ICUC9, Toulouse, France, 20-24th July, 2015

UCP12:
Characteristics of scalar dispersion from a continuous area source over cubical array

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*Naoki Ikegaya, Aya Hagishima, Jun Tanimoto

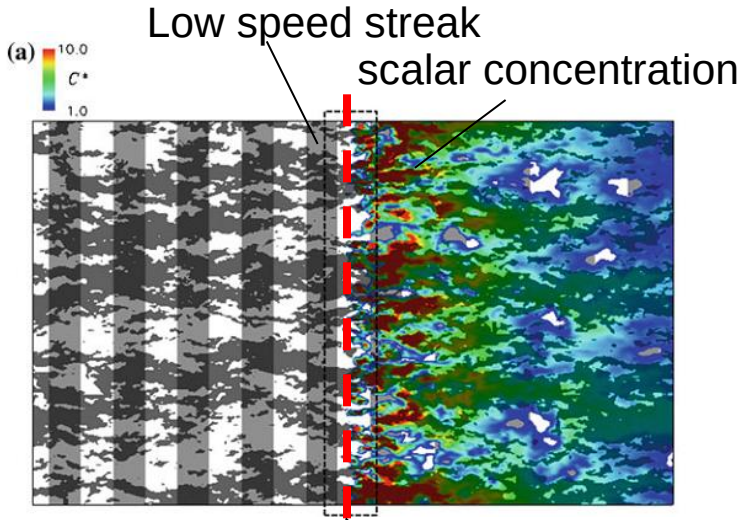
Introduction -on scalar dispersion-

Measurement of bulk scalar transfer efficiency:

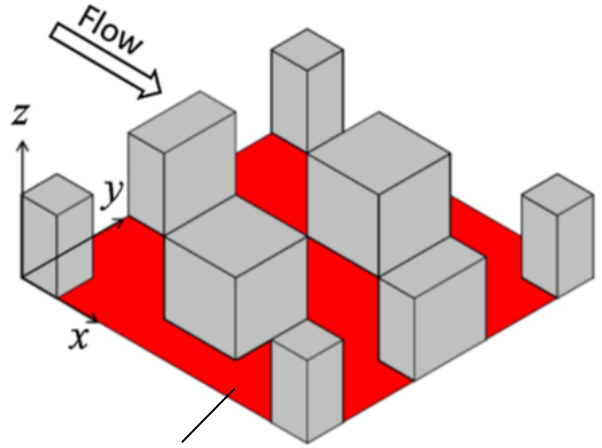
- Naphthalene sub. method, Barlow et al. (2002, 2004)
- Wet-filter method, Narita (2007)
- Salinity method, Ikegaya et al. (2009) …etc.

Turbulence characteristics:

- LSS and scalar dispersion, LES, Michioka et al. (2010)
- Quadrant analysis for scalar, LES Boppana et al. (2014) etc…



Michioka et al. 2010



Boppana et al. 2010

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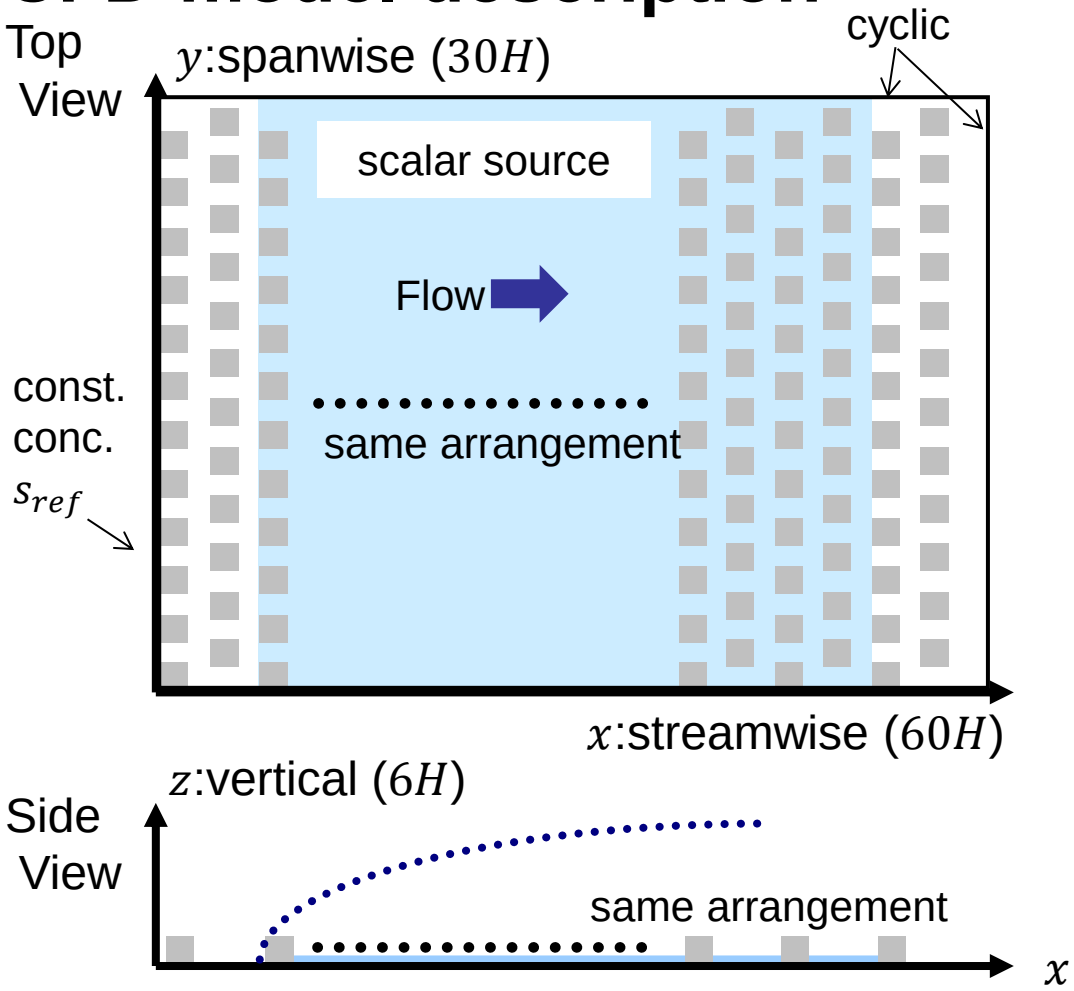
- **Simultaneous measurement of scalar and vel. (Exp.)**
- **Treatment of surface conditions (CFD)**

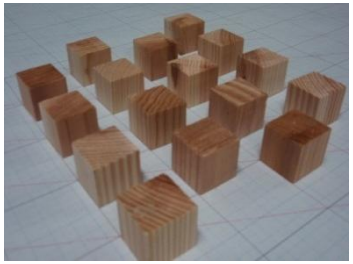
(1) surface flux determination by CFD
(2) characteristics of scalar turbulent statistics

CFD model description



- Parallelized LES Model (Raasch et al. 2001)
- continuity, Navier-Stokes, budget eq. of SGS-TKE
- 1/2th Deardorff scheme (Deardorff, 1980)
- Constant pres. gradient driven (u^*~0.2m/s)
- Simulation period:400T($T = H/u^*$)

Roughness Configuration



- cubical block
- block height H=24mm
- staggered arrangement
- plan area index $\lambda_p = 0.07$

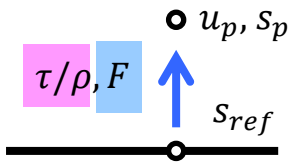
Surface boundary condition

Surface friction τ/ρ [m²/s²]

$$\frac{\tau}{\rho} = \left(\frac{u_p}{\frac{1}{\kappa}\ln\left(\frac{z}{z_o}\right)} \right)^2$$

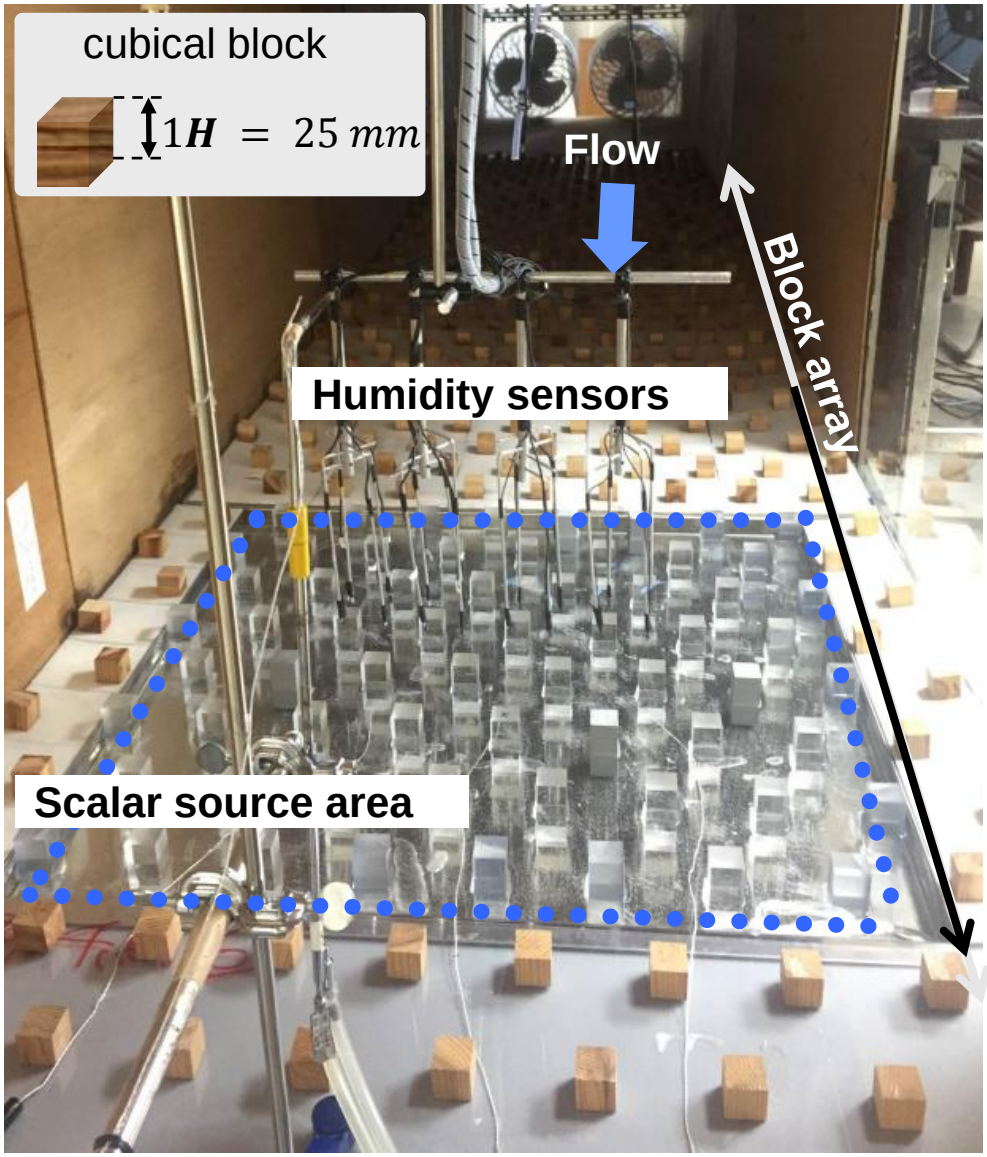
Surface scalar flux F [kg/m²s]

$$F = \frac{u_p\left(s_{surf} - s_p\right)}{\left(\frac{1}{\kappa}\ln\left(\frac{z}{z_o}\right)\right)\left(\frac{1}{\kappa}\ln\left(\frac{z}{z_{os}}\right)\right)}$$

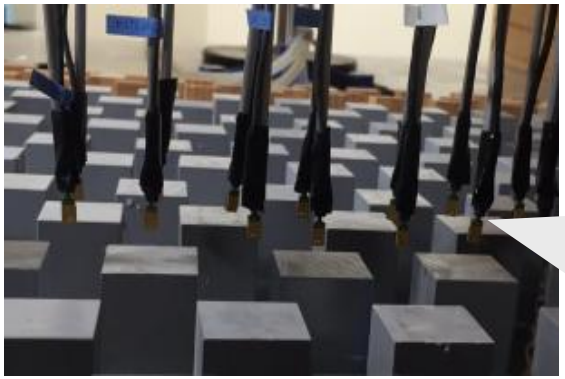


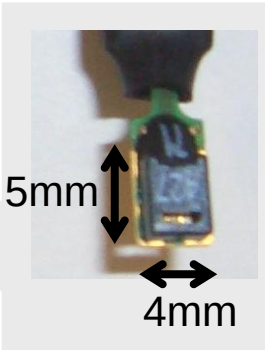
z_o, z_{os}: roughness length

Wind tunnel / Humidity sensor

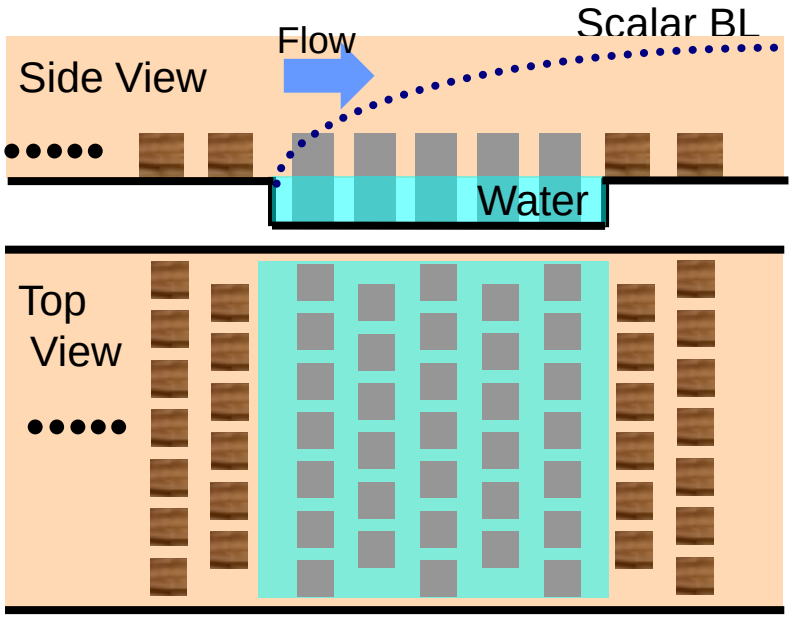


Humidity sensor (Sensiron STH75)





Scalar source area



u^*, s^* obtained from Hagishima et al. (2009), Ikegaya et al.(2012)

