School of Geography
FACULTY OF EARTH AND ENVIRONMENT

UNIVERSITY OF LEEDS

Properties of the wake structure behind fences with a fractal arrangement of horizontal struts

Chris Keylock

Context

- Traditional experiments on turbulence have forced the flow at a particular scale (wave number) and then have looked at the flow from the perspective of Kolmogorov.
- More recently, there has been attention paid to forcing the flow at a number of scales simultaneously:

Fractal grids – Hurst D, Vassilicos JC, Scalings and decay of fractal-generated turbulence, *Phys. Fluids* 19, 035103, 2007.

Fractal stirrers – Staicu A, Mazzi B, Vassilicos JC, van de Water, W, Turbulent wakes of fractal objects, *Phys. Rev. E* 67, 066306, 2003.

Fractal generated DNS – Mazzi B, Vassilicos JC, Fractal-generated turbulence, *J. Fluid Mech.* 502, 65, 2004.

Broadband DNS forcing – Kuczaj AK, Geurts BJ, McComb WD, Nonlocal modulation of the energy cascade in broadband-forced turbulence, *Phys. Rev. E* 74, 016306, 2006.

- Kuczaj AK, Geurts BJ, Mixing in manipulated turbulence, *J. Turbulence* 7 (67) 1-28, 2006.

Some results:

- Fractal grids generate higher turbulence intensities and Reynolds numbers than conventional grids.
- What appears to be an energy cascade process in fractal-generated turbulence actually involves a significant amount of dissipation (>80% of dissipation occurring over the range of forced scales).
- Broadband forcing transfers energy more effectively to smaller scales – mixing is enhanced.
- A wider range of scales are responsible for energy transfer than is the case for classic forcing.

Two types of singularity structure seen in turbulence data:

- **Cusps: y = |x|^{c}**
- **Chirps or spirals: y = |x|^{c} sin (1/|x|^{b})**
- **b and c are positive and real**

Pointwise Holder/Lipshitz regularity: (degree of *P* < *s*)

$$\alpha_p(x_i) = \sup\left(f \in C^s\right) \qquad \left| f(x) - P_{x(i)}(x) \right| \le C\left|x - x_i\right|^s$$

Local Holder regularity:

$$\alpha_L(\Omega) = \sup\left(f \in C_L{}^s\right) \qquad \left| f(x) - f(y) \right| \le C\left|x - y\right|^s$$

Two types of singularity structure seen in turbulence data:

- **Cusps: $y = |x|^c$**
- **Chirps or spirals: $y = |x|^c \sin(1/|x|^b)$**

- **In the case of the cusp:** $\alpha_p = \alpha_L = c$

- **In the case of the chirp:** $\alpha_p = c$

$$\alpha_L = c/(1+b)$$

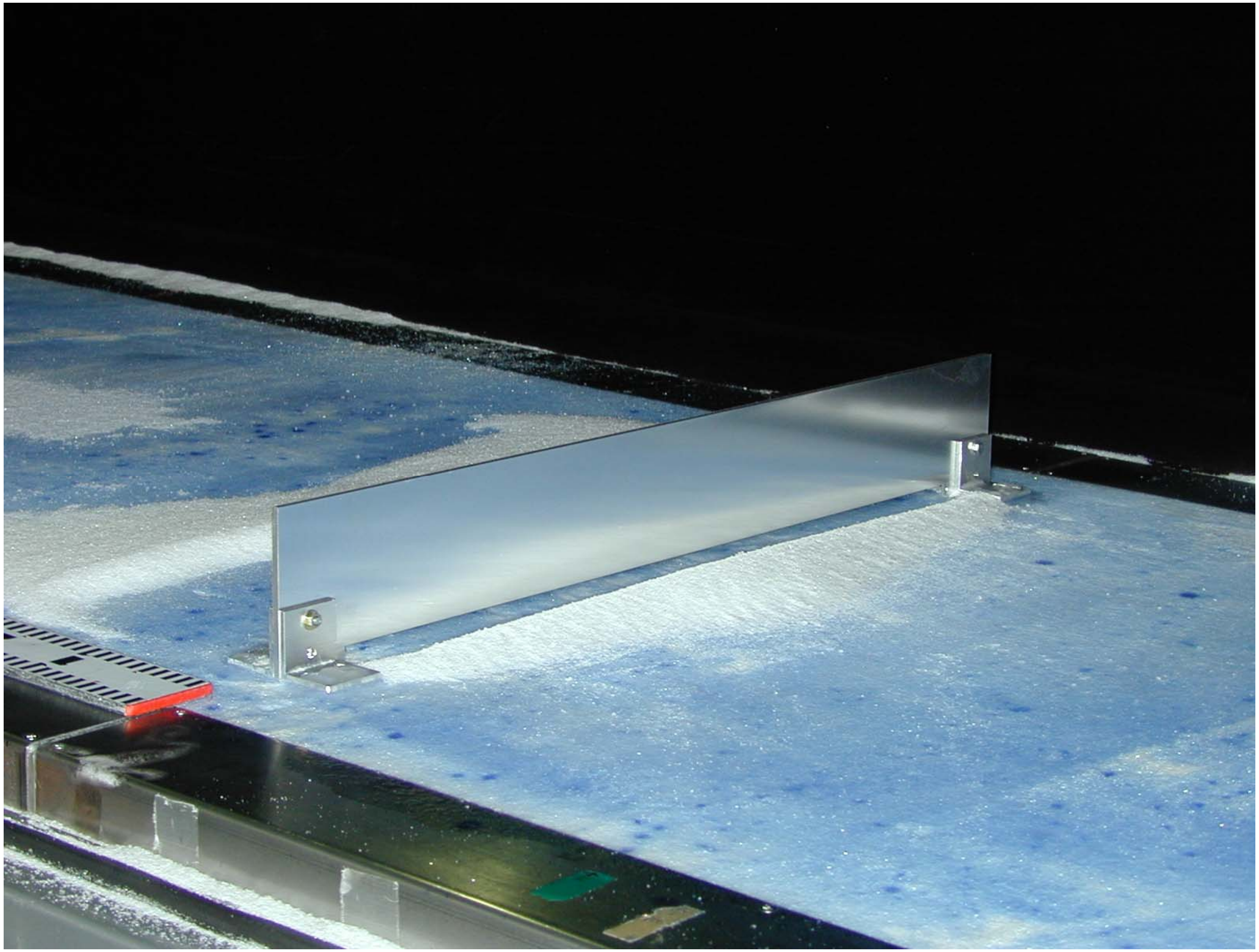
Plate10 (circle) – A solid plate with a 10% gap at the bottom.

