

Effects of rainfall on wind turbulence in a Universal Multifractal framework



Ángel García Gago⁽¹⁾, Daniel Schertzer⁽¹⁾,
Auguste Gires⁽¹⁾
(angel.garcia-gago@enpc.fr)

(1) HM&Co, École des Ponts
ParisTech, France

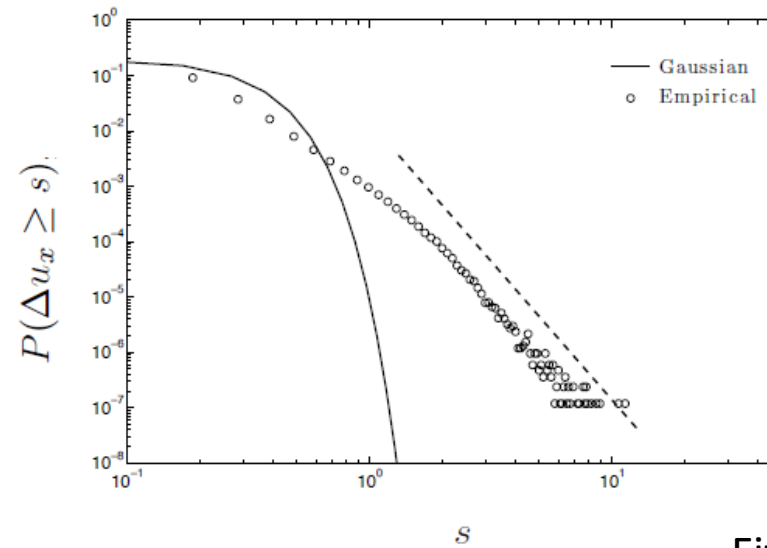


<https://hmco.enpc.fr/portfolio-archive/rw-turb/>

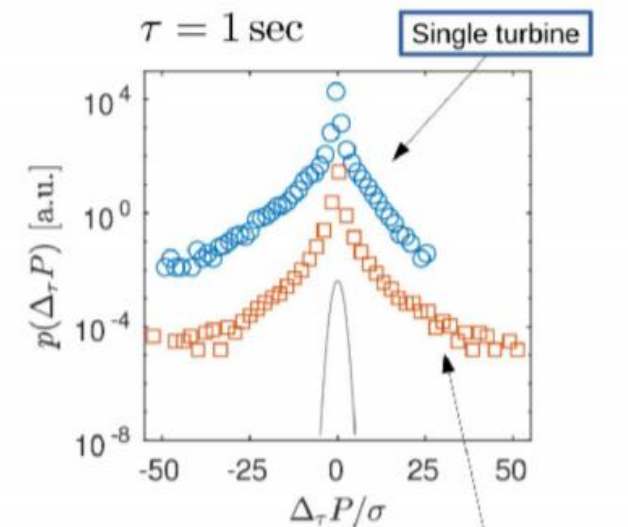
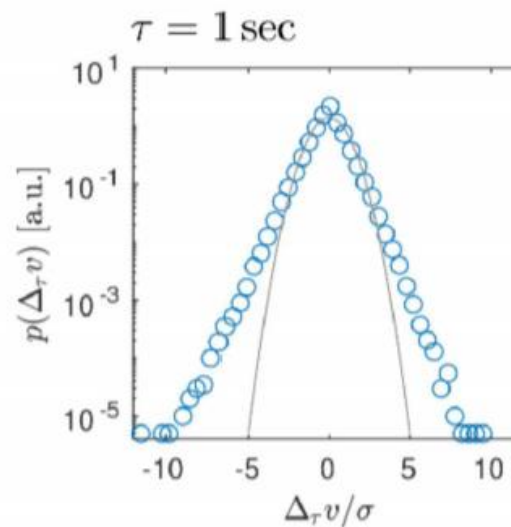
Introduction

Intermittent nature of wind turbulence

- **Complex** to observe and analyse
- **Standard tools** (10 min average, Gaussian approach ...) are not appropriate for this extreme variability
- **Transferred** to loads on turbine (torque), and power production.
- **Similar behaviour** in rainfall
- **Characterizing** the effects of rainfall on wind turbulence



Fitton et al. 2014



M. Anvari et al., *New J. Phys.* **18** (2016) 063027

Outline of the project

What RW-Turb is about ?