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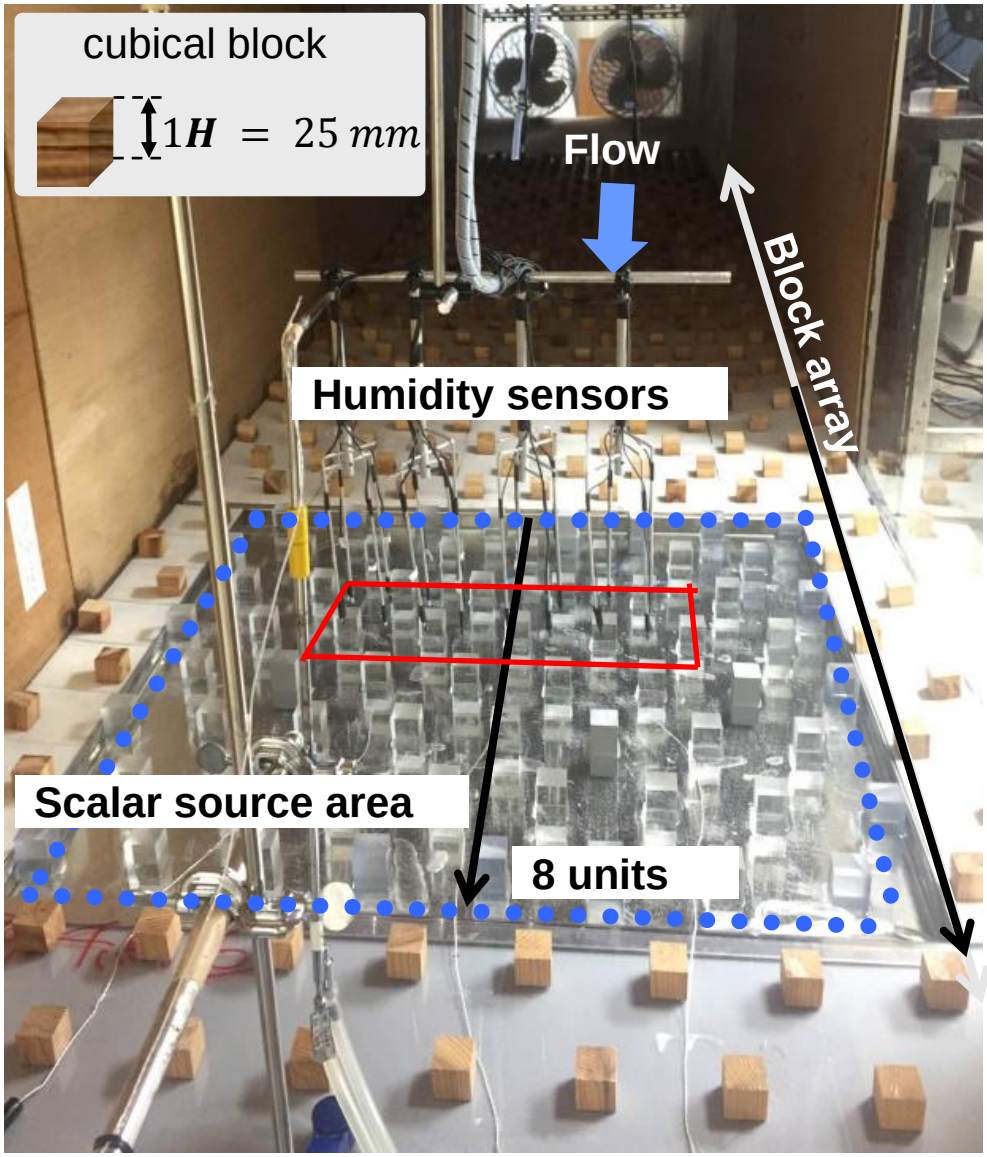

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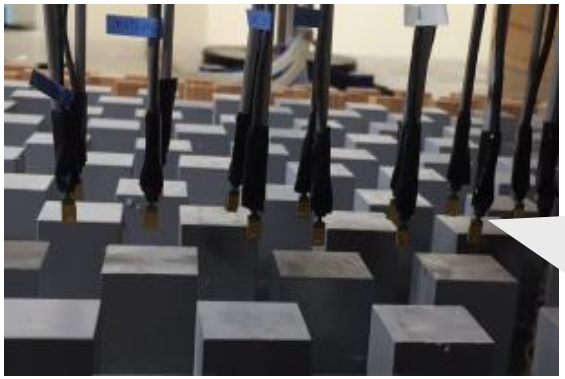
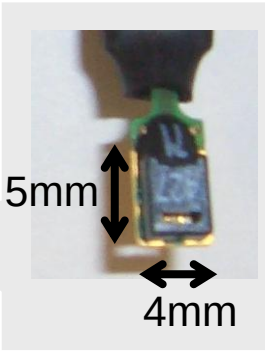
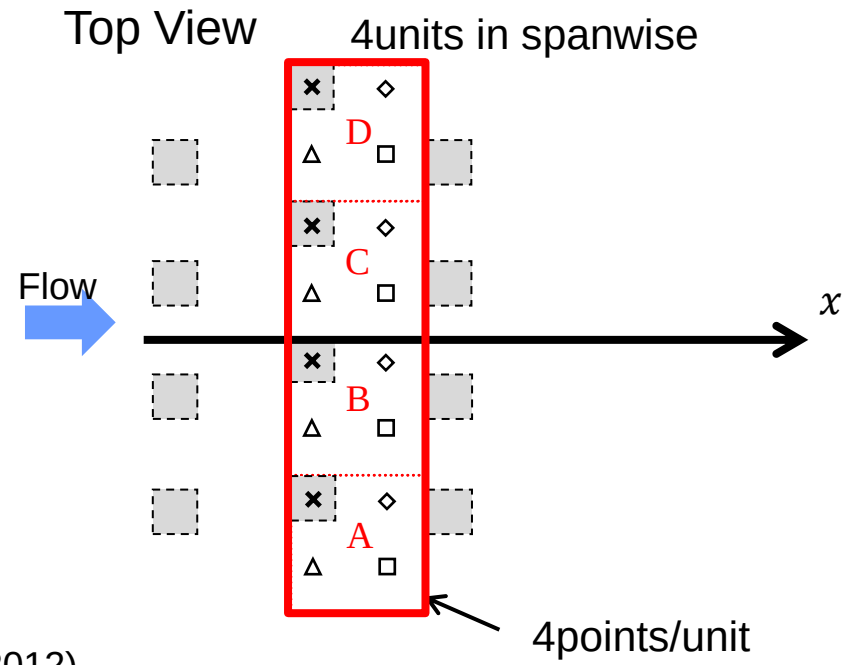




Measurement locations



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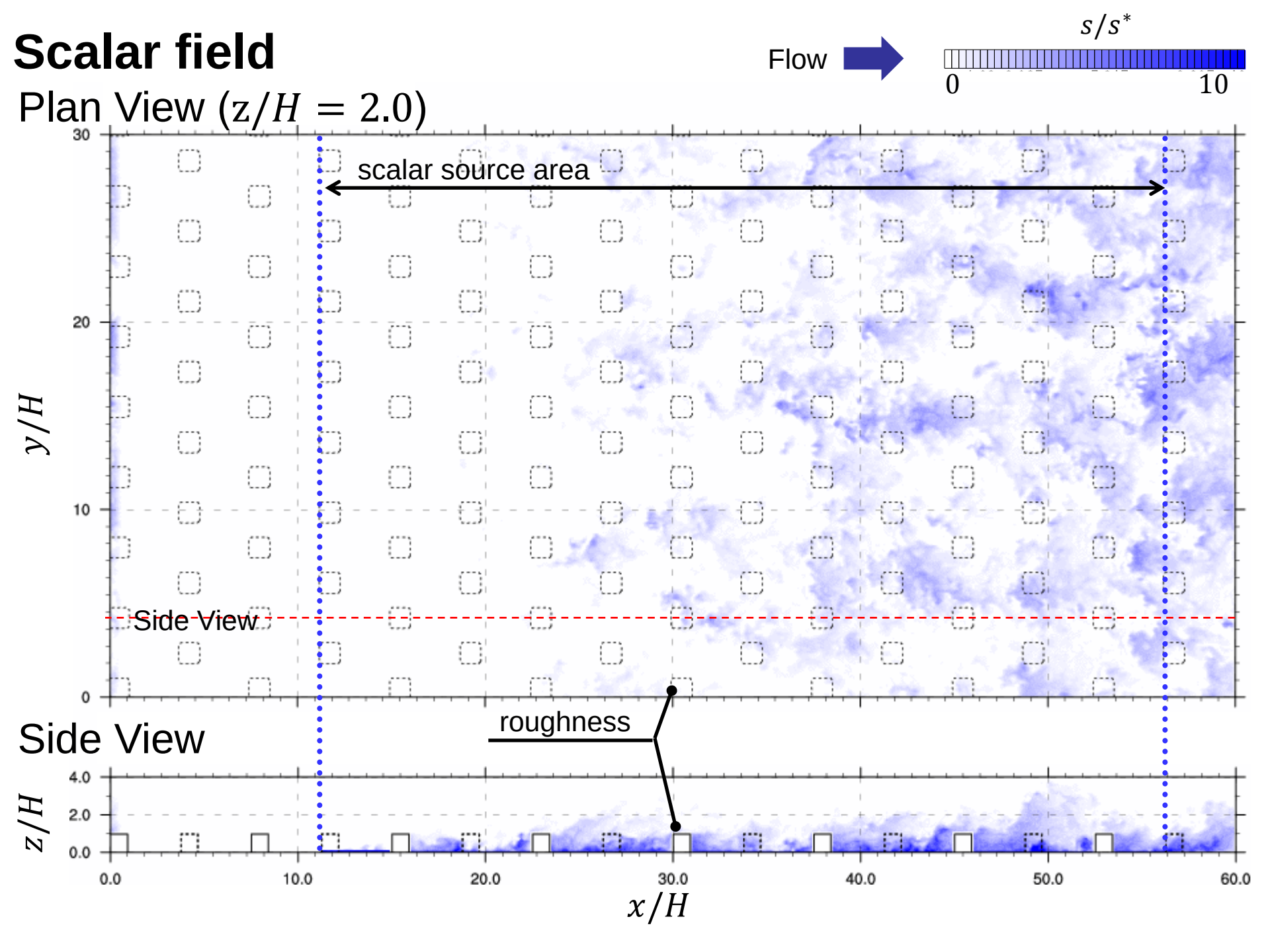
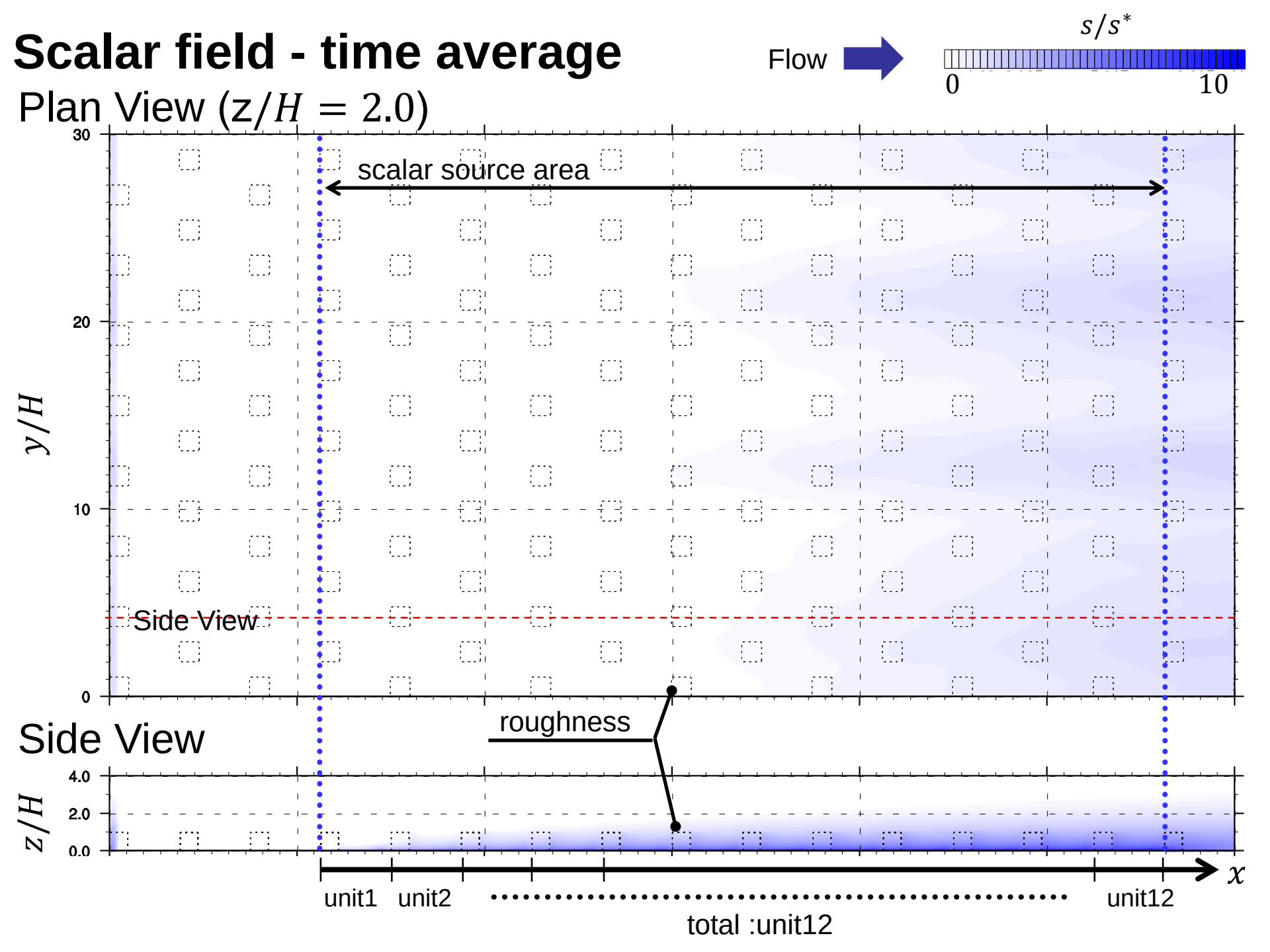
Scalar field



