Harmo, 1.- 4. 6. 2010, Paris

Comparison between flow dynamics inside street canyon with two geometries of roof shape

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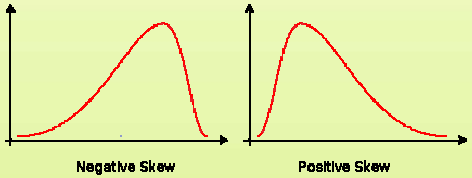
Ventilation of the street canyon

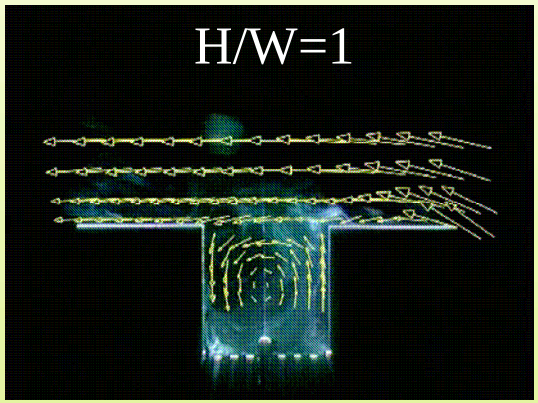
Janet F.Barlow and Bernd Leitl, 2007

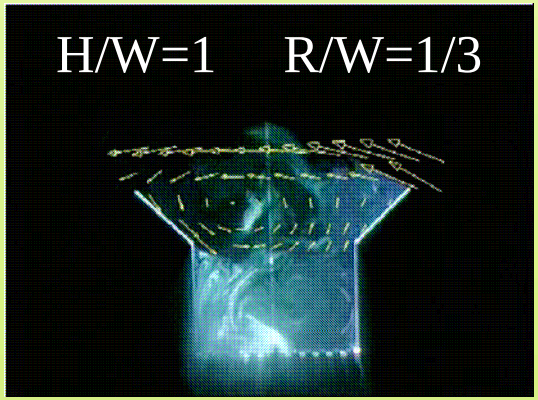
- Different roof shapes produce different dynamics
  - stationary and intermittent (Barlow, 2007) ⟶ effect on ventilation.

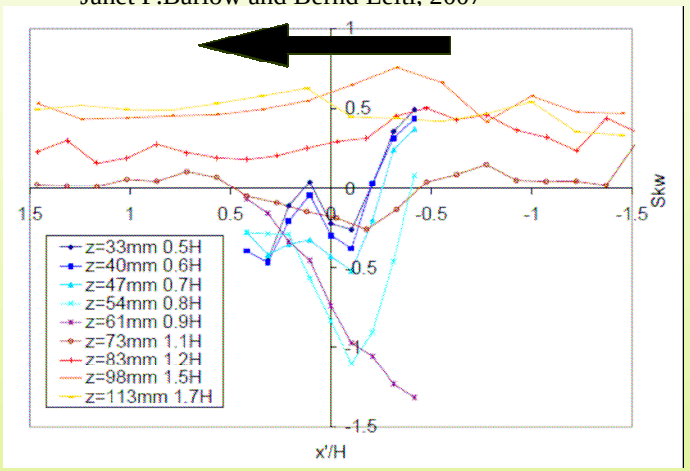
- Skewness of velocity brings an information about apperance of intermittent motion.

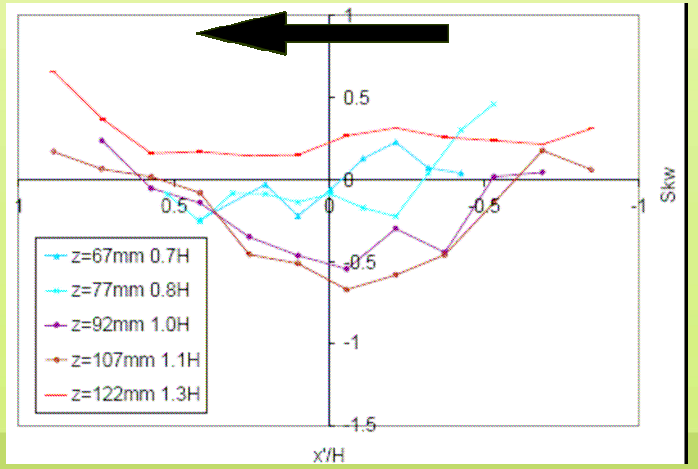
3. moment
$Sk_W = \langle w'^3 \rangle / \sigma_w^3$





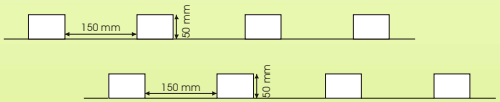






H...Height of street
W...Width of street
R...height of Roof

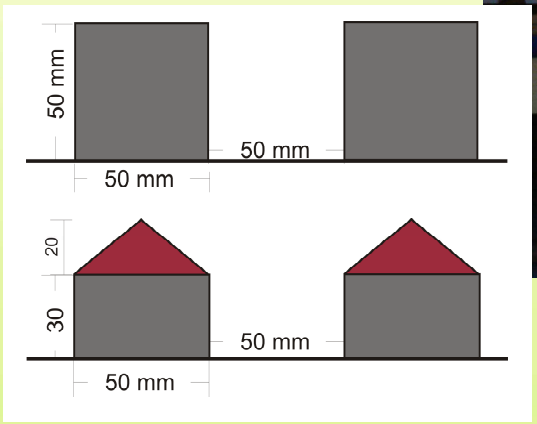
Experimental set-up – Wind tunnel



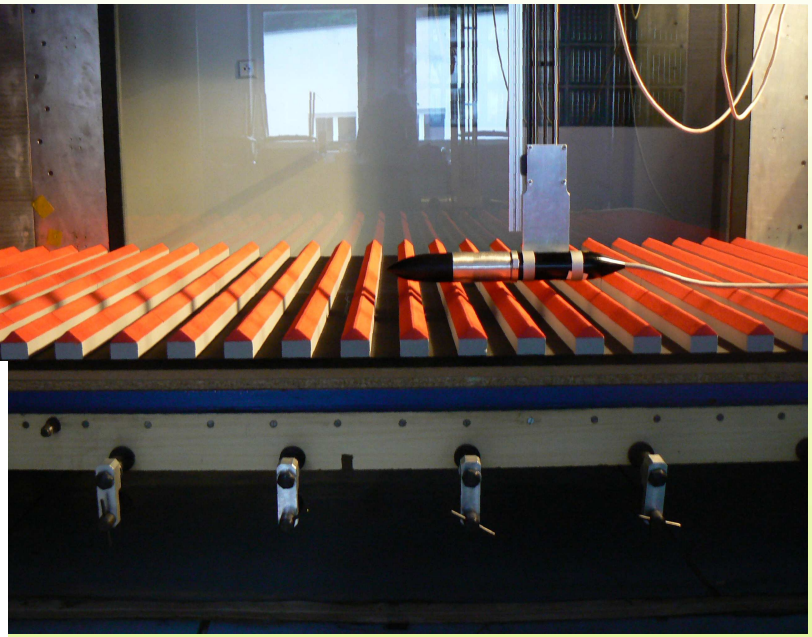
Cross-section 1.5 m x 1.5 m
Reference wind speed 3 m/s

