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Multiscale Analysis of Wind Energy Fluctuations

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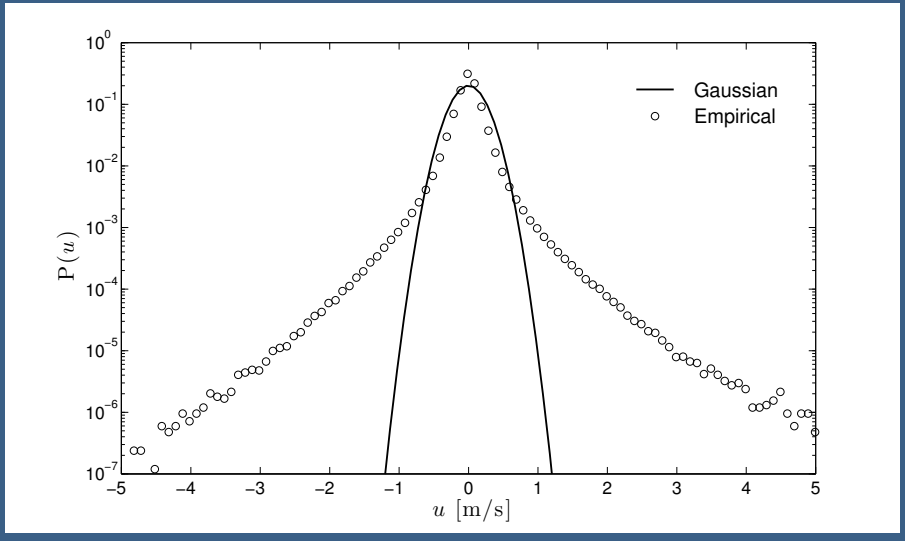
Background

- The failure of the pitch mechanism is correlated to turbulence with a statistical significance in excess of 99.9% [1].
- The study *Reliability Analysis for Wind Turbines* [3] uses 10 years of failure rate data to predict subassembly failures.
- PDF of 10 days shows extremely non-Gaussian statistics.



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Test Site

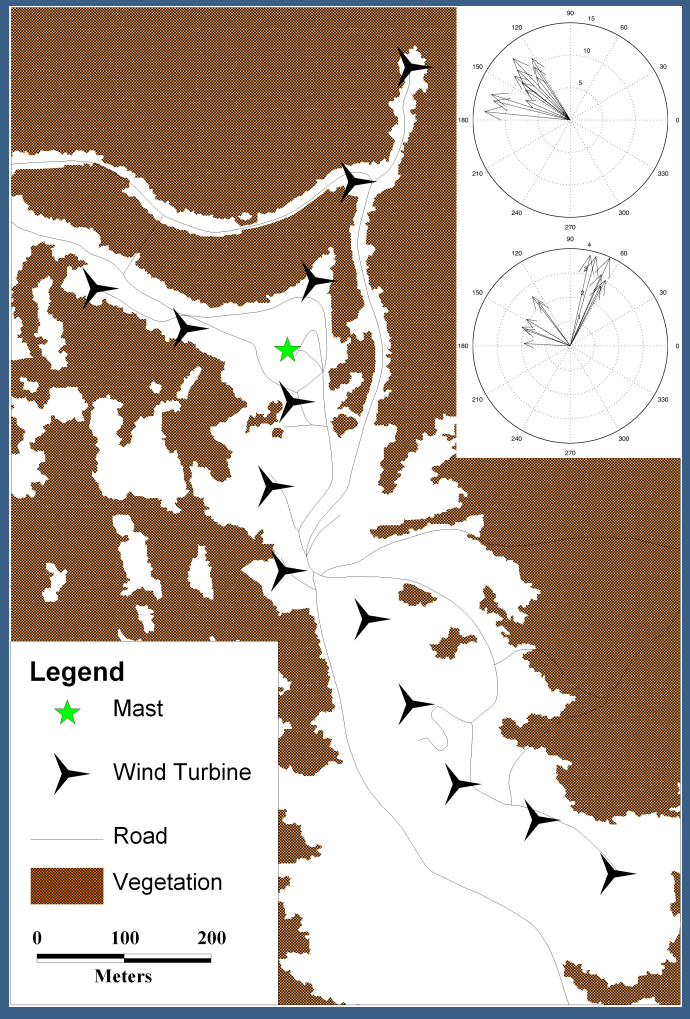

Figure: Created by Julien Richard at ENPC LEESU.

