Radar Rainfall drop size distribution and wind (Ra2DW)

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Kick-off meeting,
Online (05/02/2024)

(1) HM&Co, École des Ponts ParisTech, France
(2) National Taiwan University, Taiwan

Ra2DW kick-off schedule

Time	Presenter(s): title
14:00-14:05	**Welcome and round table**
14:05-14-30	**Auguste Gires (HM&Co, ENPC)** and **Li-Pen Wang (NTU)**: Project overview
14:30-14-35	**Ching-Chun Chou (NTU)**: Observation of different multifractal phase transitions over three typhoon events (follow-up previous collaborations)
14:35-14:45	**Q&A**
14:45-15:00	**Remko Uijlenhoet (TU Delft):** Parameterizing DSDs and their variability
15:00-15:05	Break
15:05-15:20	**Alan Seed (Weather Radar New Zealand):** Some thoughts on using real-time rain gauge observations in quantitative precipitation estimation
15:20-15:35	**V. Chandrasekar (Colorado State University):** From raindrops to floods: the role of dual polarization radars in unraveling the microphysics of rainfall
15:35-15:50	**Daniel Schertzer (HM&Co, ENPC):** Beyond scalar modelling of multifractal precipitation and wind fields
15:50-16:00	**Q&A / Wrap-up**

Outline of the project

Why this project ?

An overall context :

- IPCC AR 6 Report released in 2021 (Masson-Delmotte, 2021) further confirmed that "the frequency and intensity of heavy precipitation events have increased since the 1950s over most land area for which observational data are sufficient for trend analysis (high confidence);
- As shown in a recent study called "Rain stops gain" (Kotz, 2022), rainfall has a negative impact on economic development;
- The portion of population living in cities is constantly growing (already more than 50% and 80% by 2050 according to UN forecasts).

To summarize this boldly, people are living in cities and rainfall extremes, which negatively impact economic developments, are increasing because of climate change.

Challenges of storm water management in urban areas

- High level of imperviousness
- Strong heterogeneity of land cover
- Impact of small scale rainfall variability (a need for data at ~ 100 m x 1 min)
- A need for tailored modelling tools

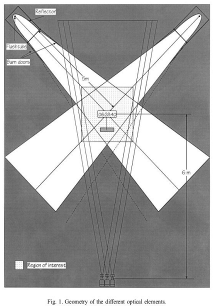
Sceaux, France, 19/06/2021

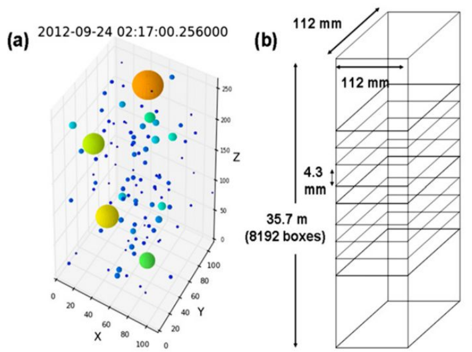
Consequently, progress on the understanding, measuring and modelling of rainfall in urban areas as well as storm water management is much needed.

Outline of the project

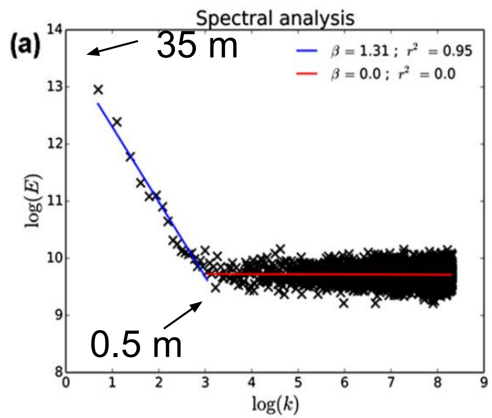
Why this project ?

Rainfall (rain rate and DSD) exhibits scale invariant multifractal features from drop scale to large scale

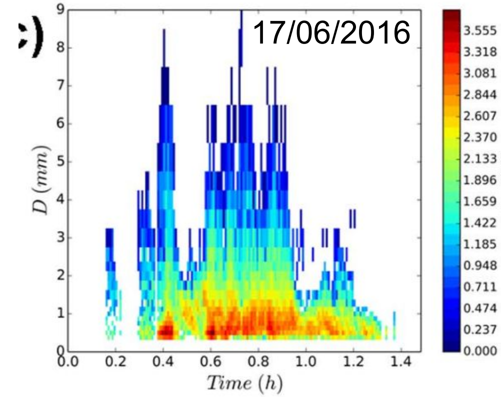




(Desaulnier-Soucy et al. 2001;
Lilley et al 2006)

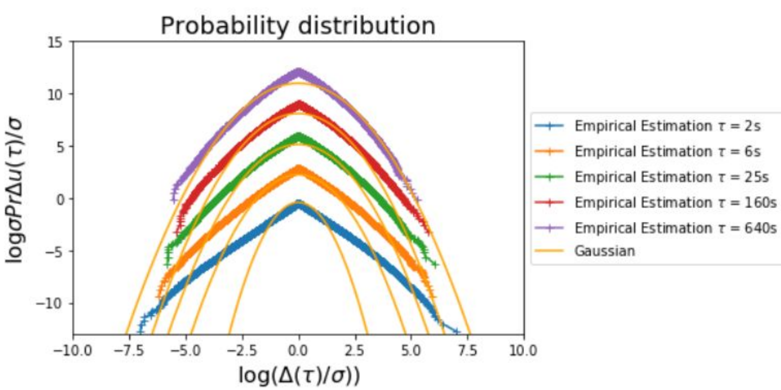


(Gires et al, 2015)

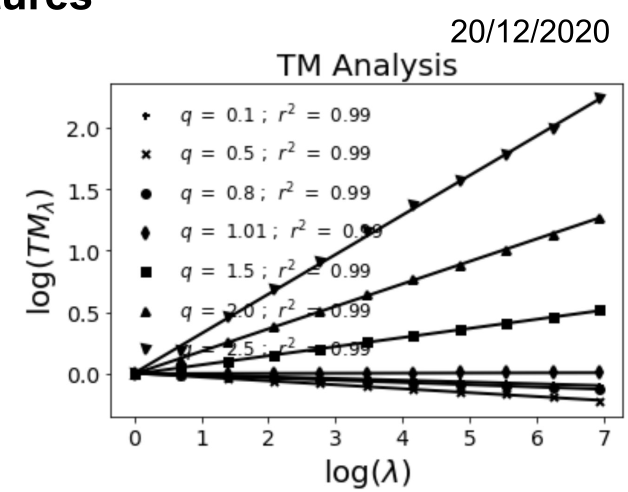


(Gires et al, 2018)

Wind also exhibits scale invariant multifractal features



(RW-Turb, measurement campaign)



Outline of the project

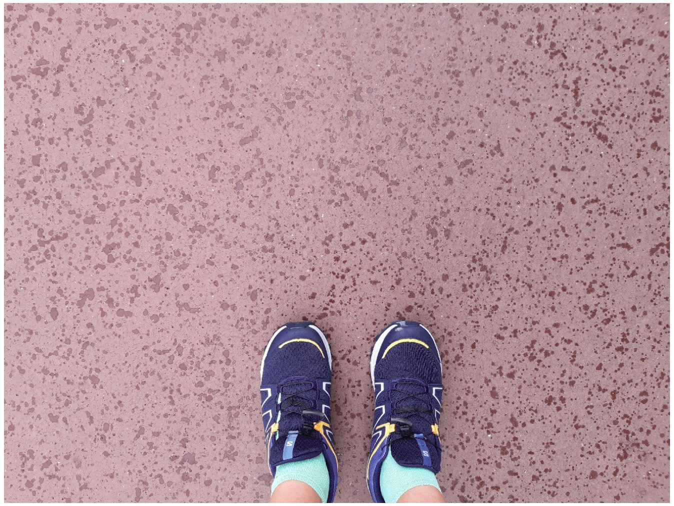
What is it about ?

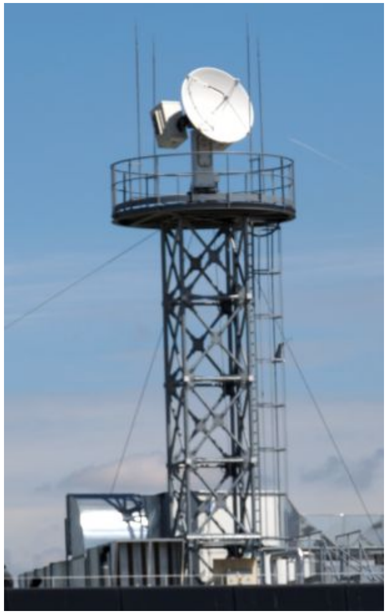
Ra2DW aims to improve the quality of radar QPE at high space-time resolution and their applicability to urban storm water management by addressing two issues:
- Accounting for DSD variability, and notably the one occurring below radar observation scales (DSD variability across scales)
- Better understanding and quantifying the wind drift effect (coupling between rainfall and wind; tracking rainfall cells in 4D)

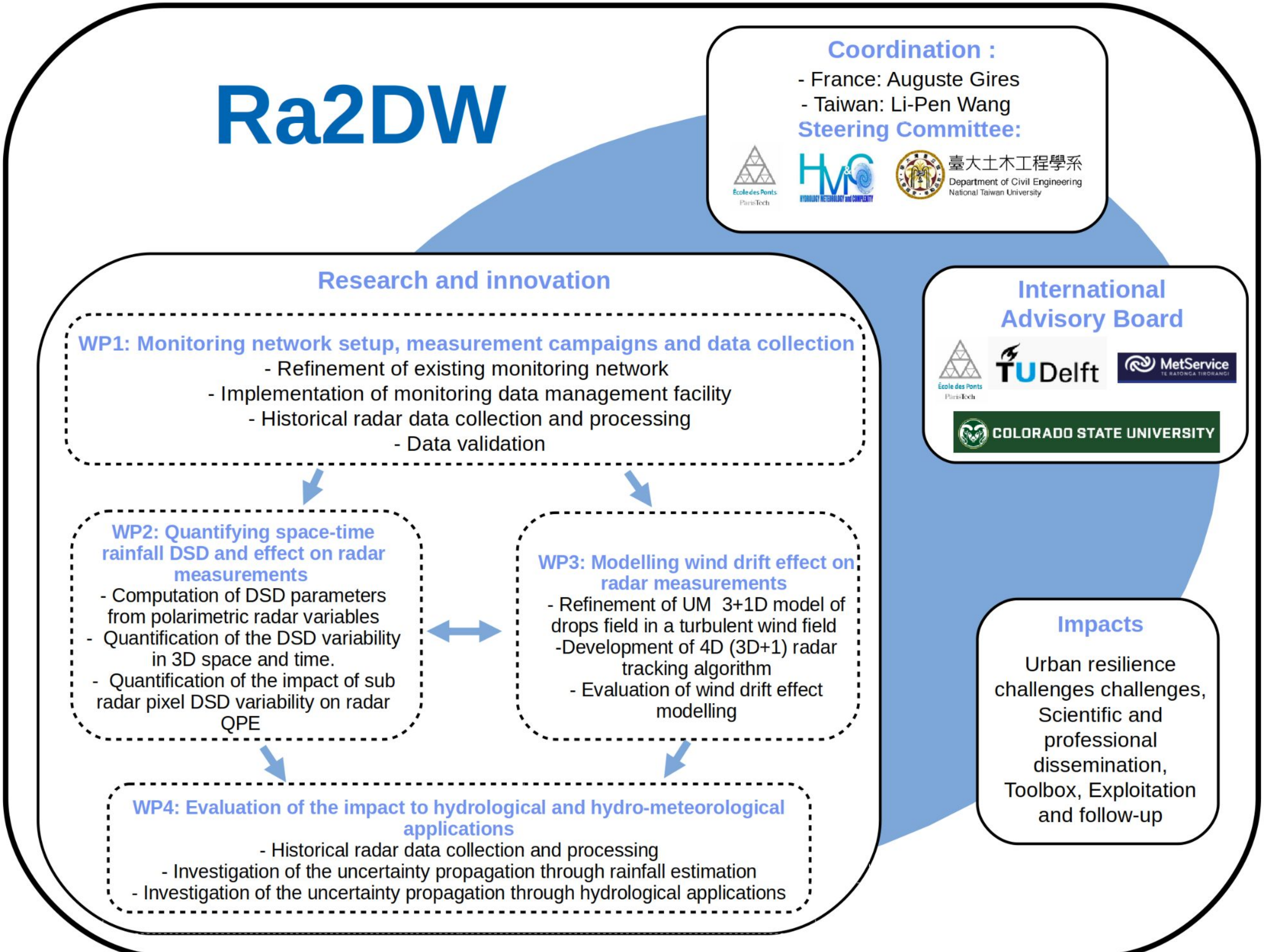
Then, quantification of the impact of both aspects on storm water management