5struts50 (*) – Regular spacing based on five struts with a 10% gap at the bottom and a total porosity of 50%.

9struts50 (+) - Regular spacing based on nine struts with a 10% gap at the bottom and a total porosity of 50%.

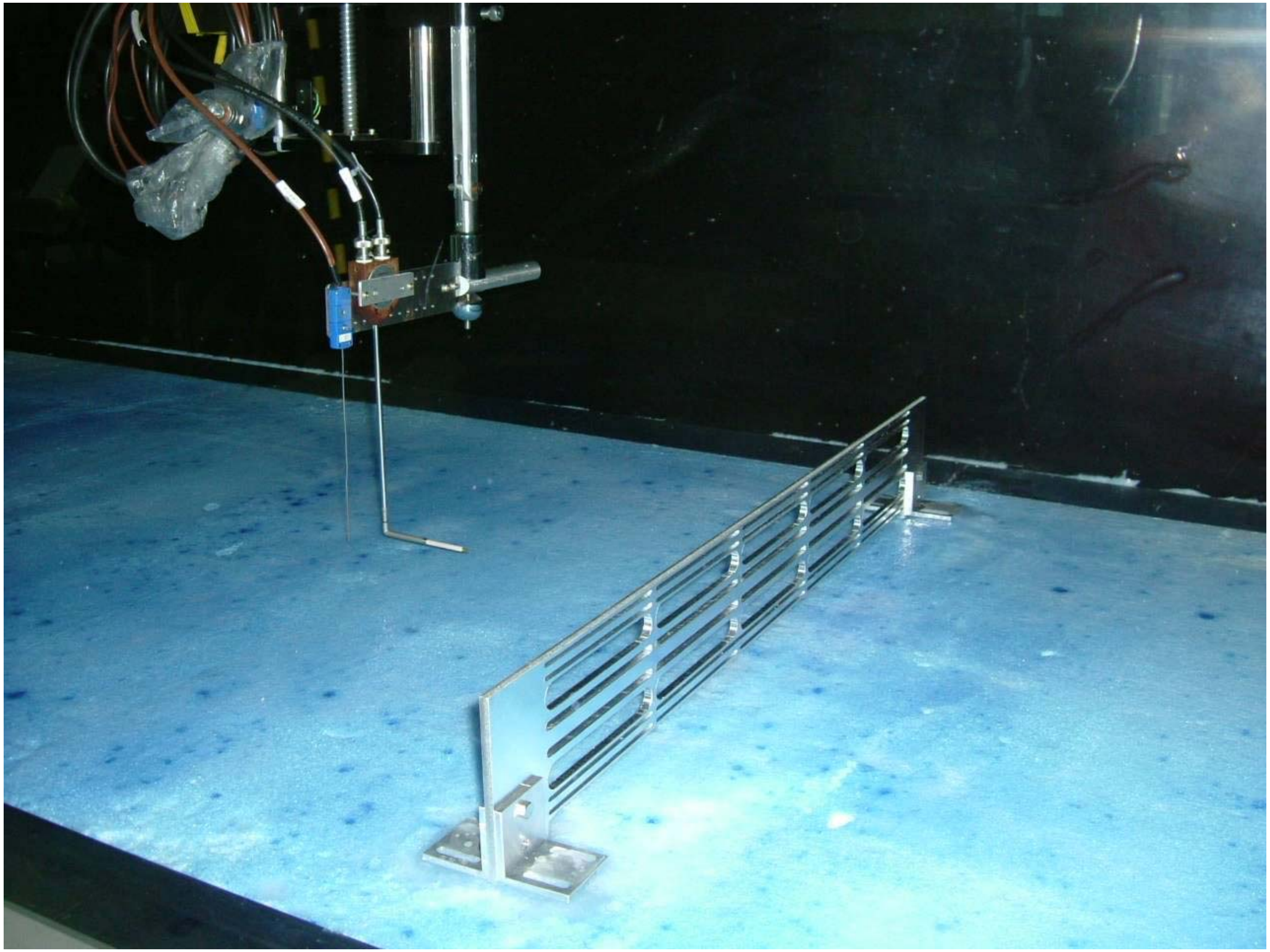
Frac50 (triangle) – Fractal design based on nine struts with a 10% gap at the bottom and a total porosity of 50%.