Scalar field - time average



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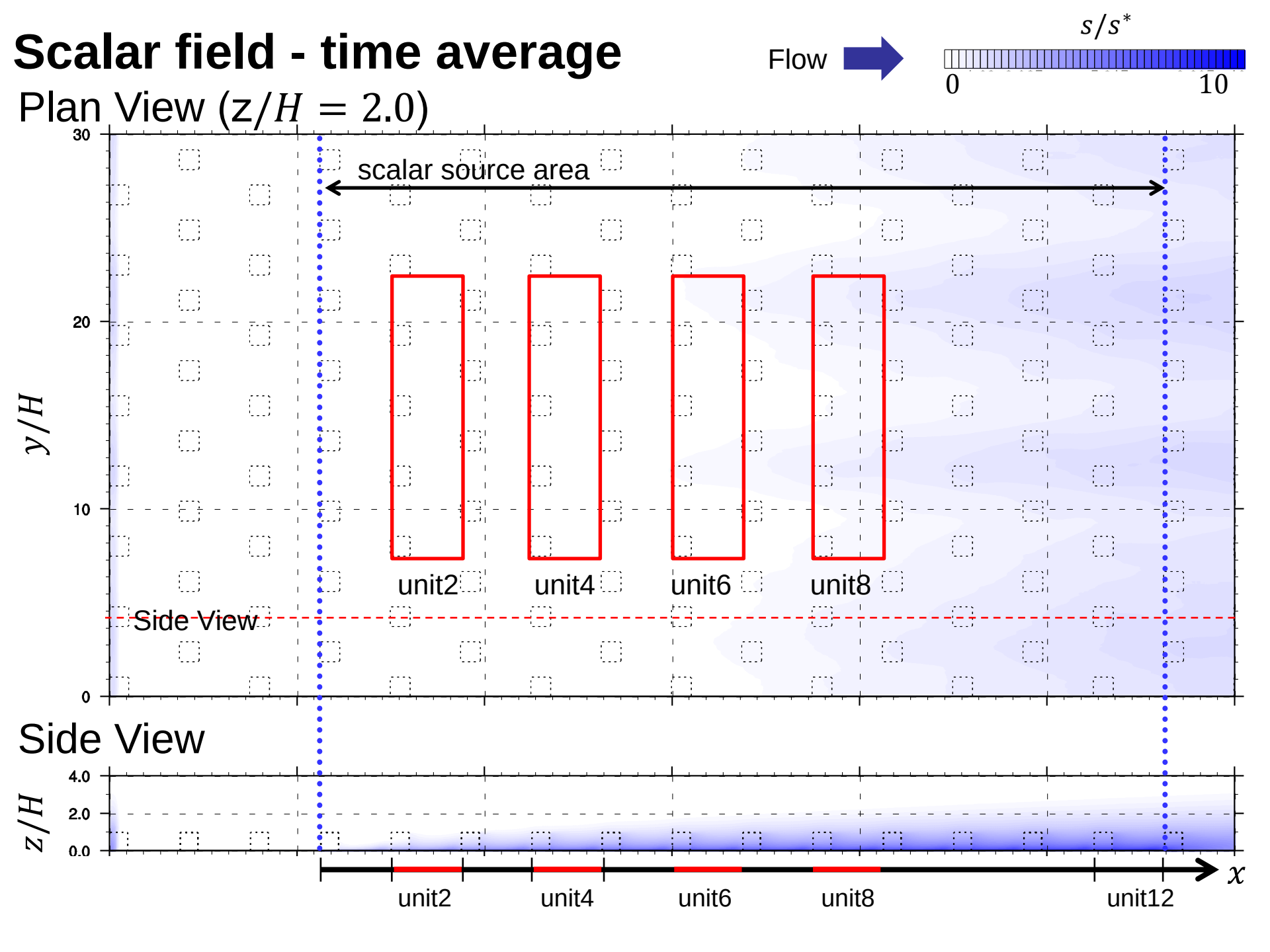
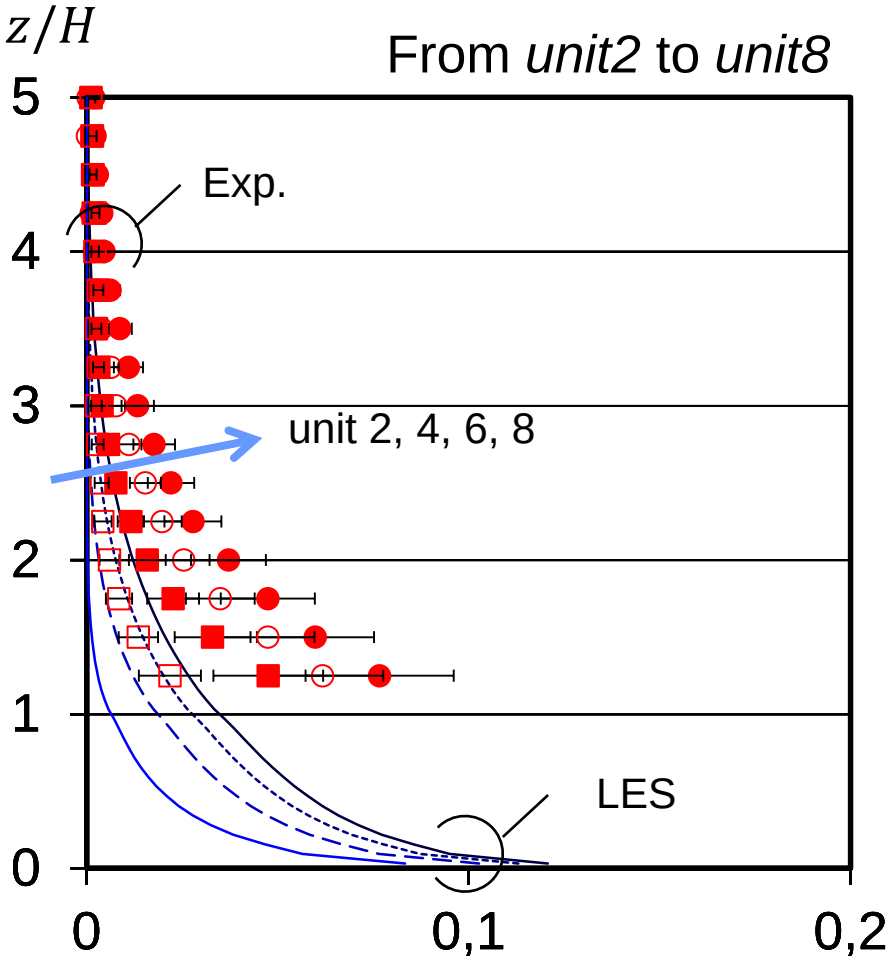
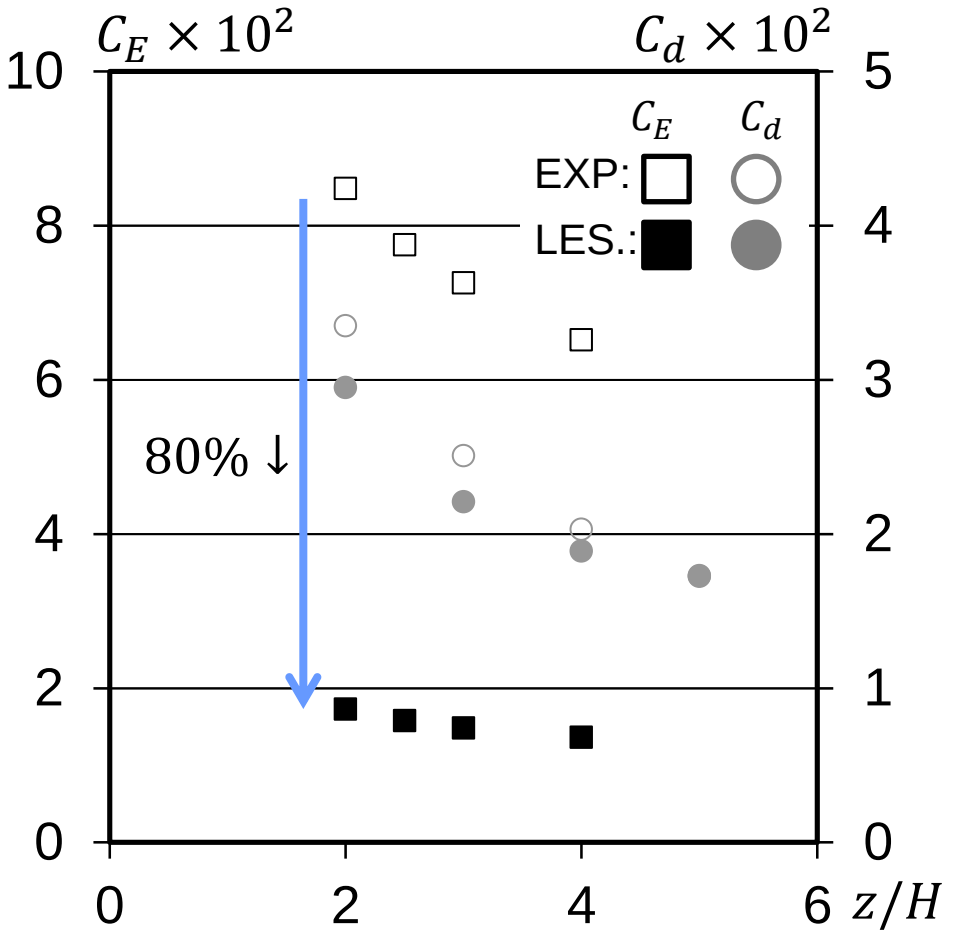


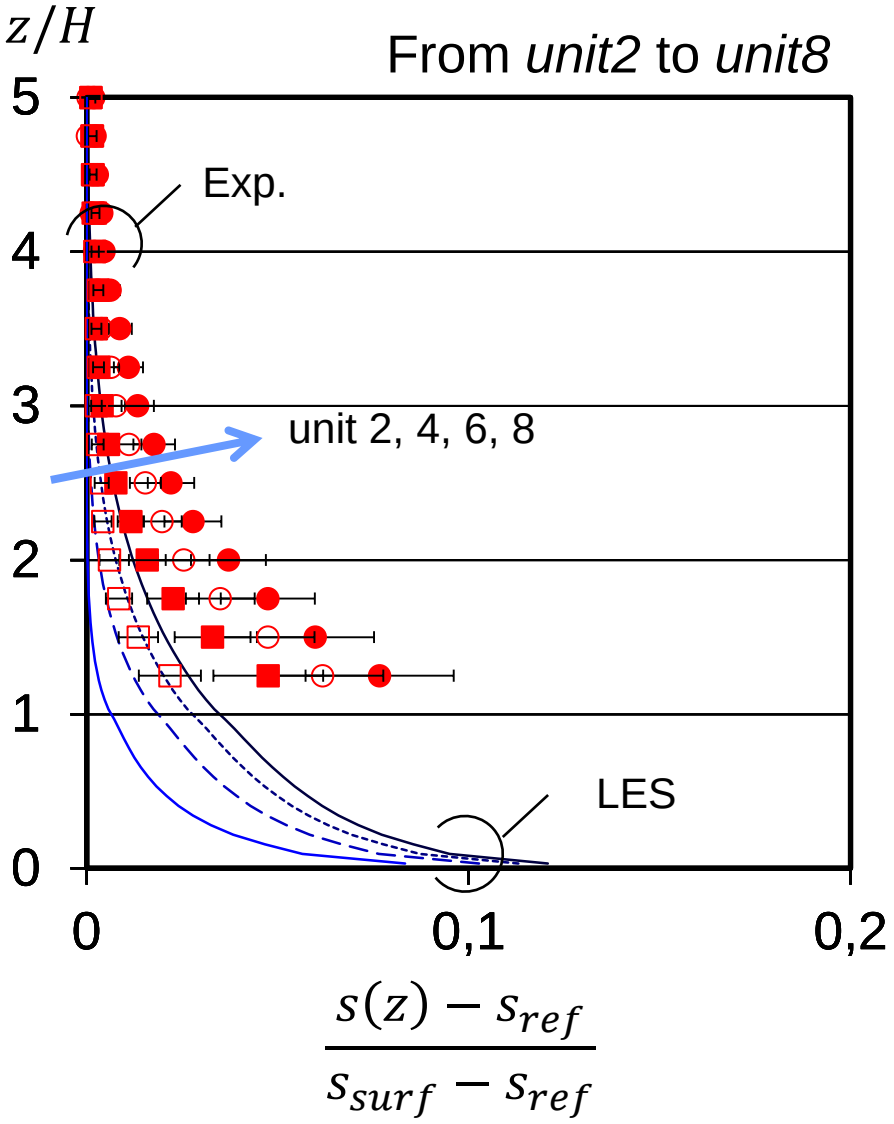
Comparison with Exp. -1-





$C_d = \tau/\rho u^2$: drag coeff.
$C_E = F/(u(s_{surf} - s))$: scalar trans coeff
τ: surf. friction
F: surf. friction
s_{surf}: surf. concentration
s_{ref} : ref. concentration

Comparison with Exp. -1-



Friction velocity:

$$\tau/\rho = u^{*2}$$

scaling velocity

Friction scalar:

$$F = u^* s^*$$

scaling scalar

Normalized scalar conc.:

$$\frac{s(z)-s_{ref}}{s_{surf}-s_{ref}} \longrightarrow \frac{s(z)-s_{ref}}{s^*}$$

τ: surf. friction
F: surf. friction
s_{surf}: surf. concentration
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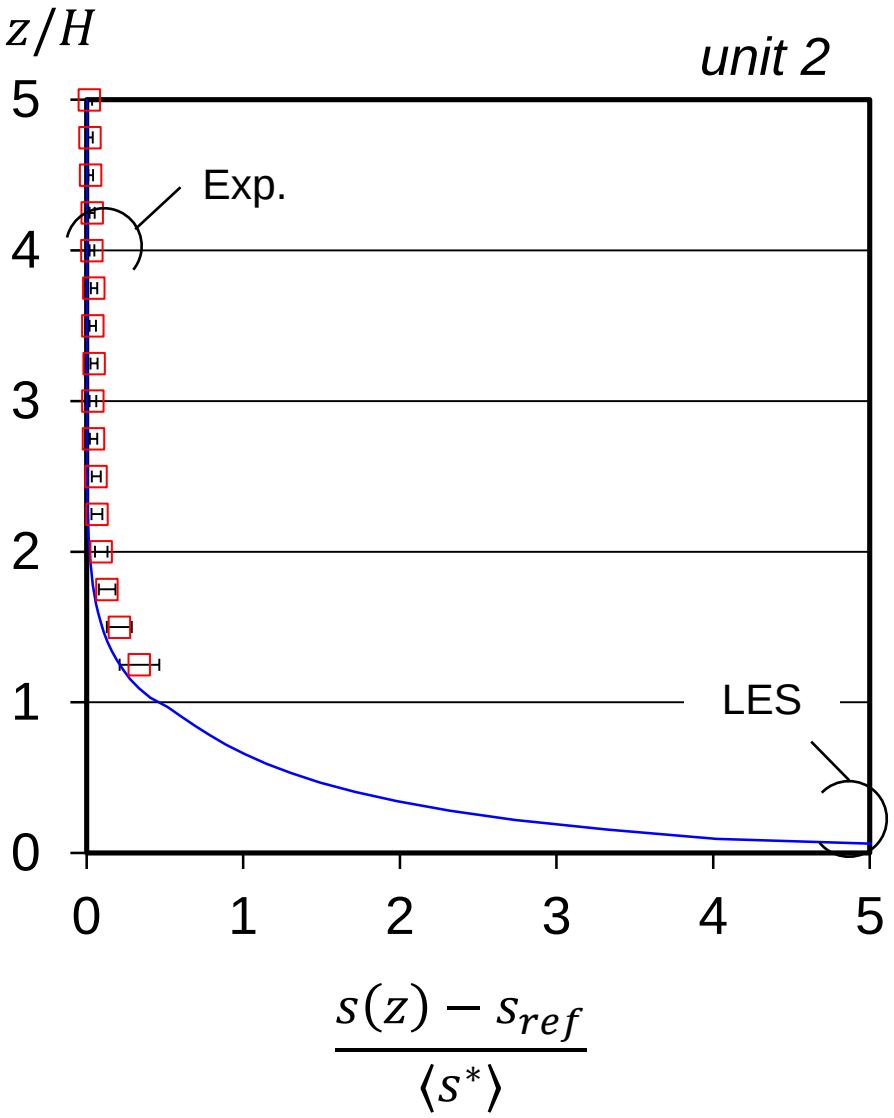
Comparison with Exp. -2-



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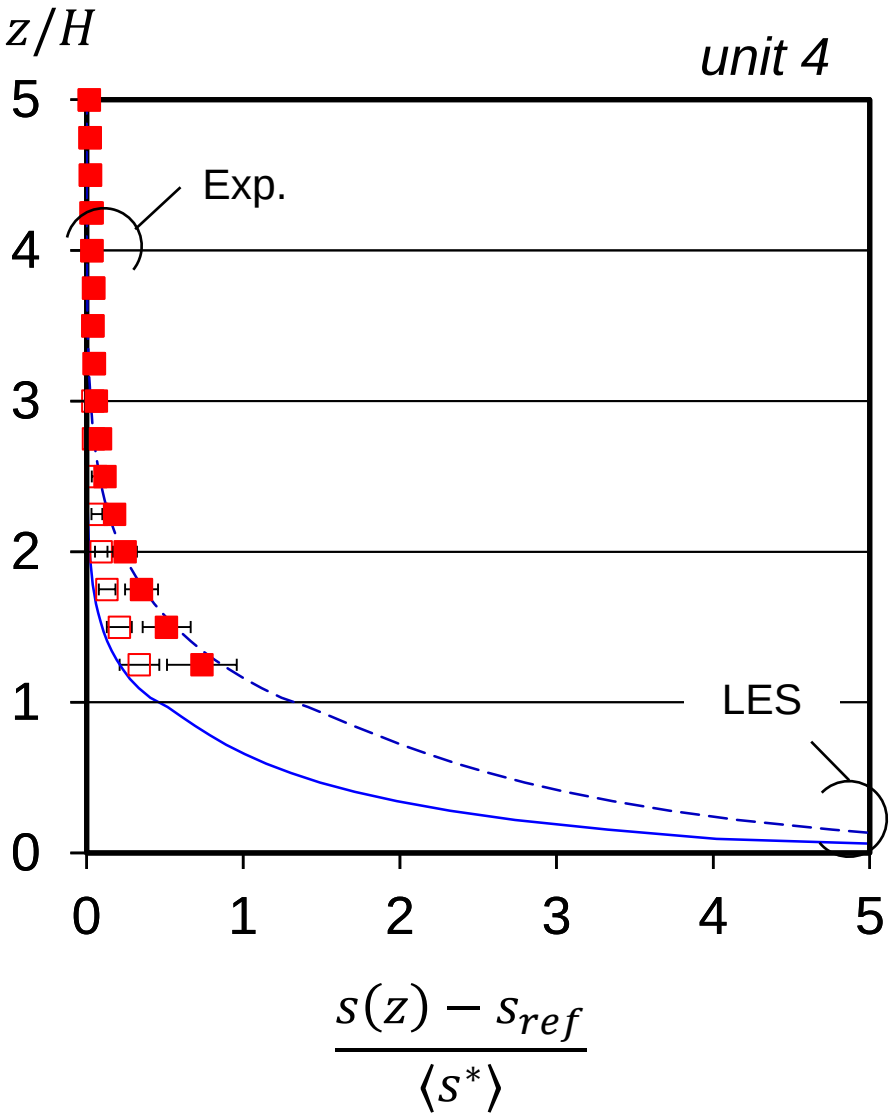