- Corsica case study with mast and turbine positions detailed in the adjacent map.
- Meteo France has difficulty obtaining wind velocity predictions (typically less than 40% accurate).
- Mean wind speed is related to the scaling properties of the data.

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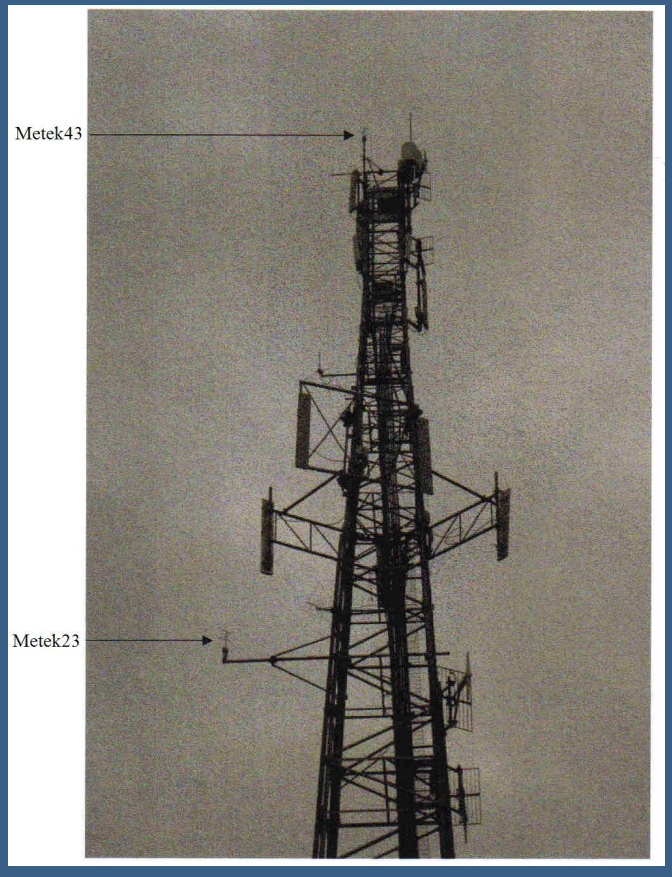
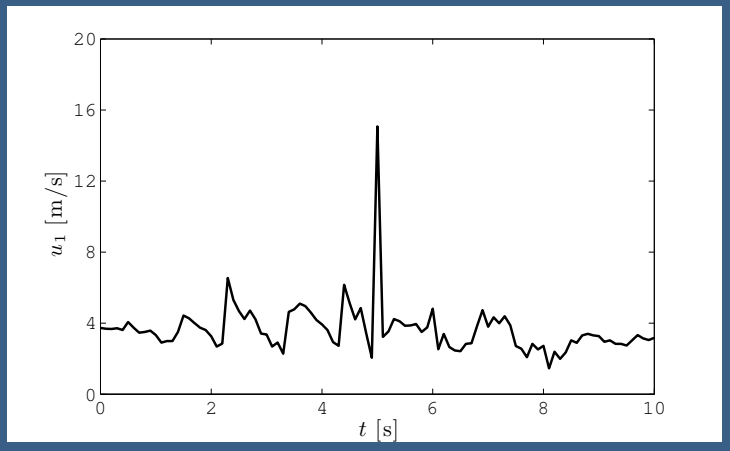
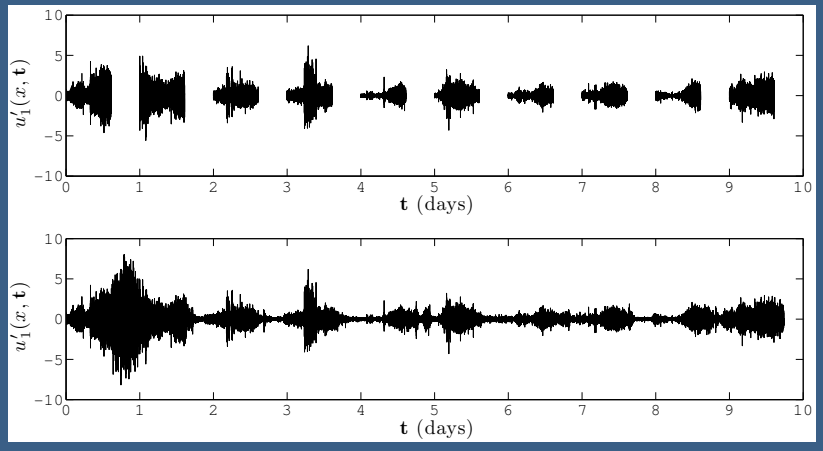
Measurements