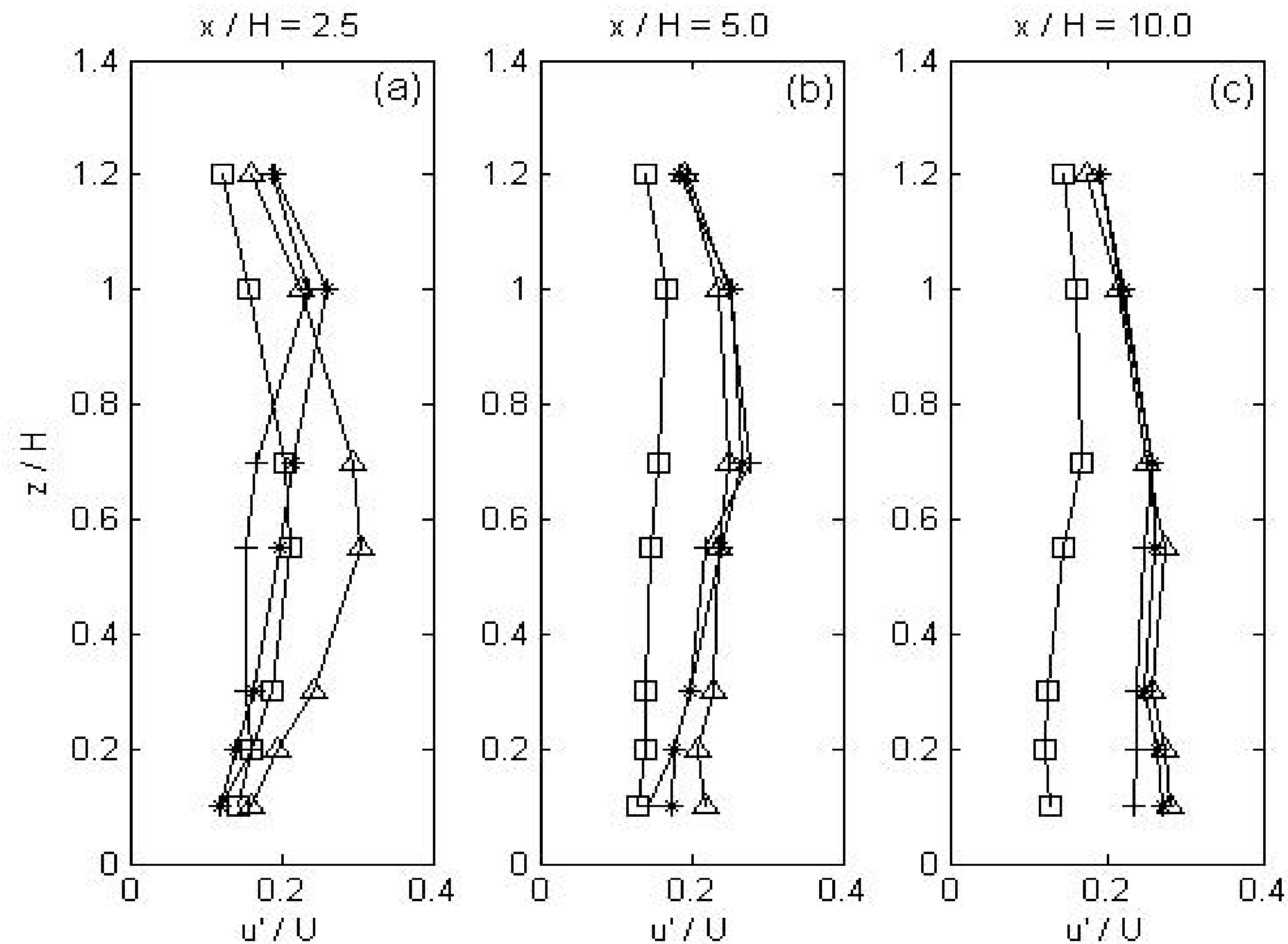
Frac60 – (square) Fractal design based on nine struts with a 10% gap at the bottom and a total porosity of 60%.