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scaling velocity

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scaling scalar

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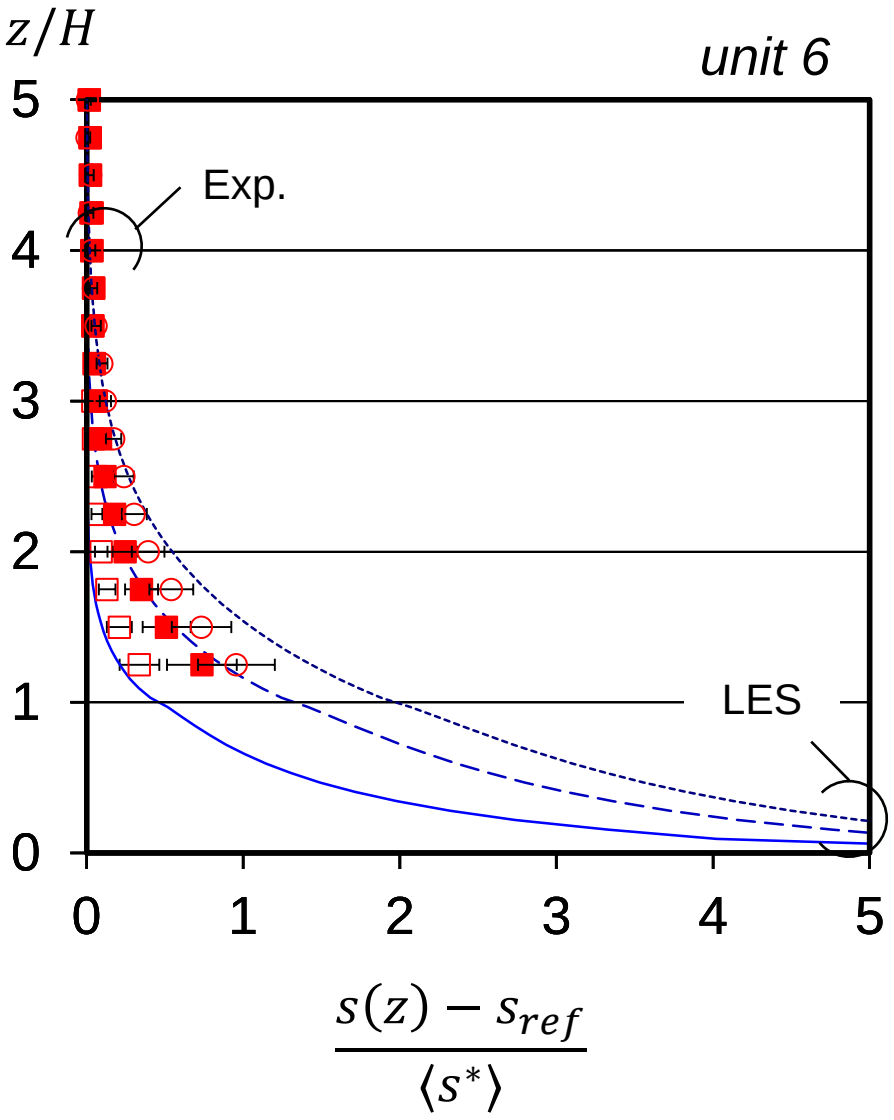

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scaling velocity

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scaling scalar

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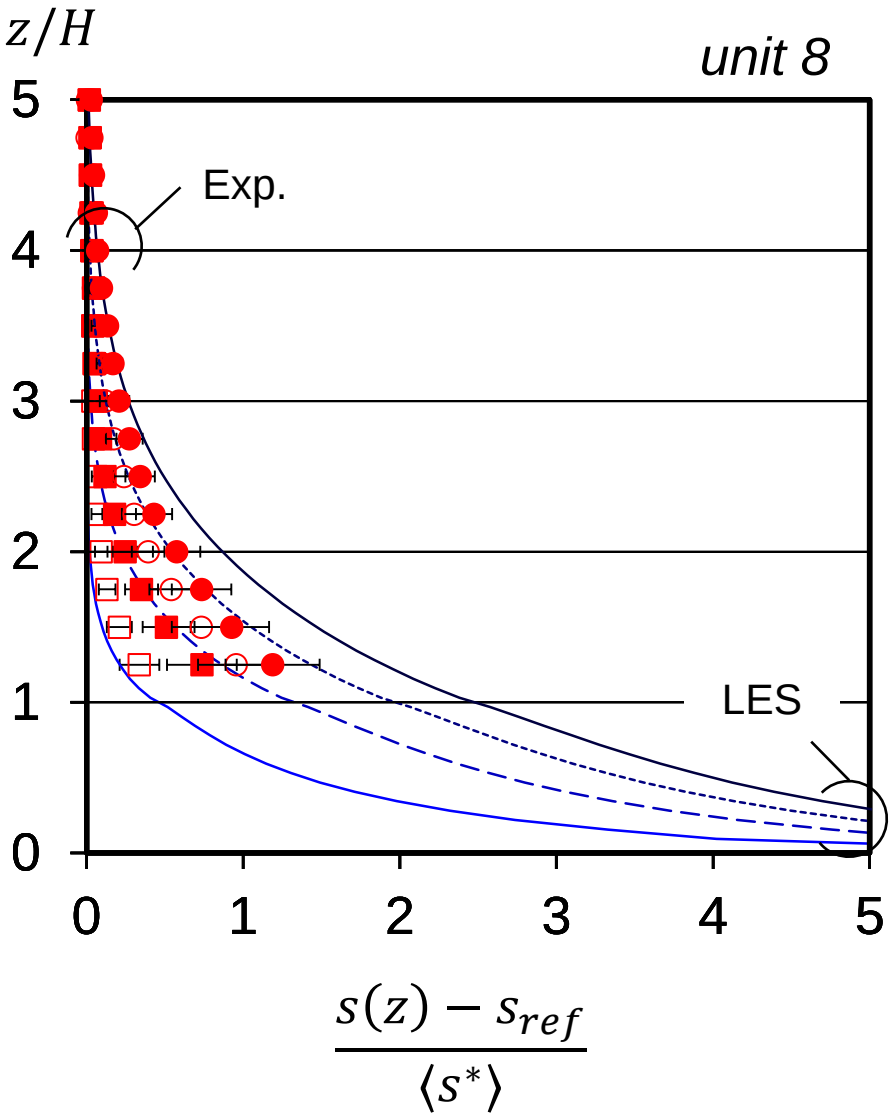

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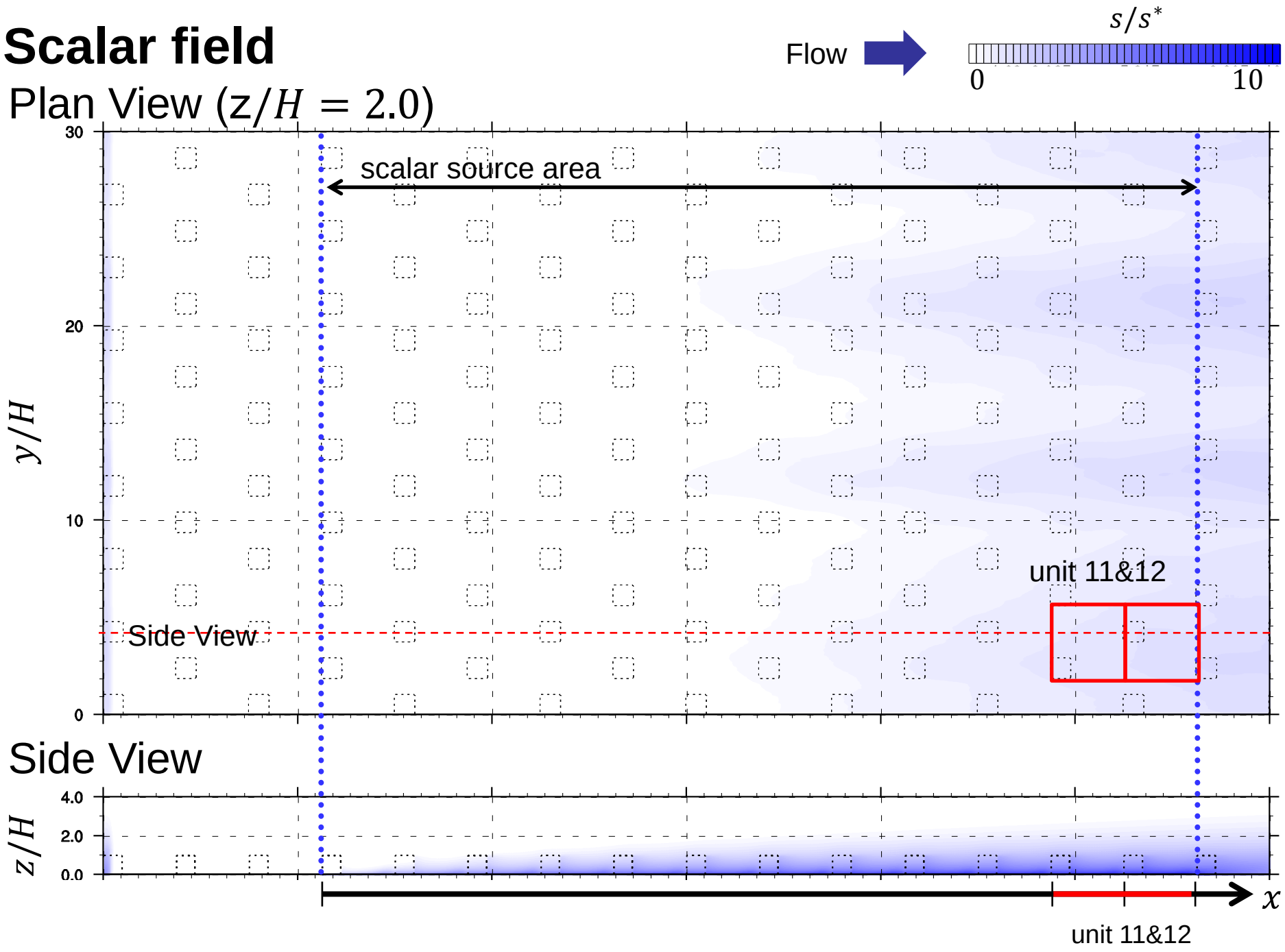
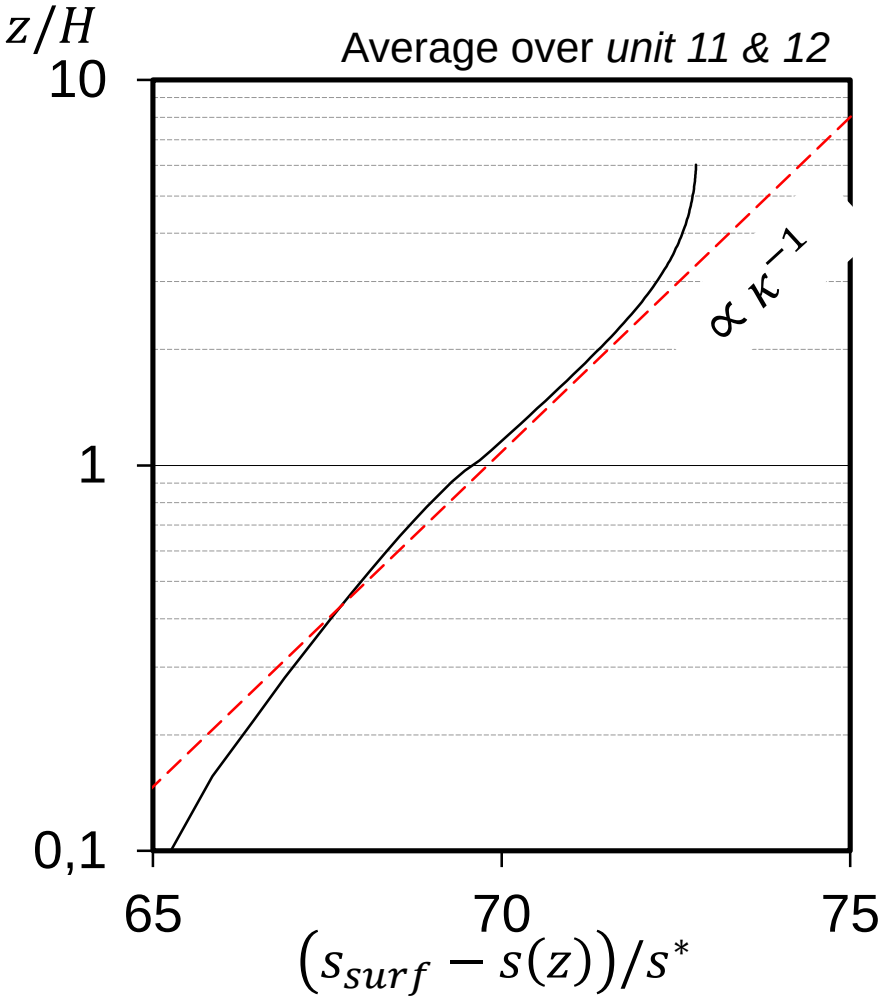
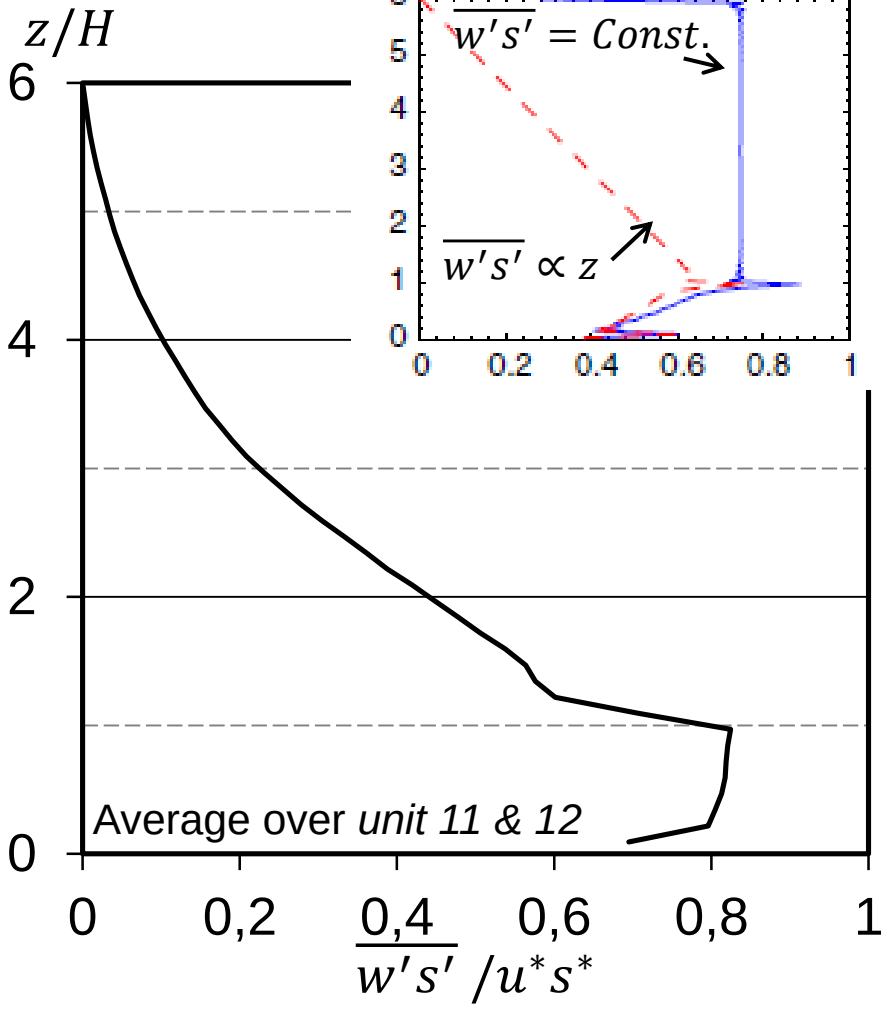

