Karlsruhe Institute of Technology

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Inner-outer layer interaction in drag-reduced turbulent channels

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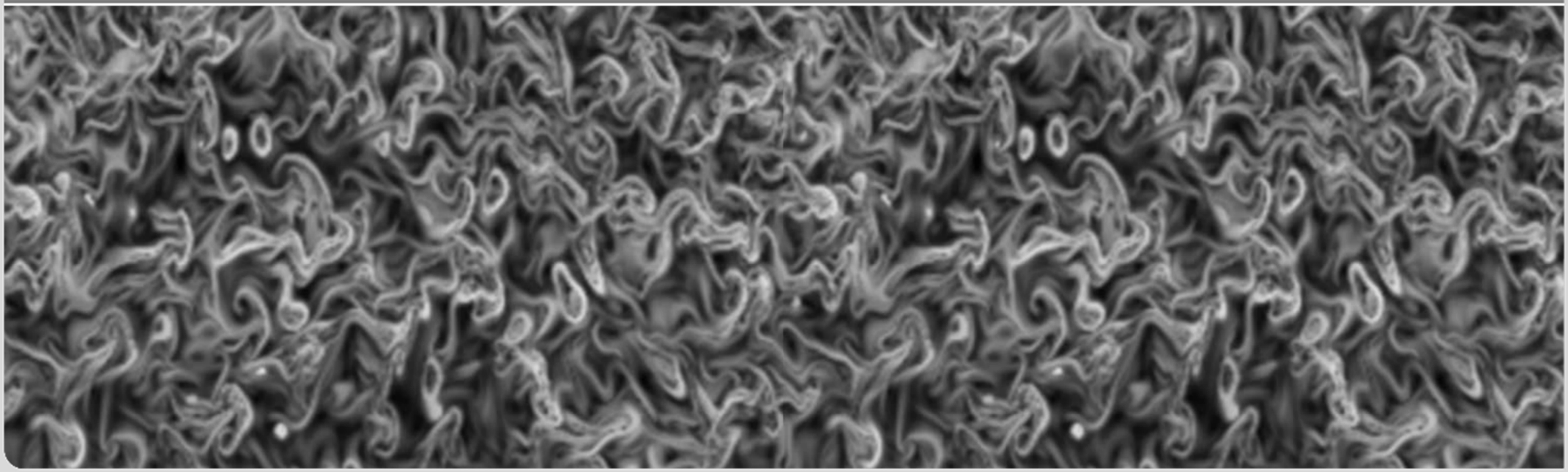
DFG Turbulent Superstructures

11th European Fluid Mechanics Conference, Sevilla, Spain

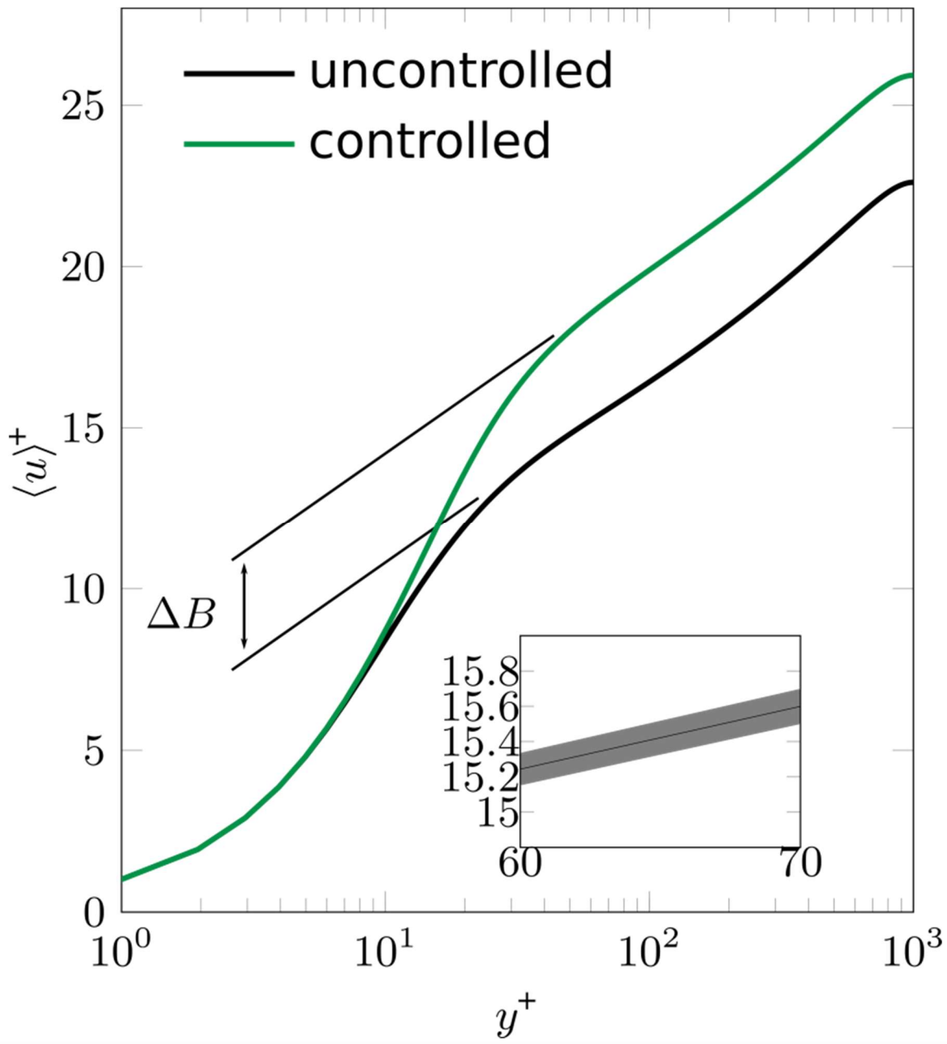


Background

active wall-based turbulent skin-friction drag reduction:
is it possible at large values of Re?

YES sizeable amount of drag reduction can be achieved at high Re
(Gatti & Quadrio, JFM 2016)

$$\Delta B = \sqrt{\frac{2}{C_{f,0}}}\left[(1-R)^{0.5}-1\right] - \frac{1}{2\kappa}\ln(1-R)$$



Background

active wall-based turbulent skin-friction drag reduction:
is it possible at large values of Re?