- Consist of 180 days of 10Hz samples at three heights 22m, 23m and 43m.
- Tested for either a string character (corrupted data) or -9999 (missing data). If the element tested true it would be removed and indexed.
- Preprocessing gave 10 days of temporally continuous error/corruption free data and a 102 days of error/corruption free independent sample data.





- Left figure shows an extreme change four times the mean velocity over a period of about 0.2 seconds.
- Right below figure shows $\mathbf{u}' = \mathbf{u} - \overline{\mathbf{u}}$ for 10 days of continuous data. Fluctuations appear symmetric.
- Right above shows the subsamples taken to reduce the spectral spikes at high frequencies. Loss of data due to power of 2 subsamples needed for downscaling.

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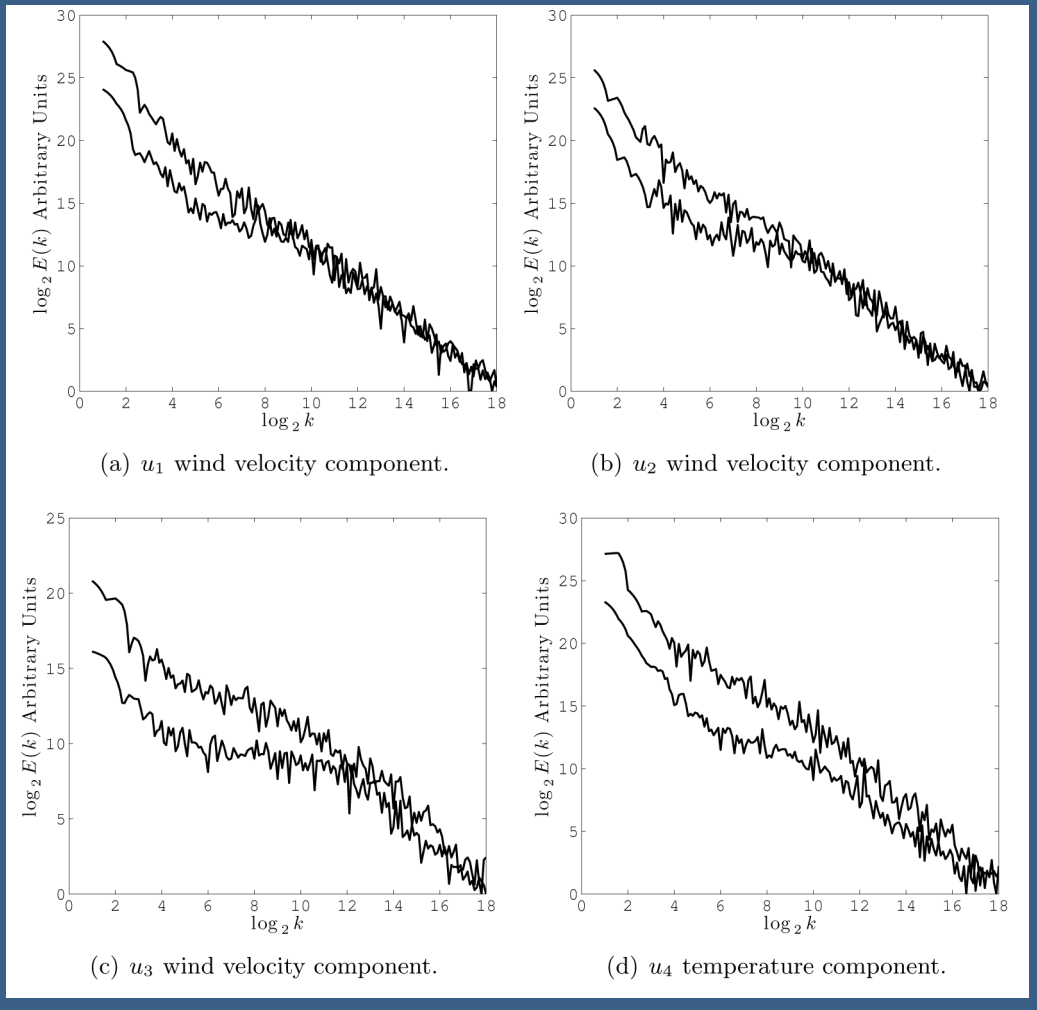
Spectra