Scalar field
Flow
s/s^*
0
10
Plan View (z/H = 2.0)
scalar source area
30
20
10
0
y/H
unit 11&12
Side View
Side View
4.0
2.0
0.0
z/H
x
unit 11&12

Scalar concentration & flux



Unstable (Boppana et al. 2014)



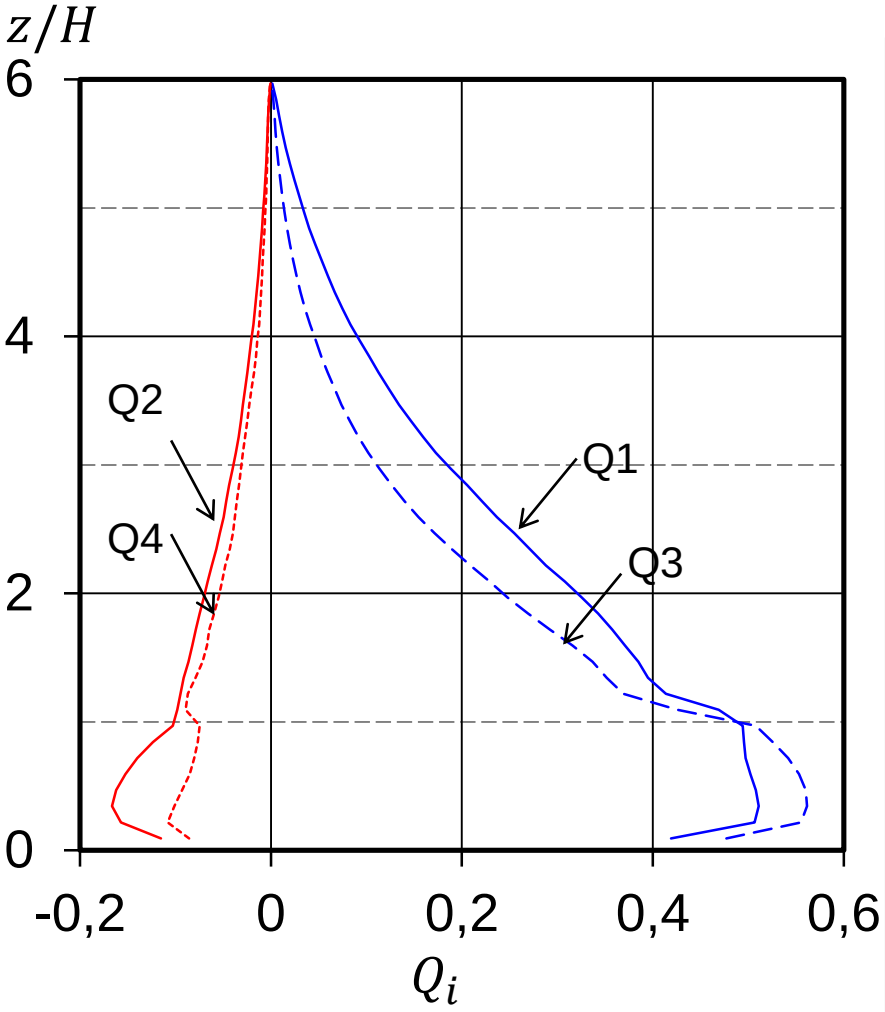
Log-law for scalar

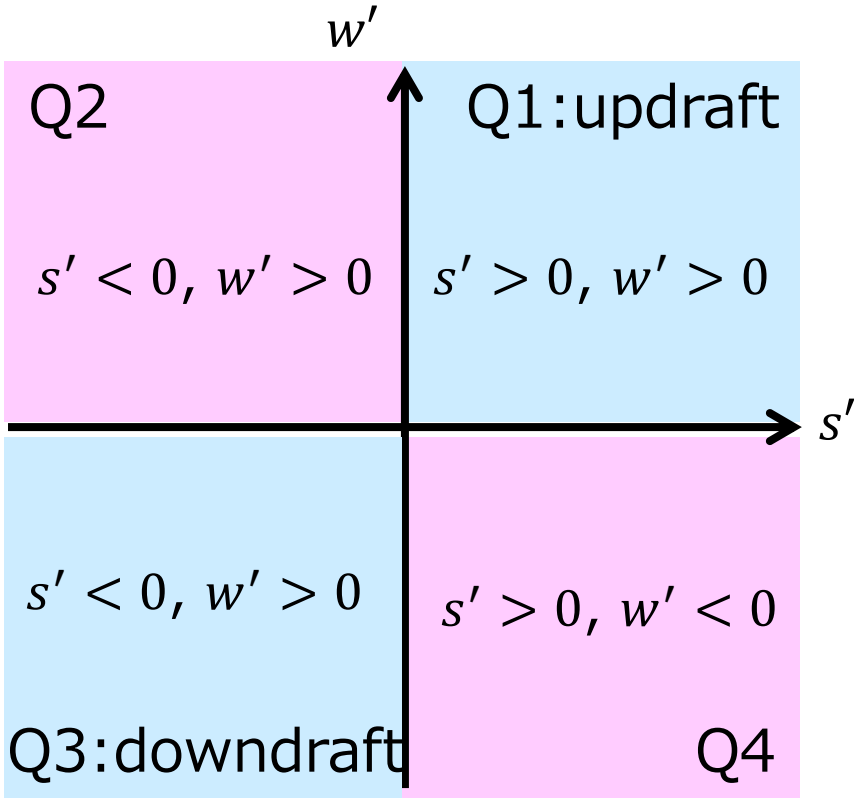
$$\frac{s_{surf} - s(z)}{s^*} = \frac{1}{\kappa}\ln\left(\frac{z}{z_{os}}\right) \longrightarrow \frac{\partial s}{\partial z} = \frac{s^*}{\kappa z}$$

$\overline{w's'} = const.$: zero. grad. at top

$\overline{w's'} \propto z$: body source

Turb. flux in each quadrant



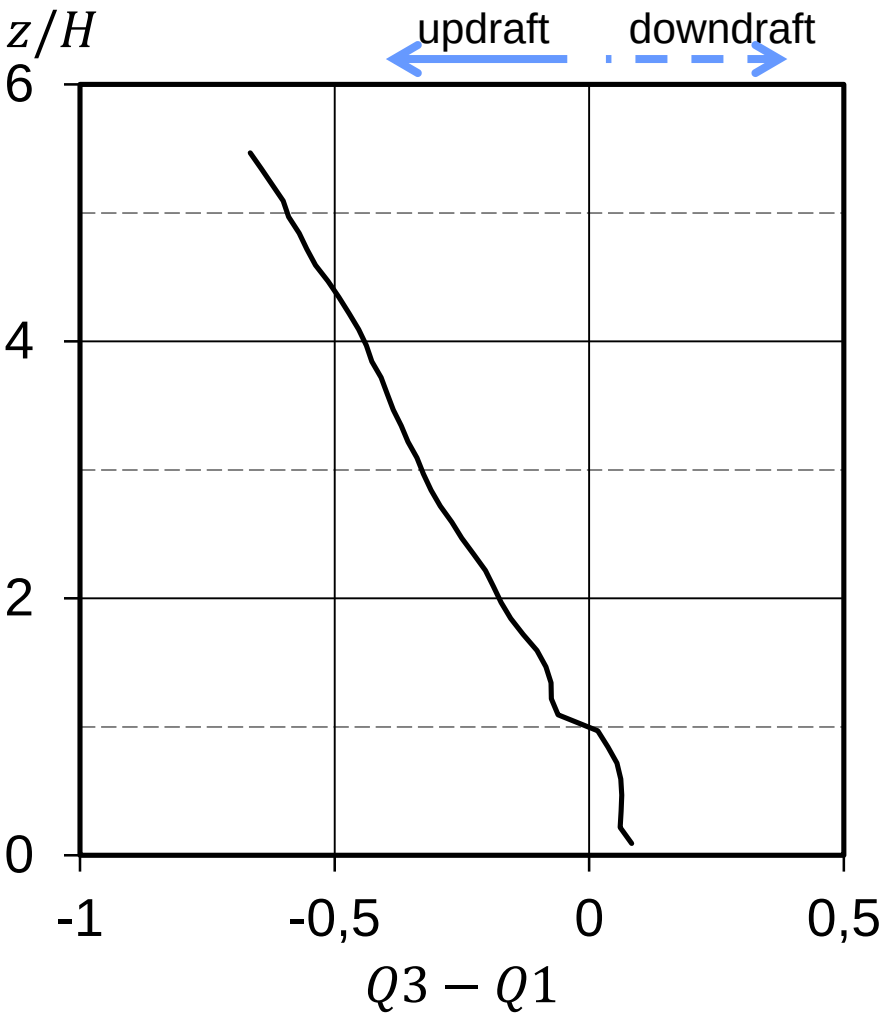


$$Q_i = \frac{\sum s'w'}{N\overline{s'w'}}$$

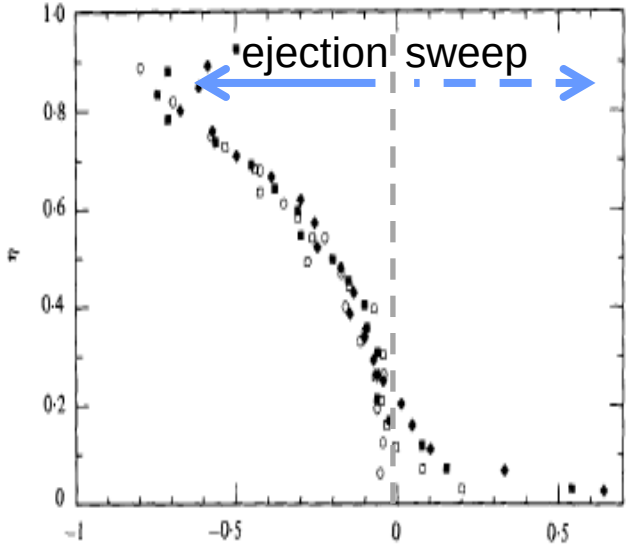
if $s' > 0,\ w' > 0$ in i-th quadrant

*N:# of sample

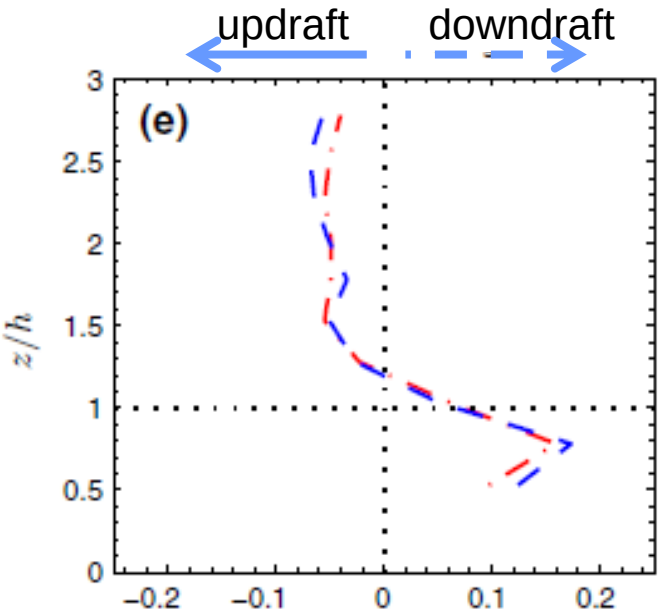
Dominant contribution



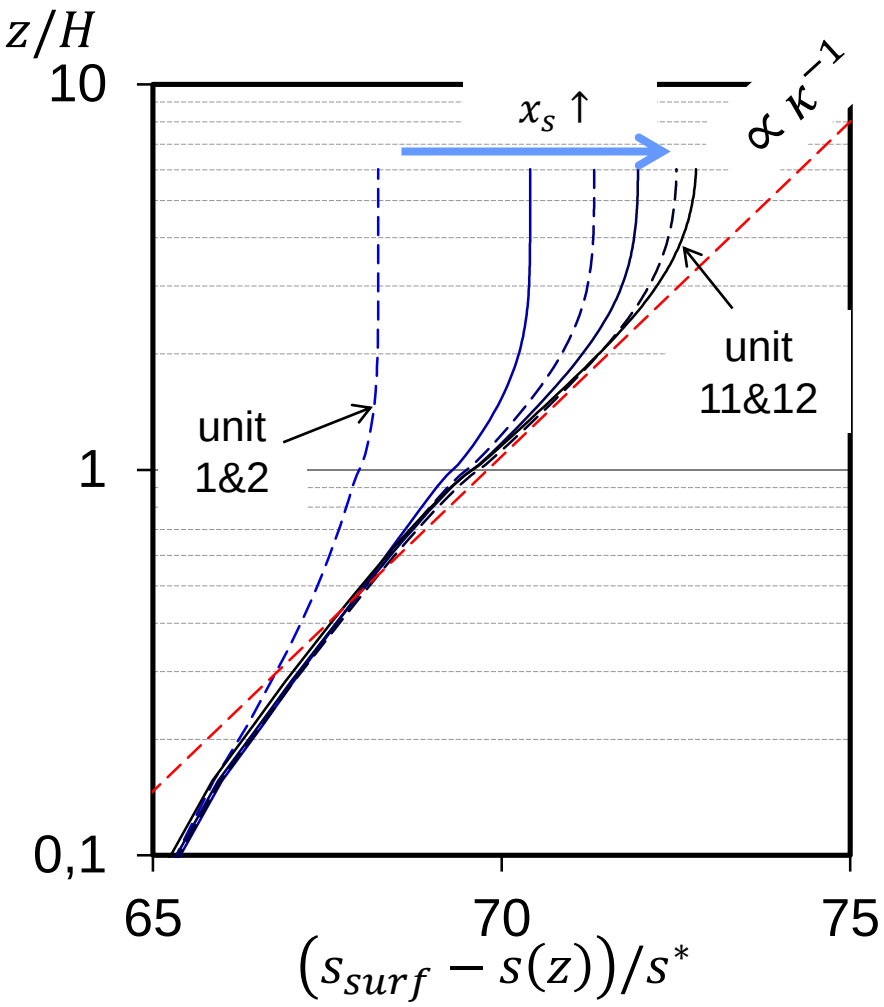
Momentum (Raupach 1981)