YES sizeable amount of drag reduction can be achieved at high Re
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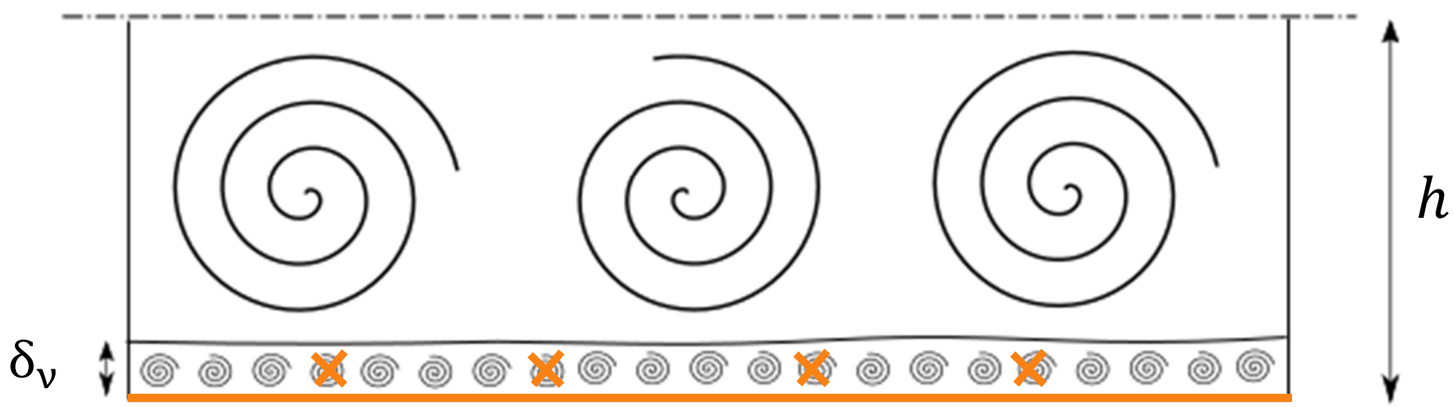
NO turbulent large-scale structures

- carry large amount of Reynolds shear stress
- can not be affected by wall-based control



Goal

turbulent drag reduction as mean to assess

How do large scale structures interact
with the near-wall turbulence?

today's actual goal

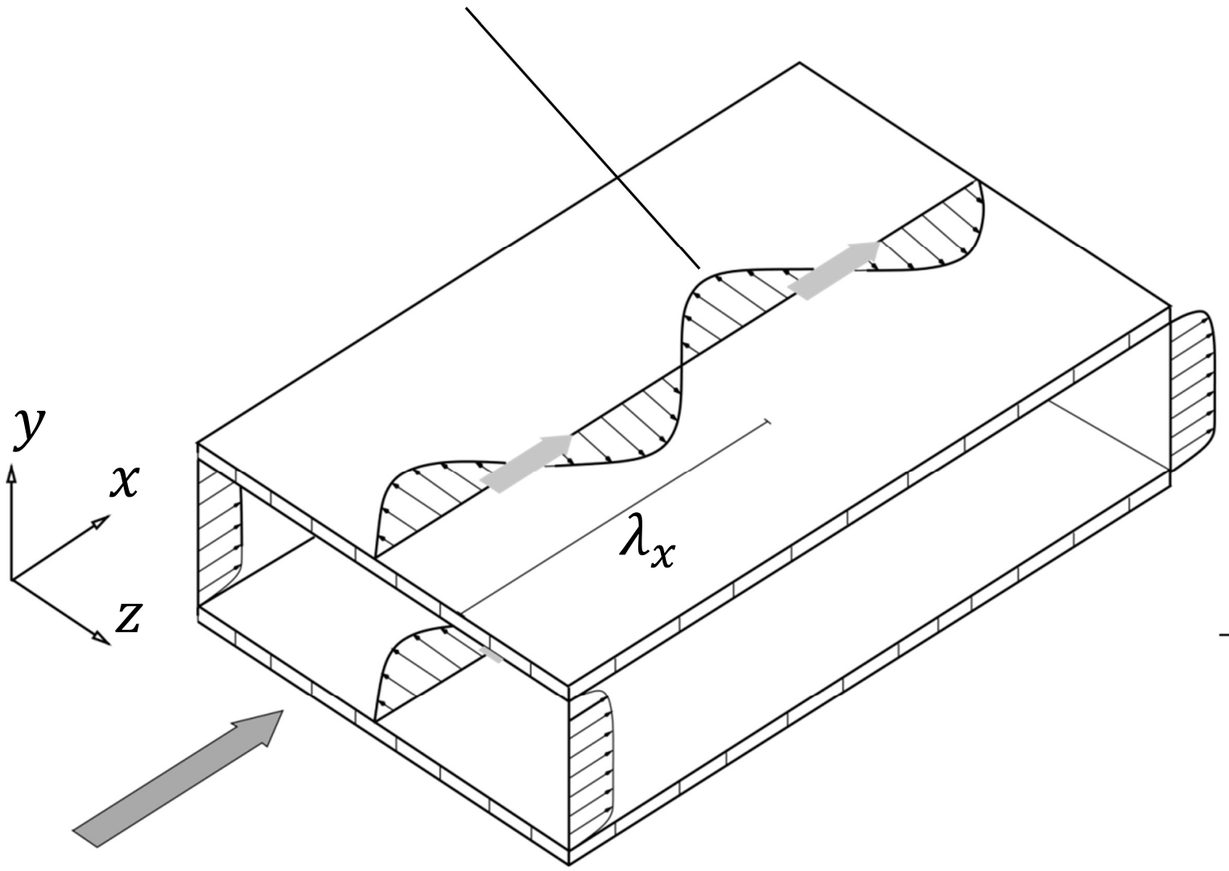
Is a particular realization of large-scale structures
affected by wall-based flow control?

in particular: is the near-wall "footprint"
affected by the control?