(a) u_1 wind velocity component.

(b) u_2 wind velocity component.

(c) u_3 wind velocity component.

(d) u_4 temperature component.

Assume Kolmogorov' self similarity hypothesis [2]

Definition

$$\bar{\varepsilon} \propto \Delta \bar{v}^3 / \Delta \ell$$

$$E(k) \propto k^{-\beta}$$

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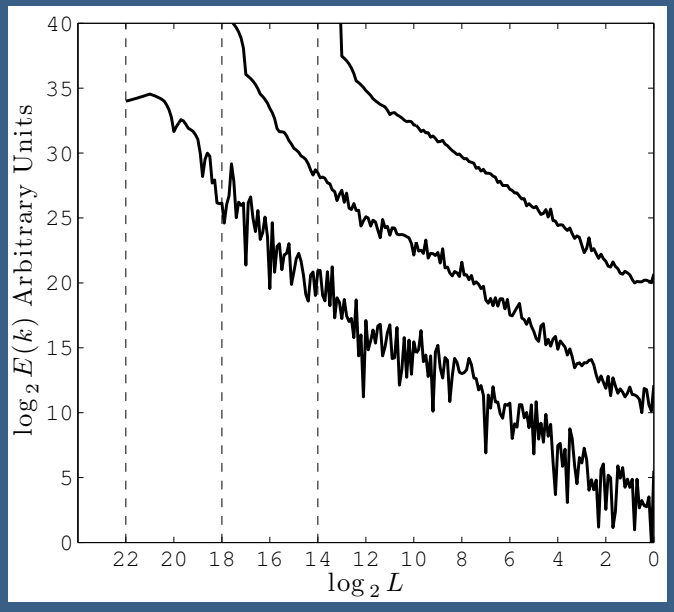

Figure: Comparison of a 10 day sample with 1 day and 1 hour subsamples.