RW-Turb relies on the expertise of HM&Co in measurement and modelling across **wide range of spatio-temporal scales** of atmospheric **turbulence and rainfall** to quantify the impact of the latter on **wind power production**.

This project benefits from an industrial partnership with Boralex, a wind power producer.

RW-Turb will open new paths to improve **nowcasts of power production**, a major challenge in a framework of increasing use of **renewable energies** in France and Europe.



Coordination :



Steering Committee:



Research and innovation

WP1 : A high resolution measurement campaign

- Selection, purchase and installation of measurement devices
- Data base preparation
- Data validation.



WP 2: Analysis and simulation of rainfall effects on the wind power available

- Characterization of wind intermittency and air density under various rainfall conditions
- A 3+1D model of drops field in a turbulent wind field
- Development and validation of wind simulation



WP 3: Analysis of rainfall effects on energy conversion by wind turbine

- Characterization of the transfer of wind intermittency to power production under various rainfall conditions
- Computation of the torque fluctuations under turbulent wind constraints.
- Numerical simulation of wind turbine behaviour

International Advisory Board



Impacts

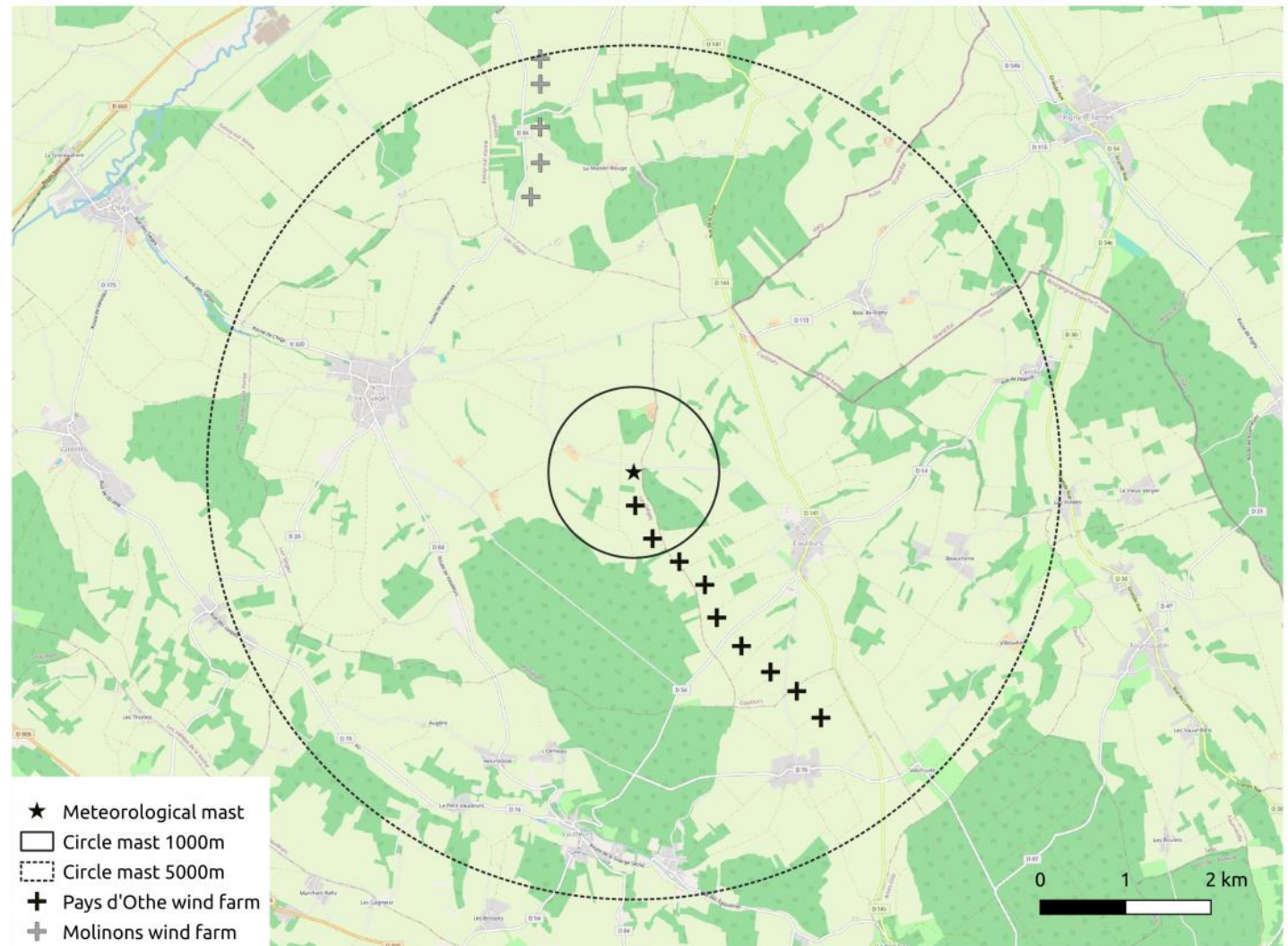
Wind Energy challenges,
Scientific and professional dissemination,
Toolbox,
Exploitation and follow-up