Les Estables, France, 10/07/2013

Sceaux, France, 31/08/2023






Ra2DW
Coordination :
- France: Auguste Gires
- Taiwan: Li-Pen Wang
Steering Committee:
École des Ponts ParisTech
HM&Co HYDROLOGY METEOROLOGY and COMPLEXITY
臺大土木工程學系
Department of Civil Engineering
National Taiwan University
International Advisory Board
École des Ponts ParisTech
TUDelft
MetService TE RATONGA TIRORANGI
COLORADO STATE UNIVERSITY
Research and innovation
WP1: Monitoring network setup, measurement campaigns and data collection
- Refinement of existing monitoring network
- Implementation of monitoring data management facility
- Historical radar data collection and processing
- Data validation
WP2: Quantifying space-time rainfall DSD and effect on radar measurements
- Computation of DSD parameters from polarimetric radar variables
- Quantification of the DSD variability in 3D space and time.
- Quantification of the impact of sub radar pixel DSD variability on radar QPE
WP3: Modelling wind drift effect on radar measurements
- Refinement of UM 3+1D model of drops field in a turbulent wind field
-Development of 4D (3D+1) radar tracking algorithm
- Evaluation of wind drift effect modelling
WP4: Evaluation of the impact to hydrological and hydro-meteorological applications
- Historical radar data collection and processing
- Investigation of the uncertainty propagation through rainfall estimation
- Investigation of the uncertainty propagation through hydrological applications
Impacts
Urban resilience challenges challenges, Scientific and professional dissemination, Toolbox, Exploitation and follow-up

Outline of the project

HM&Co - ENPC team:

École des Ponts ParisTech

HYDROLOGY METEOROLOGY and COMPLEXITY

Researchers :
- **Auguste Gires** (coordination)
- **Ioulia Tchiguirinskaia**
- PhD (36 months) : to be hired
- Post-doc (18 months): to be hired
- MSc interns (x2): to be hired

NTU team:

臺大土木工程學系
Department of Civil Engineering
National Taiwan University

Researchers :
- **Li-Pen Wang** (coordination)
- **Tsang-Jung Chang**
- PhD (48 months): to be hired
- MSc students (x4): to be hired

International advisory board:

Involvement of a wider academic and industrial consortium :

TU Delft
- **Remko Uijlenhoet**

COLORADO STATE UNIVERSITY
Chandra V Chandraseka

MetService TE RATONGA TIRORANGI
Alan Seed

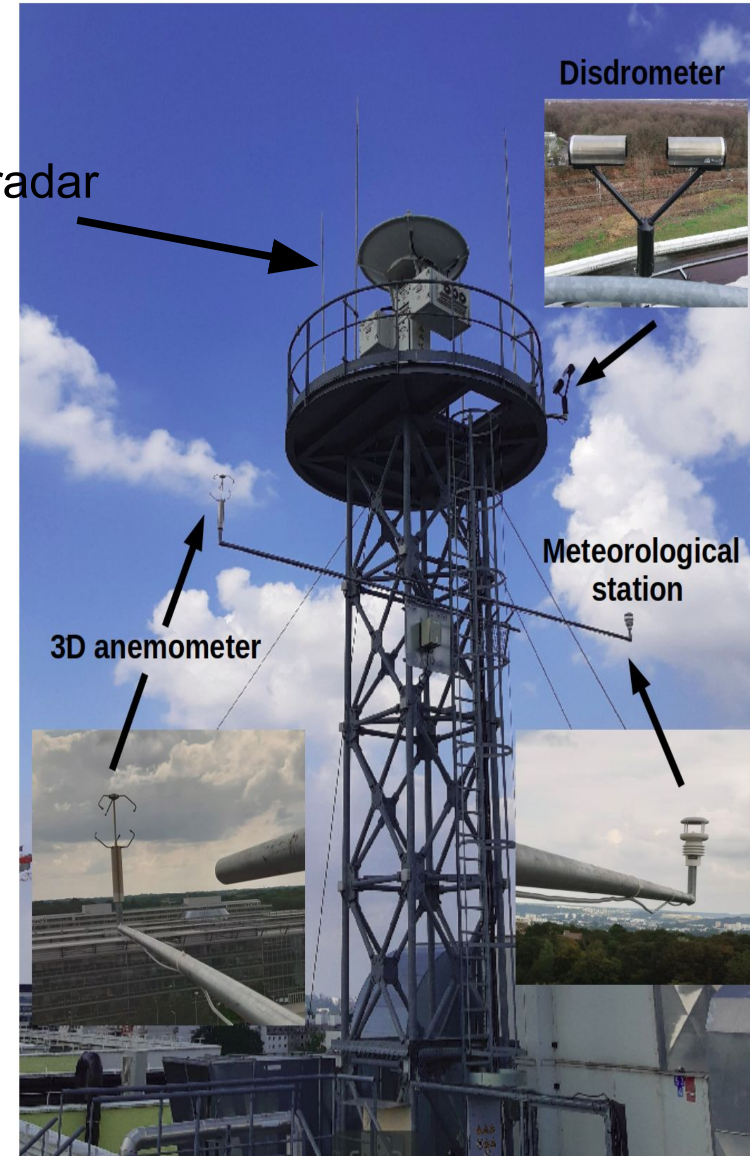
École des Ponts ParisTech
- **Daniel Schertzer**

WP1: Monitoring network setup, measurement campaigns and data collection

École des Ponts
ParisTech

HYDROLOGY METEOROLOGY and COMPLEXITY

Dual-pol X-band radar



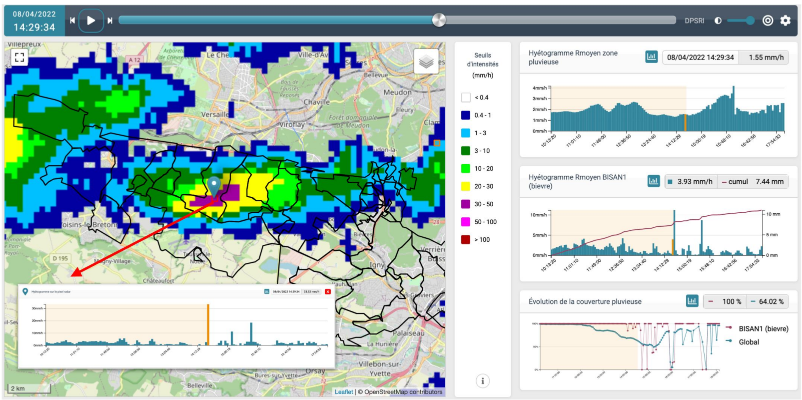
MRR has been ordered

https://metek.de/product/mrr-pro/

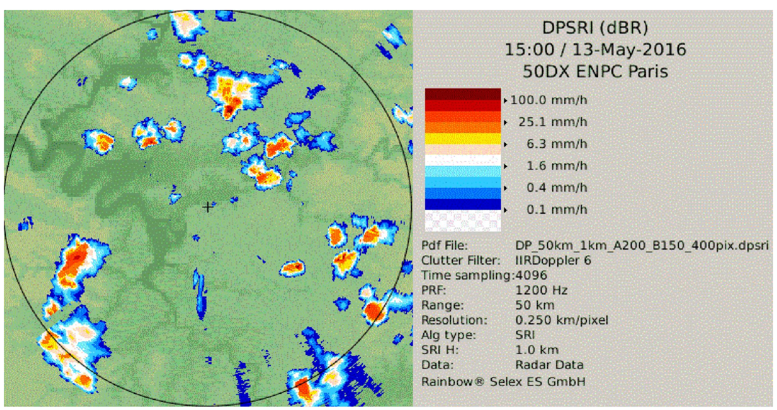
WP1: Monitoring network setup, measurement campaigns and data collection