School of Geography
FACULTY OF EARTH AND ENVIRONMENT

UNIVERSITY OF LEEDS

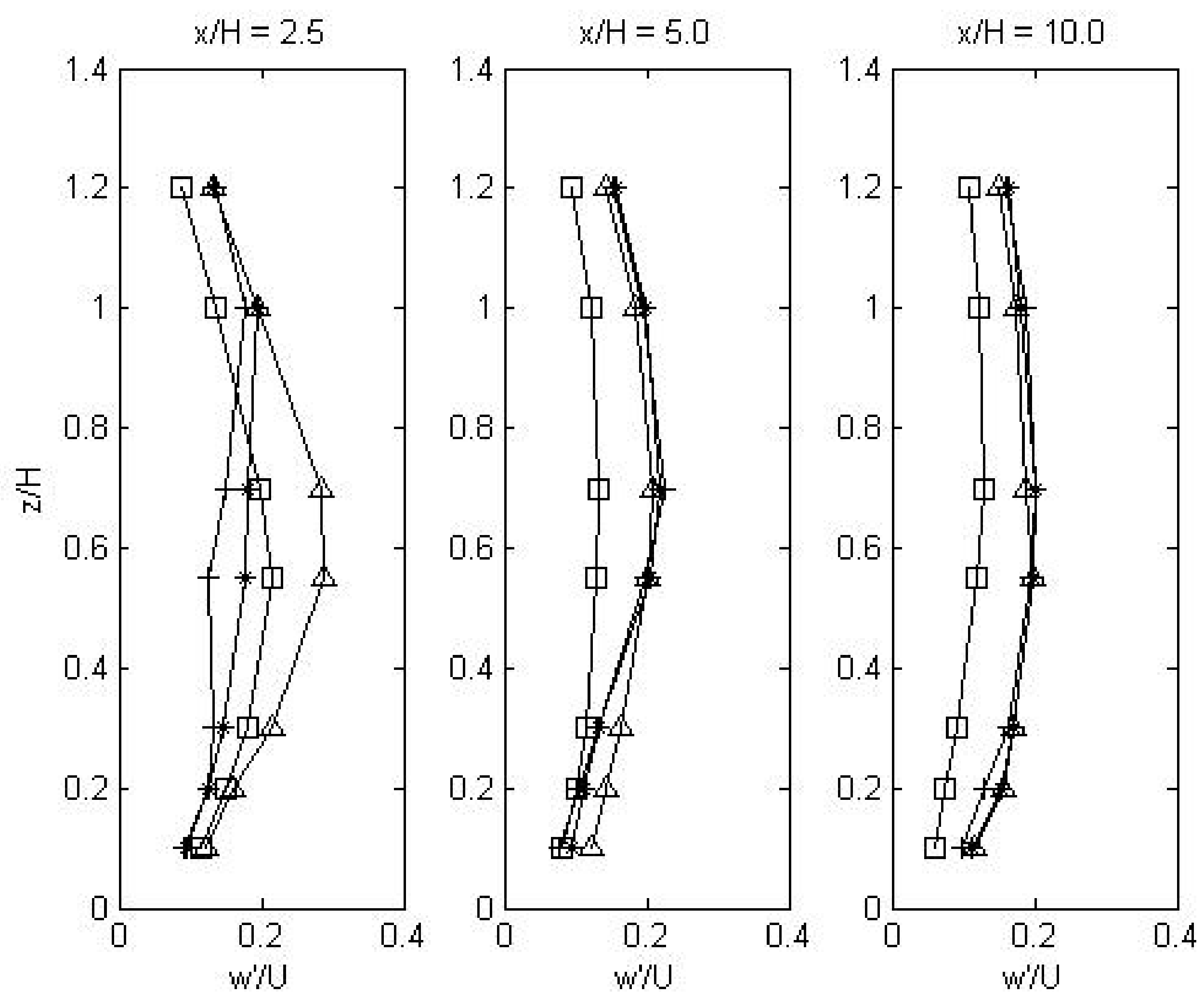




x / H = 2.5
x / H = 5.0
x / H = 10.0
(a)
(b)
(c)
z / H
u' / U
0
0.2
0.4
0.6
0.8
1
1.2
1.4

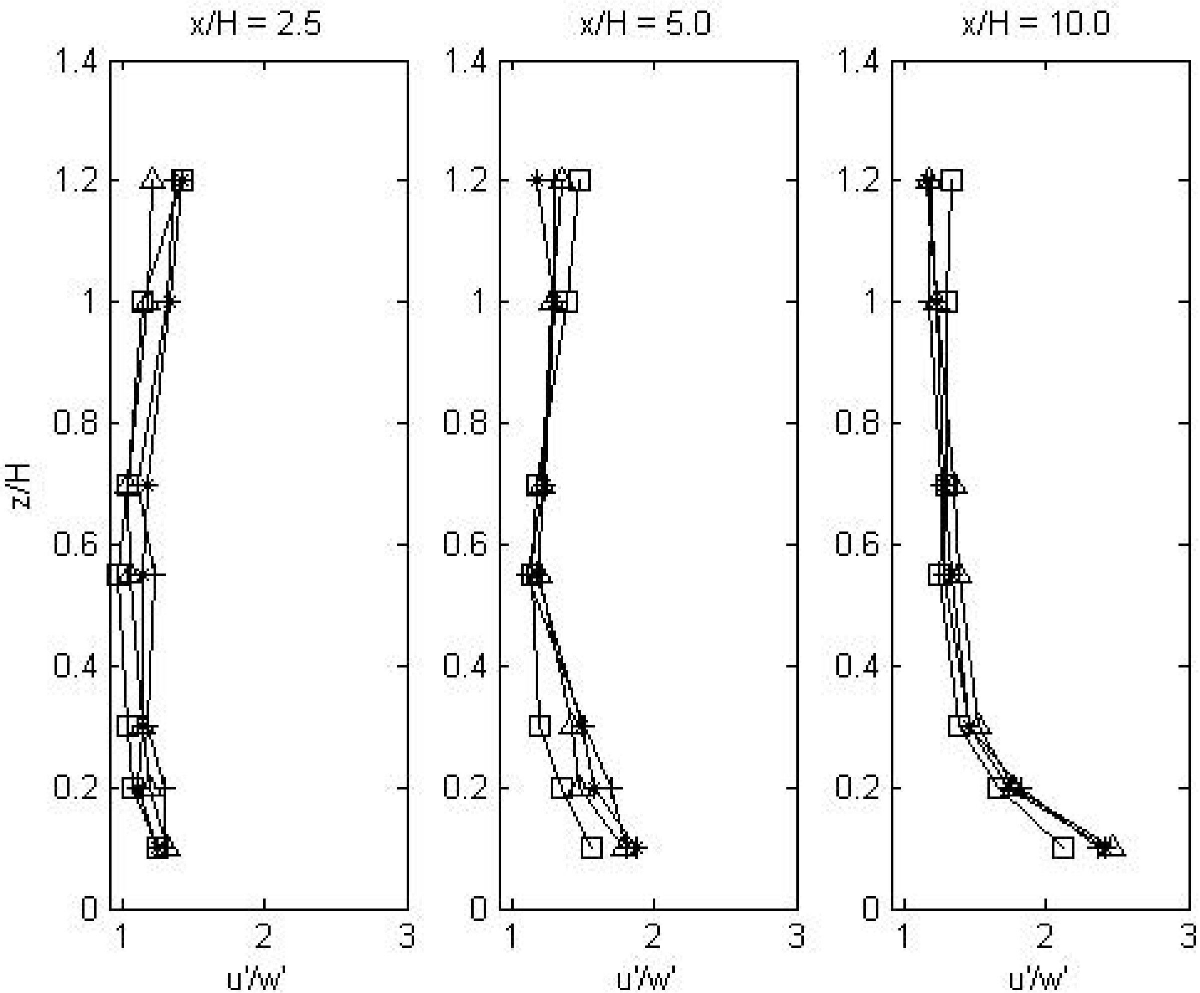
School of Geography
FACULTY OF EARTH AND ENVIRONMENT