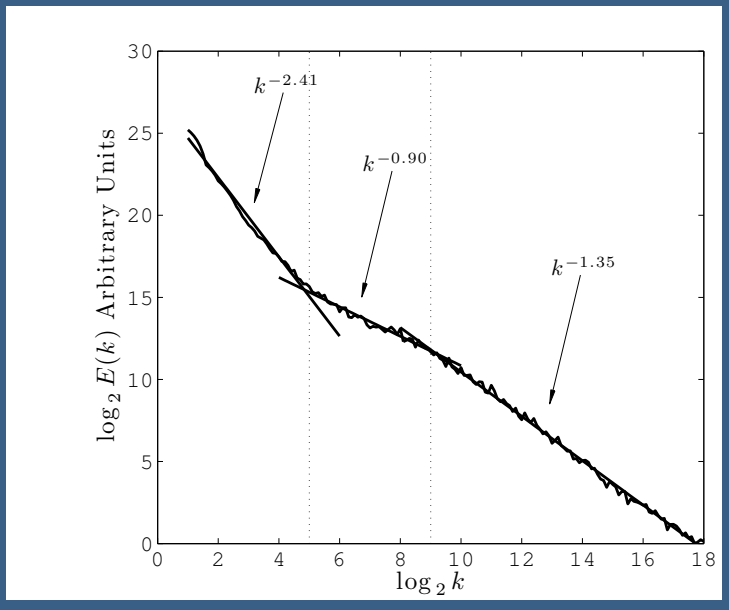

Figure: Sample of 102 independent 1 day subsamples. Three power law scaling regions.

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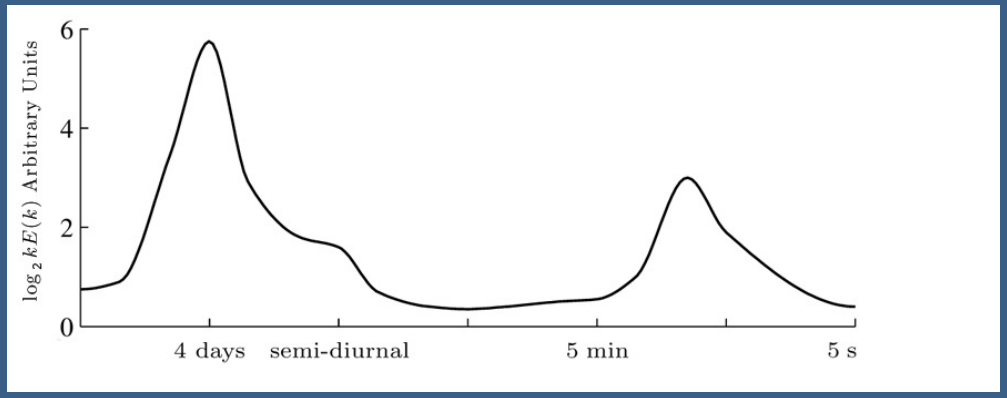
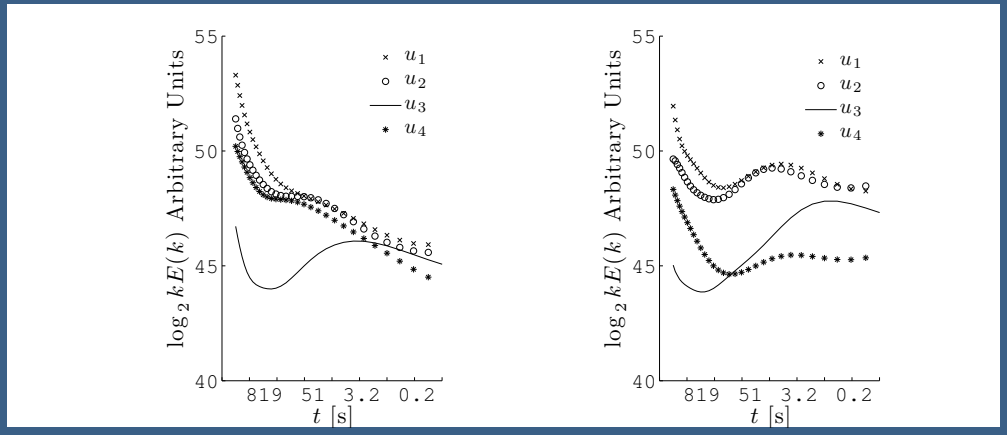
Integrated Spectra





- Van de Hoven integrated spectra.
- Position of energy peaks in agreement.
- Confirmation of the influence of wind turbines.