2-D model

Scale 1:400
Building B/H= 1
Width W/H = 1
Roof R/W=0.4

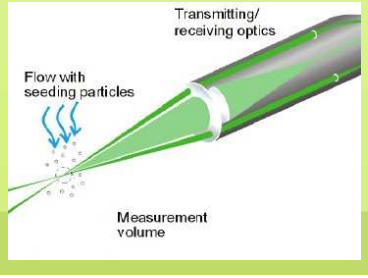


Model scale H = 5cm ≈ Full scale H = 20m



Measurement: 32 rows upstream
10 downstream

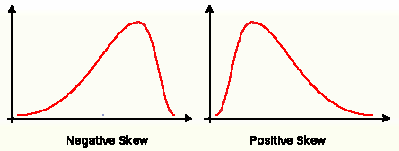
Reynolds number Re_{2H}= 10 000



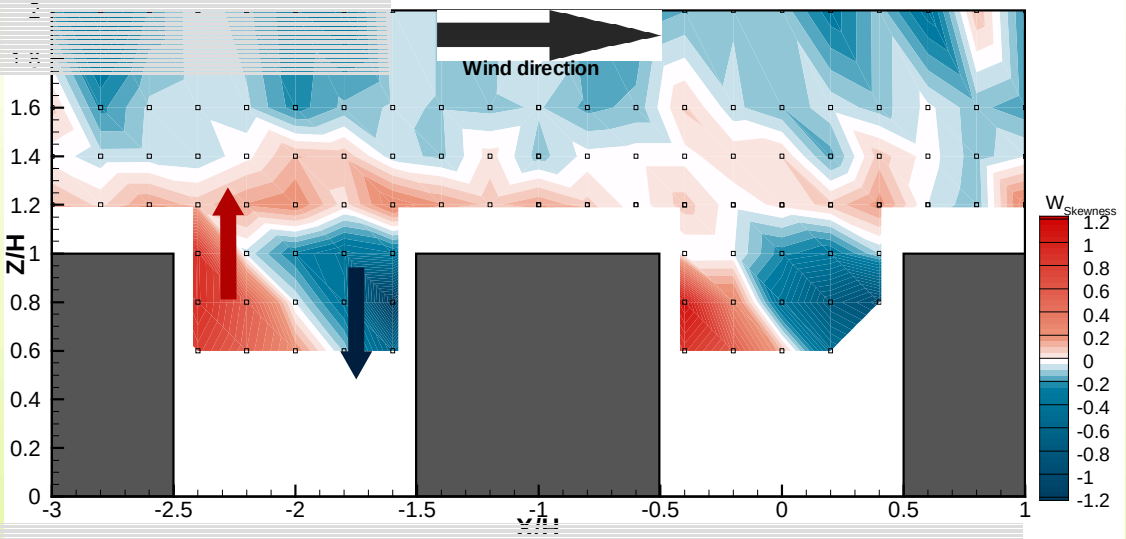
LDA 2-D components
Focal length 400 mm
Data rate 200 - 600 Hz
Volume 0.2 x 0.2 x 5 mm^3
Acquisition time 180 s

$\lambda_P = 0.5$ $\lambda_F = 0.5$ Blockage 3.3%

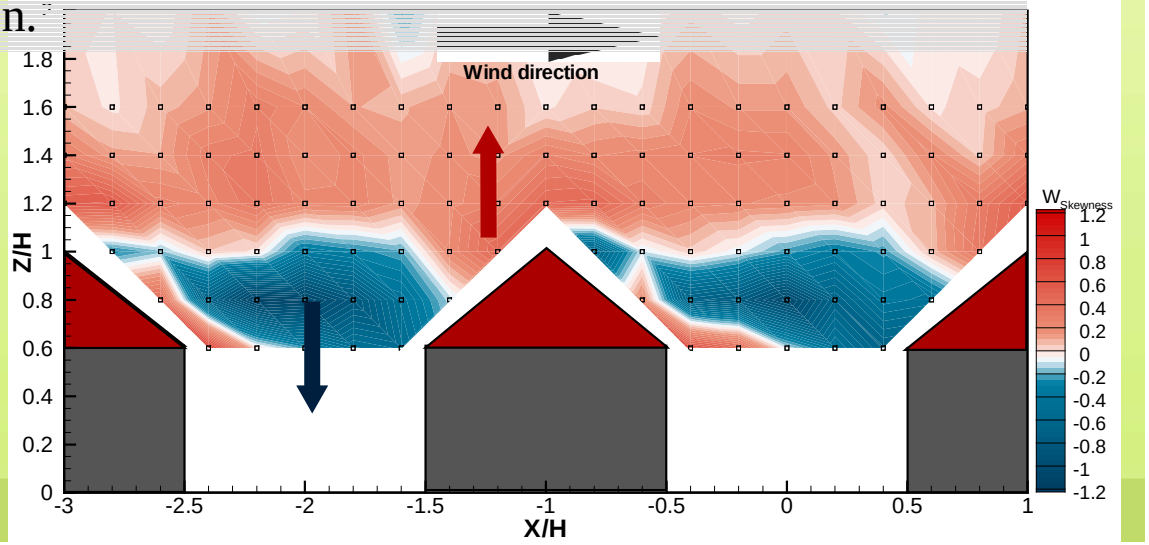
Vertical skewness



- Vertical penetration is strongest on the windward side.
- Recirculation tends to speed up.



- Negative skewness extents over whole roof area with extreme behind the upstream edge.
- This could rather disturb a ventilation.



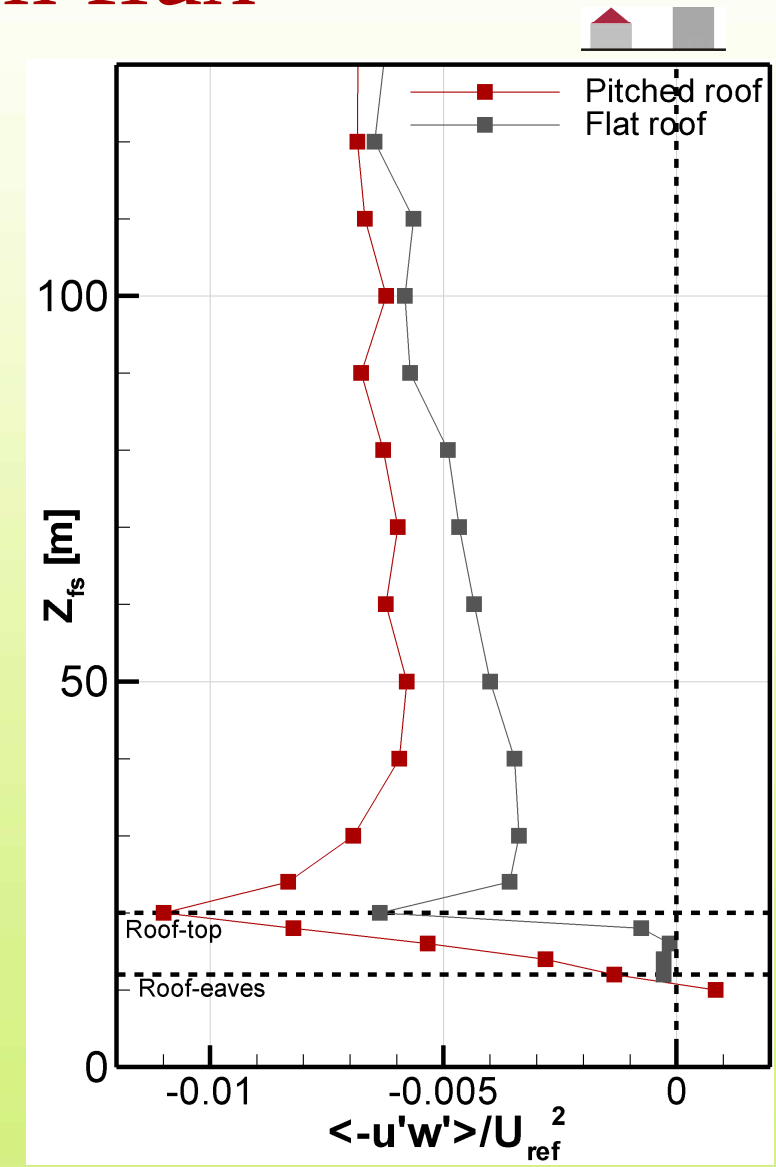
Momentum flux

- Large deflection in momentum flux profiles above flat and pitched roof (Rafailidis, 1997).
- Momentum flux exhibits maximum just at roof-top level.
- Magnitude is double for pitched roof.
- Parameters difference