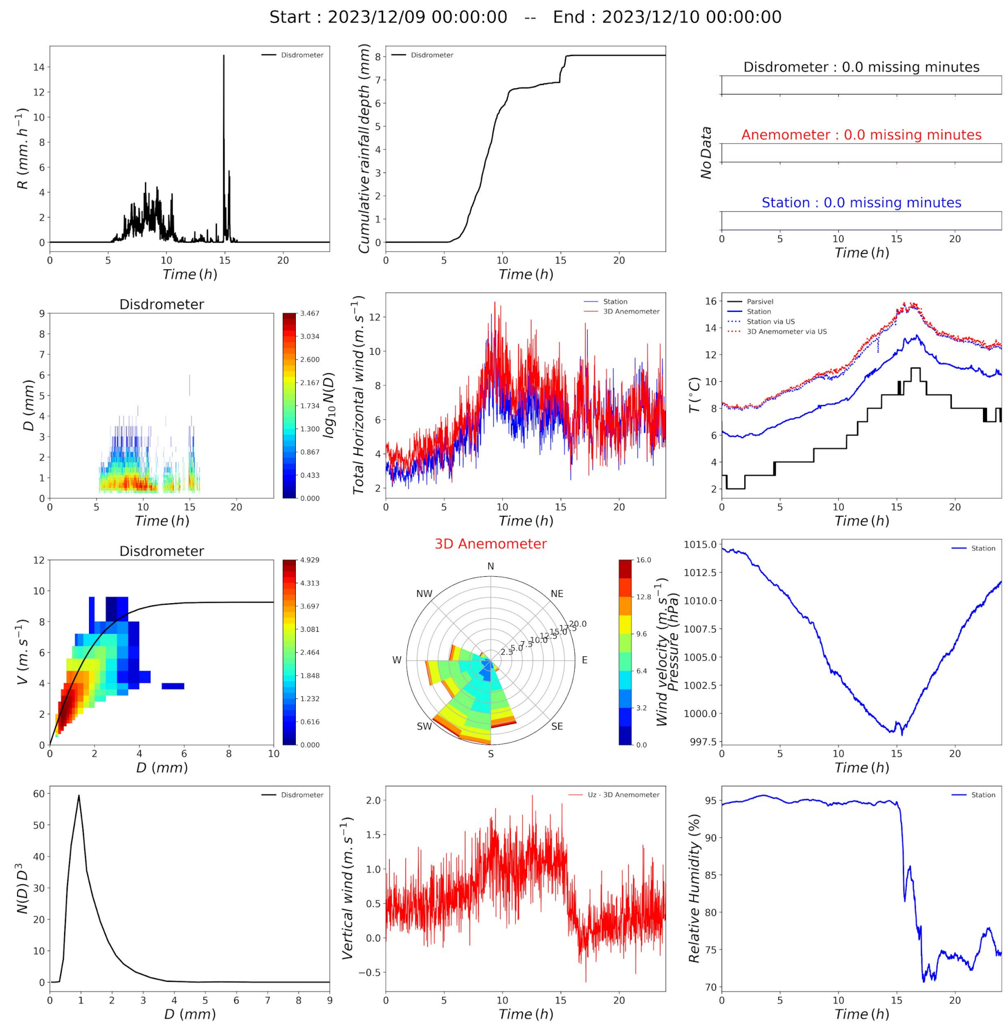
École des Ponts ParisTech

HYDROLOGY METEOROLOGY and COMPLEXITY



https://radx.enpc.fr/



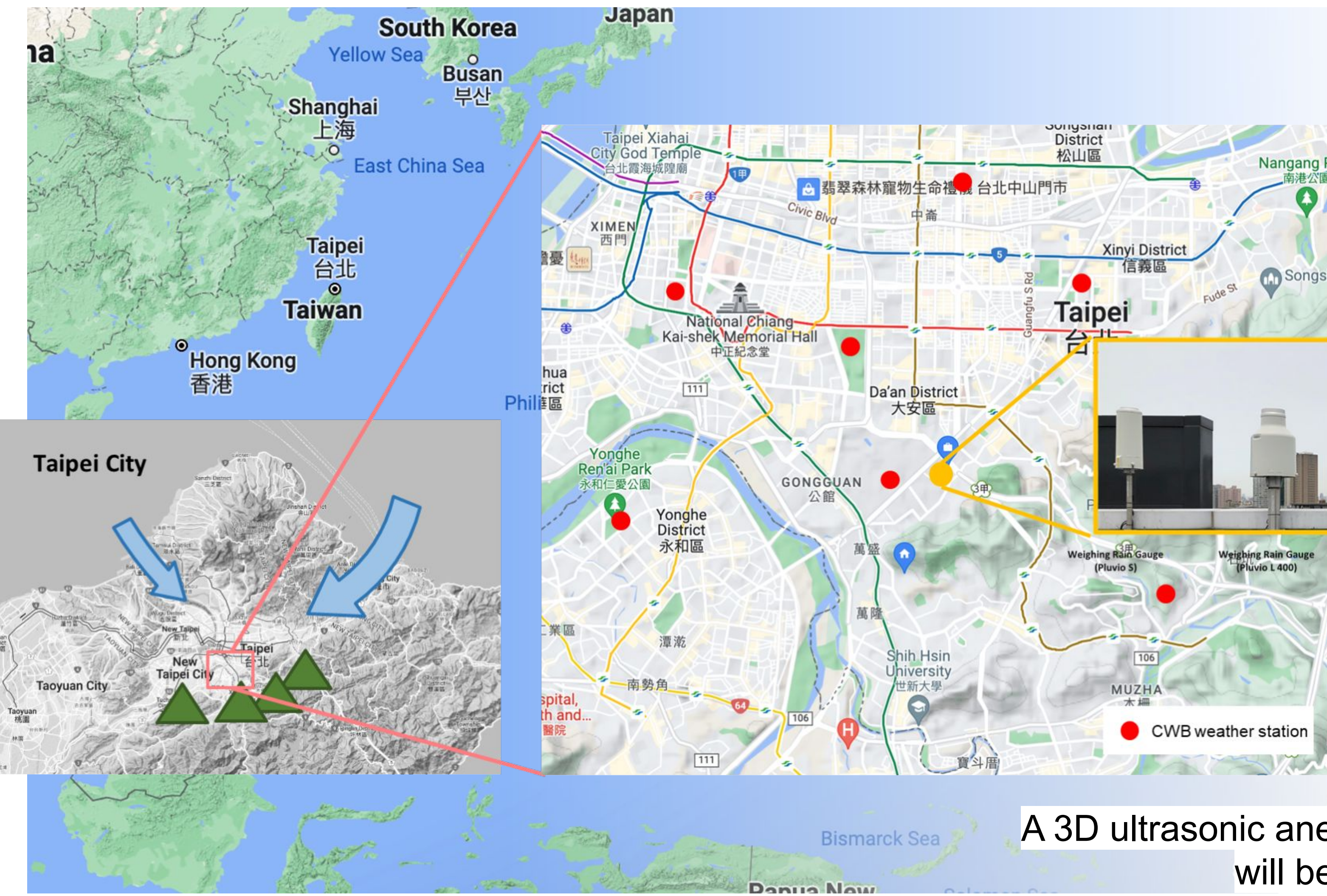


https://hmco.enpc.fr/portfolio-archive/taranis-observatory/

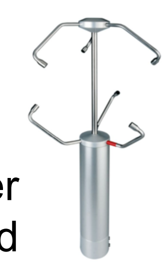
WP1: Monitoring network setup, measurement campaigns and data collection

臺大土木工程學系
Department of Civil Engineering
National Taiwan University

A network of 5 catching and non-catching gauges, providing high-resolution rainfall records (10s-1 min), located at a thunderstorm hotspot in Taipei.



A 3D ultrasonic anemometer will be installed

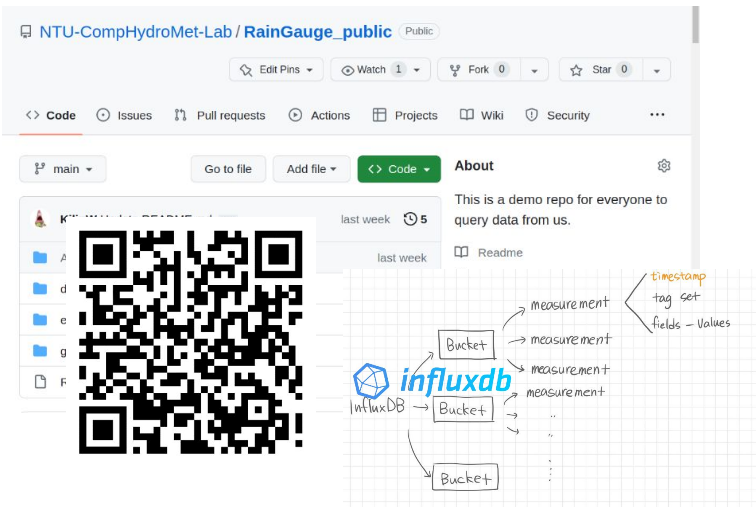


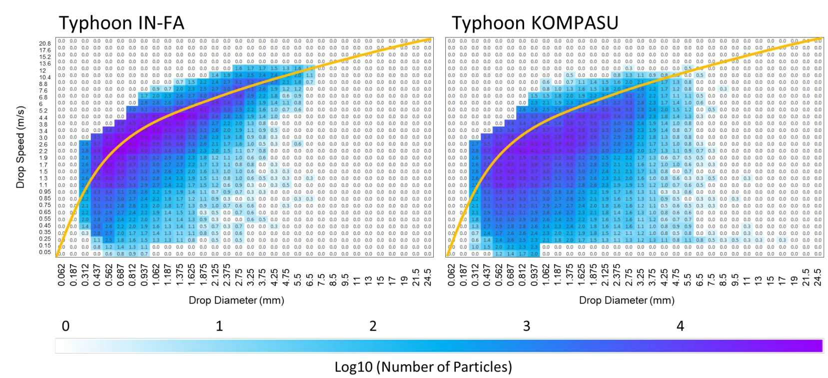
WP1: Monitoring network setup, measurement campaigns and data collection

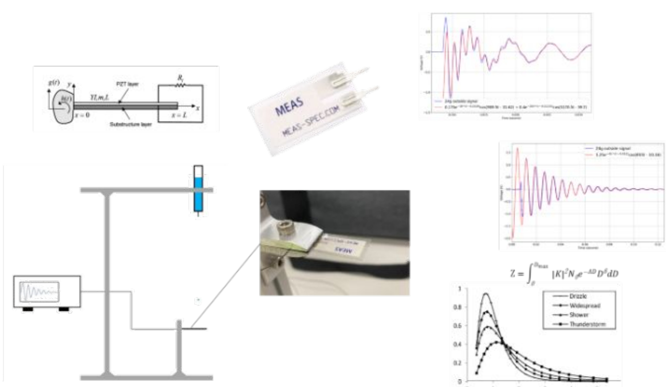
臺大土木工程學系
Department of Civil Engineering
National Taiwan University

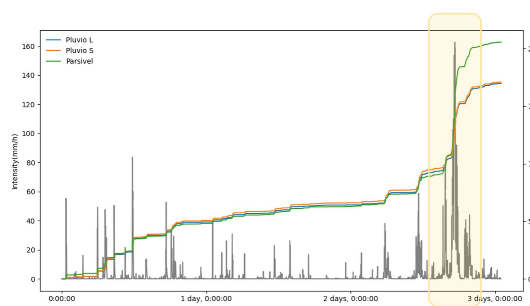
High-resolution rainfall records are used for:

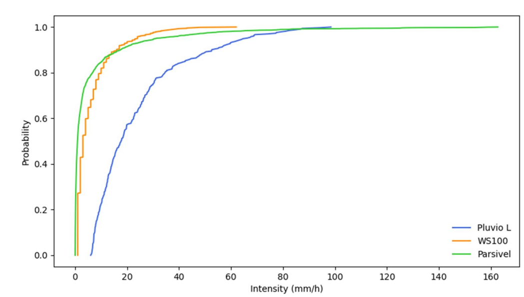
1. Comparing gauges with different collection mechanisms.
2. Developing QC and data processing algorithms and platform.
3. Prototyping new raindrop sensors.
4. Observing physical transition of rainfall process (focus 3)











Focus 1 : preliminary study on “Where are drops falling in a turbulent wind field ?”

Wind drift of drops and impact on radar measurements

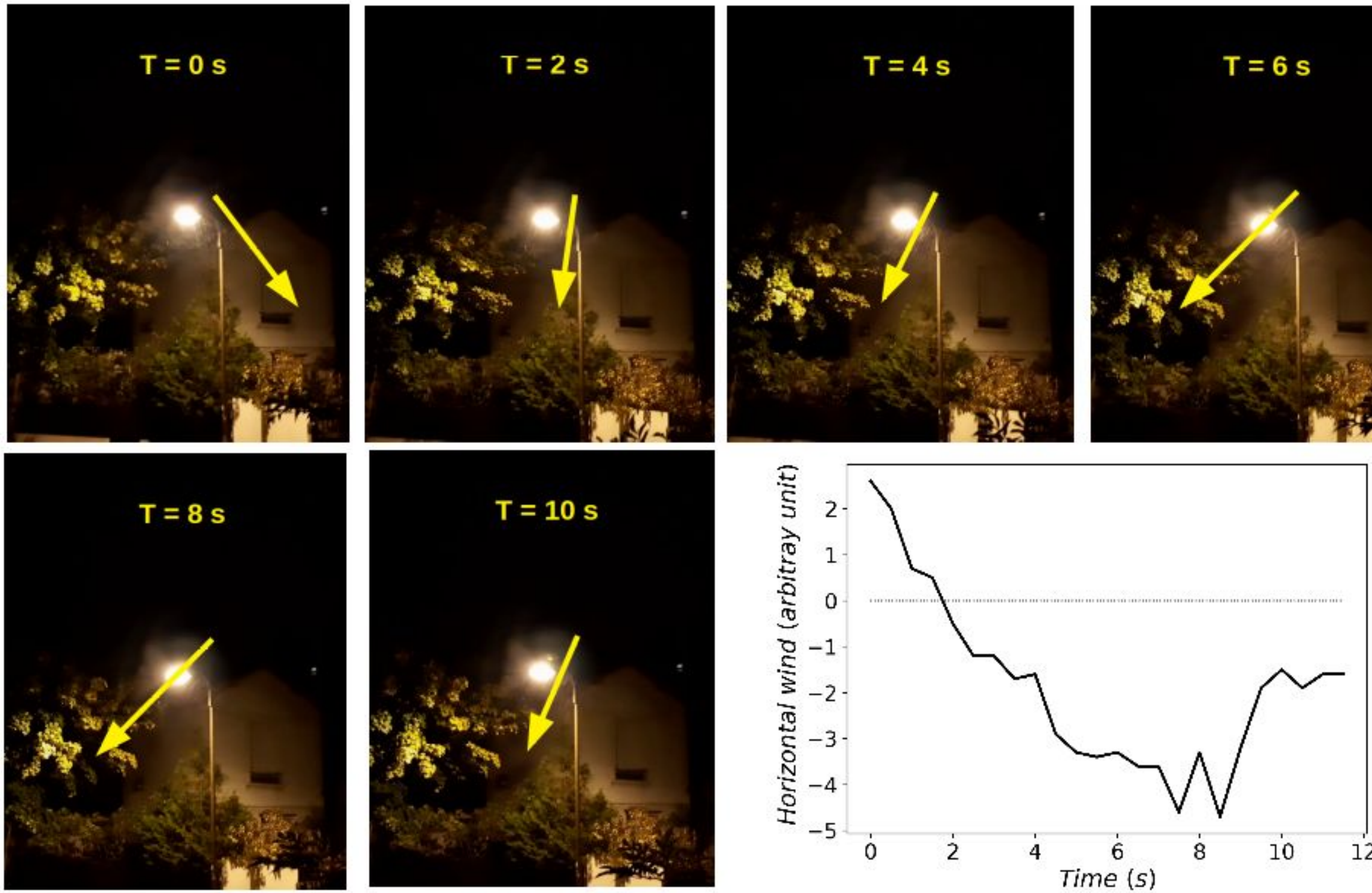
Gires, A., Tchiguirinskaia, I., and Schertzer, D.: 3D trajectories and velocities of rainfall drops in a multifractal turbulent wind field, Atmos. Meas. Tech., 15, 5861–5875, https://doi.org/10.5194/amt-15-5861-2022, 2022.