Model control strategy

Streamwise-travelling wave of spanwise wall velocity

$$w_w = A\sin(\omega t - \kappa_x x)$$

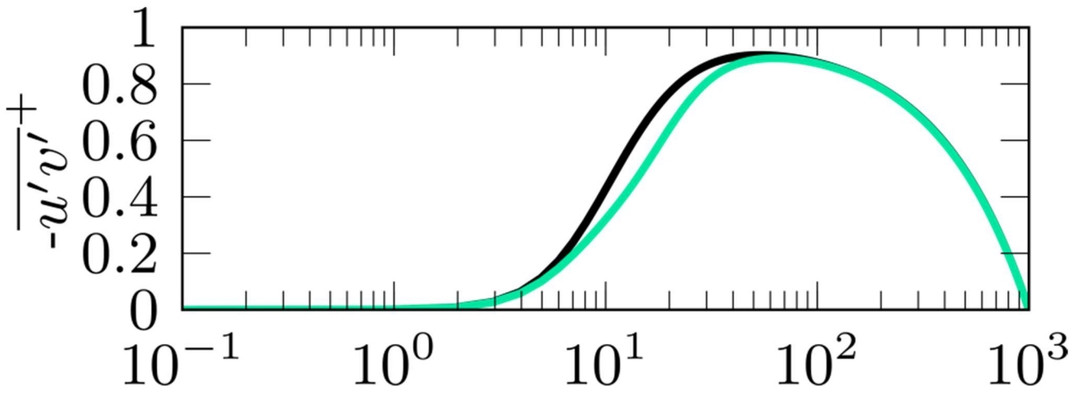


Constant Pressure Gradient

$$Re_\tau = 1000$$

$$\frac{U_b}{U_{b,ref}} = 1.17$$

$$R = 1 - \frac{C_f}{C_{f.ref}} = 26.4\% \pm 0.6\%$$



Quadrio, Ricco & Viotti, JFM 2009

Large scales?

Today‘s definition:

long meandering streamise velocity fluctuations,
very long compared to the underlying small-scale fluctuations,
as observed in wall-parallel planes.

adapted from Hutchins & Marusic, JFM, 2007

- not Galilean invariant, thus…
- Reynolds decomposition to be used with care in structural analysis

Kwon, Hutchins, Monty, JFM, 2016

Eduction strategy:

two-dimensional Huang-Hilbert Empirical Mode Decomposition

Huang et al., Proc. R. Soc. A, 1998
Agostini & Leschziner, PoF, 2014

- no filter lengthscales to be defined a priori
- “structures” do not necessarily have compact support in Fourier space

Empirical Mode Decomposition

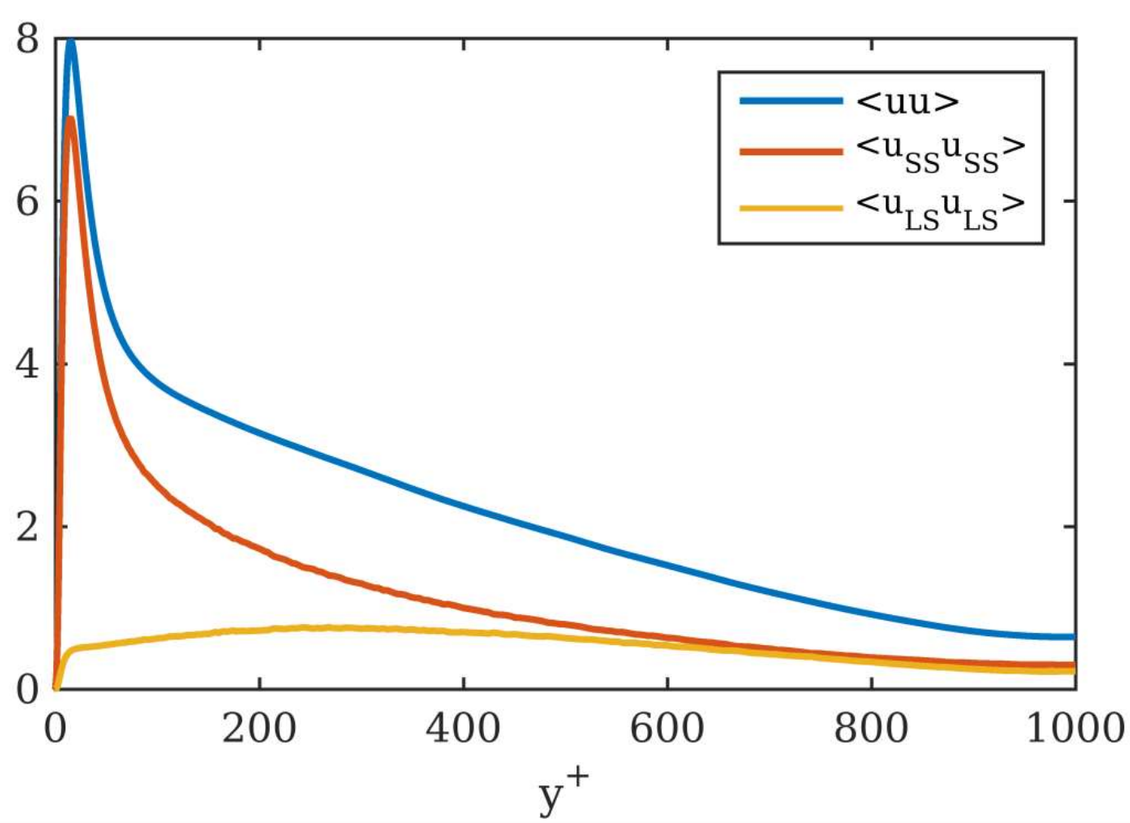
$$u(x,z) = \sum_{i=1}^{n} IMF_i + res_n$$