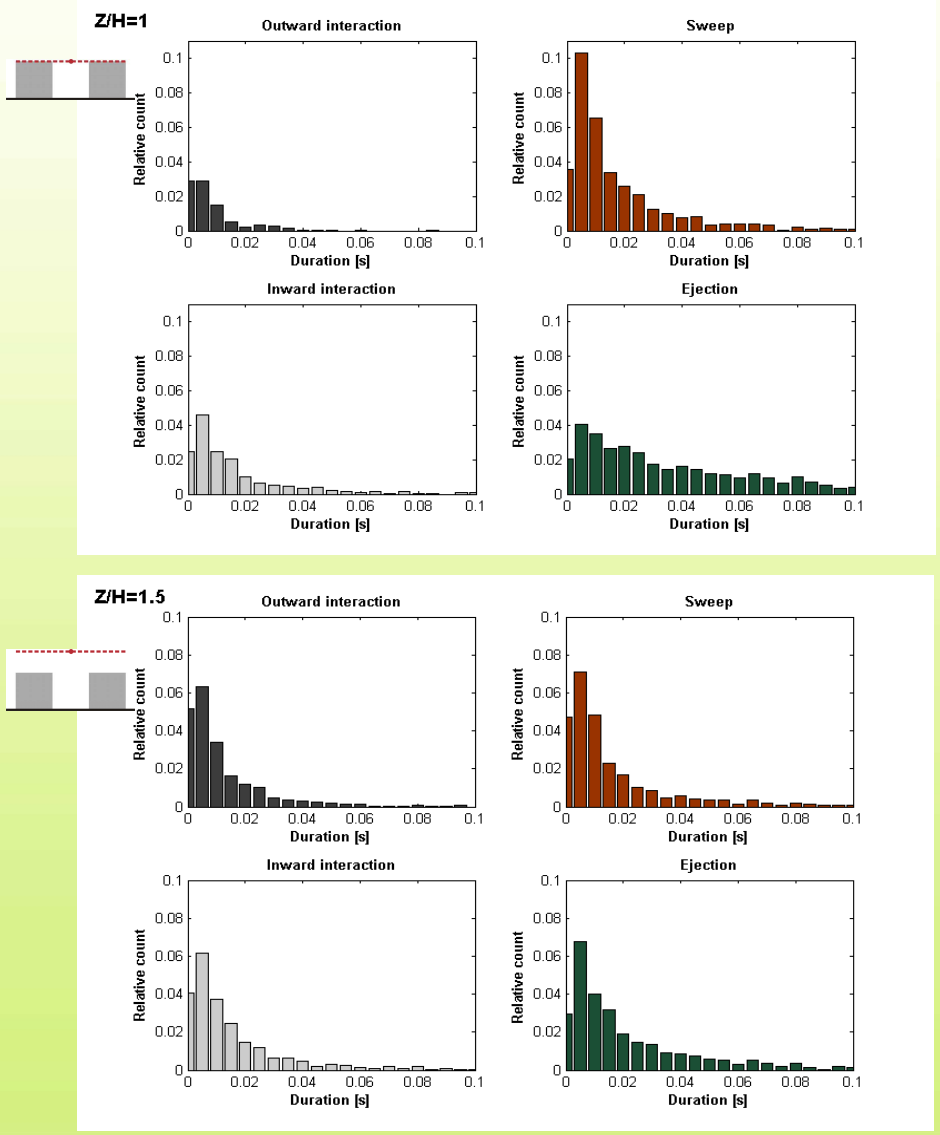
Parameter	$z_0[m]$	$d_0[m]$	$\alpha[-]$	$u_*[m.s^{-1}]$
Pitched roof	1.61	1.2	0.28	0.21
Flat roof	0.36	11.8	0.20	0.16

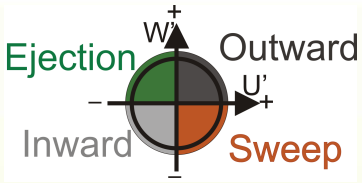
- Flat roof generates “rough“ turbulent BL.
- Pitched roof generates “very rough“ BL.

