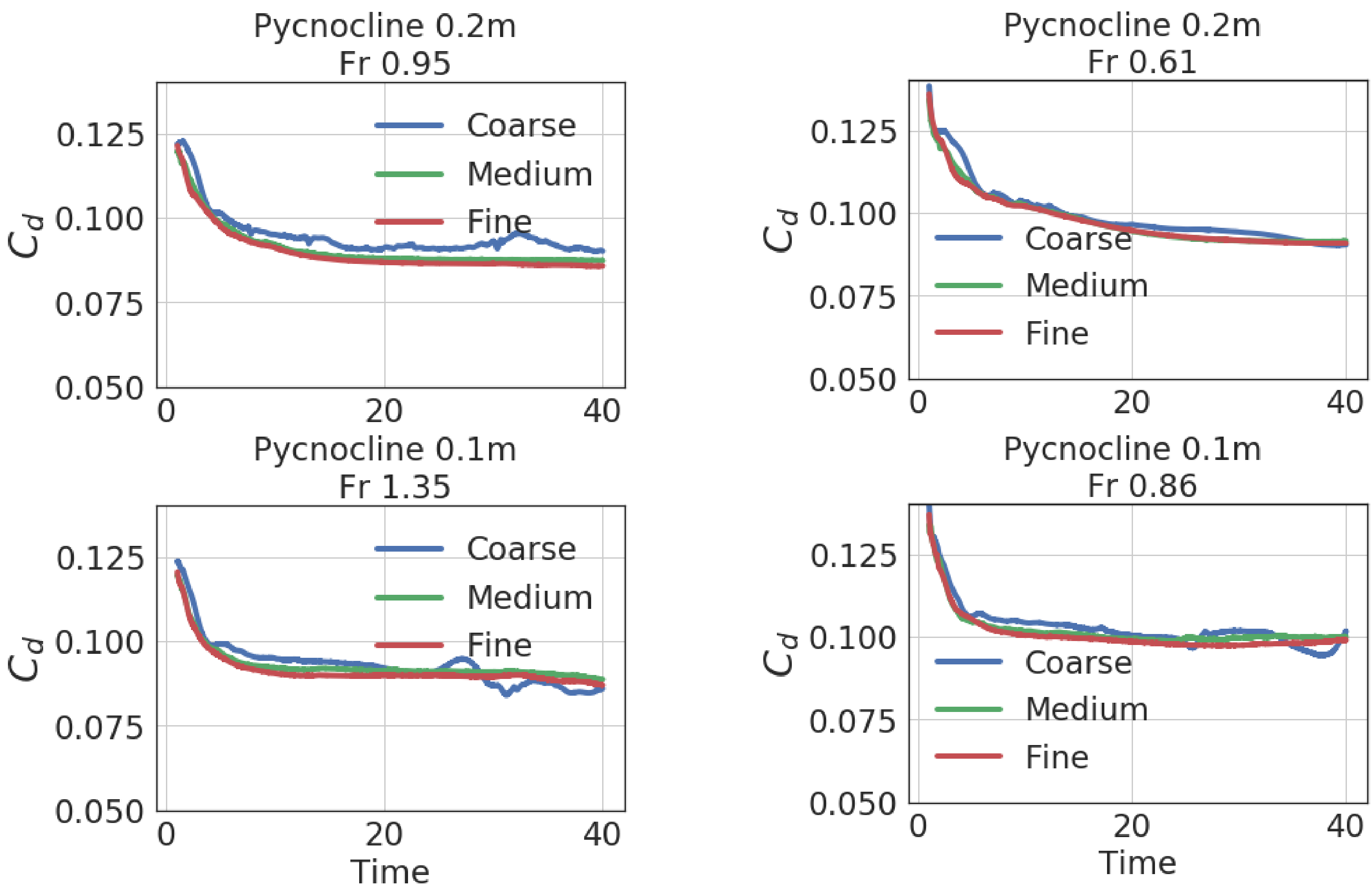
Mesh sensitivity

- Three meshes has been systematically refined for convergence tests
- A grid refinement ratio of 2 has been used on the base mesh
- The resulting course, medium and fine mesh has

4.2×10^5, 7.4×10^5 and 1.3×10^6 cells respectively.