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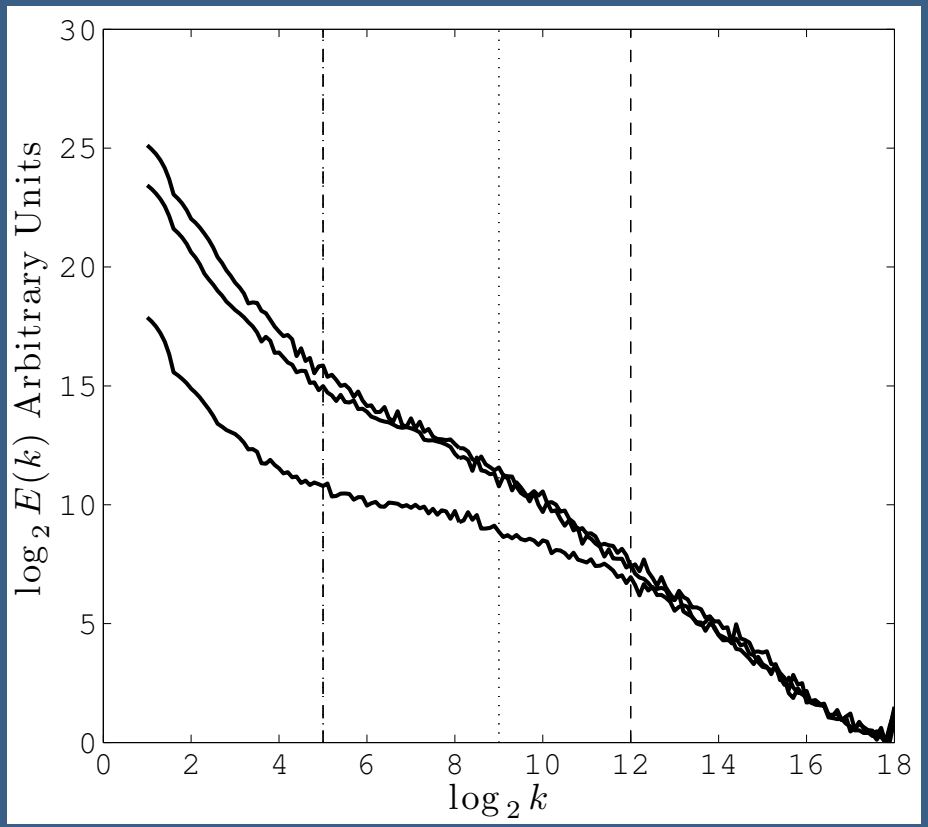
Frozen Turbulence



- Yaglom and Kader [1]

Definition

$$L_1 = L_u = 10.3z$$

$$L_2 = L_v = 7.5z$$

$$L_3 = L_w = 0.5z$$

$$L_4 = L_\theta = 8.4z$$

- Can calculate $U \sim 0.5\text{ms}^{-1}$

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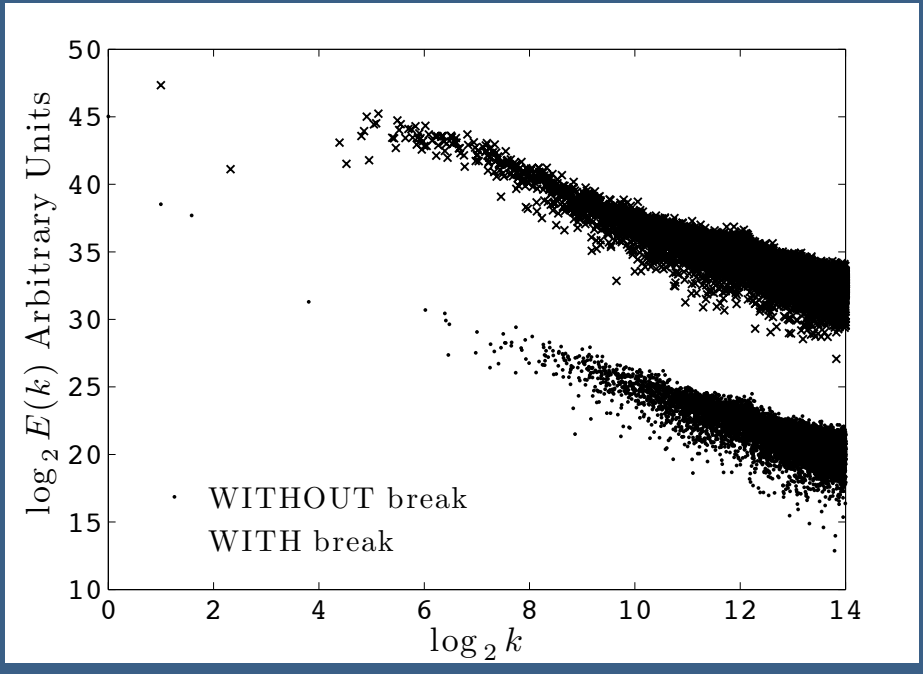
Cospectra