VDI manual, 2000



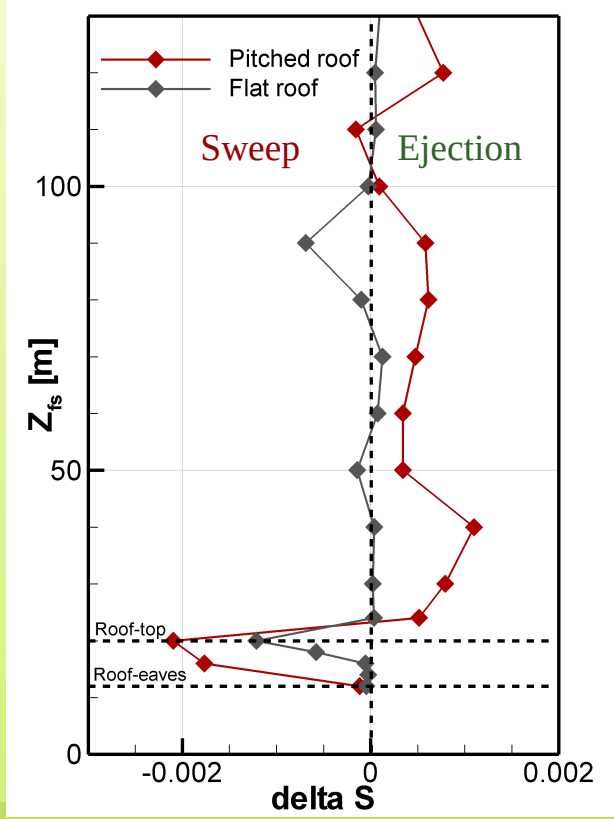
Quadrant analysis



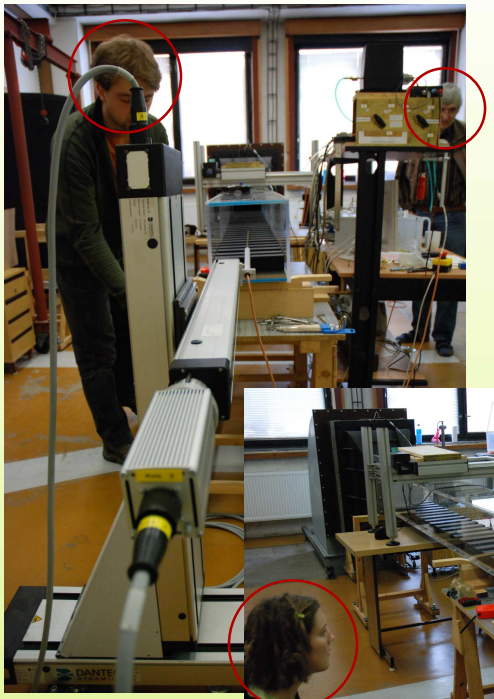


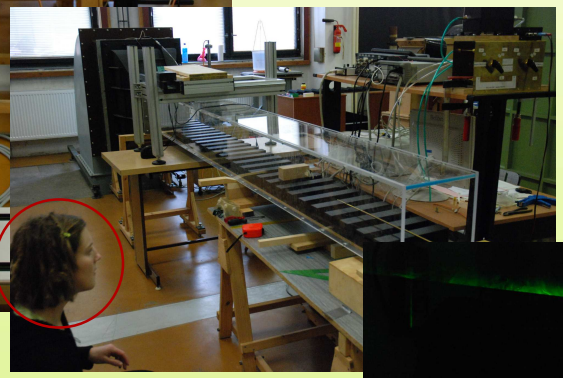
- Sweep/ejection dominates in urban canopy layer.
- Events in term of occurence are in balance above.

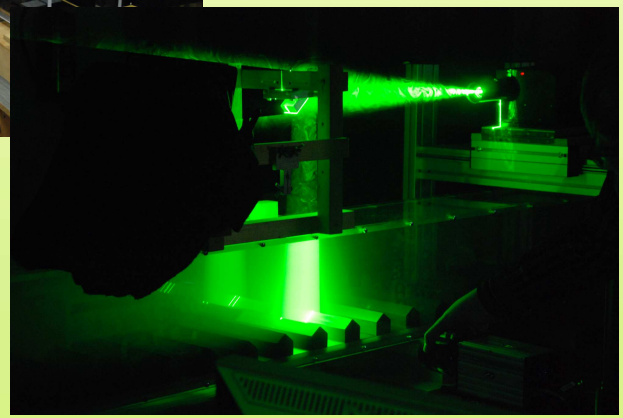
ΔS = **Sweep** - **Ejection**

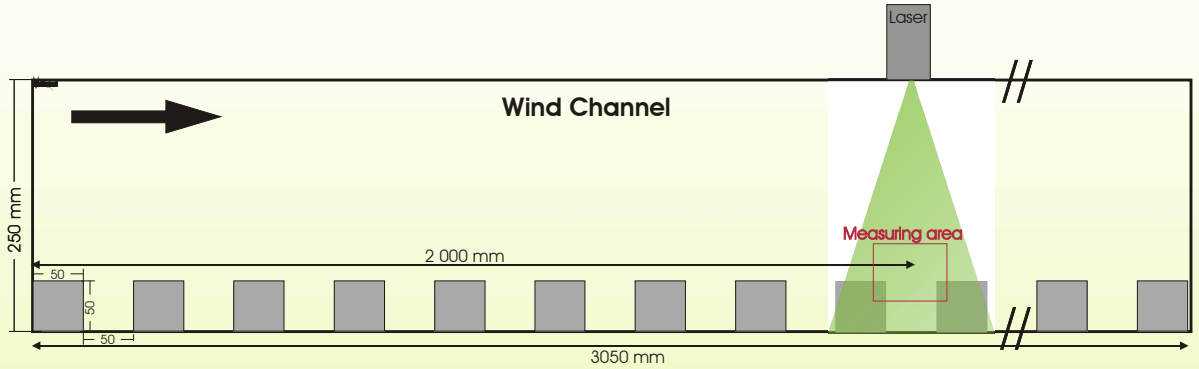


Experimental set-up: Wind channel









Measurement: 20 rows upstream, 10 downstream

Cross-section 0.25 m x 0.25 m
Reference wind speed 5 m/s

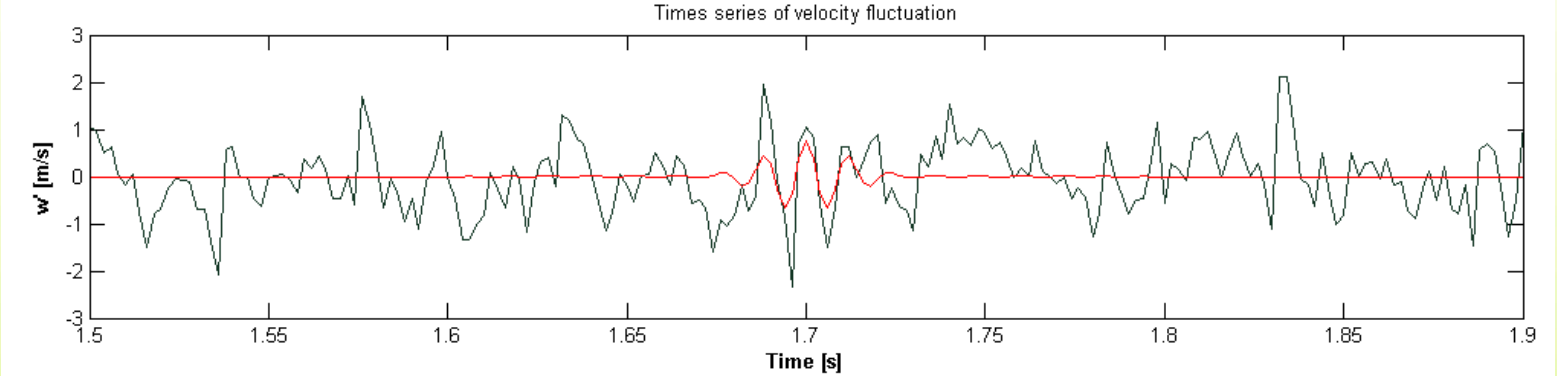
Reynolds number Re_{2H}= 40 000

PIV Diode pumped Nd:YLF
Repetition 500 -1000 Hz
Camera resolution 1280 x 1024 pxs
Interrogation area 32 x 32 pxs
Overlapping 50% (80 x 64 vectors)
Energy 10 mJ
Area 100 x 100 mm
Acquisition time 3.2 s

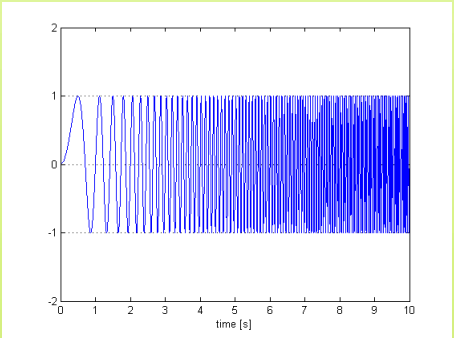
$\lambda_P = 0.5$ $\lambda_F = 0.5$ Blockage 20%