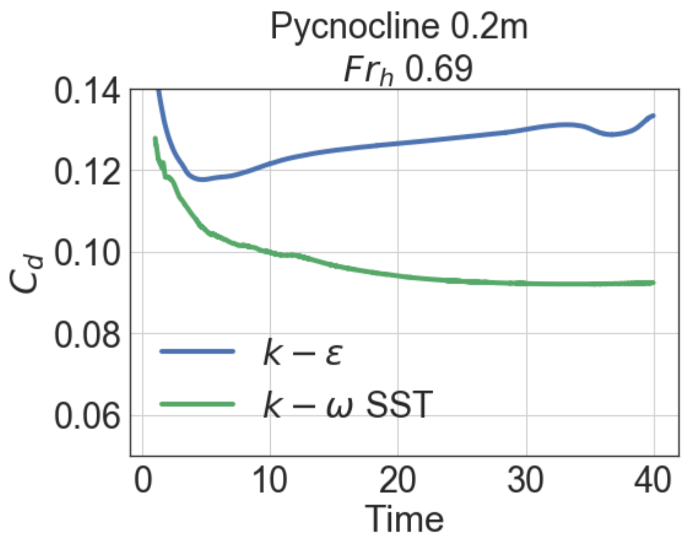
Mesh \ Fr_h	0.86	1.35
Coarse	11.14	13.10
Medium	8.39	11.33
Fine	6.8	8.95