$$u(x,z) = u_{SS} + u_{LS}$$

$$u_{LS} = \langle u \rangle + u'_{LS}$$

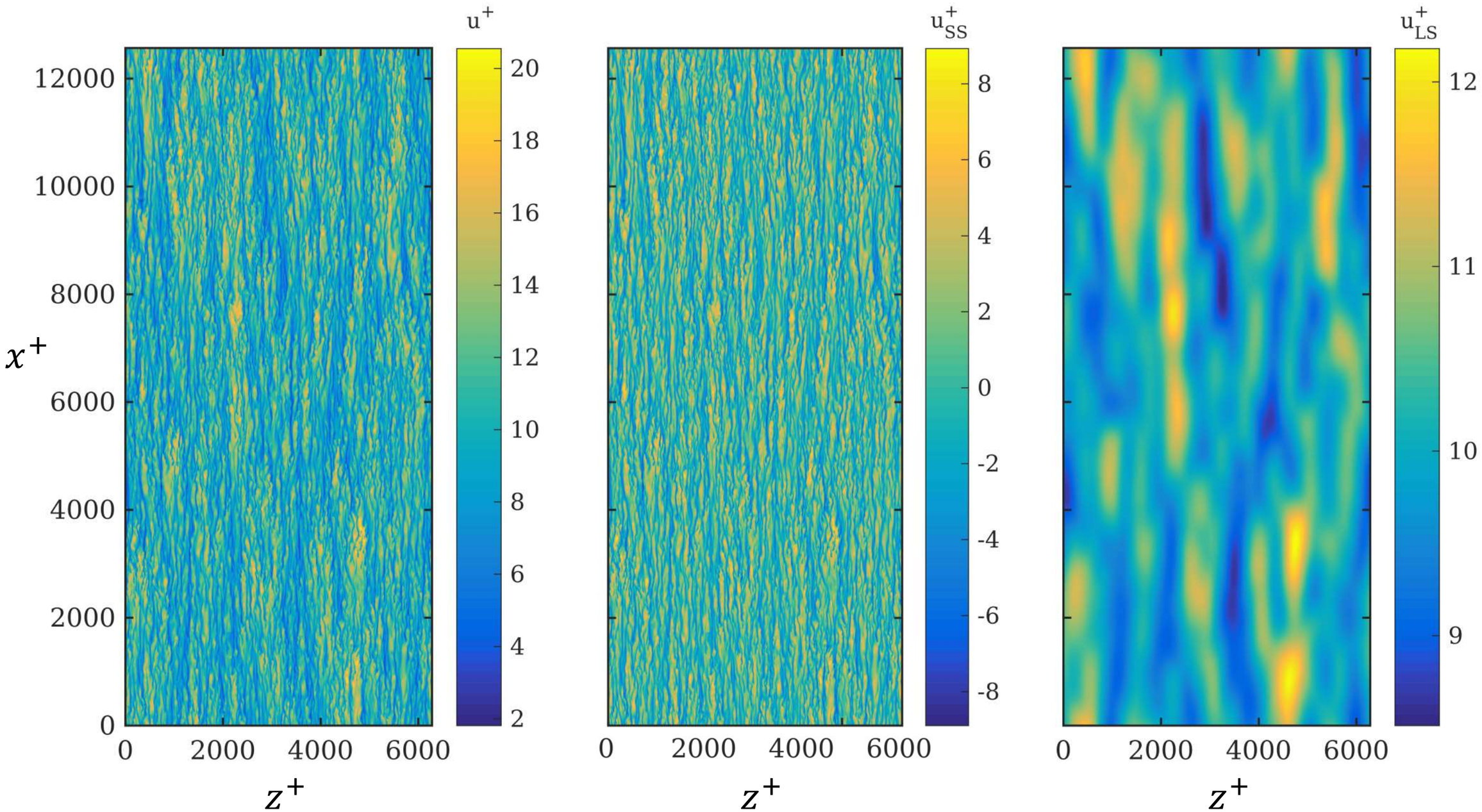
IMF_i are Intrinsic Mode Functions

- $\overline{IMF_i} = 0$
- function shape not known a priori

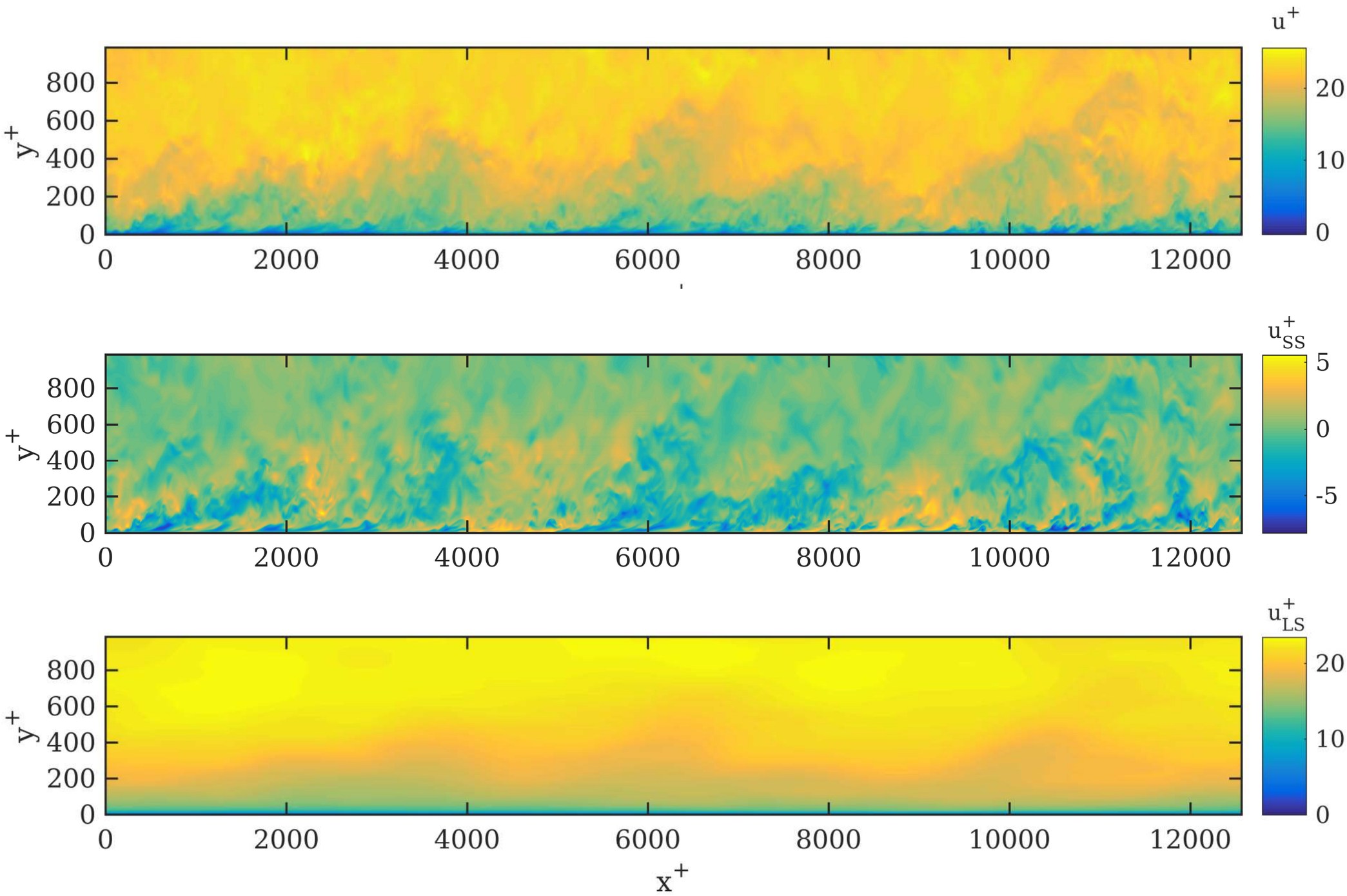


Eduction results (1)