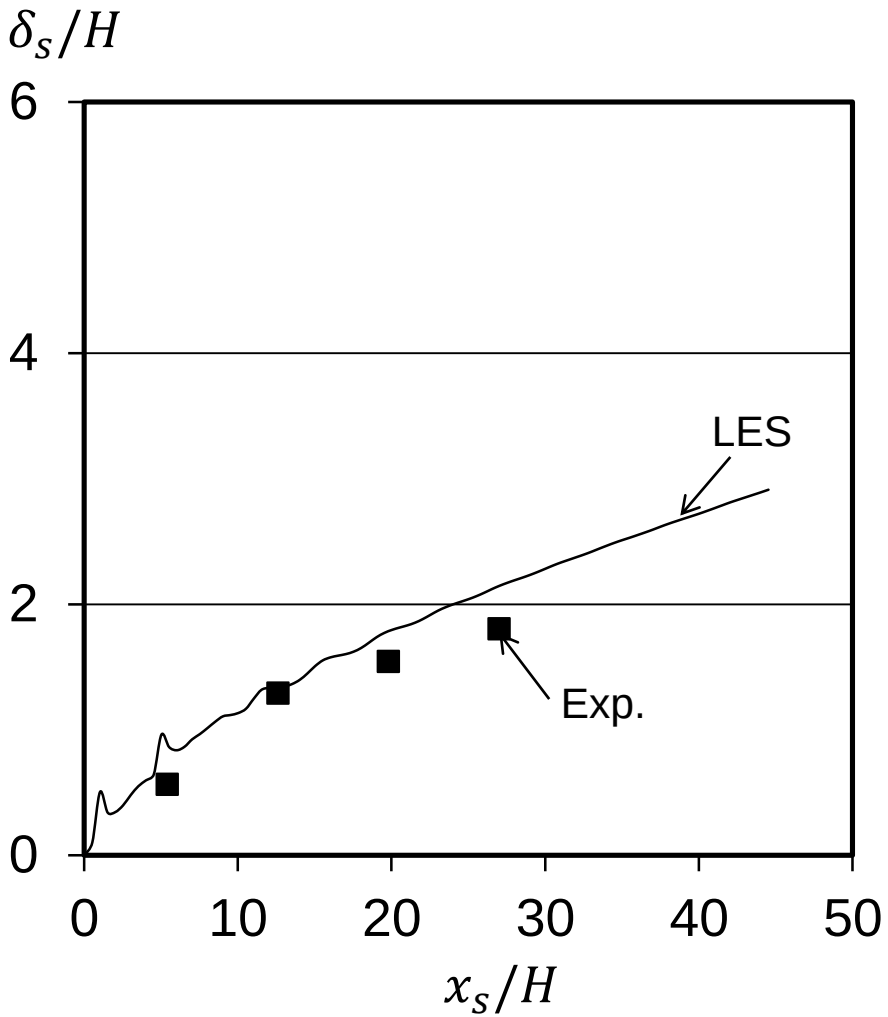


Heat, unstable (Boppana et al. 2014)



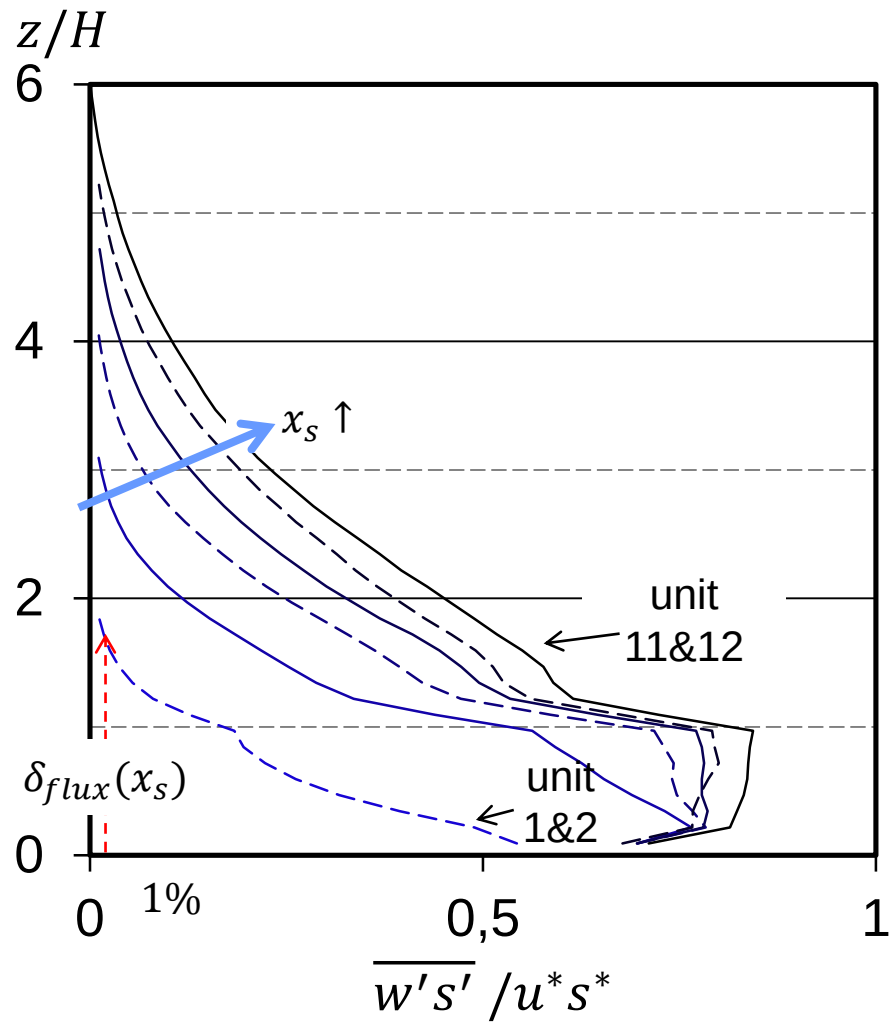
Streamwise development -concentration-

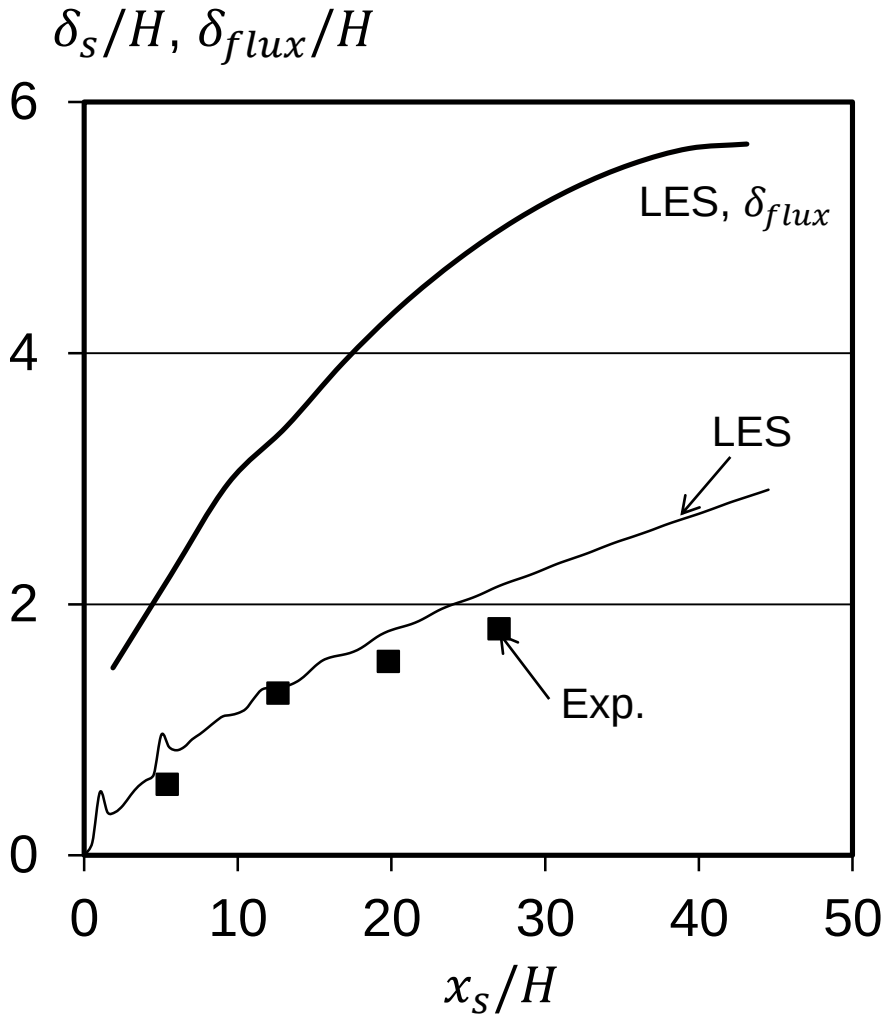




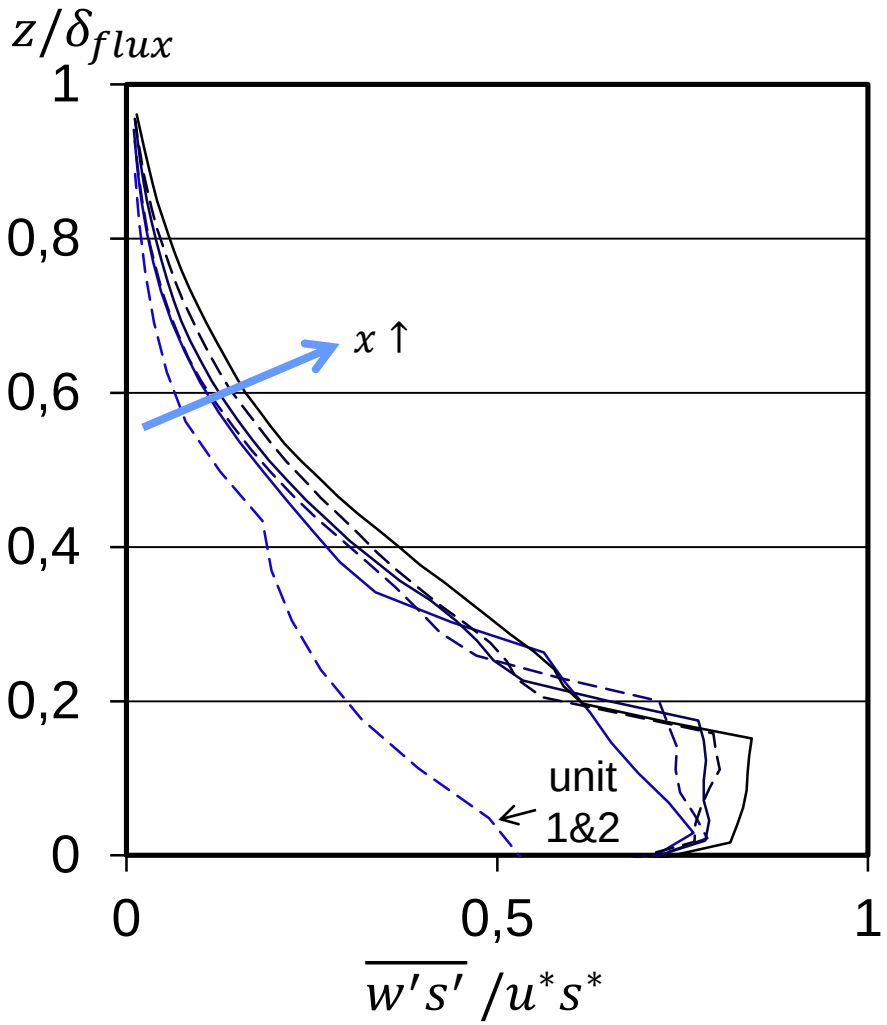
δ_s : 1% scalar BL thickness
x_s : streamwise distance
s^*: friction scale
s_{surf} : surf. conc.