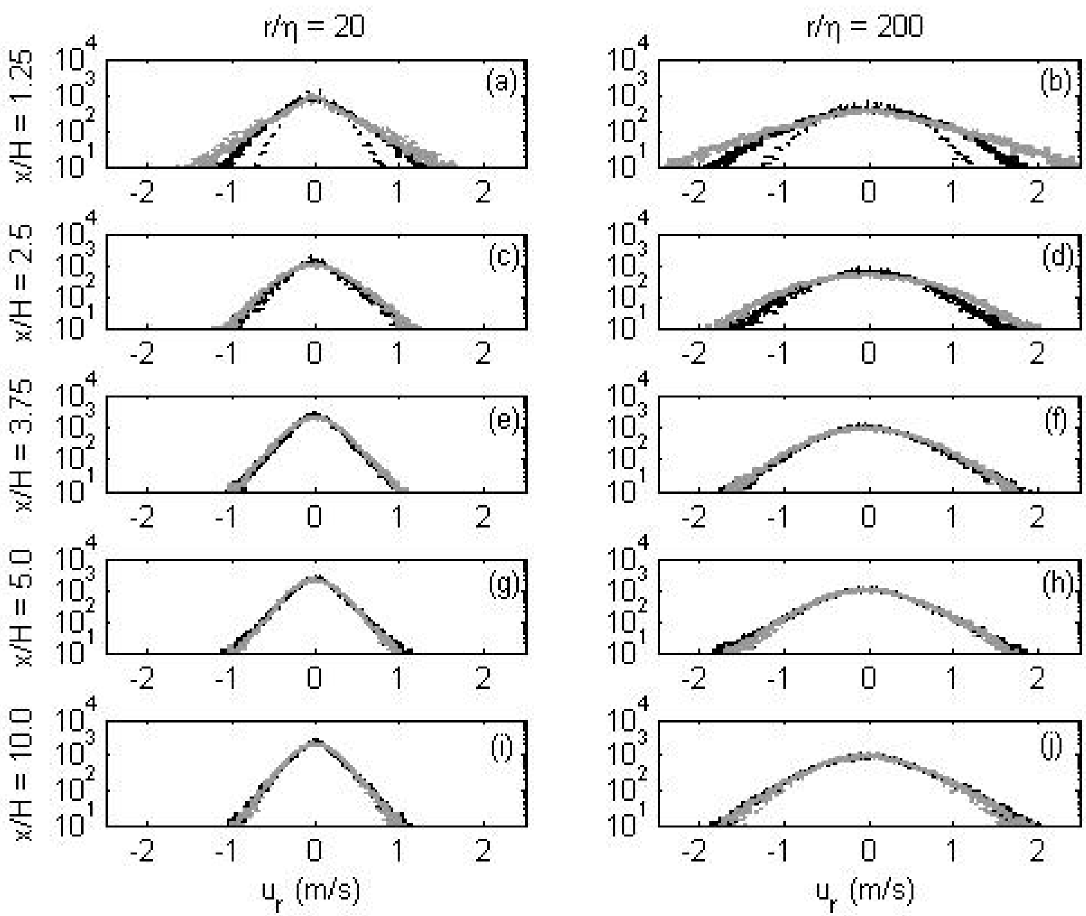
UNIVERSITY OF LEEDS

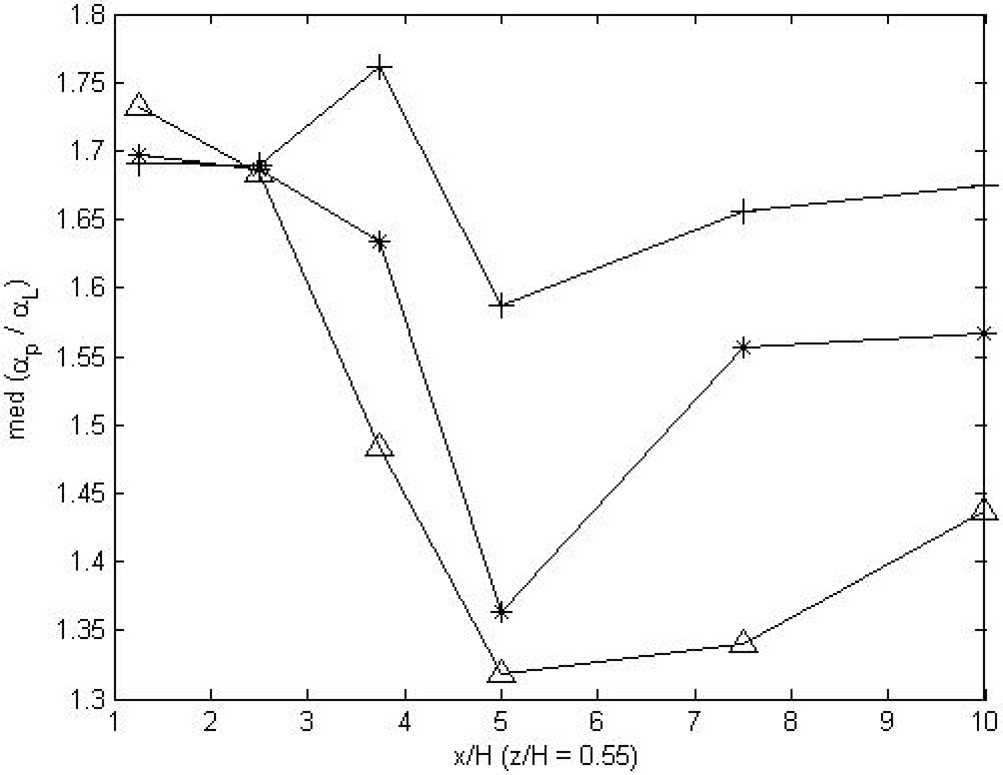


School of Geography
FACULTY OF EARTH AND ENVIRONMENT

UNIVERSITY OF LEEDS




r/η = 20
r/η = 200
x/H = 1.25
x/H = 2.5
x/H = 3.75
x/H = 5.0