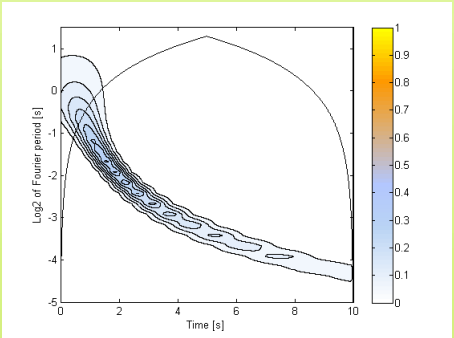
Wavelet analysis

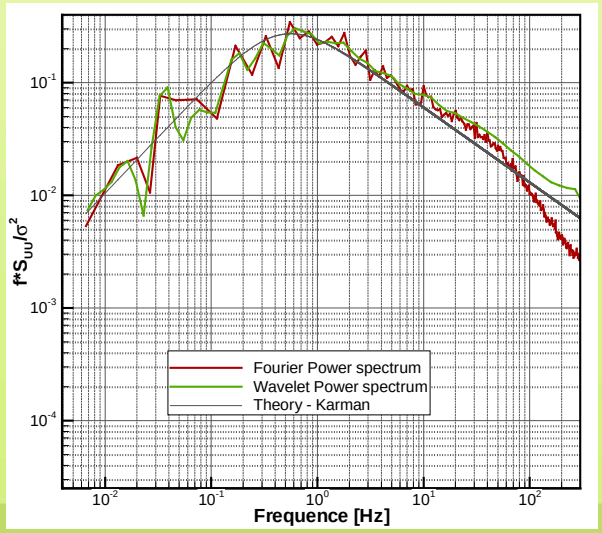
- Wavelet analysis can decomposed signal into the **frequencies** and detects the **time of their appearance**.
- **Morlet function** is used as a mother wavelet (ω_0=6).



- Daughter wavelet is inferred via dilation **s** and translation in time **t** from mother.
- Computation is run in Fourier space using algorithm of Torrence & Compo (1997) and Ge (2007).
- Square of modulus of complex wavelet coefficient => **Power spectra:**



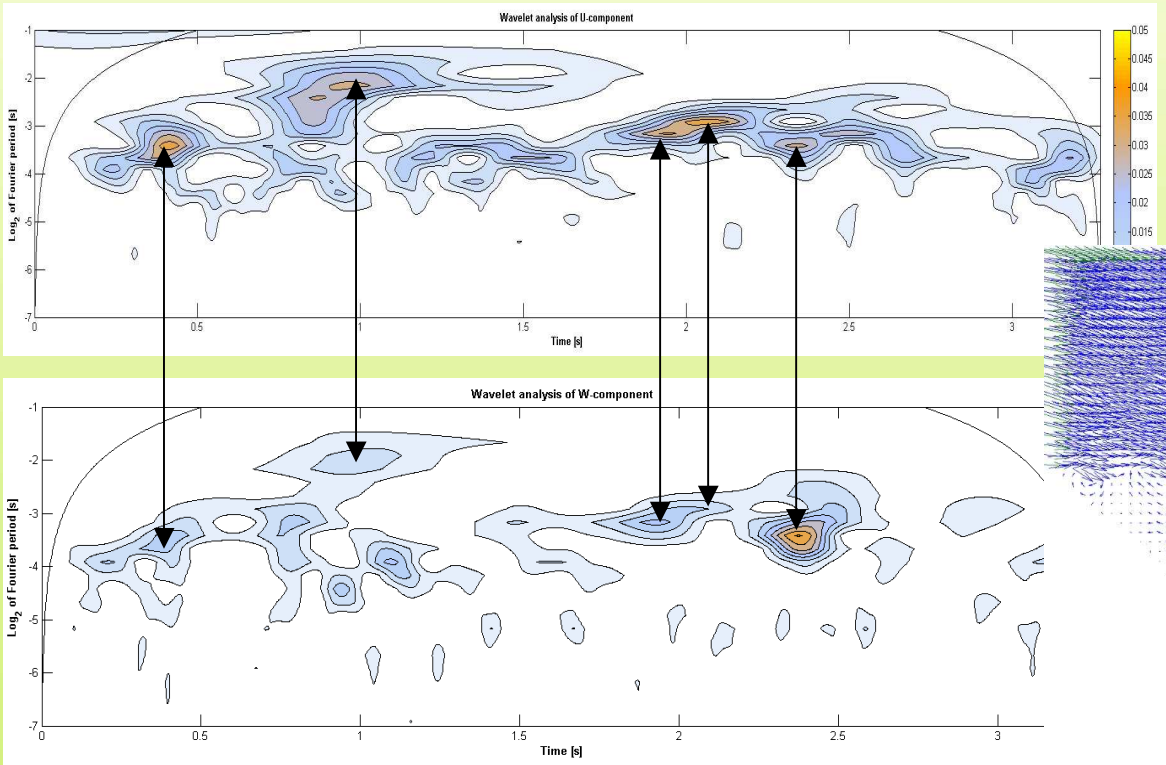


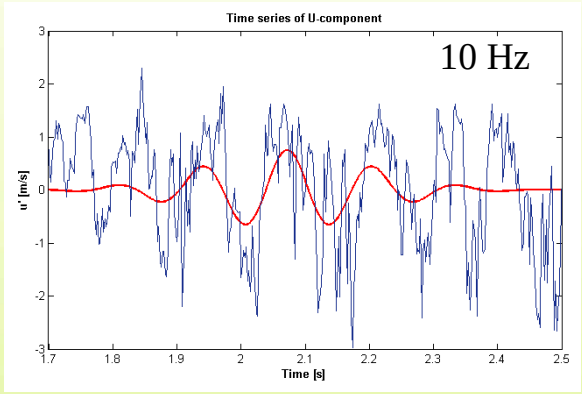


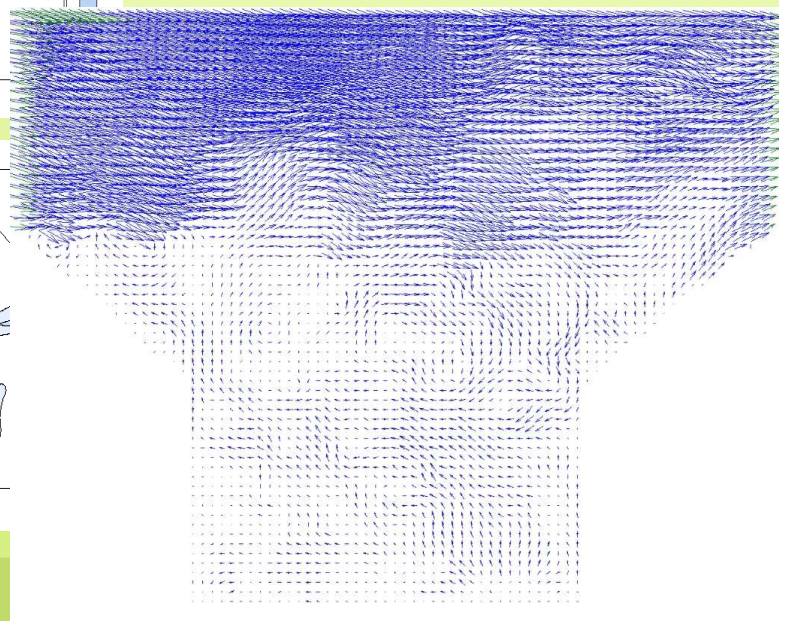
Wavelet analysis

- High correlation between **u'** and **w'** fluctuation – large momentum flux.
- Flow produces mostly sweep or ejection event.
- Large areas indicate passing the sweep or ejection "waves" rather than vortex.