Introduction and position of the problem

It is commonly assumed that a rain drop falls vertically at a speed equal to its so called "terminal fall velocity" which has been determined both empirically and theoretically by equating the net gravity force with the drag force due to the fact the drop is moving in the atmosphere. This velocity depends on the size of the drop, usually characterized by its equivolumic diameter.

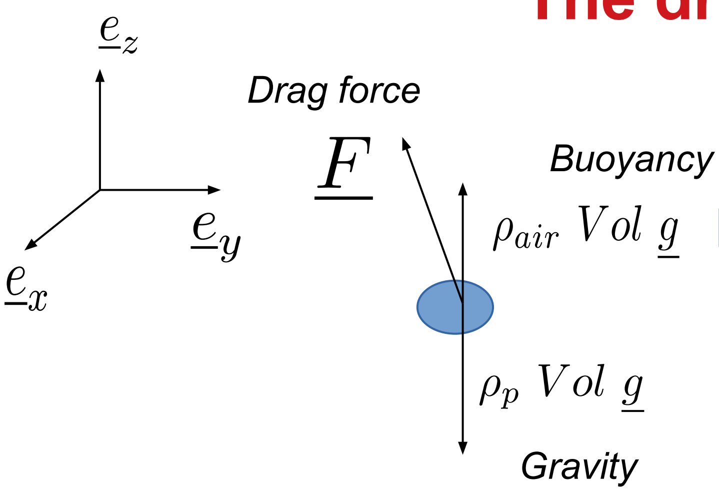
In this investigation we study the temporal evolution of the velocity of a rain drop falling through multifractal turbulent wind field varying in space and time. It enables to compute where drops are falling.

Introduction and position of the problem

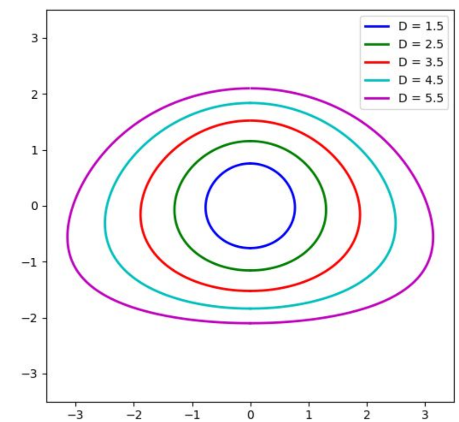


20/10/2021

The drop's governing equation



$$\frac{d\underline{v}_p}{dt} = \frac{3}{4D} c_D \rho_{air} v_{rel} \underline{v}_{rel} + \underline{g} \frac{\rho_p - \rho_{air}}{\rho_p}$$



With :

$$\underline{v}_{rel} = \underline{v}_{wind} - \underline{v}_p$$

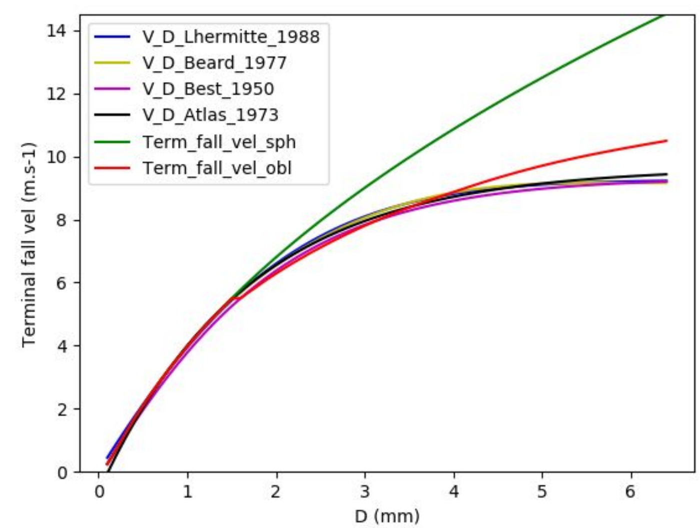
Relative velocity between the wind and the falling particle

$$c_D = f(Re, D_{eq})$$

Drag coefficient formula tailored using corrections to account for drop oblateness (Thurai et al, 2007; Hölzer and Sommerfeld, 2008; White, 1974)

$$Re = \frac{\rho_{air} v_{rel} D}{\mu_{air}}$$

Reynolds number where μ_{air} is the absolute viscosity of air



Numerical solving through an explicit scheme with $\Delta t = 0.01\ s$

Universal Multifractals

A physically based theoretical framework enabling characterization and simulation of geophysical fields exhibiting extreme variability over wide ranges of scales :

Scaling moment function

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

Conservative field

Resolution = $\lambda = \frac{L}{l}$

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

$$\phi_\lambda = \epsilon_\lambda \lambda^{-H}$$

Non-conservative field

Conservative field ($K_c(q)$)

$$K(q) = K_c(q) - Hq$$

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

Spectral slope

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

Power spectra

Wave number

Three exponents

- H: the degree of non-conservation (H=0 for a conservative field)
- C_1: the mean intermittency (how concentrated is the average field, C_1=0 for homogeneous field)
- α : the multifractality index (how fast the intermittency evolves when you slightly go away from the average field)

With straightforward consequence on the extremes

- Large α and C_1 → strong extremes
- Little α and C_1 → low extremes

Schertzer and Lovejoy (1987)

Behaviour of horizontal drop velocity with multifractal input

Methodology

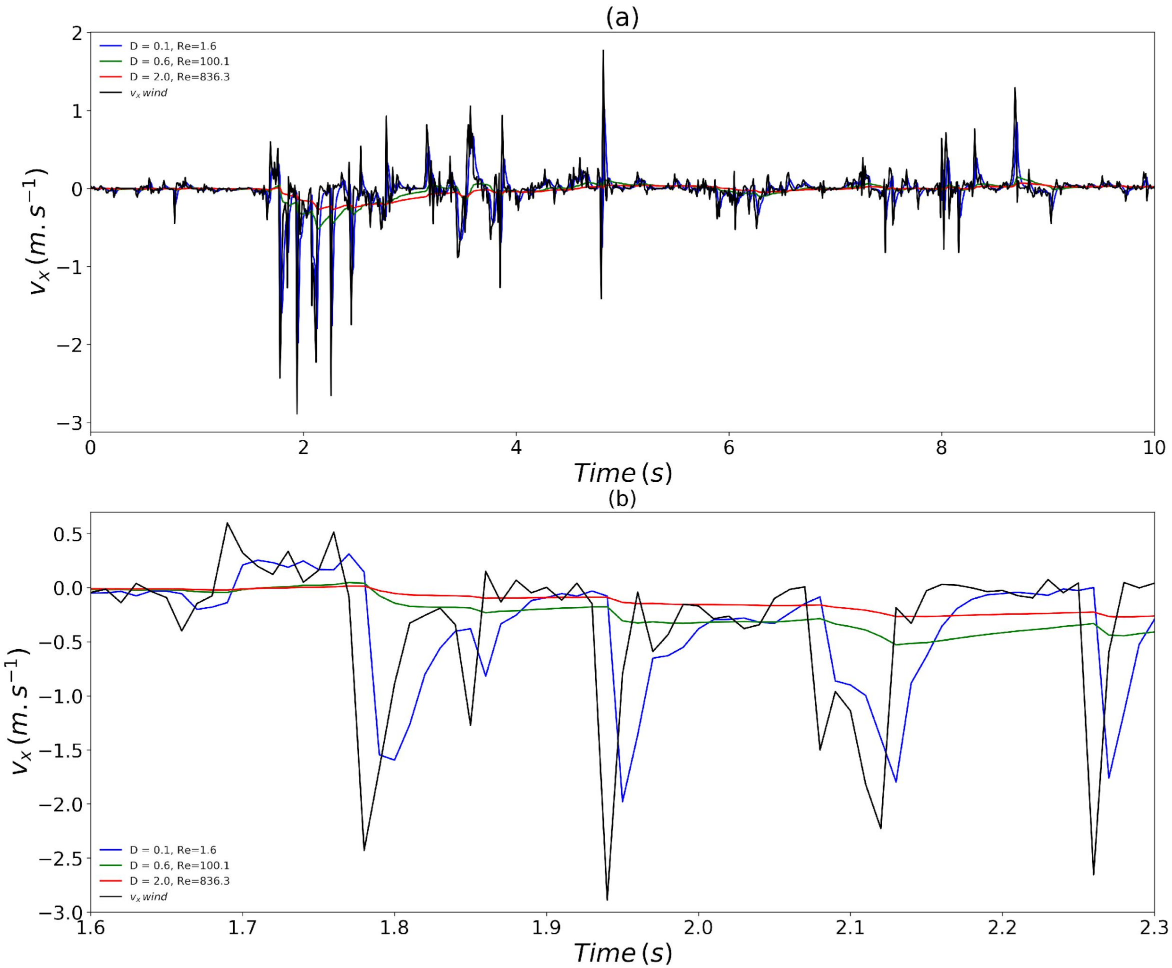
Input only a horizontal wind $v_{x,wind}$ simulated with the blunt cascades.

$$\alpha = 1.7$$
$$C_1 = 0.2$$

"complex trick" to generate field with positive and negative values (Schertzer and Lovejoy, 1995)

$$X = Real\left[\exp(\log X1 + i \log X2)\right]$$

Results



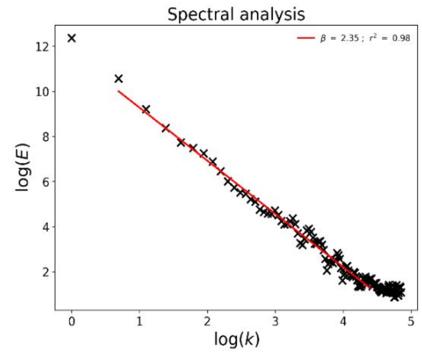
→ Dampening of wind fluctuations with larger drops

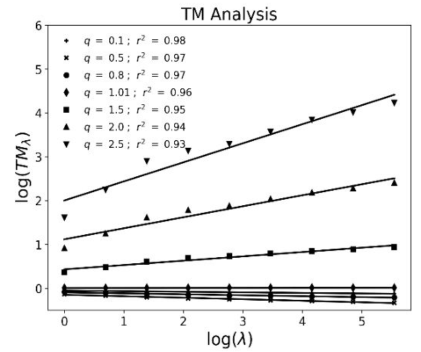
Behaviour of horizontal drop velocity with multifractal input