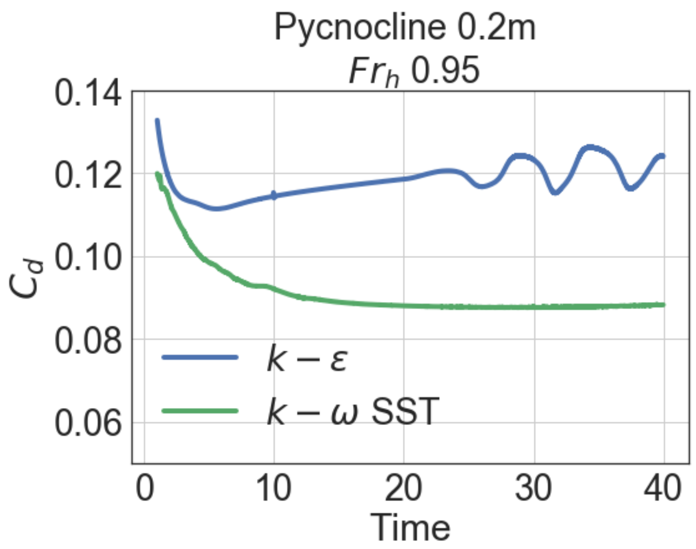
Mesh sensitivity 2



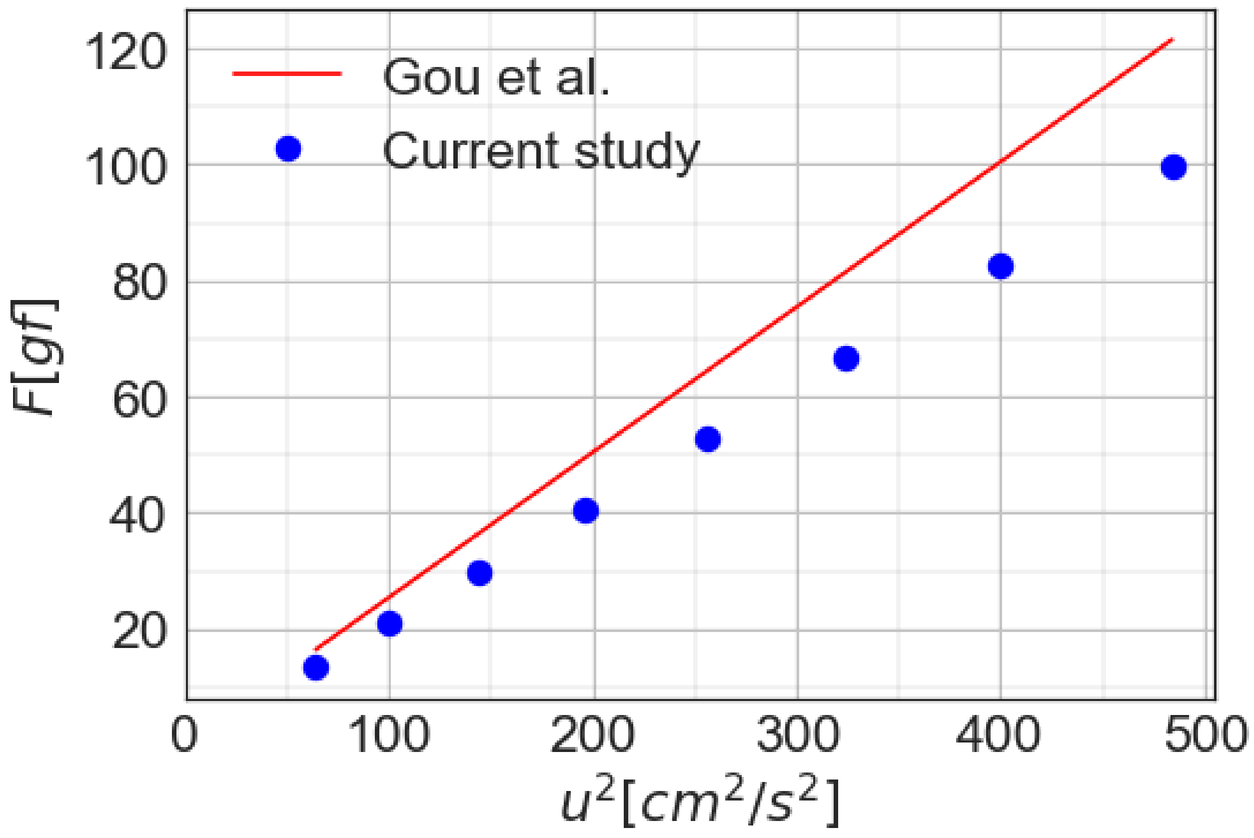
Comparison of turbulence models

- Comparison of turbulence models done at densimetric Froude numbe close to peak drag and close to critical densimetric Froude number