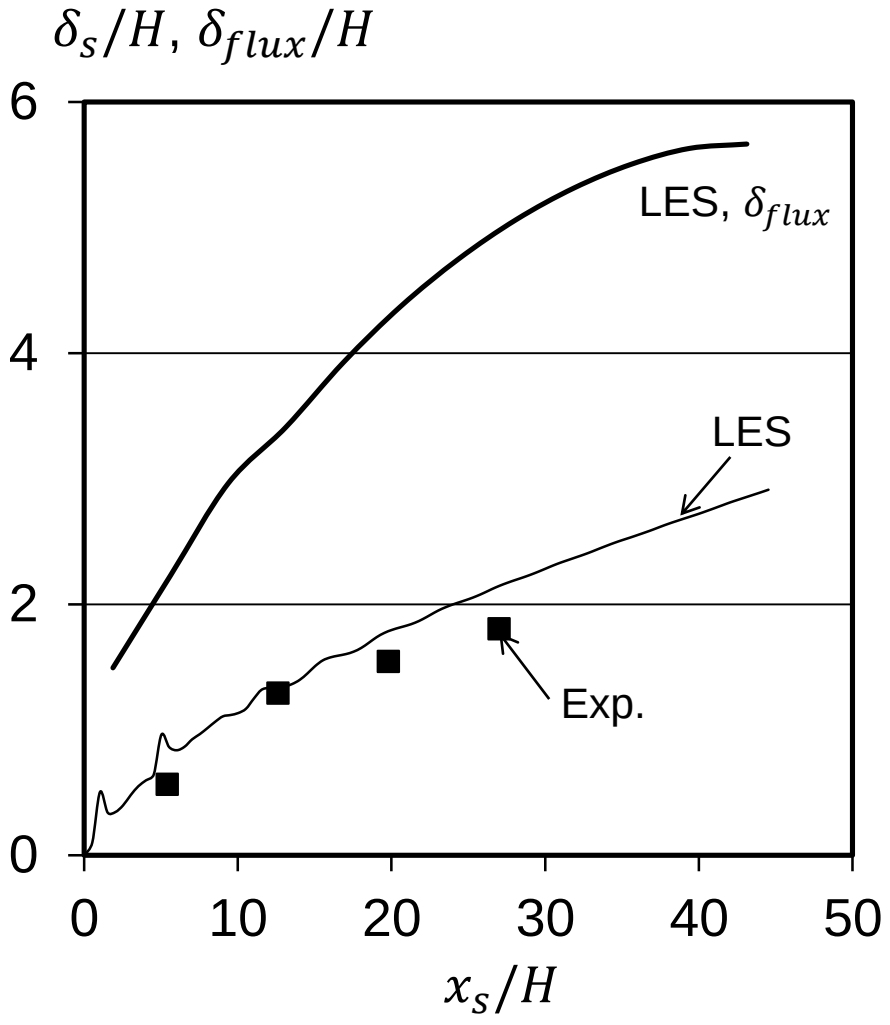
Streamwise development - turb. flux-





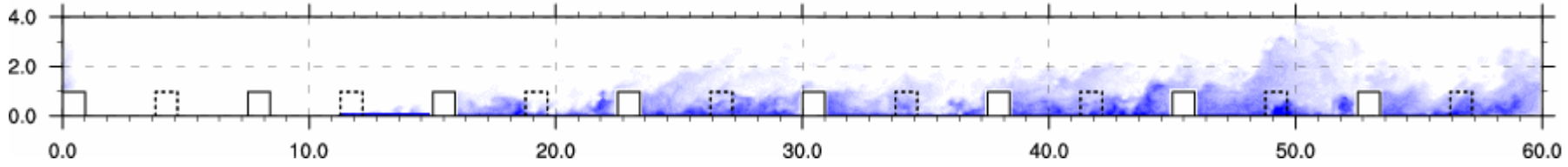
Streamwise development - turb. flux-





Conclusions

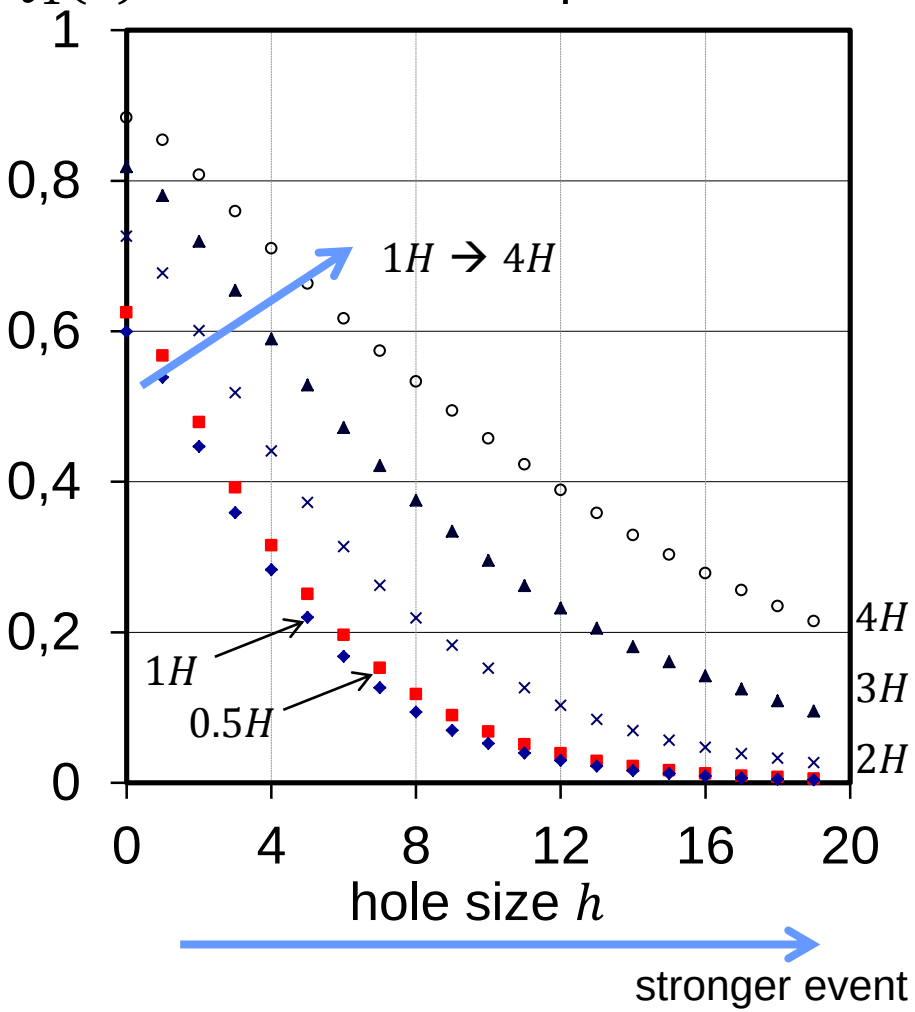
- Surface flux determination
  - friction scalar s* normalization
- Turbulent statistics
  - log-law profile for $\left(s_{surf} - s(z)\right)/s^*$
  - similar characteristics of updraft / downdraft to momentum transfer.
- Streamwise trends characteristics
  - extension of low-law region confirmed
  - self-similar profile for turbulent statistics observed



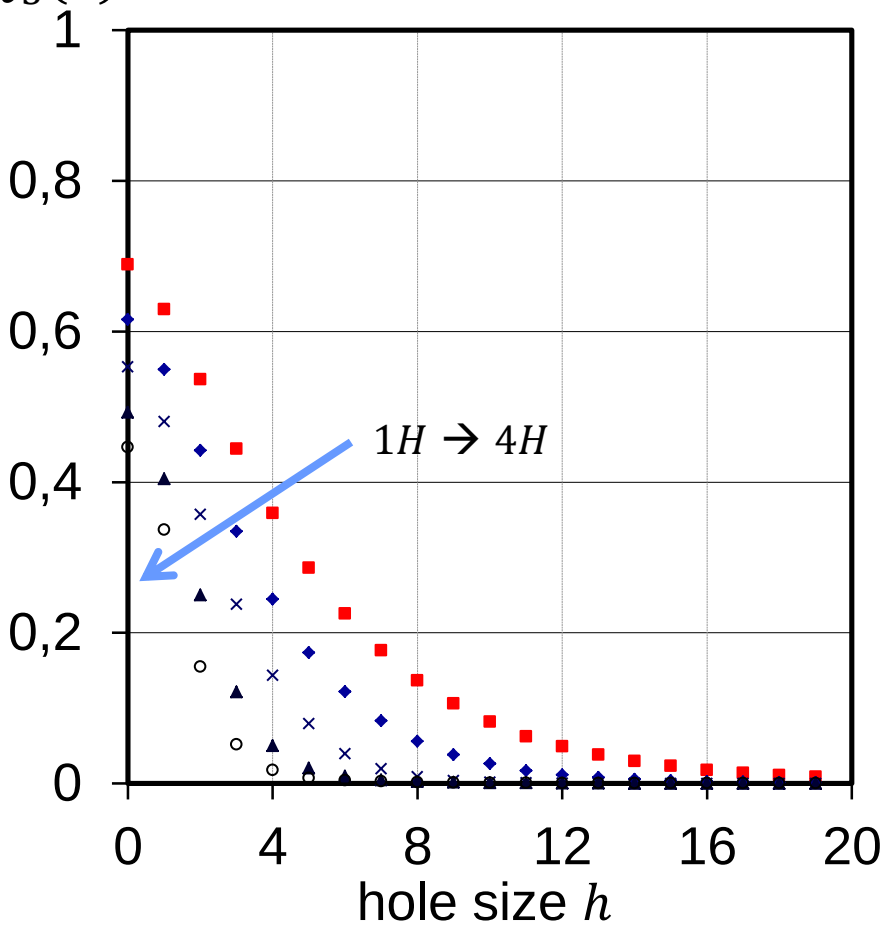
Thank you for your attention

Effect of hole size

$Q_1(h)$: Contribution of updraft



$Q_3(h)$: Contribution of downdraft



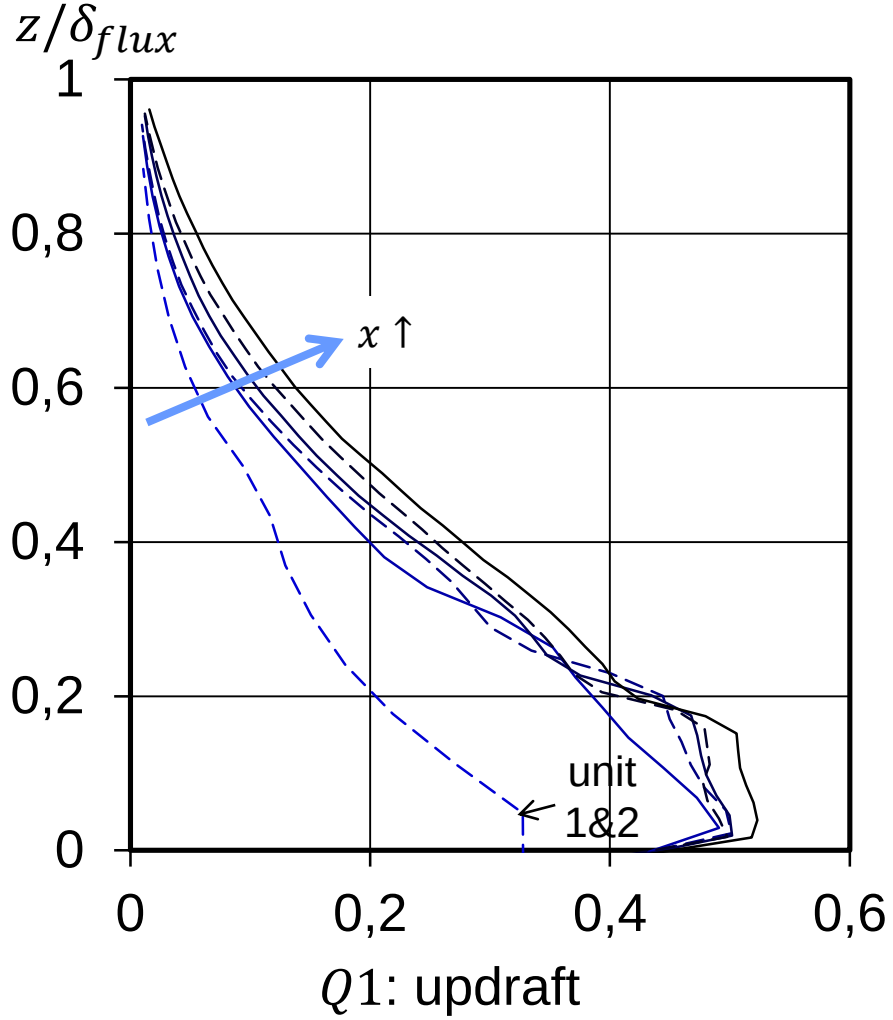
$$Q_i(h) = \frac{\sum s'w'}{N\overline{s'w'}}$$