- Horizontal cospectra i.e. $\text{fft}(u_1, u_2) \neq 0$.
- Variation in the breaks in symmetry with respect to $(x, z)-$plane correspond to spectral representations.
- $\sim 4,000$ and $\sim 20,000$ which is 10 and 60% of the 32,768 observations.

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Recap on Multifractals

Multifractal Charaterisations

Ratio of scales

$$\lambda = L/\ell$$

Scaling moment function

$$< \varepsilon_\lambda^q > \approx \lambda^{K(q)}$$

Universal Multifractals [2]

$$K(q) = \frac{C_1}{\alpha - 1}(q^\alpha - q)$$

- The moment of order q.
- The Lévy parameter α measures the multifractality of the process (*a fractal process has* $\alpha = 0$).
- The co-dimension C_1 of the mean field measures its mean fractalitiy (*a homogeneous field has* $C_1 = 0$).

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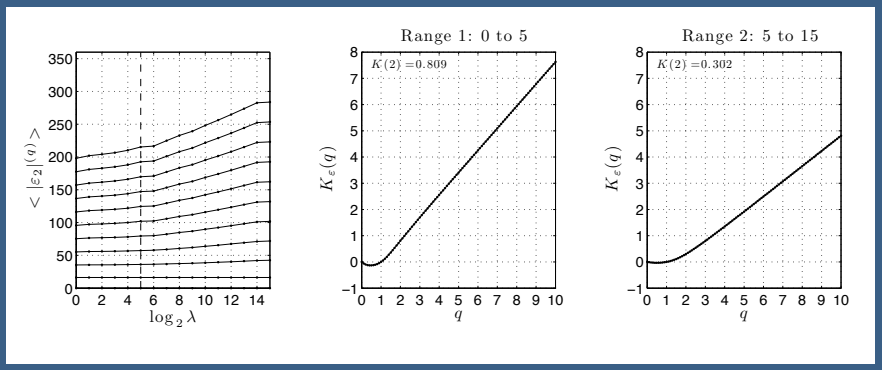
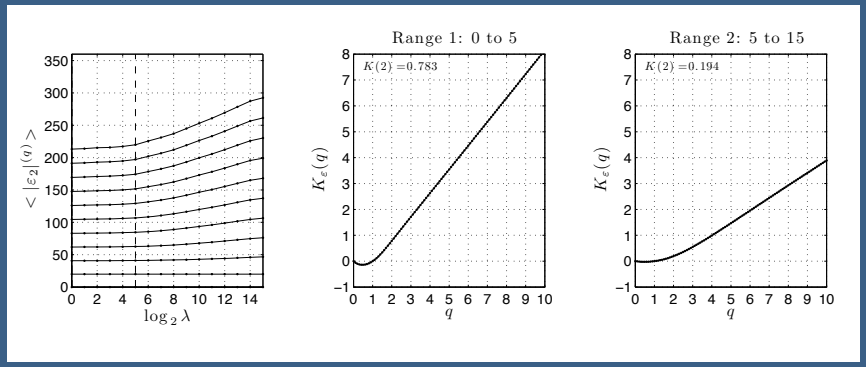
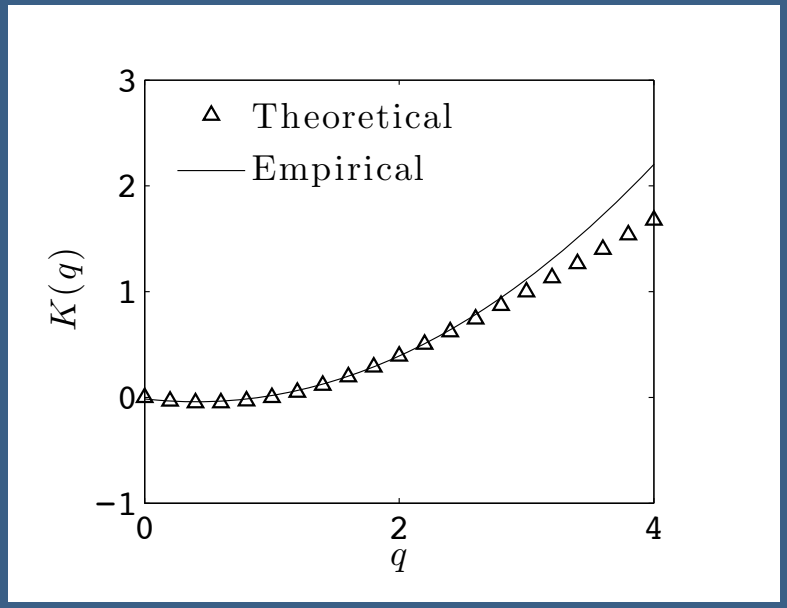
TM and K(q)