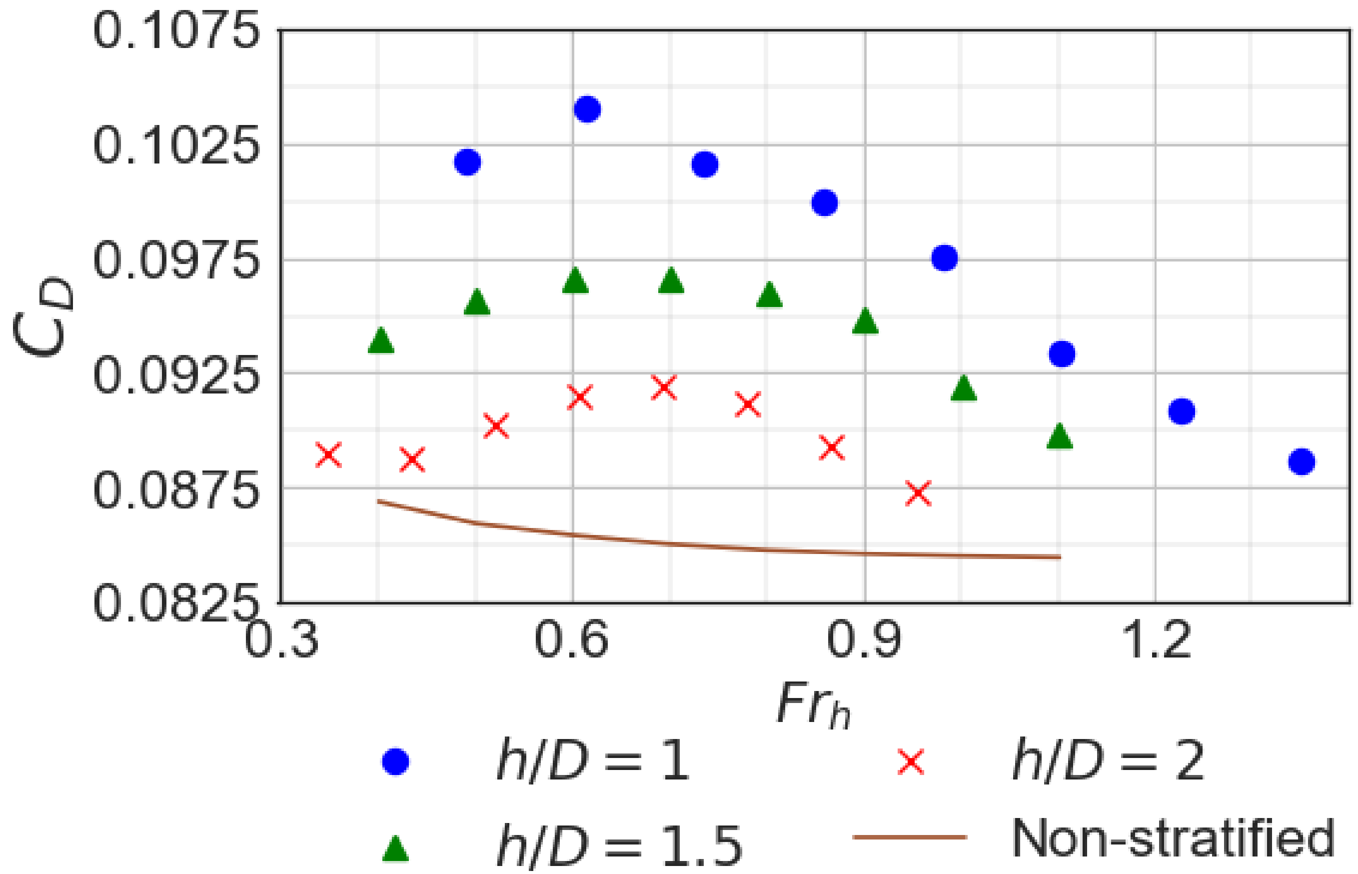


Drag



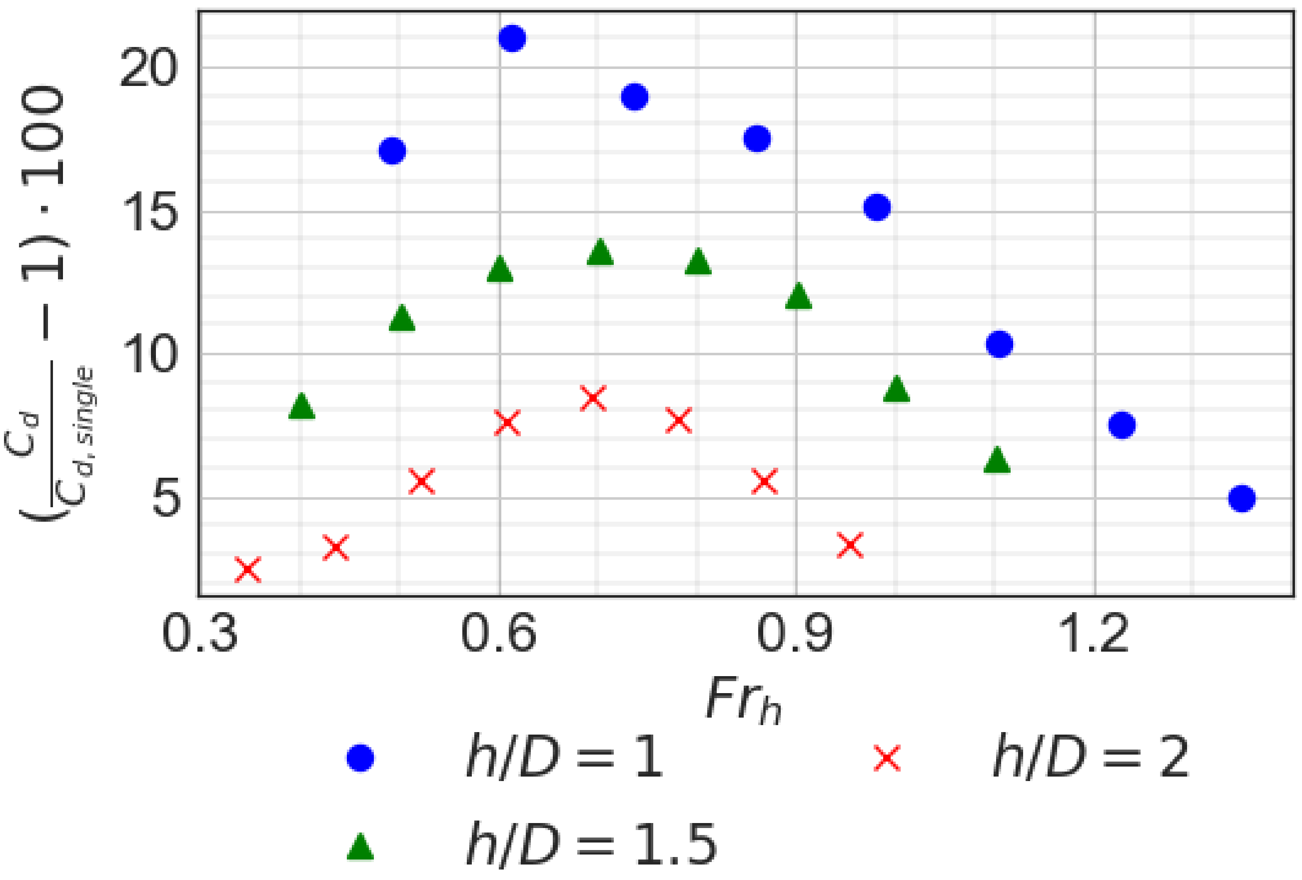
Gou et al.
Current study
120
100
80
60
40
20
F[gf]
0
100
200
300
400
500
$u^2[cm^2/s^2]$