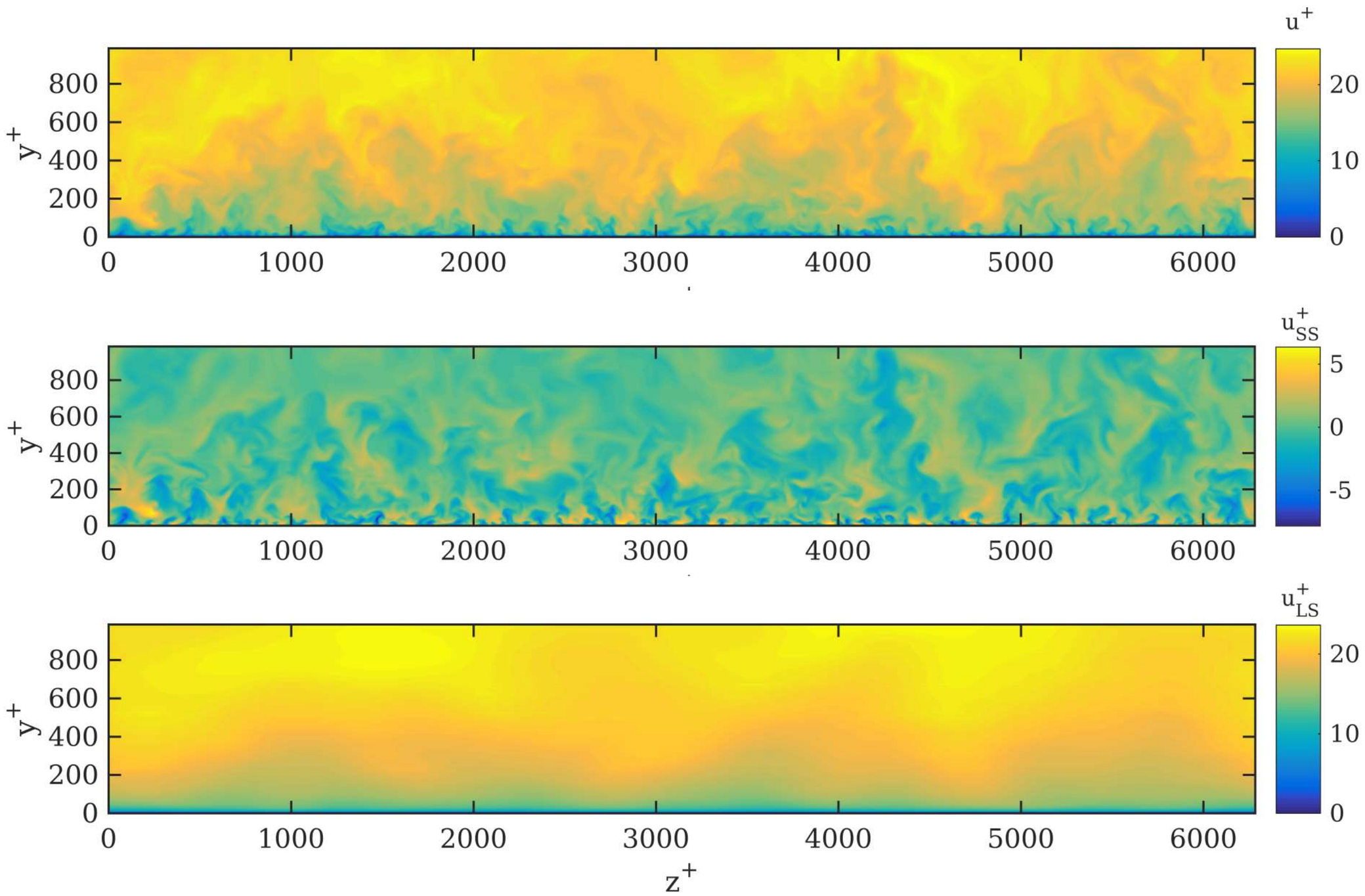
streamwise-velocity at $y^+ = 15$ (wall-parallel planes)