Pitched roof

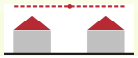


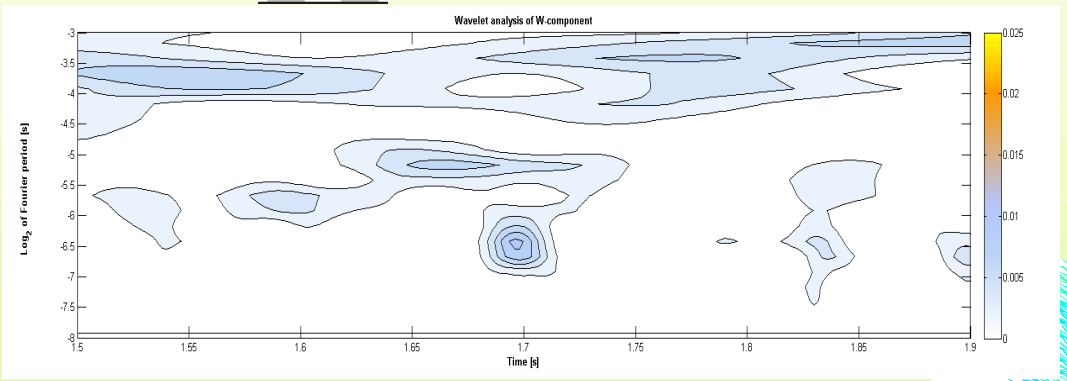


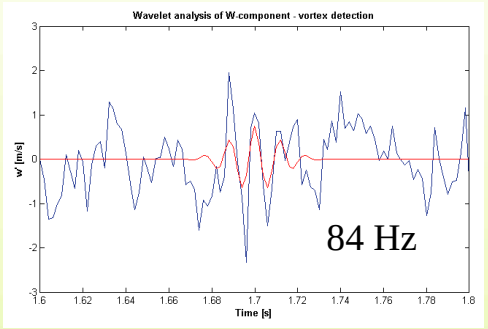


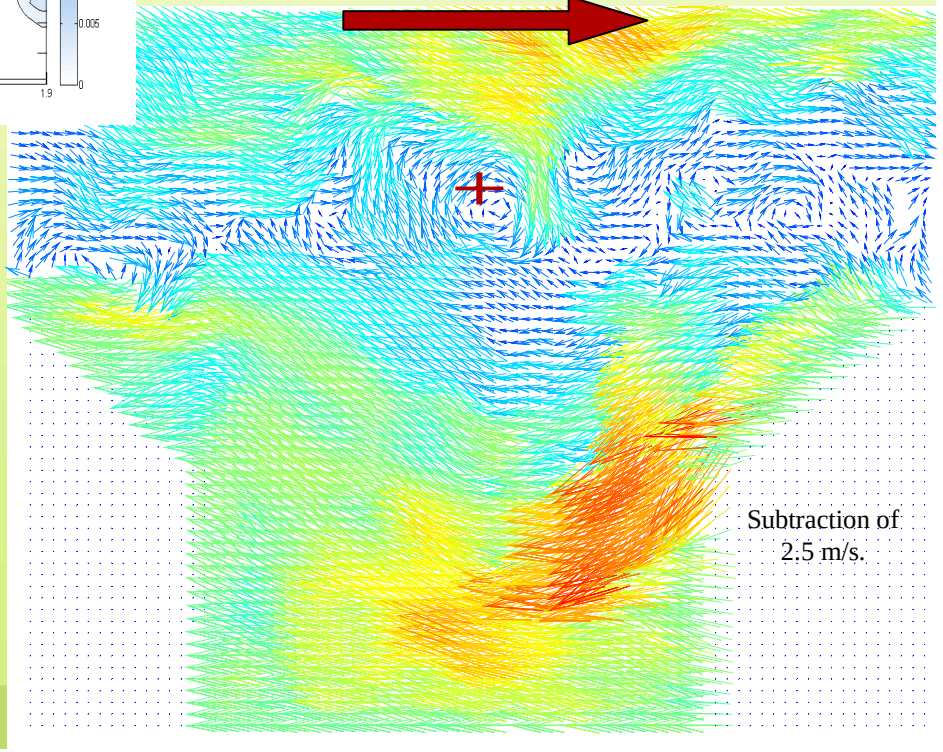
Wavelet analysis

- Subtraction of proper convective velocity reveals circular vortex core (Adrian, 2000).

Pitched roof 







Subtraction of 2.5 m/s.

- Deviation of convective velocity from advective one.

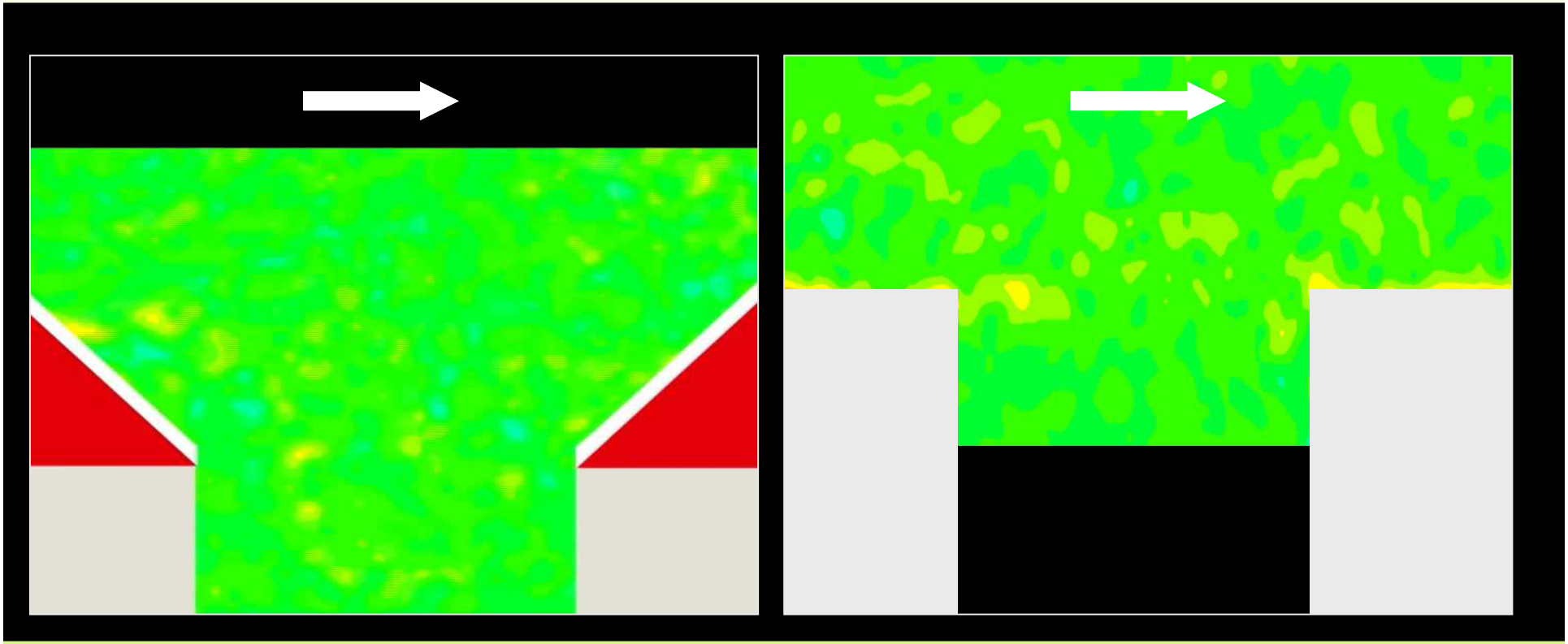
Advective velocity <u>=3.4 m/s $\lambda \approx 40 \pm 2$ mm

Convective velocity u_c=2.5 m/s $\lambda \approx 29 \pm 2$ mm

PIV $\lambda \approx 22 \pm 2$ mm

Vorticity

- Vorticity is calculated using Stokes theorem.