Drag 2



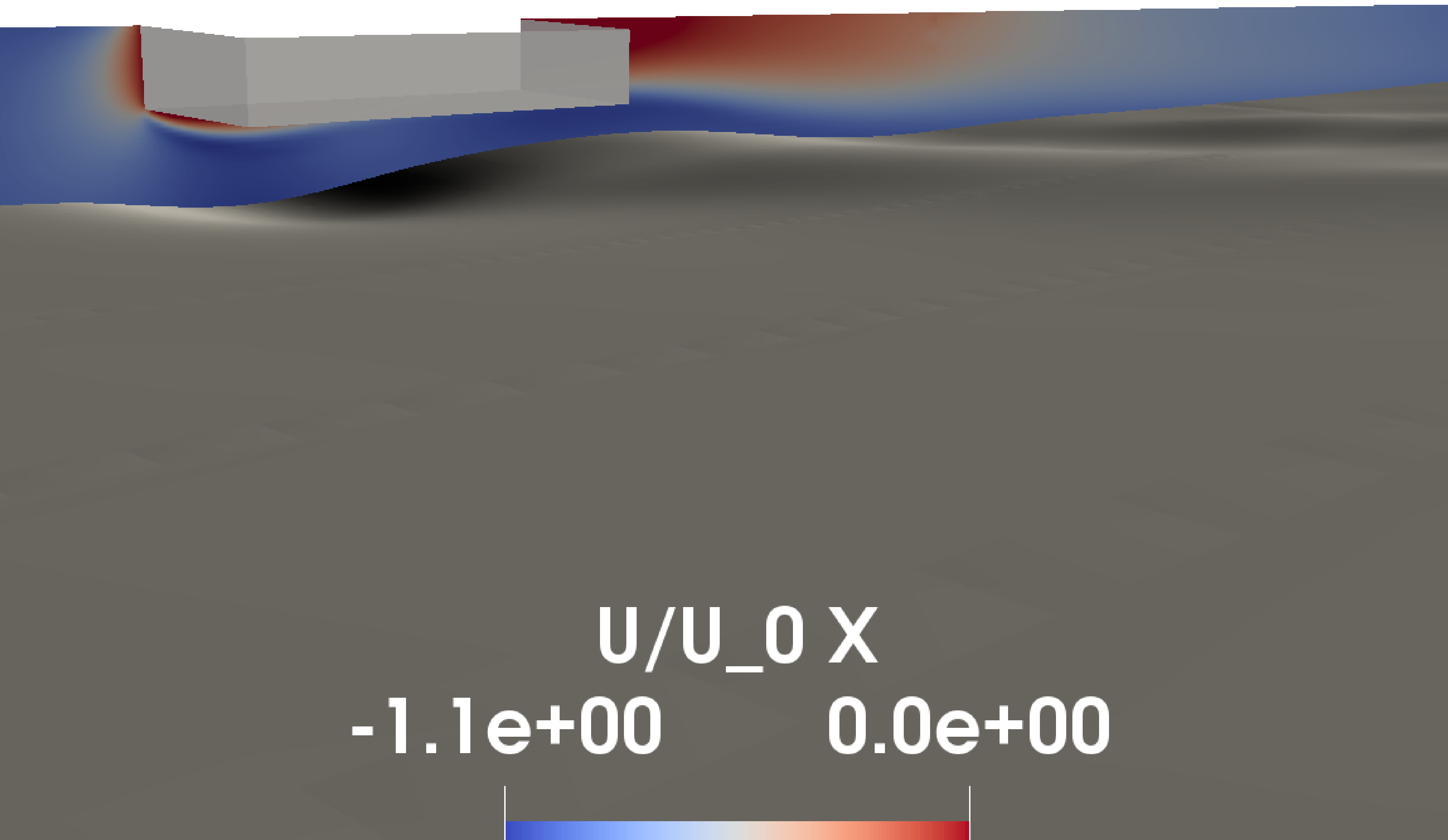
0.1075
0.1025
0.0975
0.0925
0.0875
0.0825
C_D
0.3
0.6
0.9
1.2
Fr_h
$h/D = 1$
$h/D = 2$
$h/D = 1.5$
Non-stratified