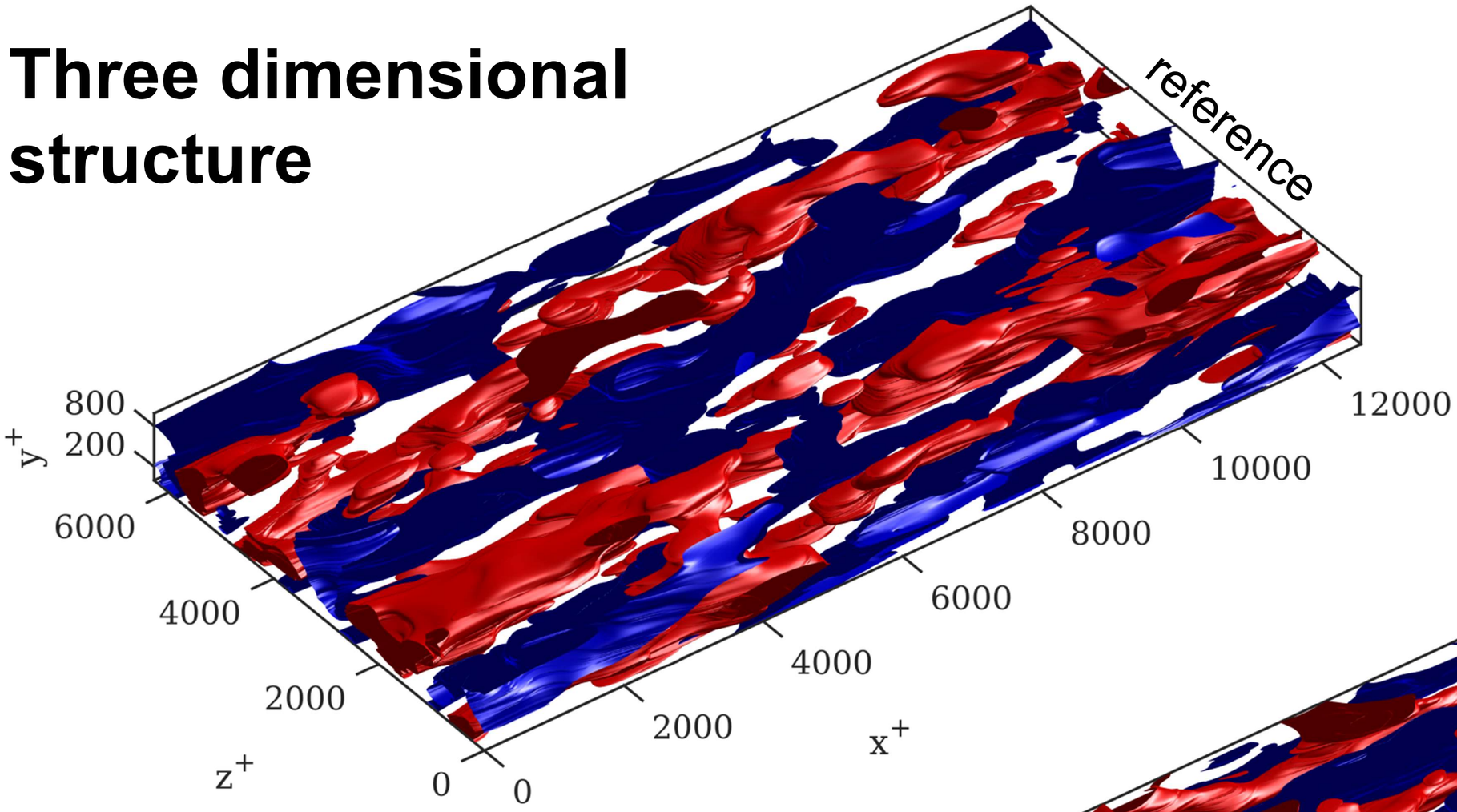
Eduction results (2)

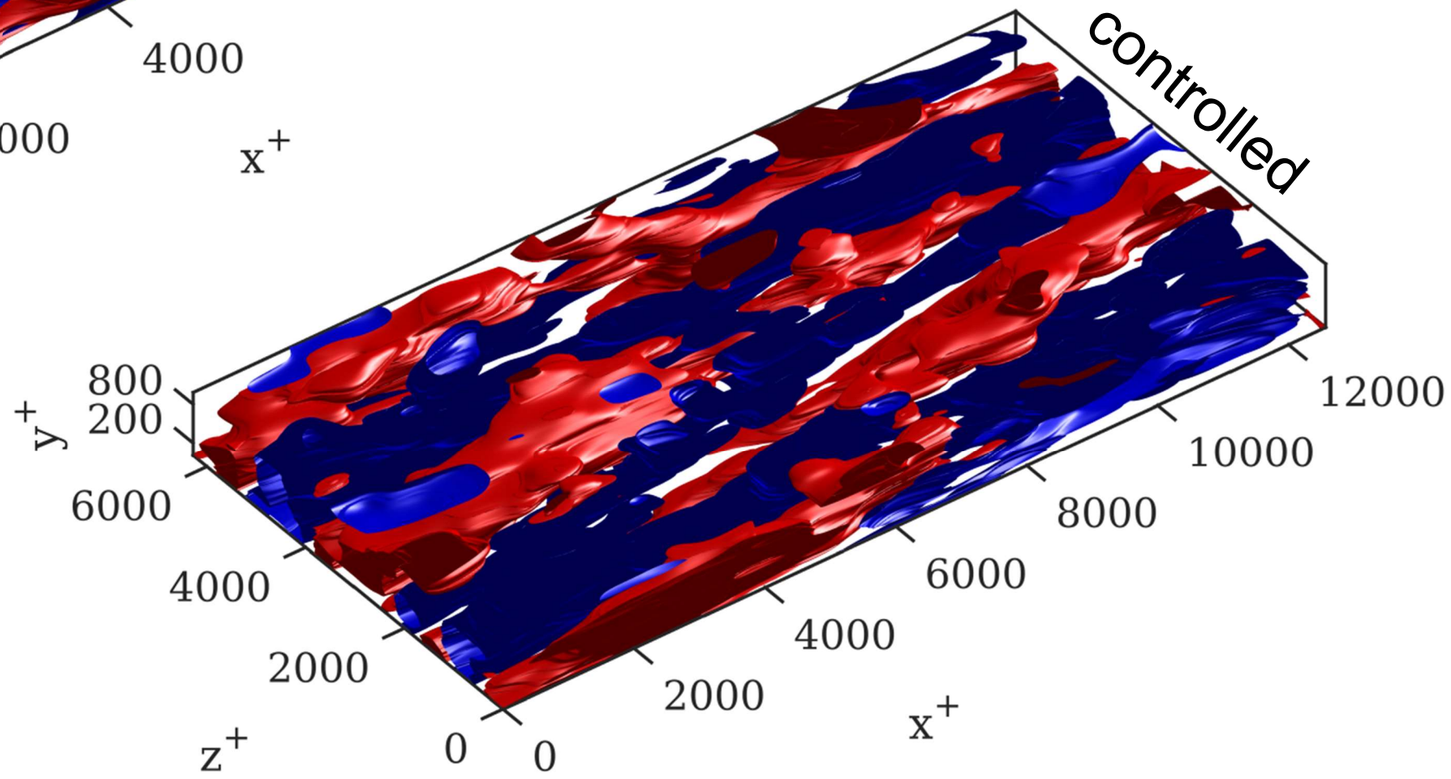


Eduction results (3)