x/H = 10.0
(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
(j)
u_r (m/s)
u_r (m/s)

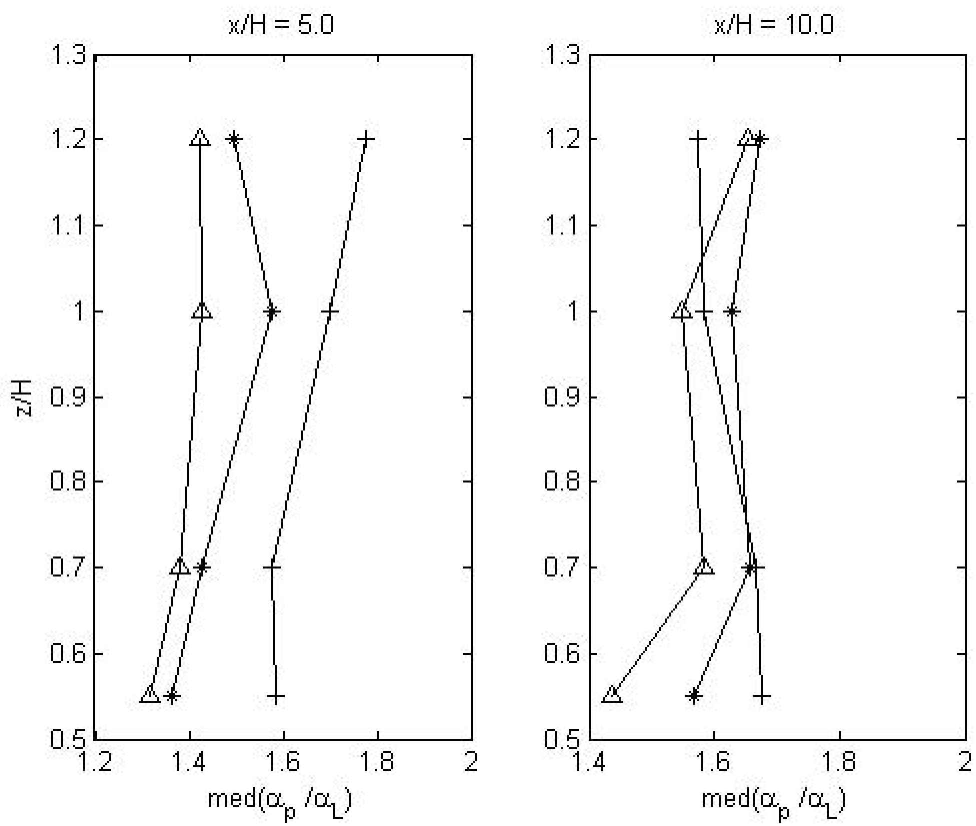


1.8
1.75
1.7
1.65
1.6
1.55
1.5
1.45
1.4
1.35
1.3
med (α_p / α_L)
1
2
3
4
5
6
7
8
9
10
x/H (z/H = 0.55)