A high resolution measurement campaign

Pays d'Othe wind farm

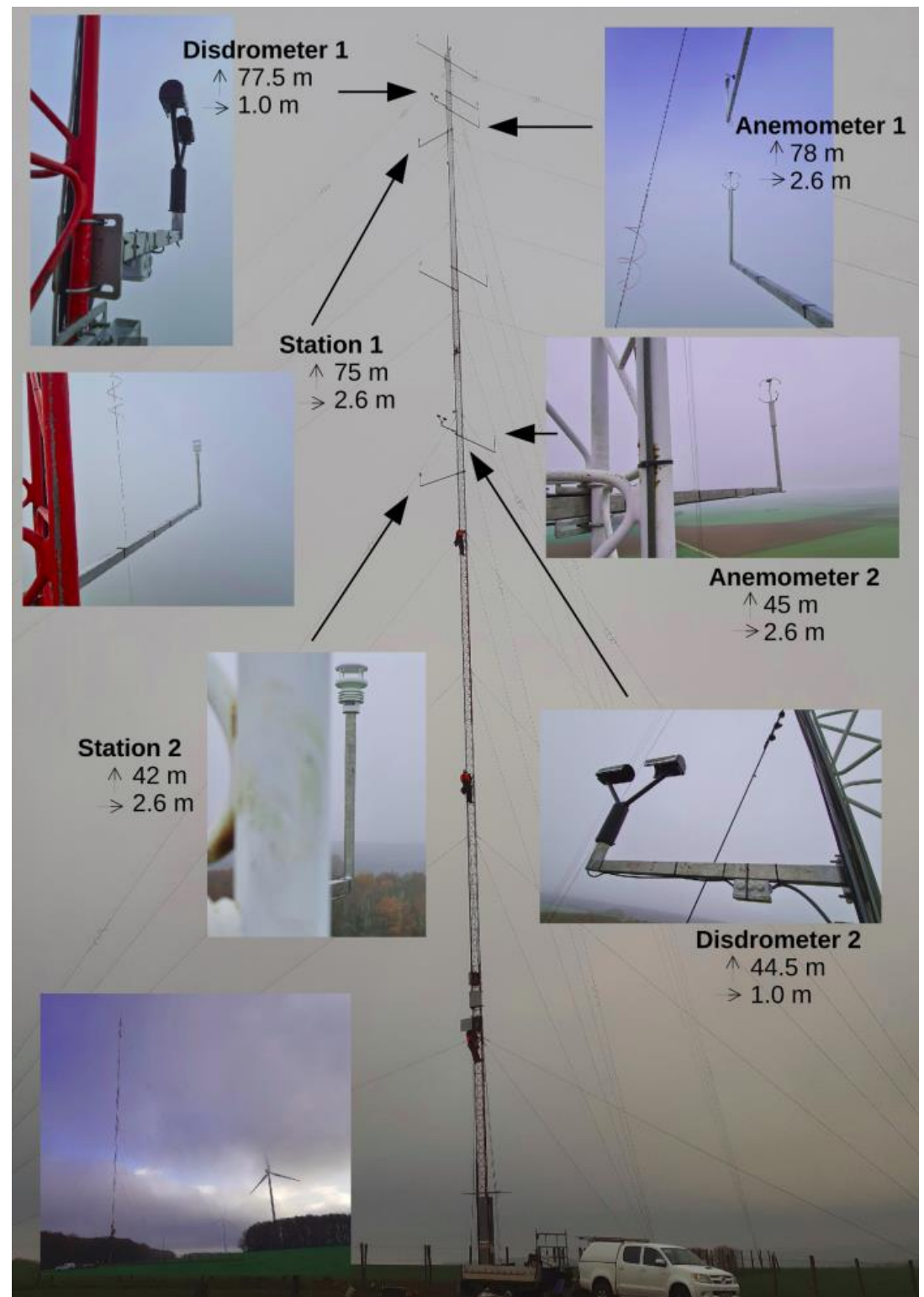
A 86 m high meteorological mast on a wind farm operated by **BORALEX**