Three dimensional structure



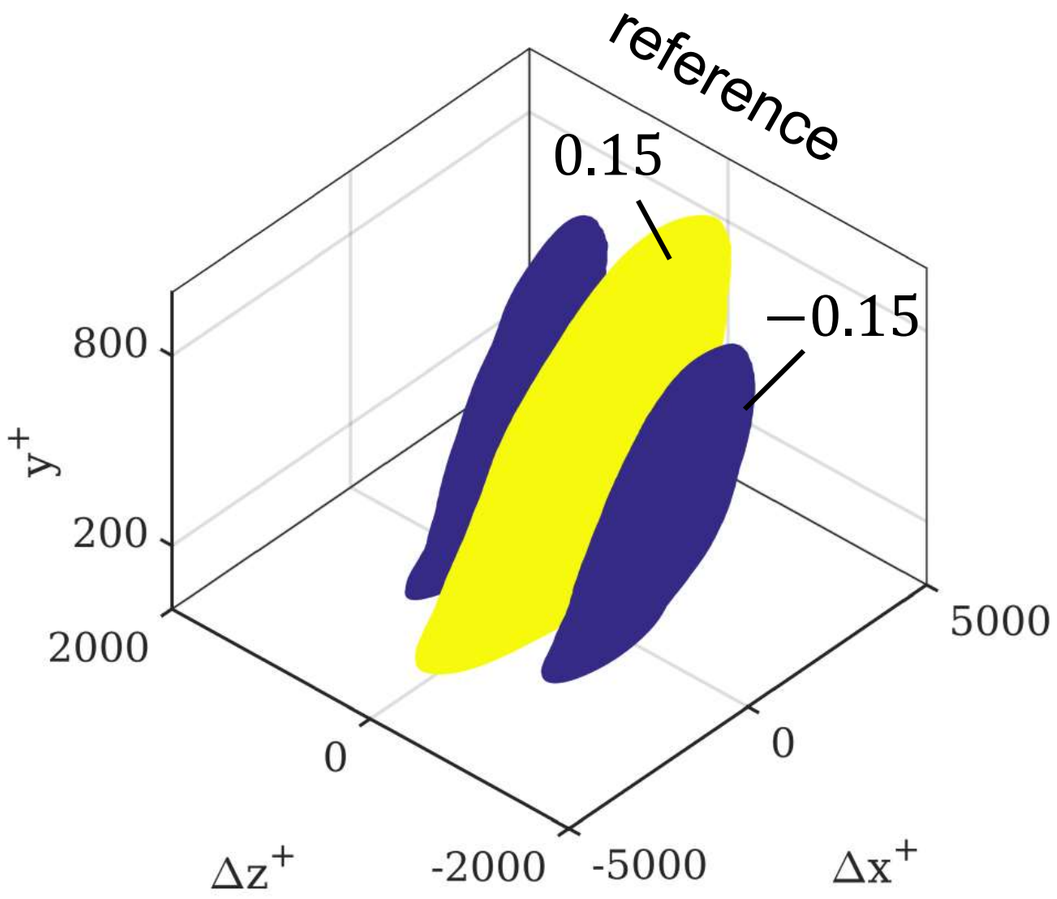


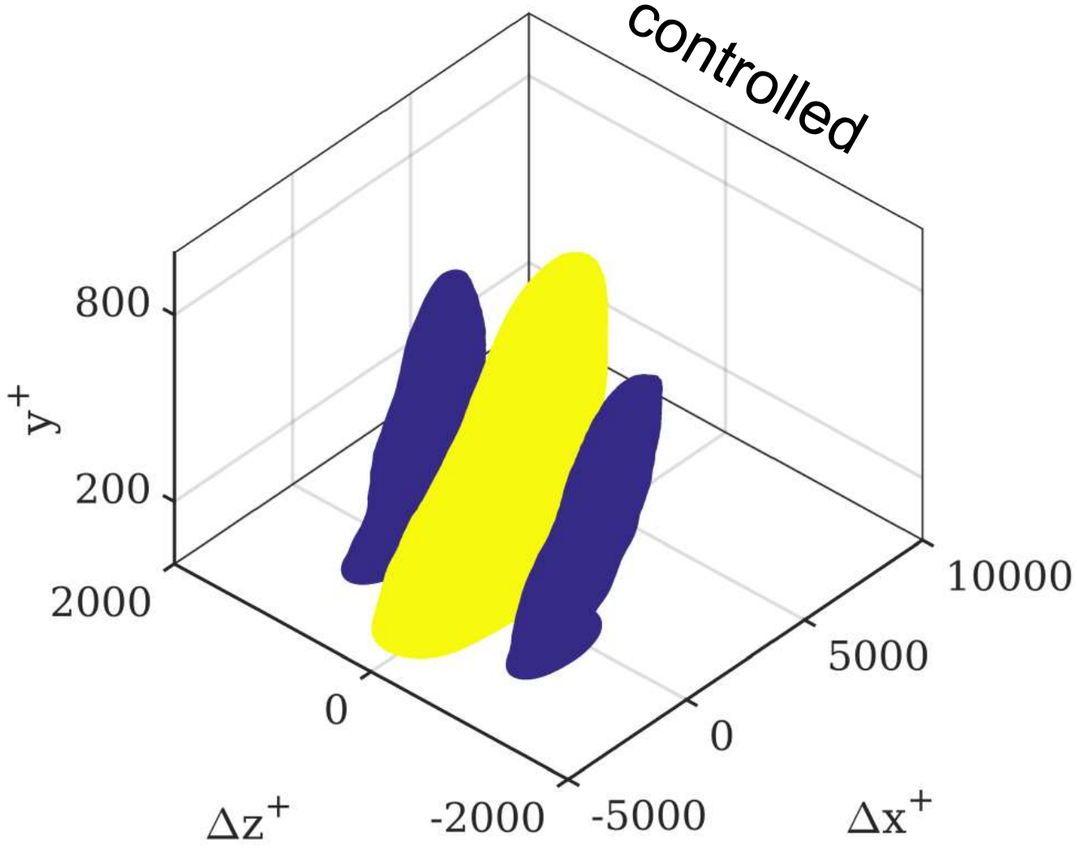
isosurface at

$$u'_{LS} = \pm \max(u'_{rms})/4$$

Footprint onto skin-friction

correlation between τ_{LS} and u'_{LS} at different channel heights





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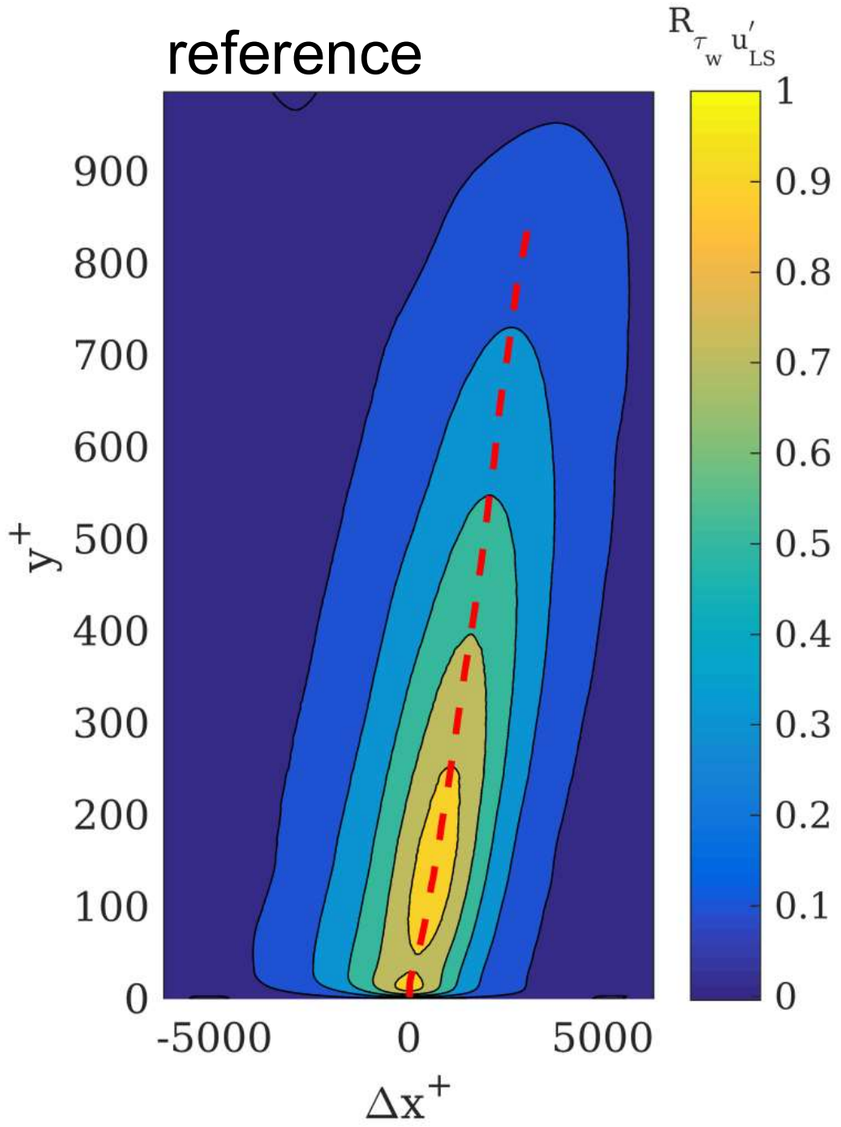

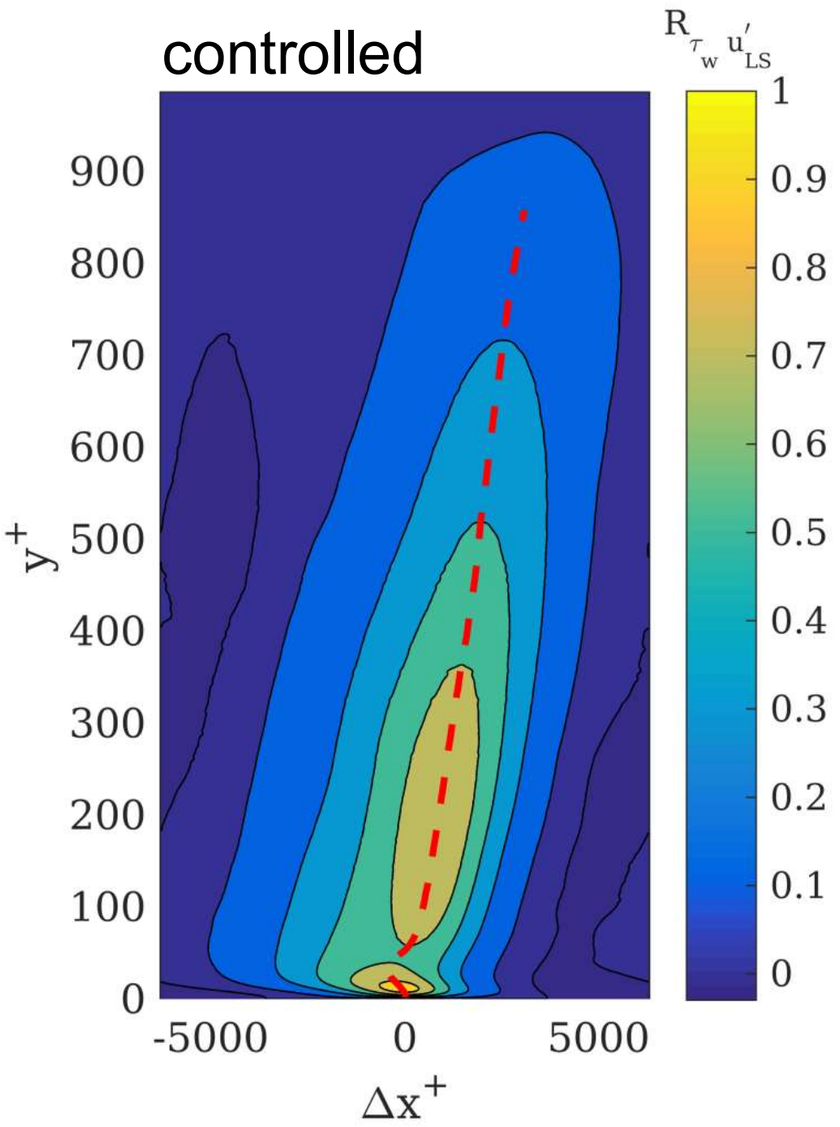

Conclusions

- Two dimensional Empirical Mode Decomposition

  arbitrary yet useful method to separate large scales

  can be applied to three-dimensional flow data

- Three dimensional topology of large scales

  long regions of positive and negative fluctuations

  alternates in the spanwise direction with spacing $\lambda_z \approx 1000$

- Wall-based drag reduction and large-scale structures

  the correlation between large scale streamwise velocity

  and wall shear fluctuations is modified beyond

  the buffer layer

Outlook

- Streamwise velocity fluctuation are one (not Galilean invariant) symptom of large scale structures. Other exists:

  connected regions of $-uv$, vortex packets

- Give the structure a dynamics

  spatio-temporal correlation

  track temporal evolution of large scales

- Deepen the description of the present qualitative observation

  what causes the two-point correlation to change?

THANKS

for your kind attention!

for questions, complaints, ideas:

davide.gatti@kit.edu

Eduction results (3)