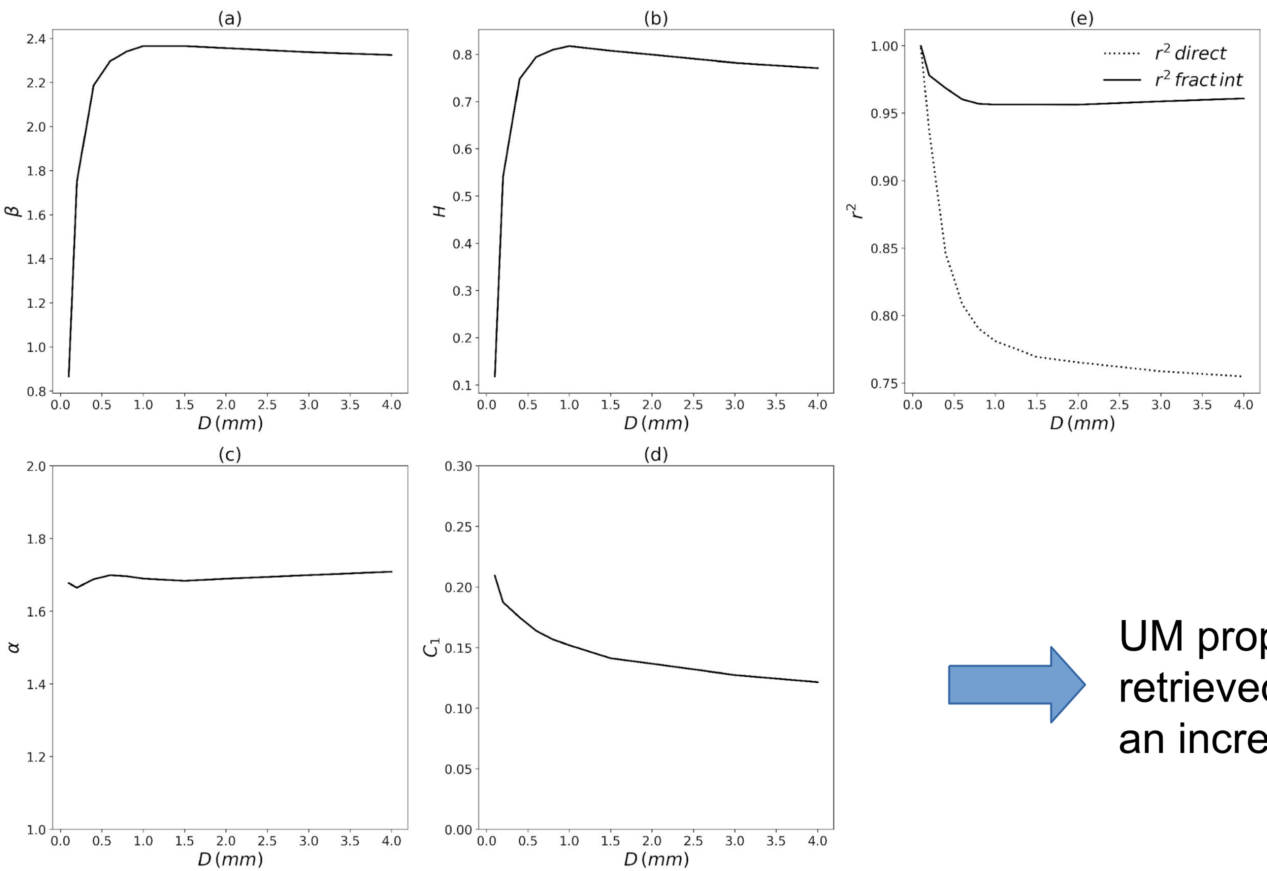
Results

Good scaling behaviour

***D* = 2 mm**





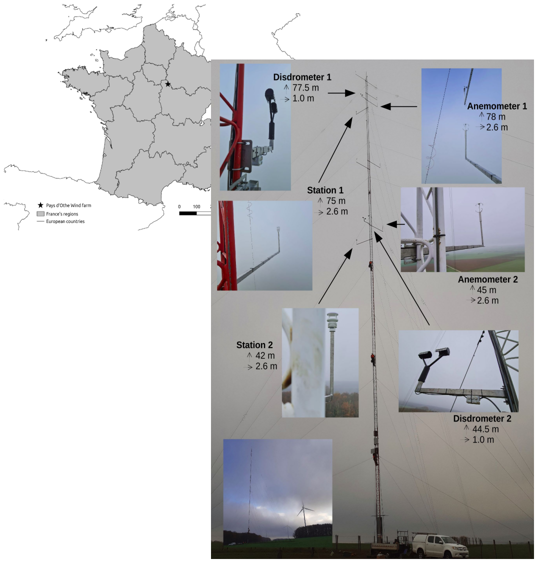


With increasing D_{eq}:
- α: remains constant
- C_1: slight decrease
- H: strong increase up to 0.8 for D_{eq}=1 mm then stable

UM properties of input wind are retrieved on drops velocities with an increased H

Ground impact location of drops falling in a turbulent wind field

Reconstructing a space-time wind from 3D sonic anemometer data : a simplistic approach



$$a_h = 1/3$$

$$\Delta l = \sqrt{\Delta x^2 + \Delta y^2}$$

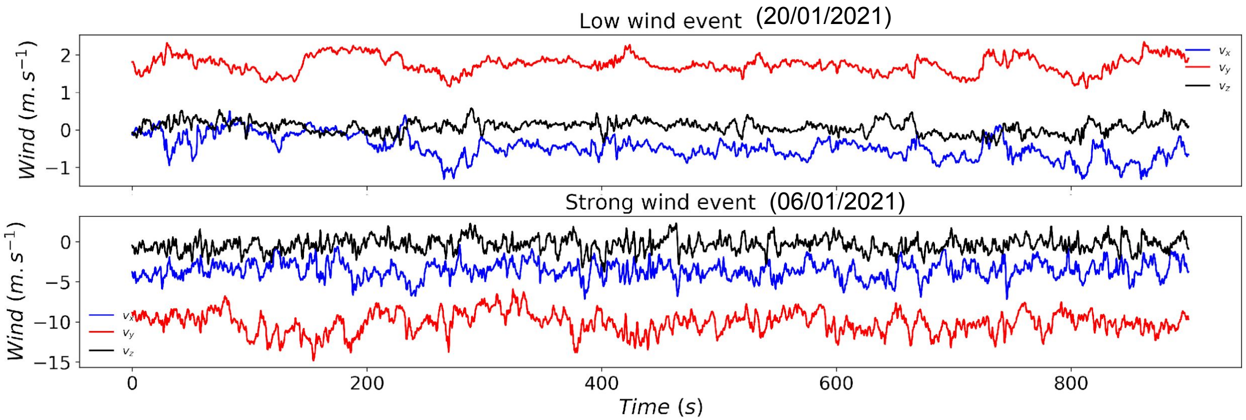
Pre-factor

$$u(x+\Delta x, y+\Delta y, t) = u(x,y,t) + c\,\epsilon(\Delta x, \Delta y, t)^{a_h}\,\Delta l^{H_h}$$

$$H_h = 1/3$$

Space time UM field with α=1.8 and C_1=0.1

Lazarev et al. 1994



+ similar approach for vertical shift accounting for an anisotropy

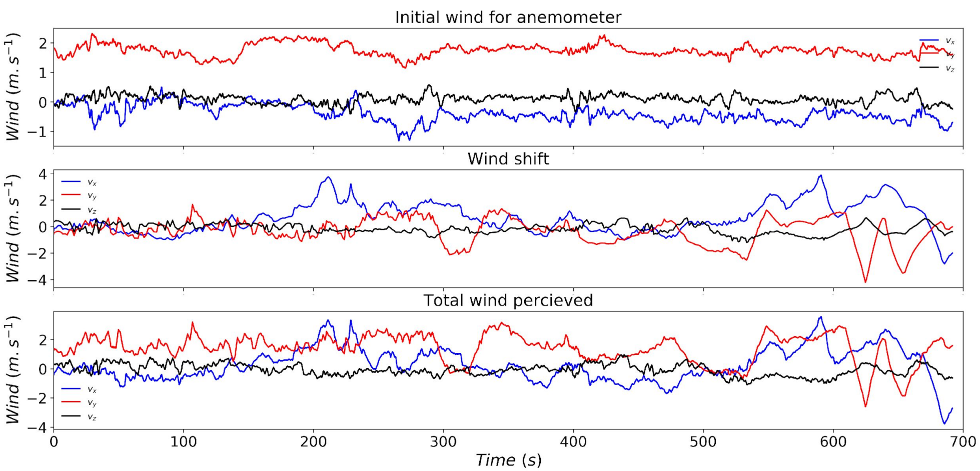
Data from a high resolution (100 Hz) measurement campaign on a wind farm

→ simulated wind over 40 km x 40 km x 1600m x 1024s (with voxels of size 53 m x 53 m x 3 m x 16 s)

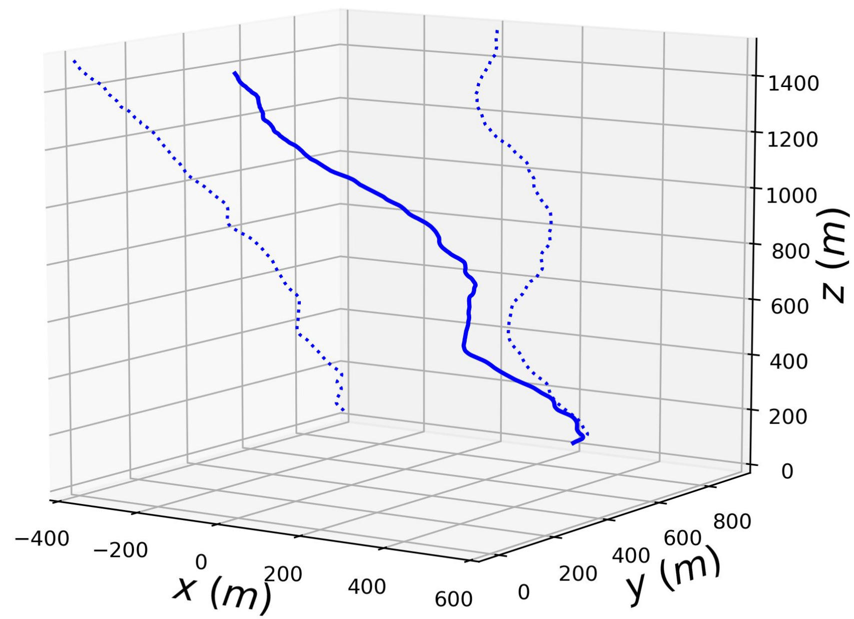
https://hmco.enpc.fr/portfolio-archive/rw-turb/