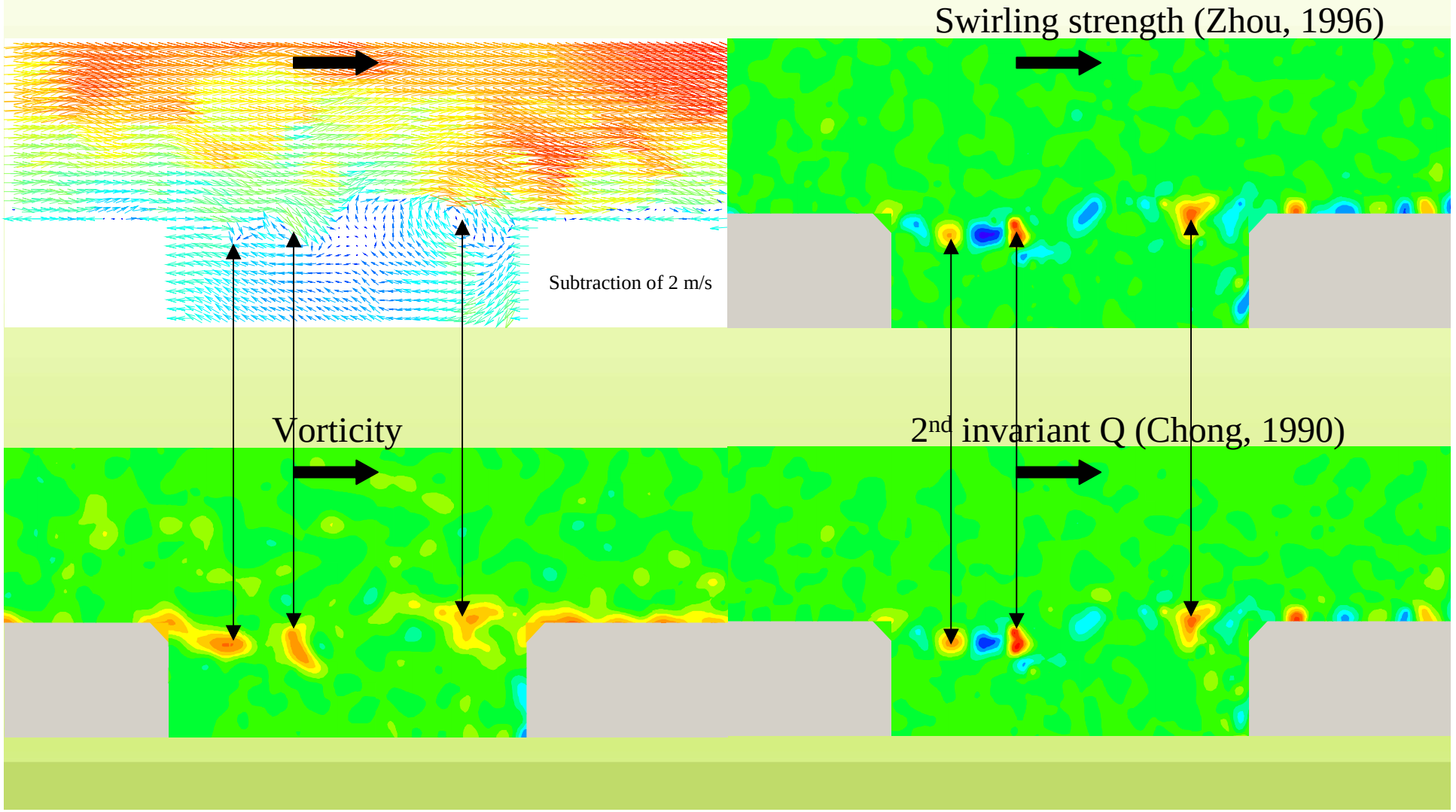


500 Hz

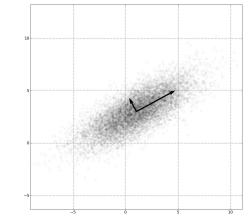
1000 Hz

Vortex tracking

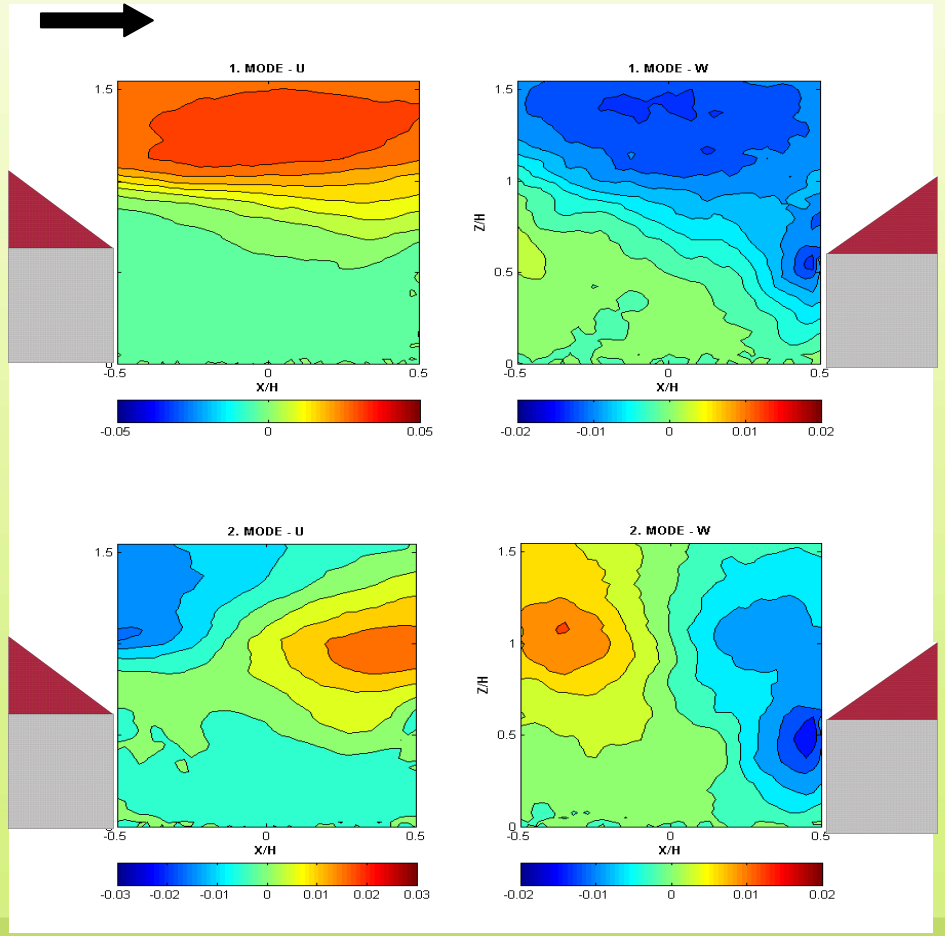
- Swirling strength and 2nd invariant Q is compared to the vorticity and vector field.