Drag 3

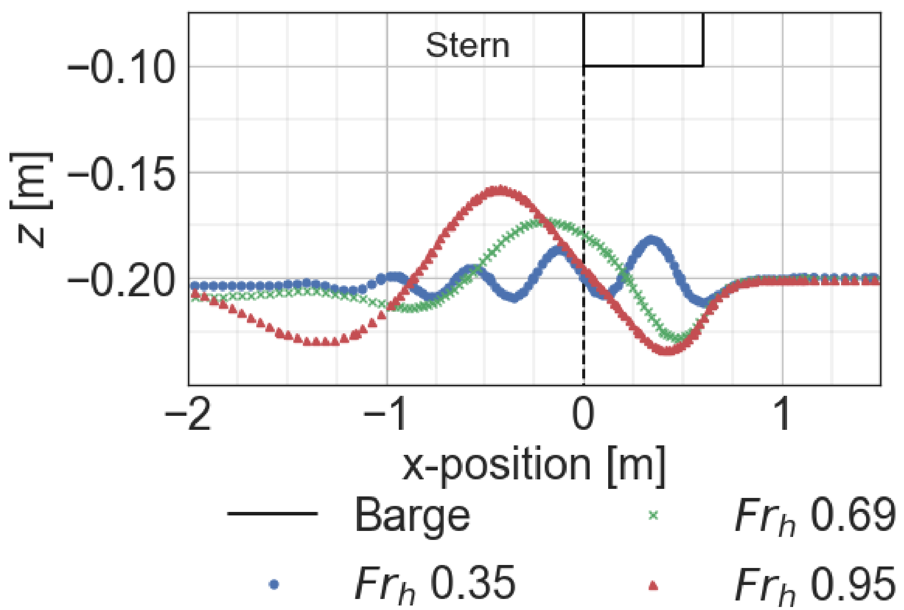


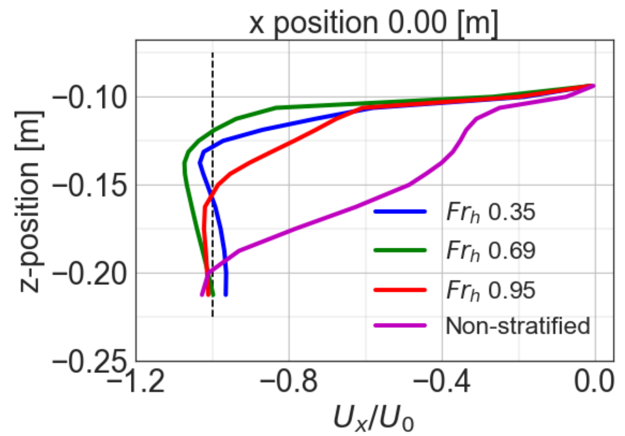
$(\frac{C_d}{C_{d,single}} - 1) \cdot 100$
20
15
10
5
0.3
0.6
0.9
1.2
Fr_h
$h/D = 1$
$h/D = 2$
$h/D = 1.5$