if

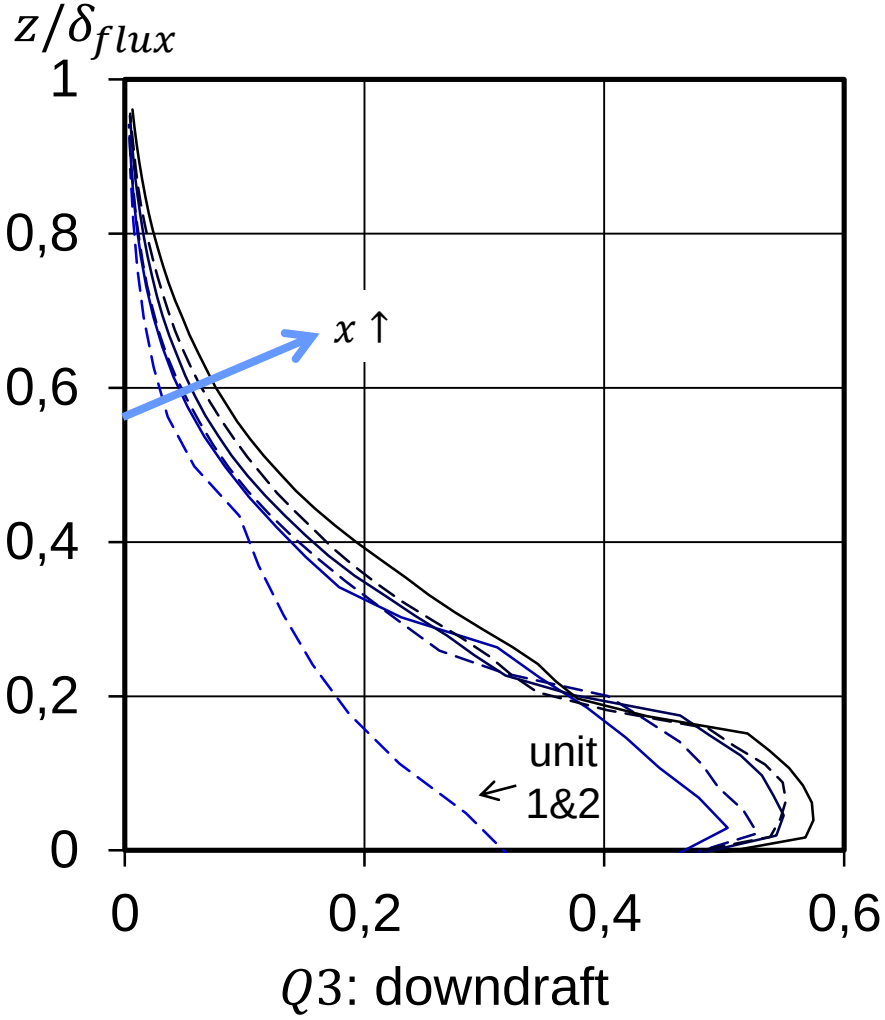
$w's' > h \times \overline{w's'}$

in i-th quadrant

Streamwise similarity - Q1, Q3

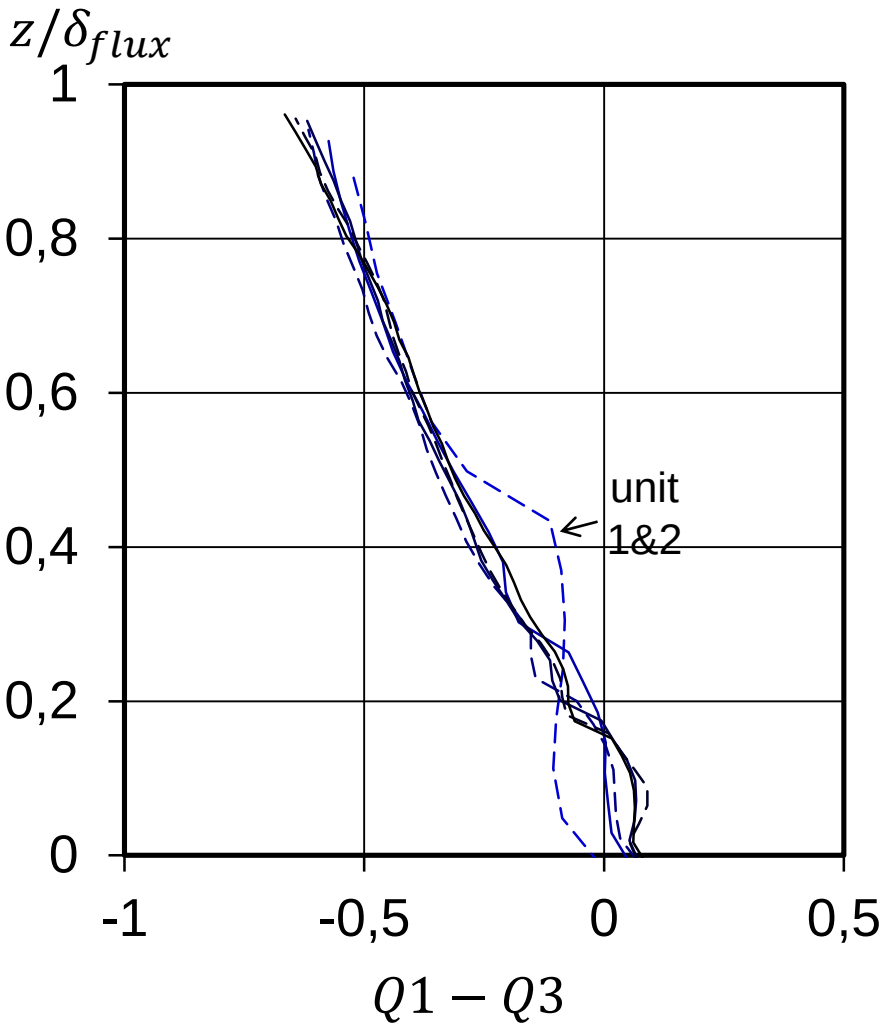


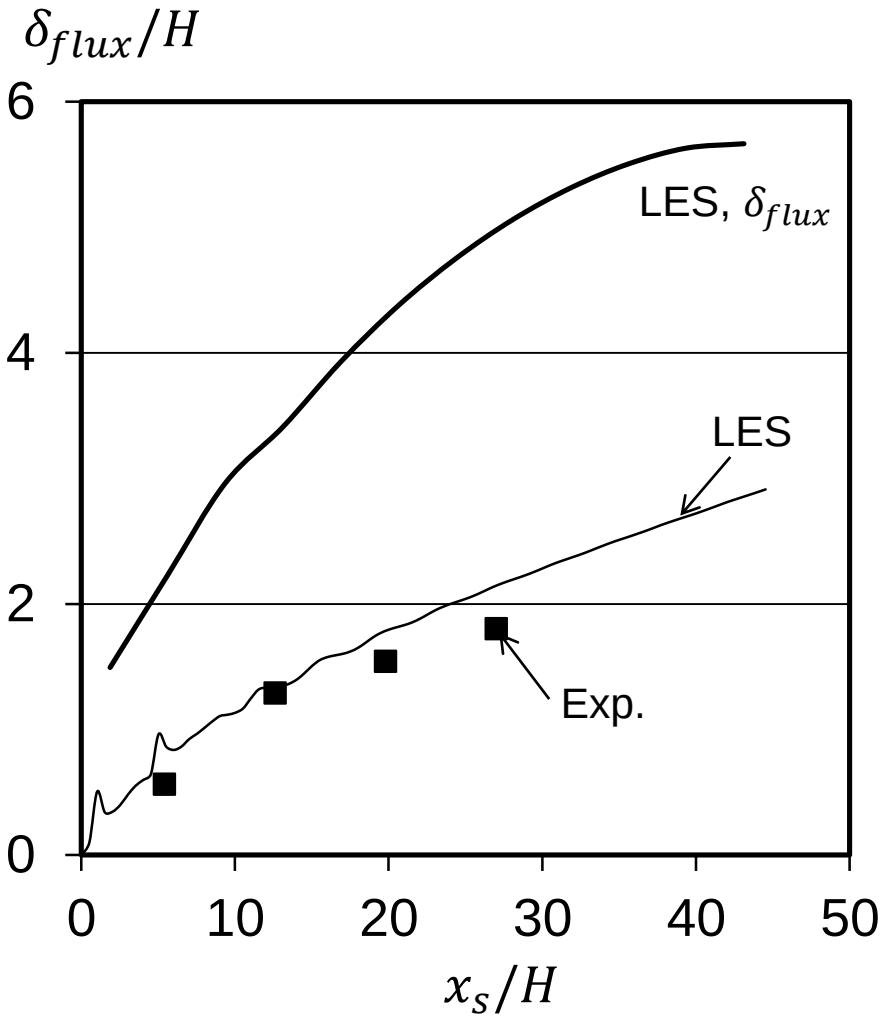
$Q1$: updraft



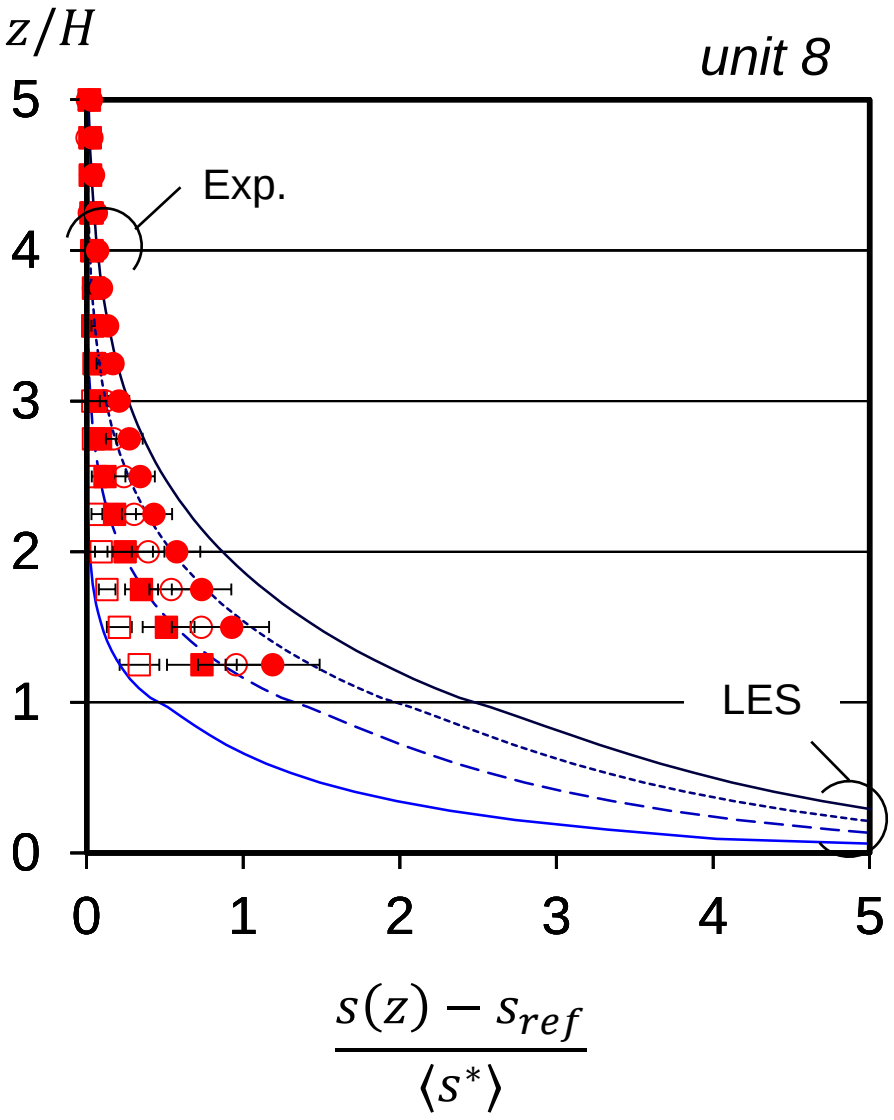
$Q3$: downdraft

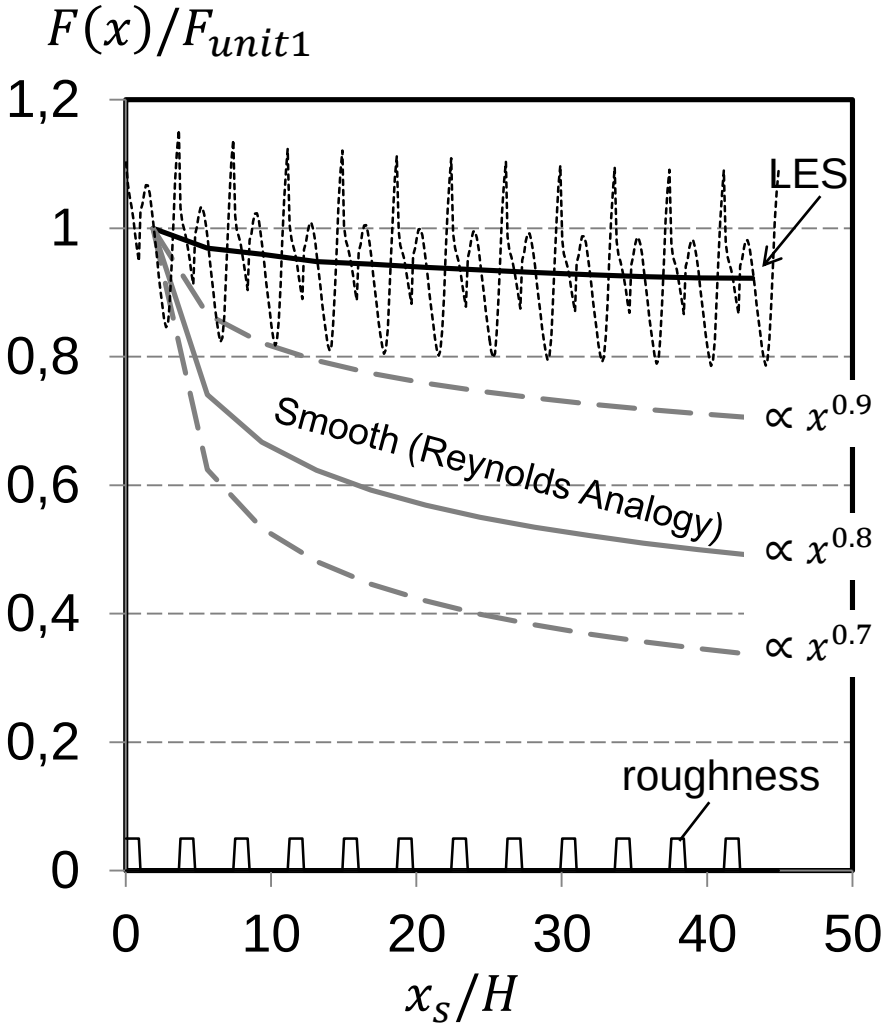
Streamwise similarity - Q1, Q3



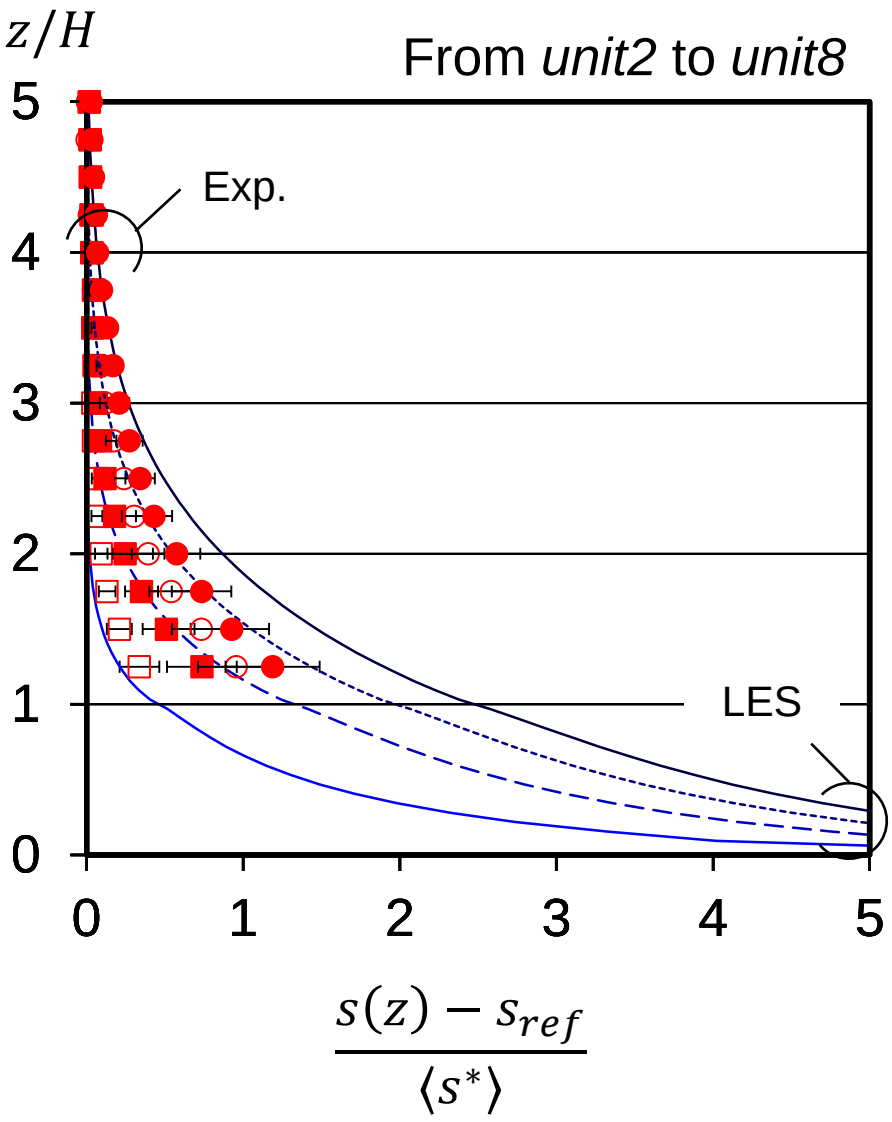


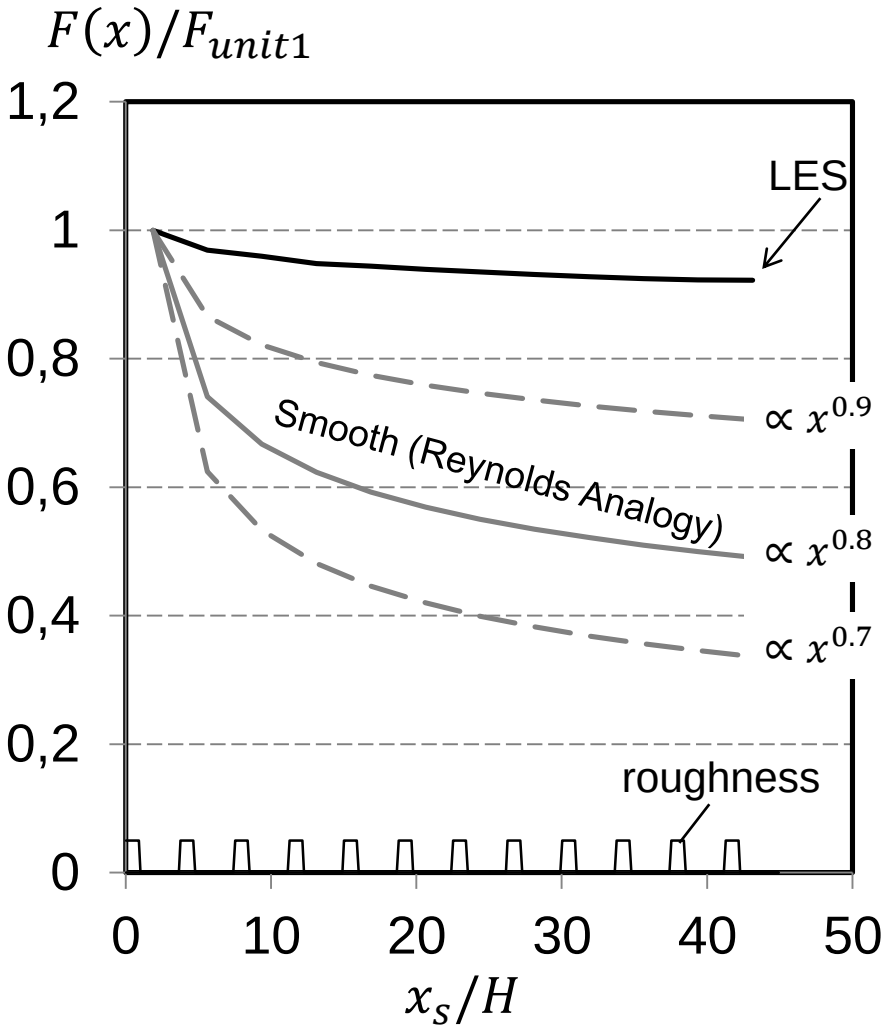
Comparison with Exp. -2-





Comparison with Exp. -2-





Introduction

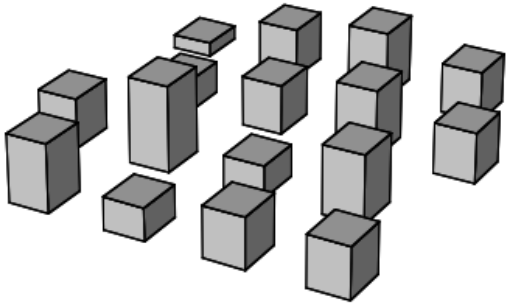
(1) Physical process of transport phenomena
(2) Modeling of surface fluxes

Atmosphere

Momentum / Scalar transport

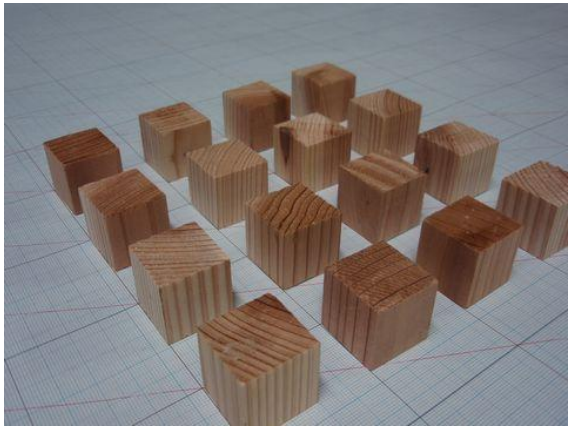
Urban area

Simplified model



Cheng & Castro, 2002

Inagaki & Kanda, 2008



Hagishima et al. 2009

Geometric dependency of transport phenomena over rough surface