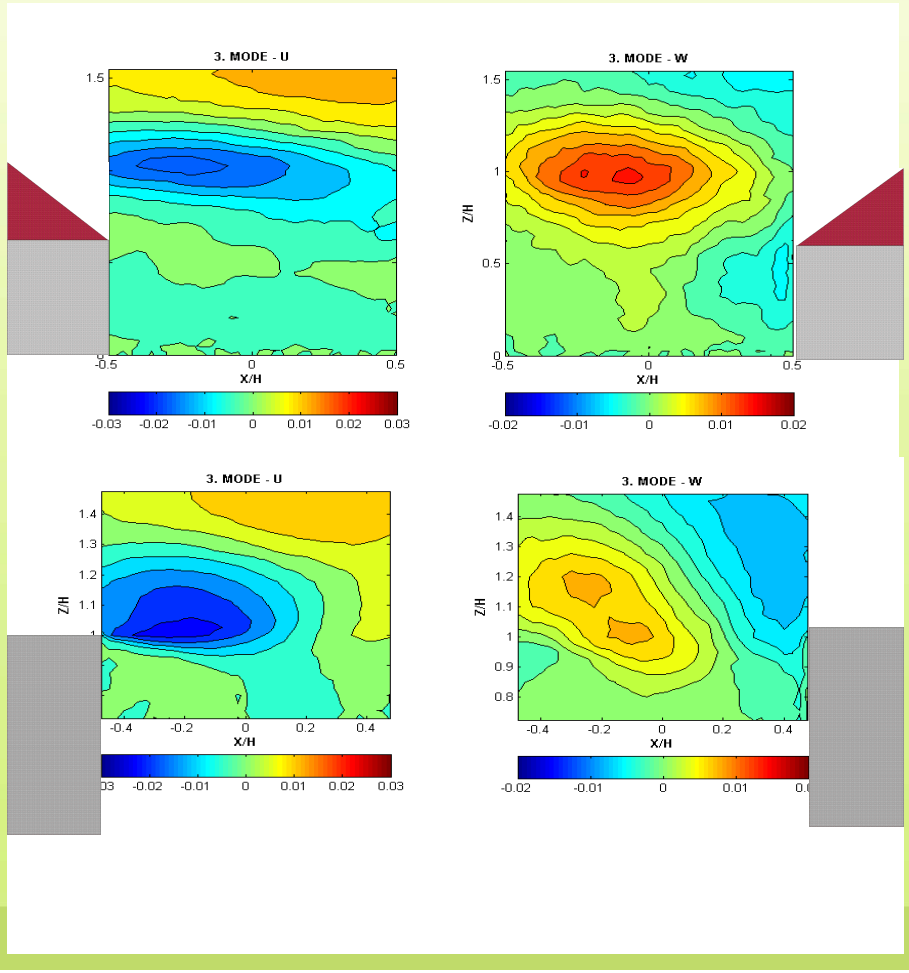


POD modes



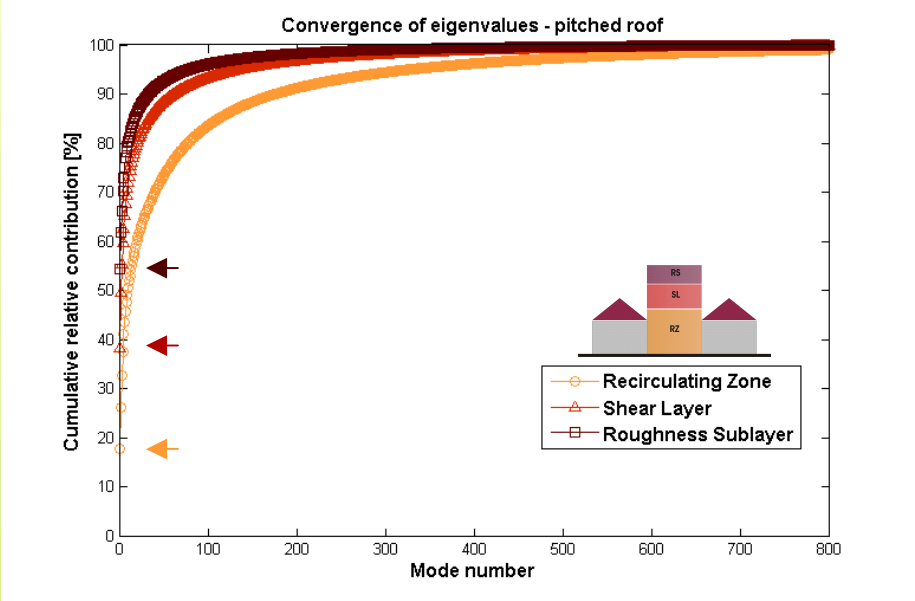
- POD (Lumley, 1967) re-expresses data set into new orthogonal basis.
- Snapshot POD (Sirovich, 1987) was applied on 2-D velocity data (N=1634 and 3270).
- Dominant modes of flow in street canyon:



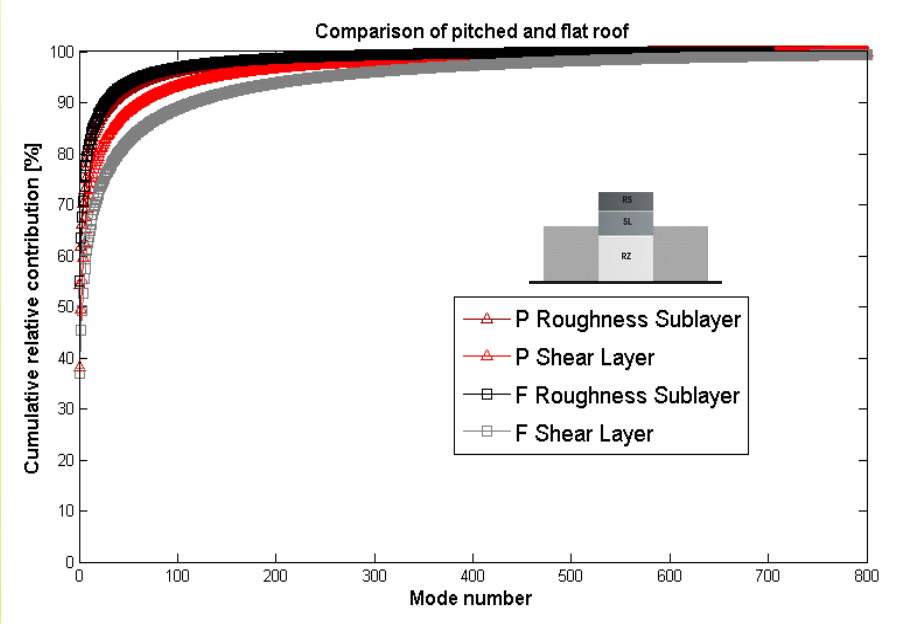


POD convergence

- Analysis of velocity data yields relative contribution to TKE for each mode.
- Fast convergence of cummulative contributions witnesses about more organised structure of flow.
- Recirculation Zone (RZ) captures generally less turbulent kinetic energy.
- SL and RS involve larger TKE contribution and more coherency.



Pitched roof	Accumulative relative contribution [%]		
Percentage of modes	RZ	SL	RS
1%	56	77	84
10%	89	96	98



Conclusion

- Flat and triangle roof generate turbulent flow of different category.
- Flat roof produces smoother flow, less turbulent with conveniently localized intermittent propagation of fresh air into canyon on windward side.
- Recirculation zone is more stable and ventilation is more effective.

- Pitched roof induces violent, disturbed flow with intensive vortex penetration into the cave.
- Perturbations affect recirculation zone and damage the natural ventilation.

- Shear layer contains more coherency than recirculation zone.
- Flat roof induces less coherent flow than pitched roof.

Thank you for your attention