A high resolution measurement campaign

Instruments

- **3D sonic anemometers** (Thies CLIMA): collection of wind data at 100 Hz
- **Meteorological stations** (Thies CLIMA): collection of temperature, pressure, humidity, wind, precipitation at 1 Hz
- **Disdrometers** (OTT Parsivel2): collection of precipitation (size and velocity of hydrometeors) at a resolution of 30s.

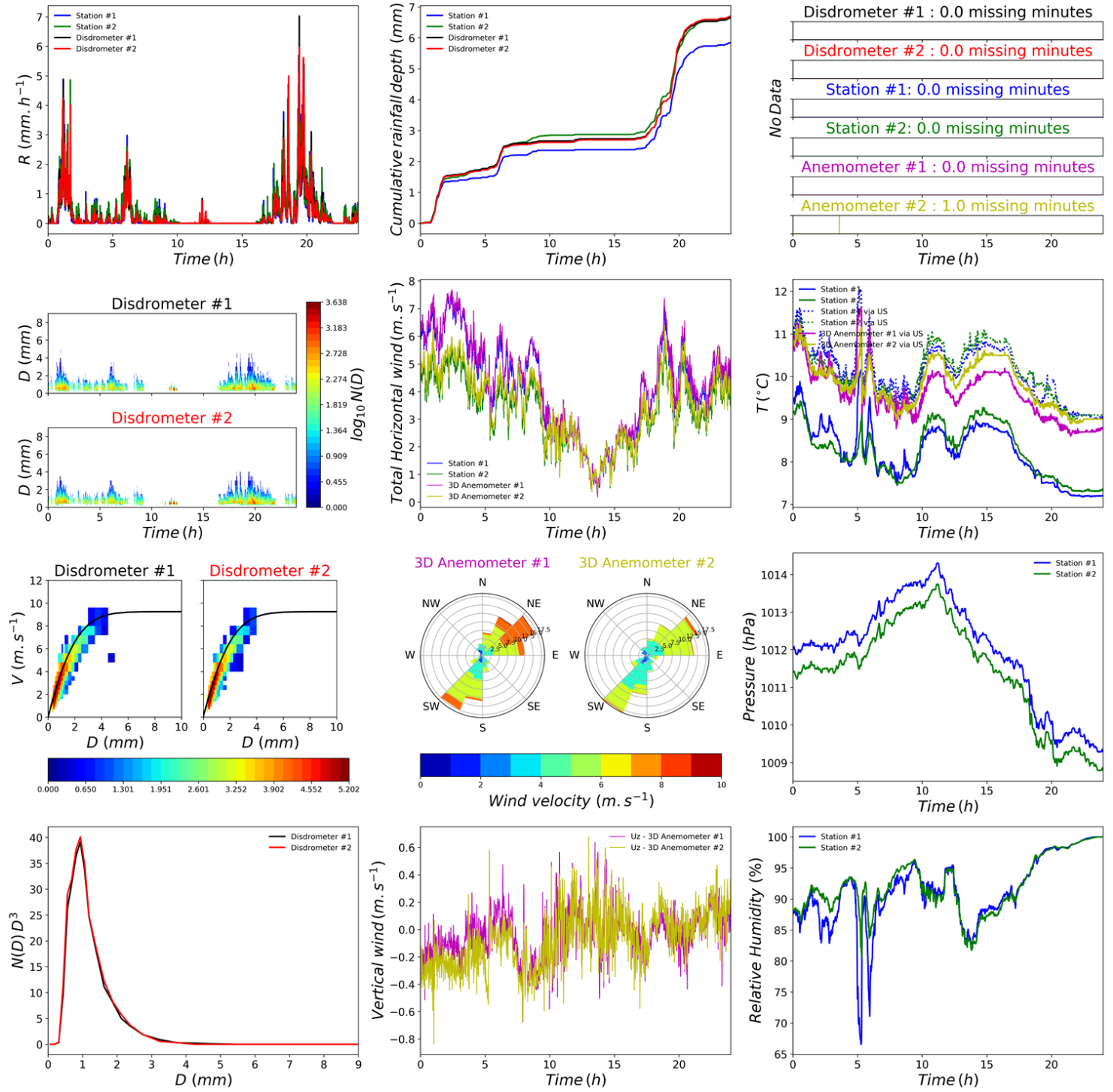


Start : 2021/02/05 00:00:00 -- End : 2021/02/06 00:00:00

A high resolution measurement campaign

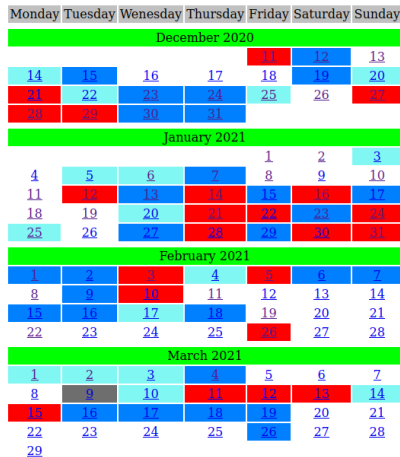
Meteorological data

- Storage on ENPC servers
- Data base with user friendly tools in Python to extract relevant data
- Quicklooks available on the project's webpage



RW-Turb campaign on Pays d'Othe wind farm

Quicklooks



Color code

No rain
 $< 1 \text{ mm}$
 $< 5 \text{ mm}$
 $> 5 \text{ mm}$
 No data

Multifractal framework

Theoretical approach

The Universal Multifractals (UM) framework allows to characterize the extreme variability of geophysical fields across scales with the help of a limited number of physically meaningful parameters. (Schertzer and Lovejoy (1987)).

The codimension function ($c(\gamma)$), determined by the probability of a scale invariant field exceeding a scale-dependant threshold (λ^γ , where γ is called singularity) at resolution (λ), and Moment scaling function $K(q)$ characterize the variability across scale.

In UM framework scaling functions are defined using 3 of parameters:

C_1 , mean intermittency co-dimension, measures how concentrated is the average field

α , multi-fractality index, measures how fast the Intermittency evolves

H , the degree of non-conservation, measures the scale dependency of the mean field

If a field is scaling, its power spectra (E) is power law related the wavenumber (k) (Mandelbrot, 1982; Schertzer and Lovejoy, 1985).

Outer scale

$$\lambda = L/l$$

Observation scale

$$p(\varepsilon_\lambda \geq \lambda^\gamma) \approx \lambda^{-c(\gamma)}$$

$$\langle \varepsilon_\lambda^q \rangle \approx \lambda^{K(q)}$$

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

$$\langle \varepsilon_\lambda \rangle = \lambda^{-H}$$

$$\beta = 1 + 2H - K(2)$$

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

Illustration of Preliminary Analysis

X component

- **Ensemble of 10 days**, sample size of 12 hours
- **Spectral analysis** with spectral slope β roughly equal to 2
- **Fractional Integration/Differentiation** is needed, as is commonly done in wind measures, to retrieve underline multifractal conservative field.