Ground impact location of drops falling in a turbulent wind field

Results



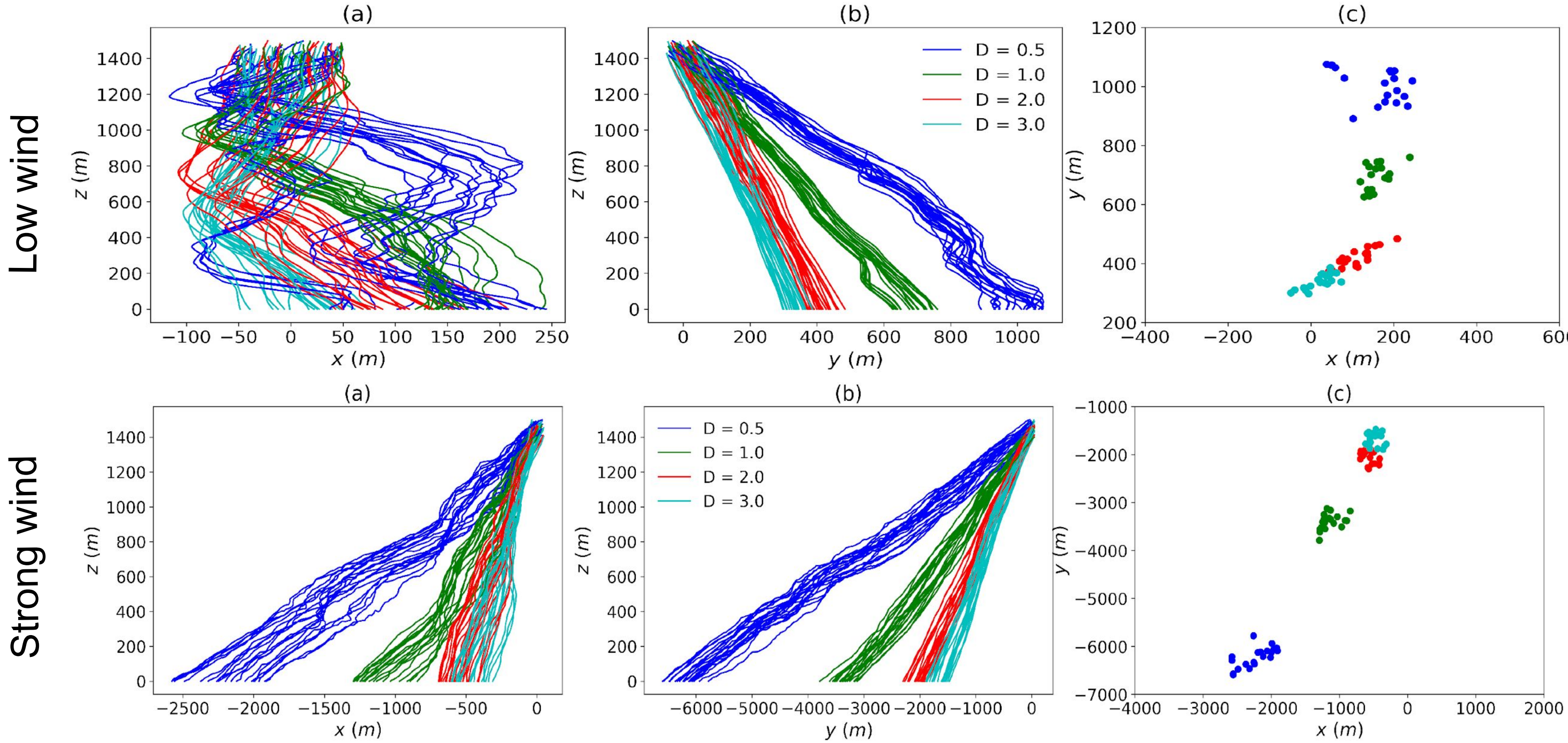
(Top) Temporal evolution with 0.01 s time steps of the wind data from 3D sonic anemometer, (middle) the wind shift and (bottom) the total wind perceived by the 0.5 mm drop falling from the position (0, 0, 1500) during the low wind event. Bottom panel is actually the wind input used to obtain the trajectory of Fig. on left



Trajectory (solid line) of a 0.5 mm drop in a turbulent wind field for the low wind event. The dotted lines correspond to the trajectory projected on the (x, z) and (y, z) plane.

Ground impact location of drops falling in a turbulent wind field

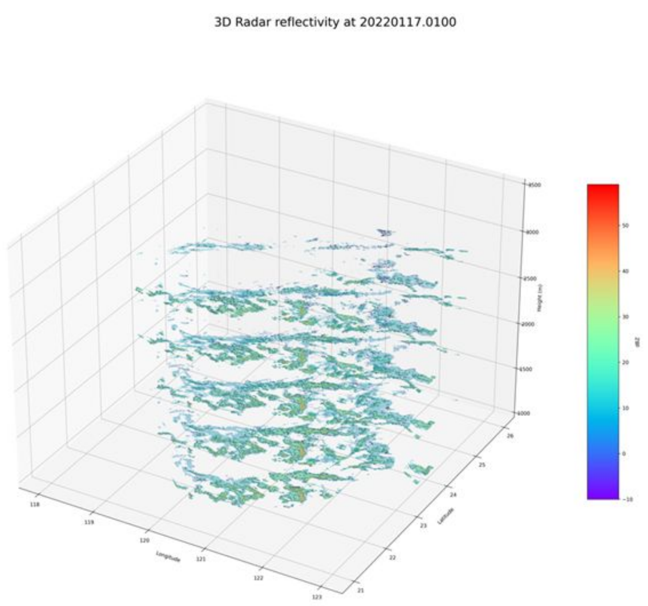
Results : illustration of impact on rainfall retrieval with weather radars



(a, b) Trajectories of drops of various sizes falling from a 100 m cubic voxel centred on a (0, 0, 1450) position, projected on the (x, z) and (y, z) plane, respectively. For each size, the 20 drops are dropped every 15 s (hence over a total duration of 5 min). A single realization of the wind shift field is used. (c) Position of the ground impact of the various drops.

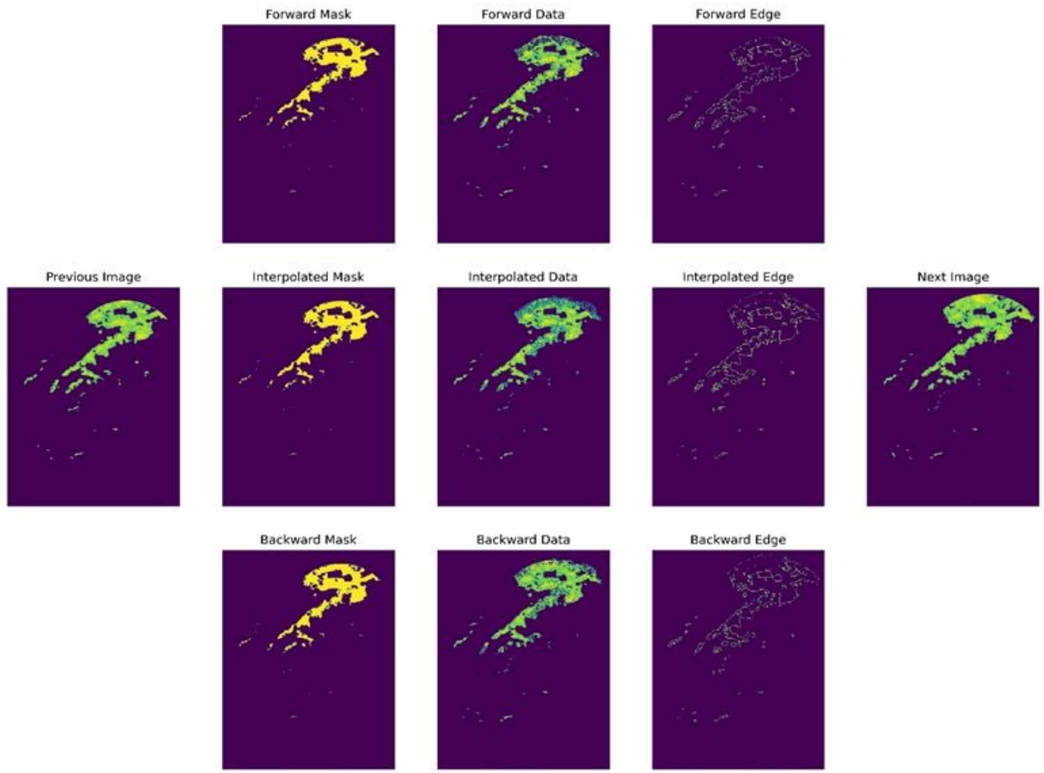
- Stronger shift for smaller drops
- Decrease of the spread of the drops as the drop size increases.
- Shift of several radar pixels !

Focus 2 : Exploring the potentials of computer vision and machine learning techniques to model wind drift effect from high-resolution 3D radar data and beyond

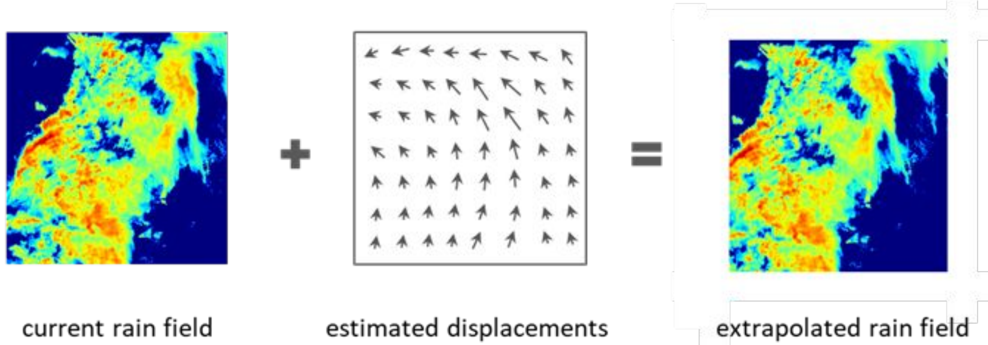


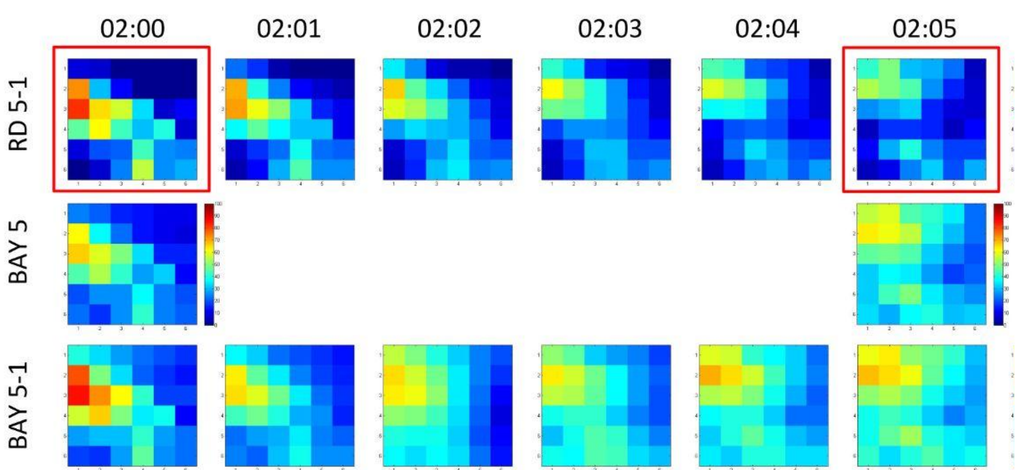
Ongoing work in this project:

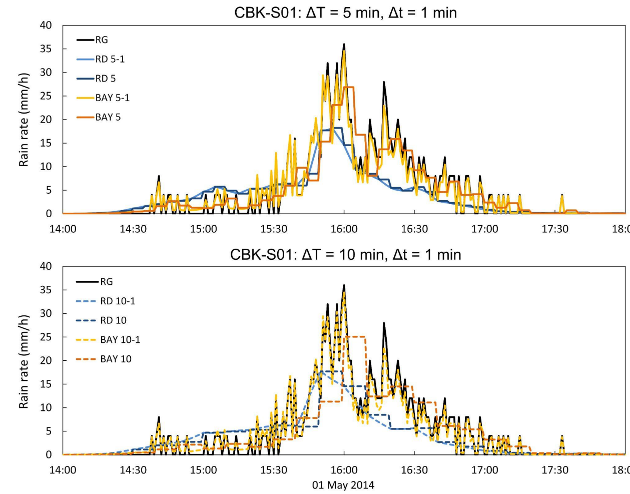
Development of an optical flow based algorithm to estimate motion fields along various altitude levels.

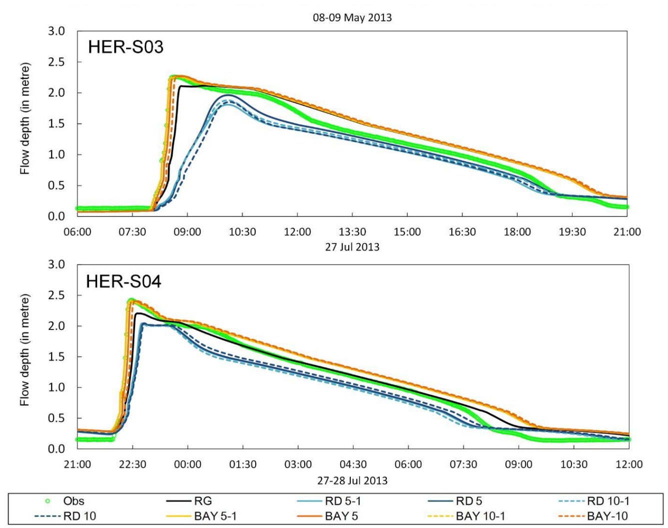


Applications of optical flow techniques to generate high temporal resolution radar images for urban hydrology.