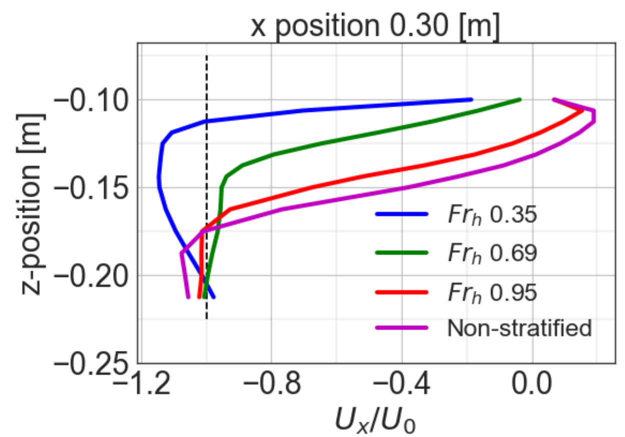
Internal waves



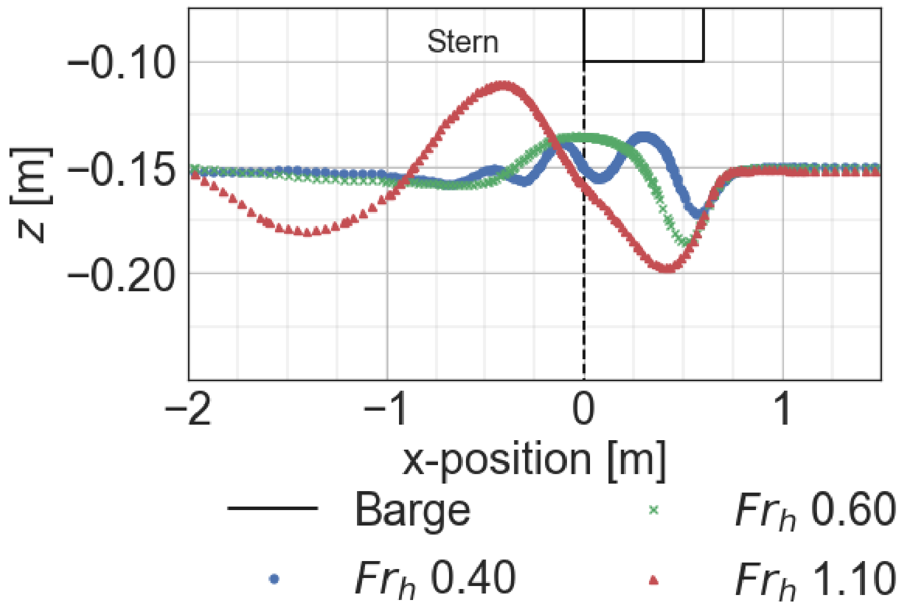
Internal waves and effect on velocity

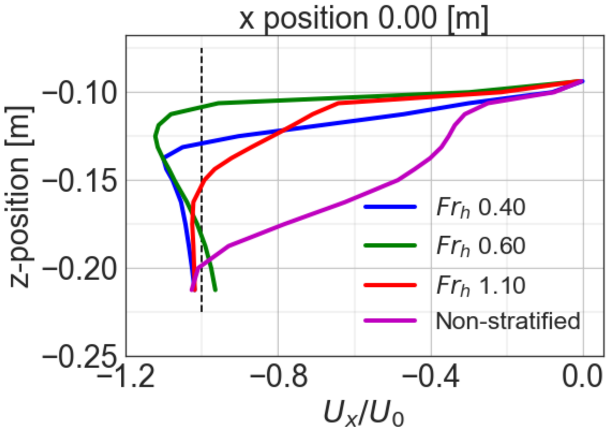


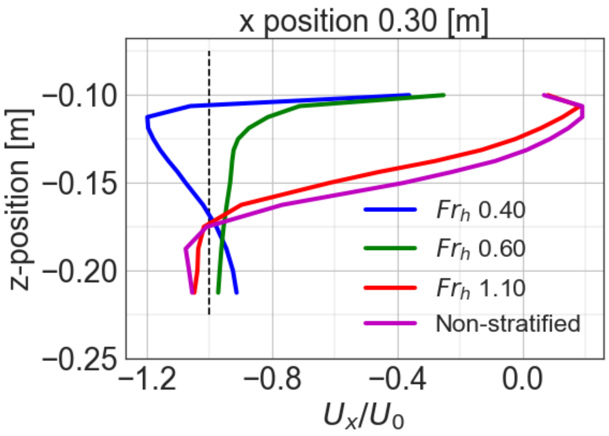




Internal waves and effect on velocity 2







Conclusions

- K-Omega SST gave better results than k-epsilon.
- Similar results as Gou et.al simulating non-stratified water
- Able to catch the dead water phenomenon
- Under estimation of the increase in drag