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

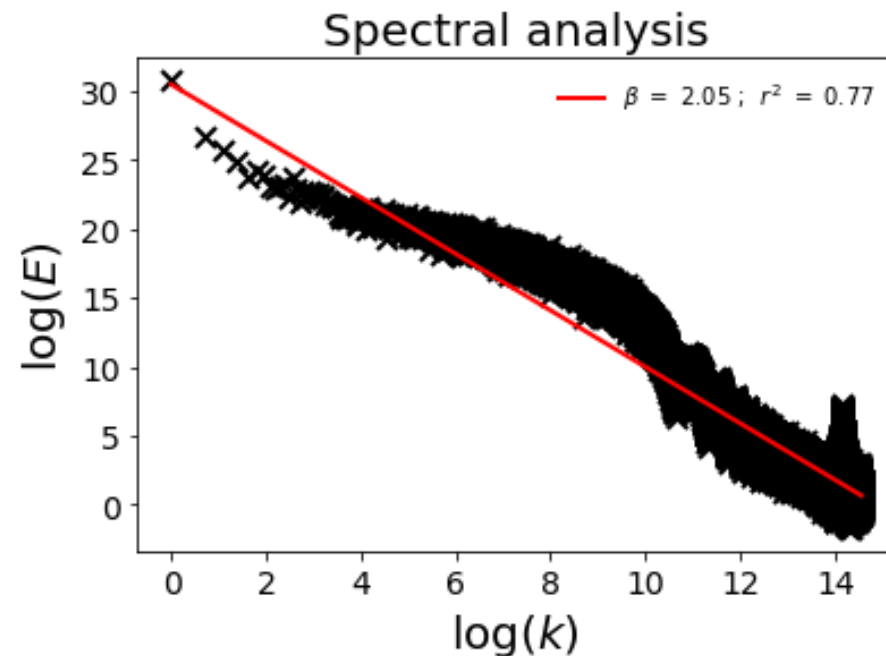
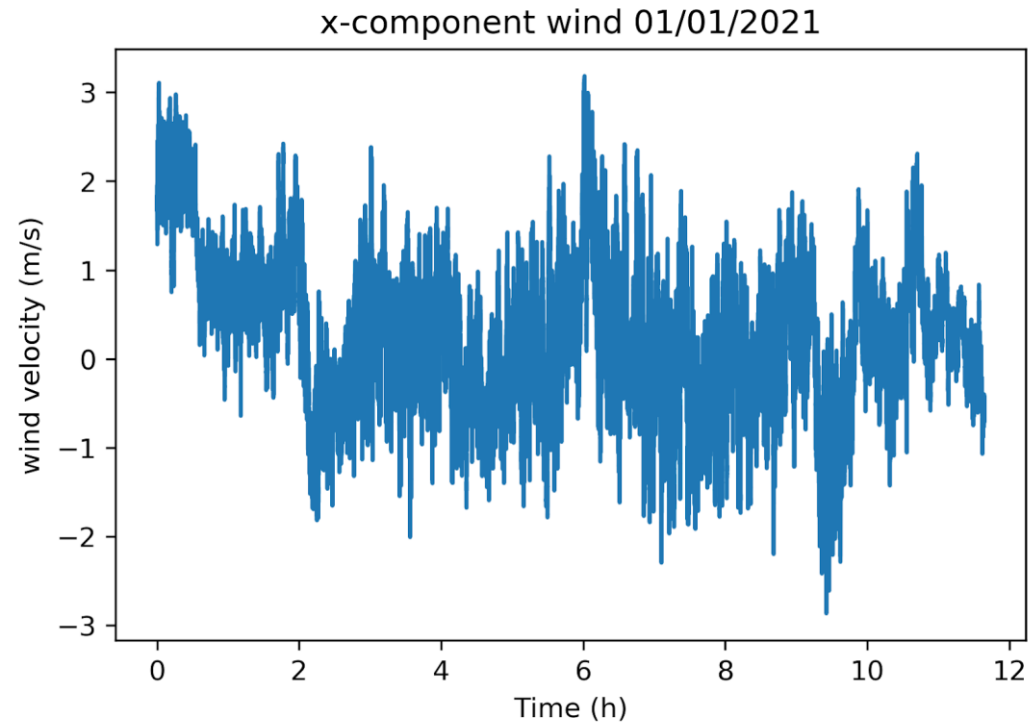
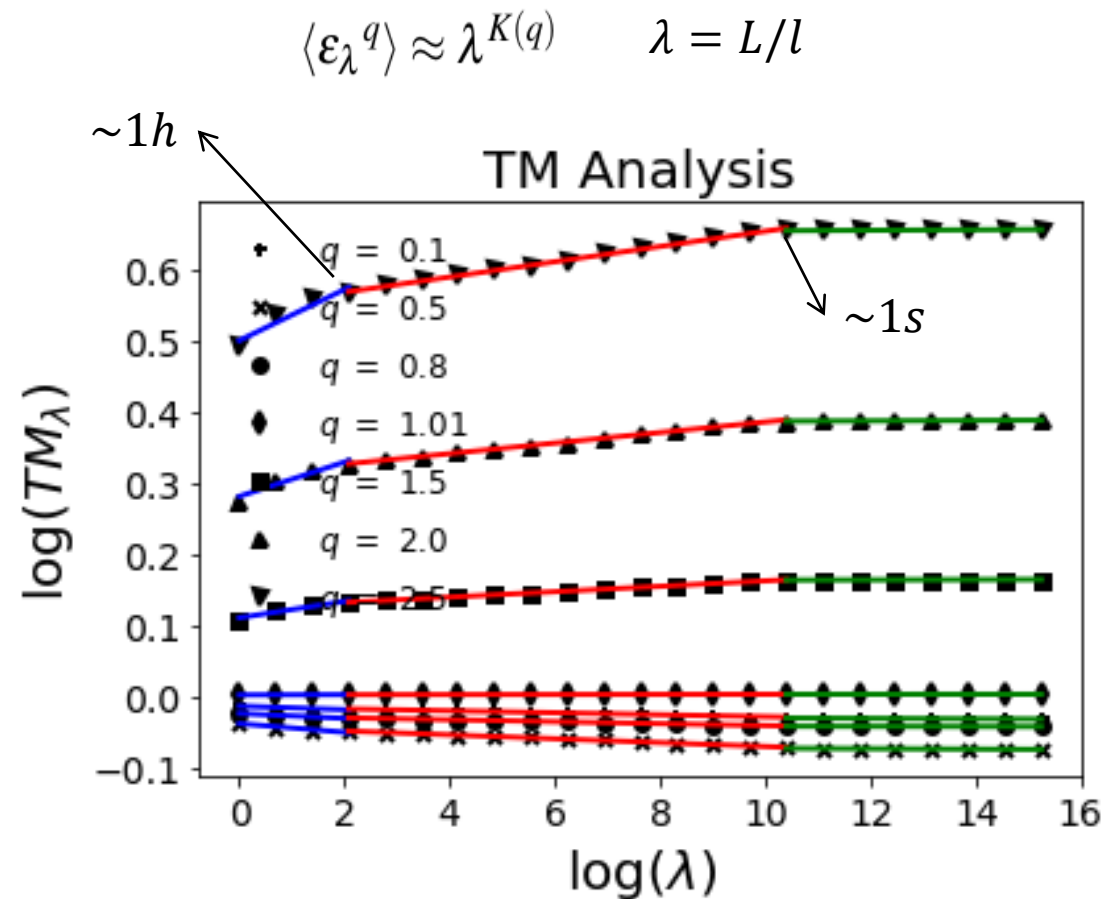


Illustration of Preliminary Analysis

Wind fluctuations

- Analysis in wind fluctuations, to determine scaling regimes.
- 3 scaling regimes with scaling breaks at ~ 1 second and ~ 1 hour respectively.
- Small values of C_1 are observed
- Refined Analysis is required



C_1	α	beta	H
0.02	1.73	2.14	0.59
0.01	1.55	2.05	0.53
0.00	1.44	1.73	0.36

Next steps

- Refine Analysis:
 - Implement Fractional Integration
 - Test different sample size
- Improve understanding
 - Analysing days with fully developed turbulence
 - Analysis in three components of the wind field looking for anisotropy
 - Analysis with different rainfall regimes