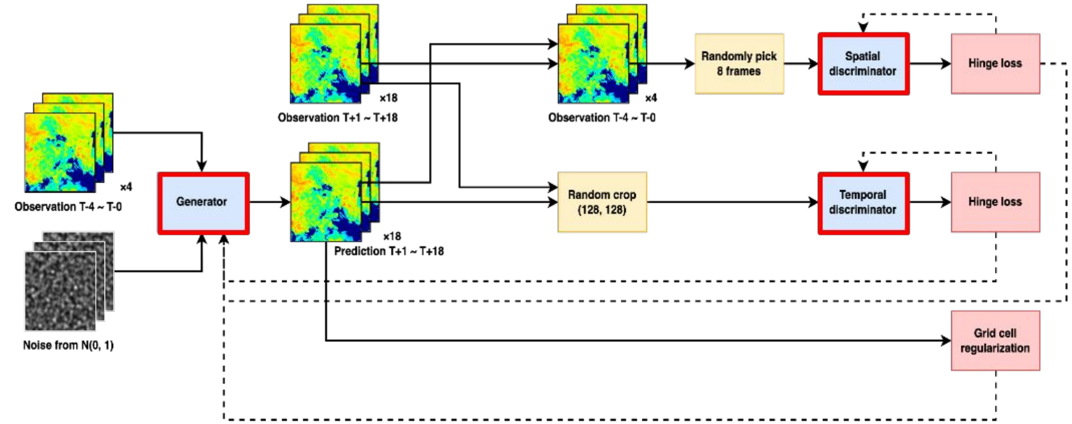




Wang et al. (2015)

Investigation of the success of deep learning based nowcasting via replicating DGMR:

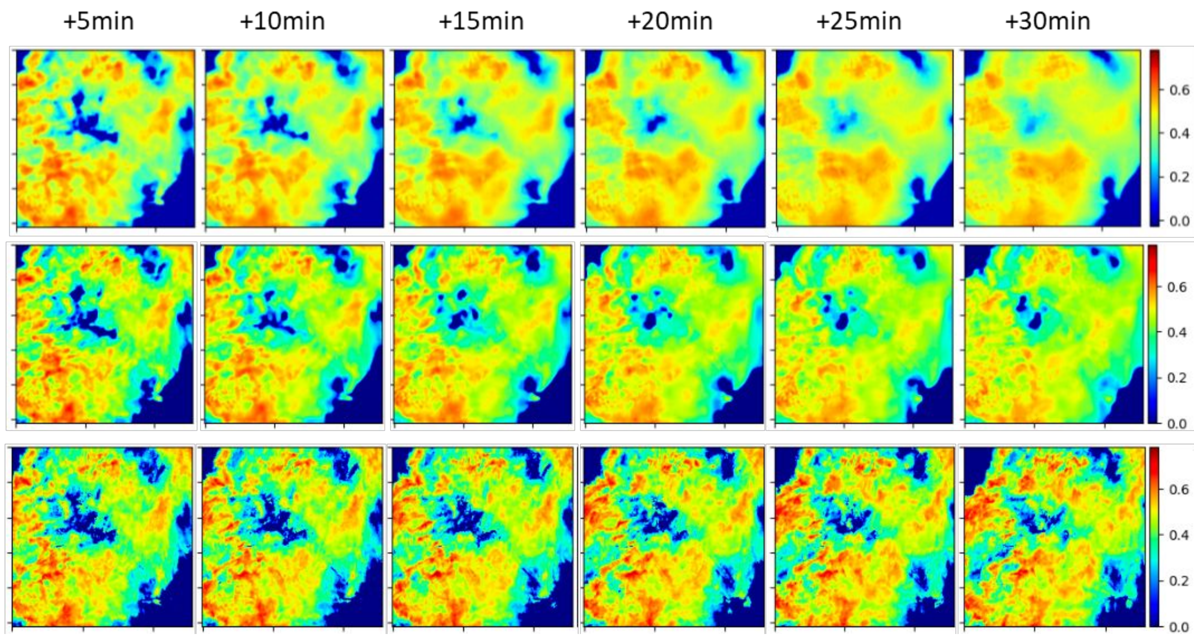
Further confirmation of the importance to account for scaling behaviour while modelling rainfall.



DGMR training **without discriminators**

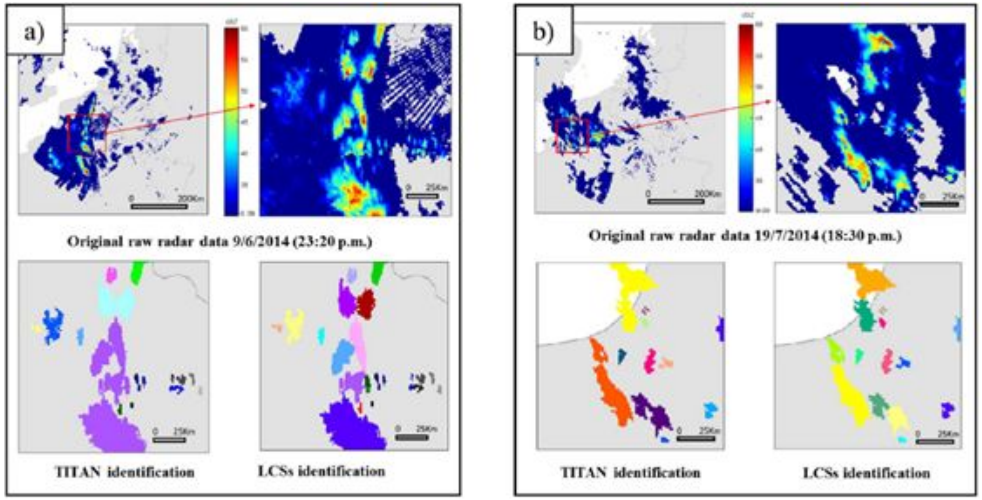
DGMR training **with discriminators**

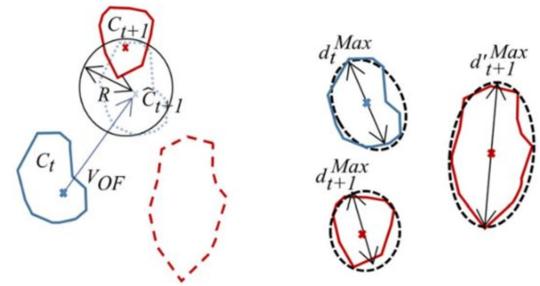
Ground truth

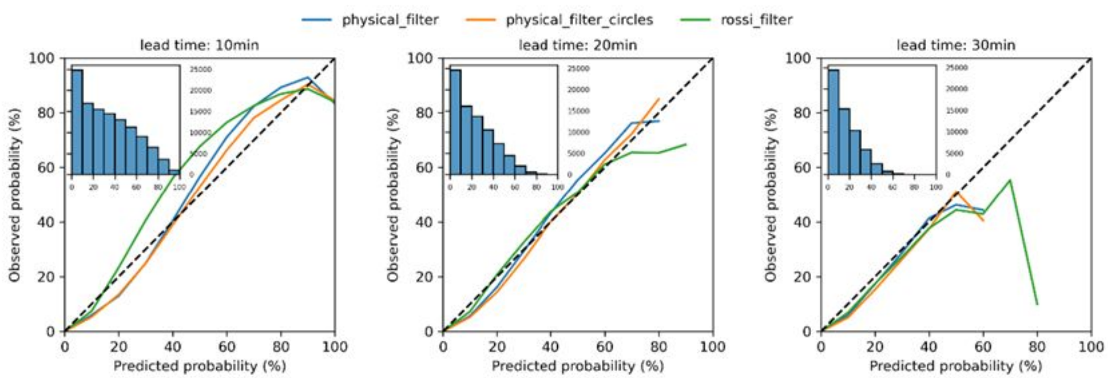


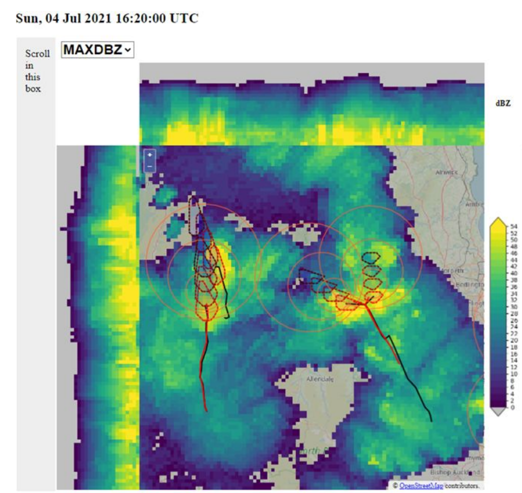
Our DGMR replica on Github!

Enhanced TITAN algorithm enables tracking the movement of convective cells from high-resolution radar images.