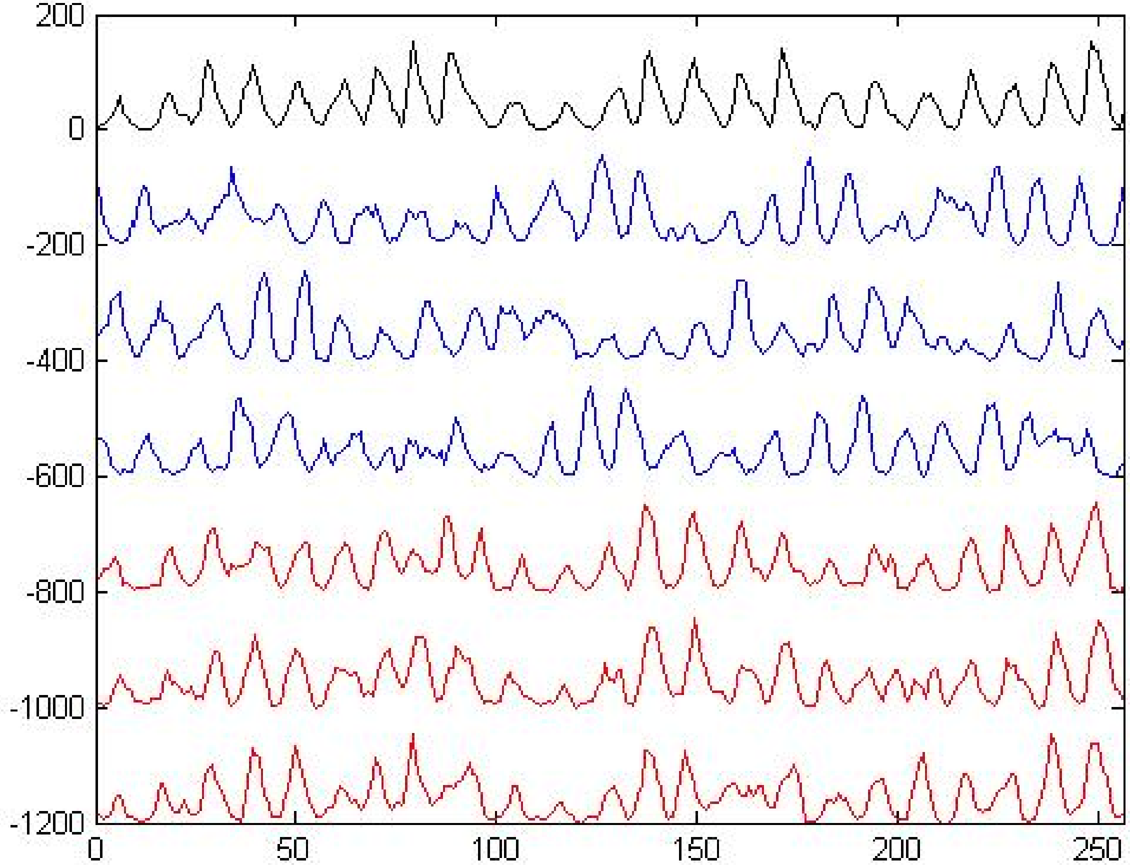
School of Geography

FACULTY OF EARTH AND ENVIRONMENT

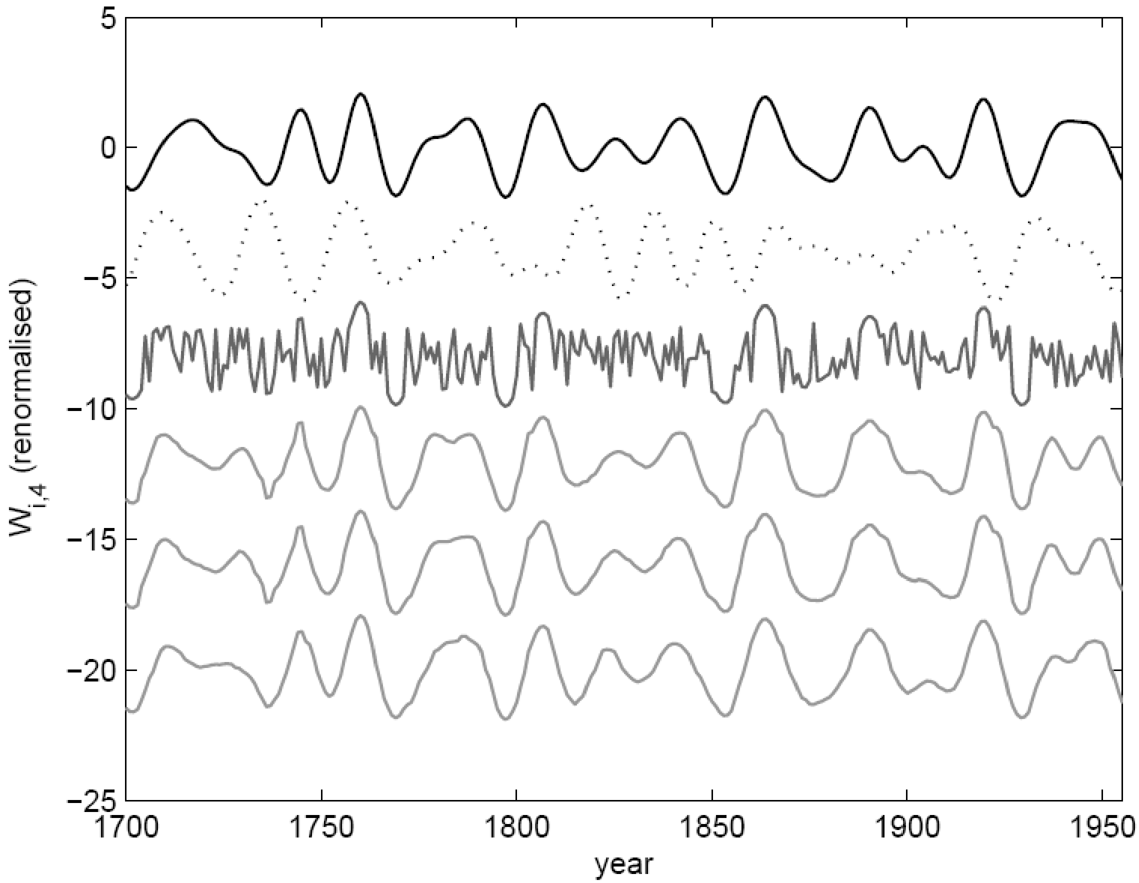
UNIVERSITY OF LEEDS



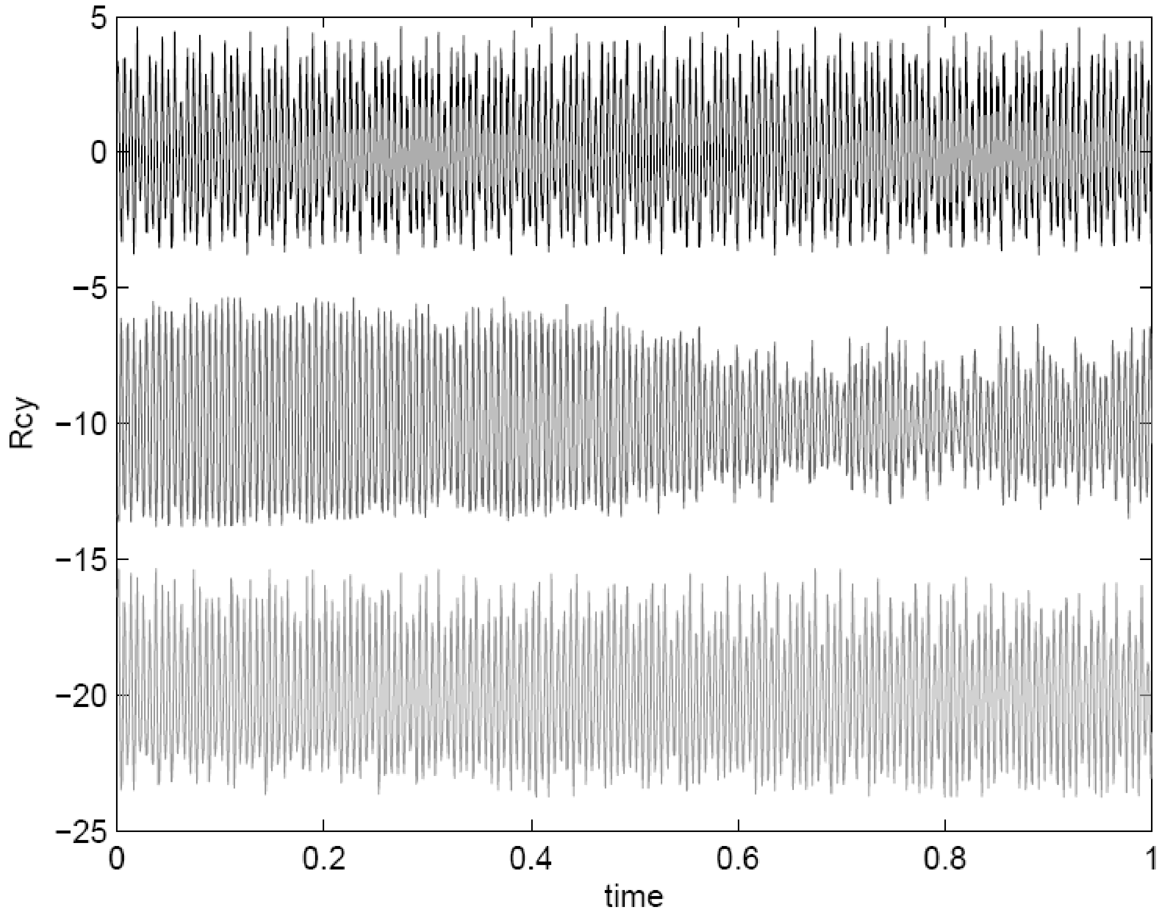
Obtaining statistical confidence in the results



Keylock CJ. 2006. Constrained surrogate time series with preservation of the mean and variance structure *Phys. Rev. E 73,* 036707



Keylock CJ. 2007. *A* wavelet based method for surrogate data generation, *Physica D* 225, 219-228



Keylock CJ. 2007. *A* wavelet based method for surrogate data generation, *Physica D* 225, 219-228

The Arneodo and Muzy approach to deriving the multifractal singularity spectrum for turbulence data (to characterise the cusp singularities) is based on using a continuous wavelet transform (with a derivative of Gaussian wavelet to guarantee propagation of maxima) to derive the Wavelet Transform Modulus Maxima skeleton.

If we fix in place the WTMM and randomise the other wavelet coefficients in accordance with the methods outlined above, we should generate a realisation of the original signal that preserves the cusp singularity structure but randomises the chirps.

Hence, surrogate data with chirp characteristics randomised, plus a measure of the chirps (α_L or oscillation spaces or 2-micro-local frontiers) can be used for statistical testing.