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Results for GOOD scaling days

$k = 2^n$	$2H+1$	$K(2)$	β	α	C_1	
$1 \leq n < 5$	-1.50	0.10	-1.60	1.83	0.03	
$5 \leq n < 15$	-1.46	0.40	-1.86	1.59	0.04	u_1
$1 \leq n < 15$	-1.44	0.29	-1.73	1.66	0.04	

$k = 2^n$	$2H+1$	$K(2)$	β	α	C_1	
$1 \leq n < 5$	-1.50	0.10	-1.60	2.00	0.03	
$5 \leq n < 15$	-1.46	0.42	-1.88	1.62	0.04	u_2
$1 \leq n < 15$	-1.39	0.30	-1.69	1.70	0.04	

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Results for BAD scaling days

$k = 2^n$	$2H+1$	$K(2)$	β	α	C_1	
$1 \leq n < 5$	-1.01	0.03	-1.04	1.85	0.01	
$5 \leq n < 15$	-1.36	0.42	-1.78	1.63	0.02	u_1
$1 \leq n < 15$	-1.26	0.29	-1.55	1.69	0.01	

$k = 2^n$	$2H+1$	$K(2)$	β	α	C_1	
$1 \leq n < 5$	-0.92	0.04	-0.96	1.89	0.02	
$5 \leq n < 15$	-1.37	0.46	-1.93	1.64	0.02	u_2
$1 \leq n < 15$	-1.30	0.32	-1.62	1.69	0.02	

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Conclusion

1. Identified two power law scaling regimes at high wave numbers
   - without the influence of turbines agrees with, superficially, the -5/3 law when using multifractals to account for intermittency.
   - with the influence of turbines with an energy plateau whose length is proportional to the energy extracted from the turbine.
2. Identified the velocity field as multifractal allowing it to be fully described by the parameters α and C_1.
3. Intermittency, $K(2)$, in the wake of the turbines is less than the intermittency not in the wake.
4. Multifractals can reproduce the fat-tailed statistics presented and can quantify the risk associated with intermittent wind velocities.

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WAUDIT

Wind resource assessment audit and standardisation

- The WAUDIT objective is the generation of a pool of researchers, in the field of wind resource assessment.
- The development of state-of-the-art measurement and numerical and physical modelling techniques for industry.
- 30 organisations from 8 different EU member states will contribute 18 PhD theses under the umbrella of the European Wind Energy Academy (EAWE).

References

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