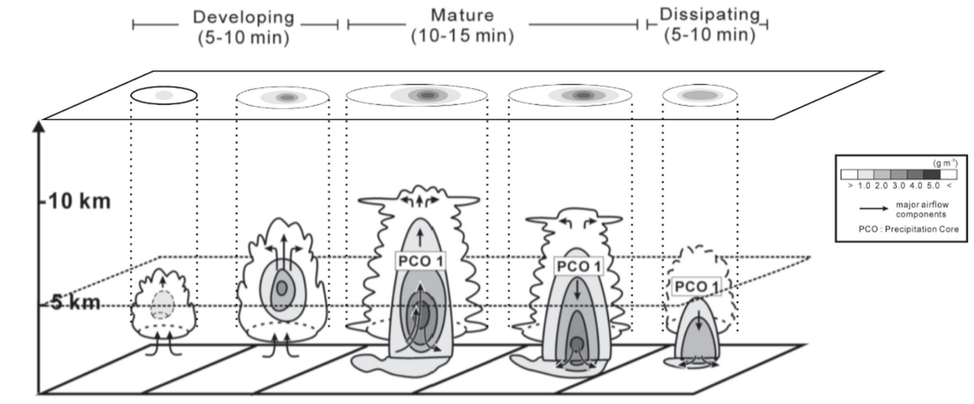


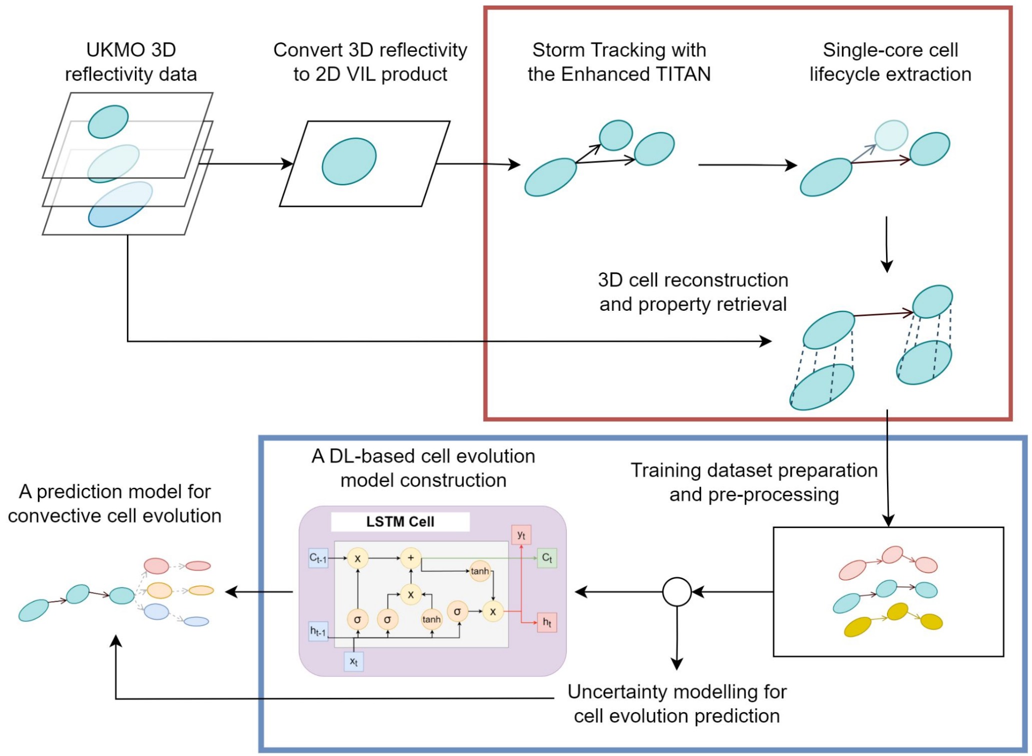


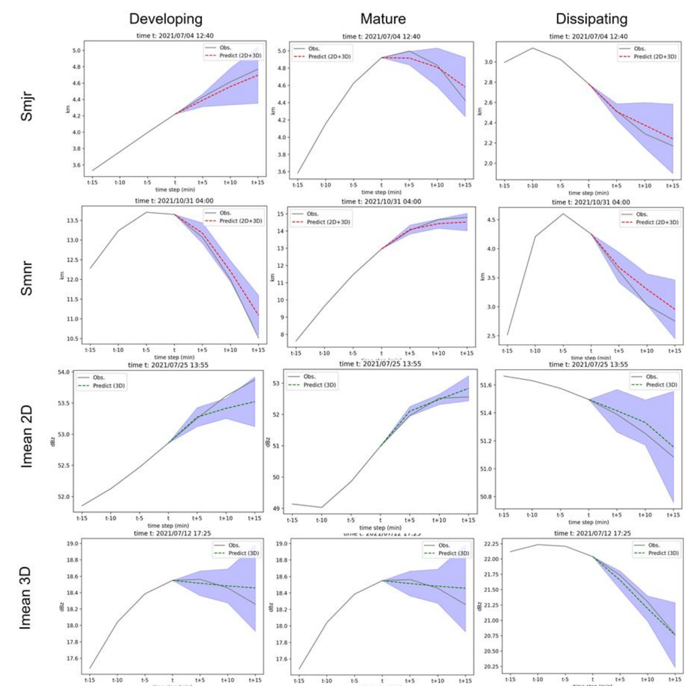
This algorithm has been integrated with Kalman filter (Rossi et al., 2015) to develop a probabilistic convective storm (positional) nowcasting system for the UKMO.

[Munoz et al (2018)]

Development of a deep learning model to predict the evolution of convective cell life cycles with the help from 3D radar data







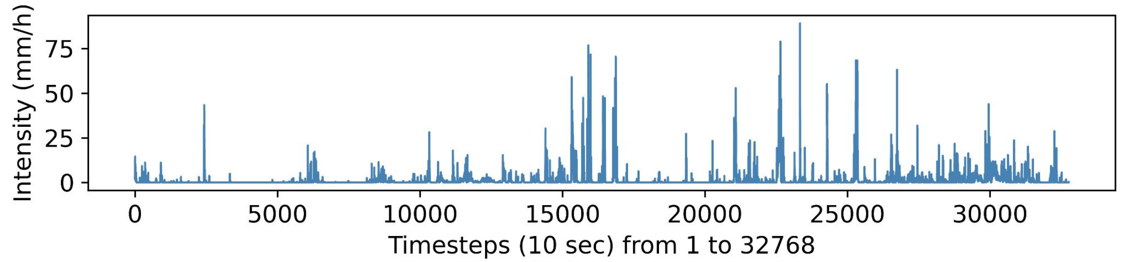
[Cheng and Wang (2023)]

Focus 3 : Observation of different multifractal phase transitions over three typhoon events

Rainfall intensity records collected by Parsival 2 disdrometer at the 10s resolution for three typhoon events in 2022.

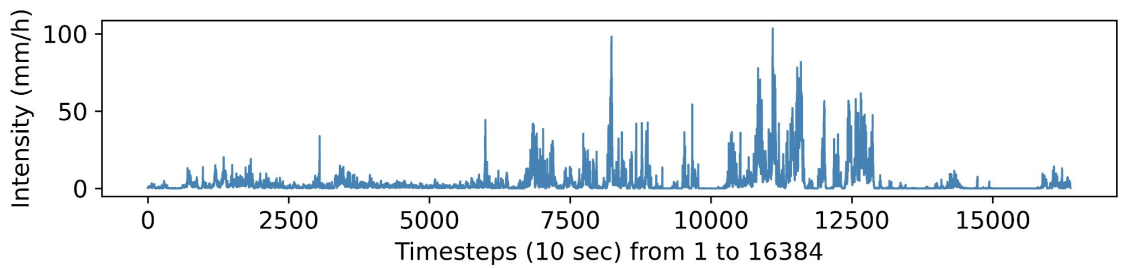
Hinnamnor

- Date: Aug - Sep 2022
- Duration: 91.02 hours
- Cumulative rainfall: 122.14 mm
- Maximum intensity: 89.15 mm/h
- pWet: 40.35%



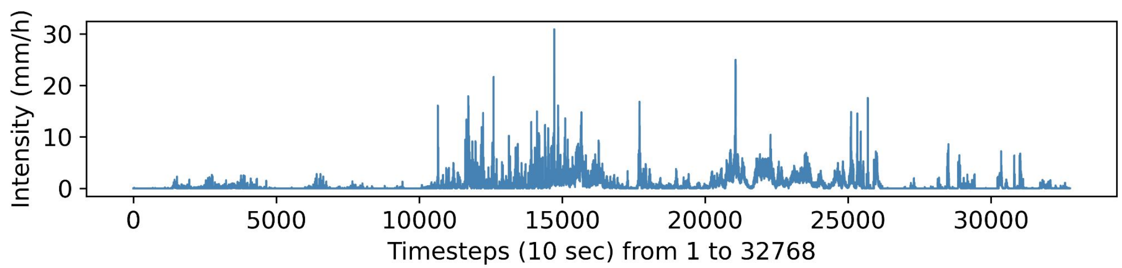
Nesat

- Date: Oct 2022
- Duration: 45.51 hours
- Cumulative rainfall: 191.57 mm
- Maximum intensity: 103.52 mm/h
- pWet: 79.99%



Nalgae

- Date: Oct - Nov 2022
- Duration: 91.02 hours
- Cumulative rainfall: 70.14 mm
- Maximum intensity: 30.92 mm/h
- pWet: 56.72%



A rare observation of the divergence of moments within a single event

Tracing moment technique

scaling moment function

moment order

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

resolution

intensity

For universal multifractals

$$K(q) = \begin{cases} \dfrac{C_1}{\alpha - 1}(q^{\alpha} - q) & \alpha \neq 1 \\ C_1 q \ln q & \alpha = 1 \end{cases}$$

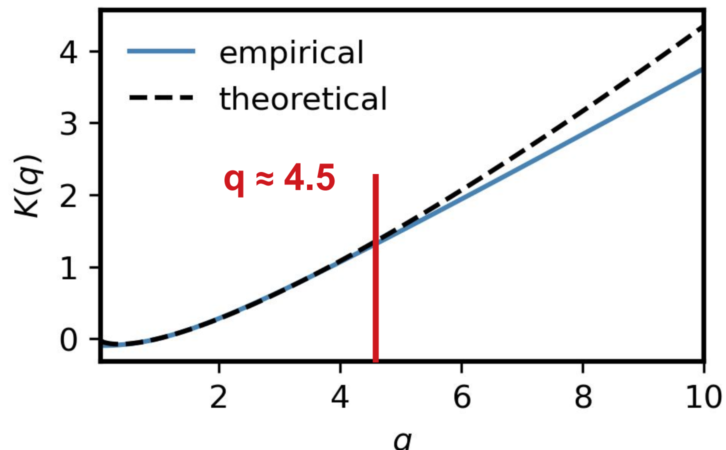
C_1: mean intermittency
α: multifractality index

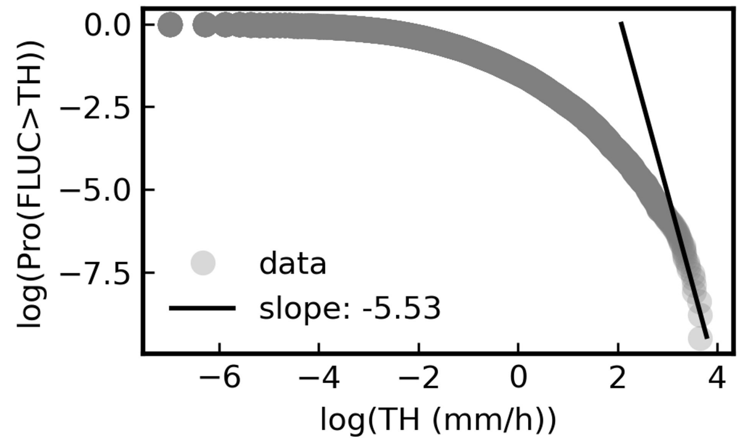
Two types of multifractal phase transitions

- Sampling limitation
  - related to the fact that great moments cannot be observed on finite series
  - beyond a certain moment q, the statistical estimate of the scaling moment function becomes unreliable
- The divergence of moments
  - related to the singular limit of the underlying cascade process
  - beyond a certain moment q, these moments start to diverge

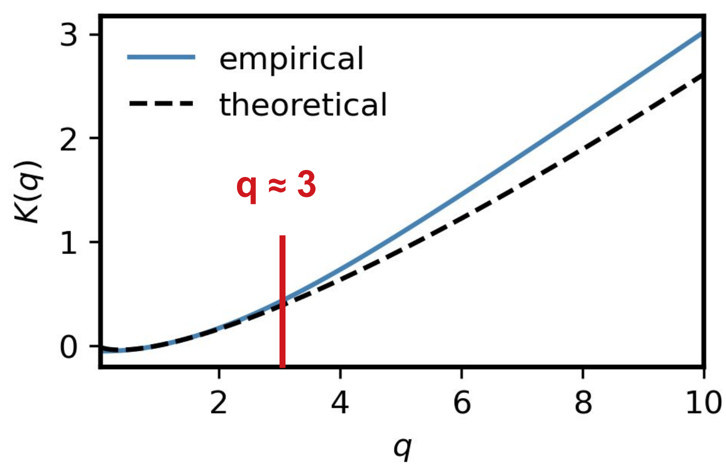
This divergence indicates the presence of extreme values or singularities in the data

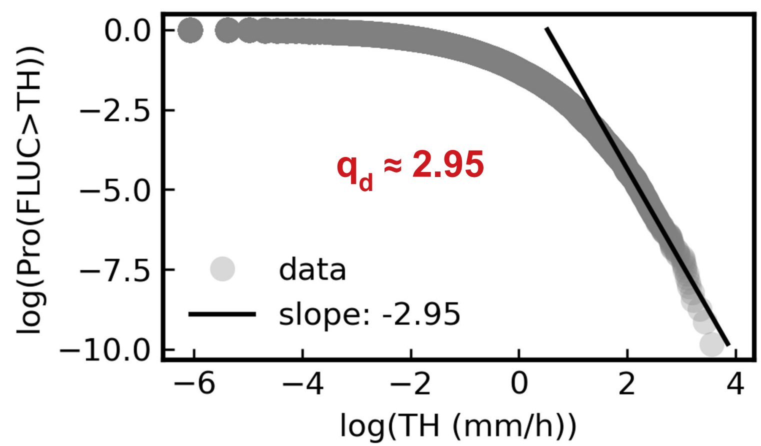
Common case (Hinnamnor)





Rare case (Nalgae)





Potential application like downscaling strategies can be improved for UM downscaling

Global | Local | Ensemble