AMERICAN METEOROLOGICAL SOCIETY

"The Development of Synthetic Wind Series Based on Gaussian and Non Gaussian Statistics".

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SCHOOL OF ELECTRICAL AND ELECTRONIC ENGINEERING

Overview

- Introduction to Wind Energy
- Data Acquisition and Statistical Summarisation
- Artificial Wind Speeds
- Results
- Future Applications
- Acknowledgements

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Introduction to Wind Energy

Kinetic wind energy is harnessed by converting to mechanical energy via the turbine rotor and then into electrical energy through the generator:

Wind Energy if fundamentally derived from an extension of kinetic energy formula!

$$P = \frac{C_p . \rho . A . u^3}{2}$$

where the mechanical output power (*P*) is a function of the performance coefficient of the turbine C_p, the density of air (ρ), the area swept by the turbine projected in the direction of the wind (*A*) and wind-speed (*u*).

It is worth considering that Cp is limited by Betz limit of 59.3% efficiency however an important fact that is often missed is that this is strictly speaking only applicable in laminar kinetic mass flow systems.

(N.B. Turbulence and Pressure drop over the blades are not considered!)

As wholly laminar environments are rarely present in real world scenarios it is evident that further investigation is required when trying to bound the likely coefficient of performance in a turbulent environment.

This model also assumes instantaneous response i.e. zero inertia model! This has a tendency to make large power prediction errors. +/- 30% error is not uncommon for microturbines in turbulent urban environments.

Known power prediction issues;

- Accuracy of power curves (standard dev and error is not published)
- Data recording issues (averaging of scalars expressed as vectors)
- Cup anemometers (values under range recorded as 0)
- Statistical Distortion due to excess 0s.
- Quantification of turbulence (There are known issues with TI)
- Lack of transient response models

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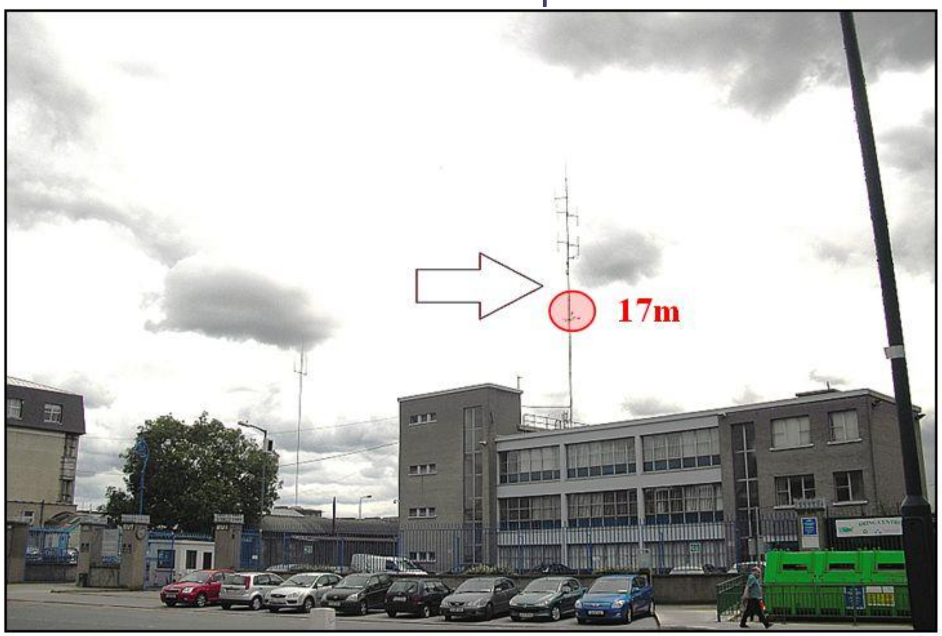
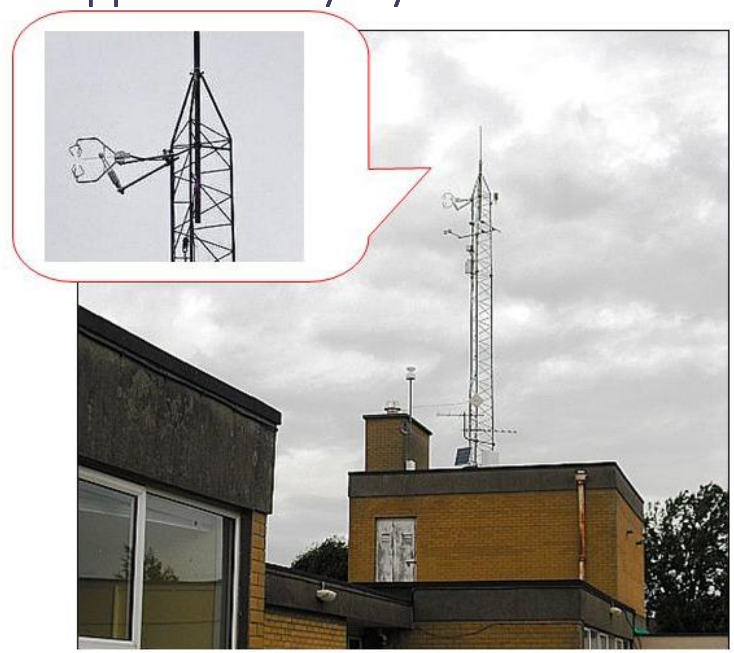
Data Acquisition and Statistical Summarisation

- DUBLex (Dublin, Urban Boundary Layer Experiment) UCD, DIT and NUI Maynooth.
- High resolution data for multiple purposes e.g. CO_2 monitoring / temp / moisture / wind speed
- Has multiple applications air quality / litter dumping / temp. hot spots / urban wind generation.
- A mast installation is on top of DIT Kevin Street for approximately 1 year also



Marrowbone Lane URB1



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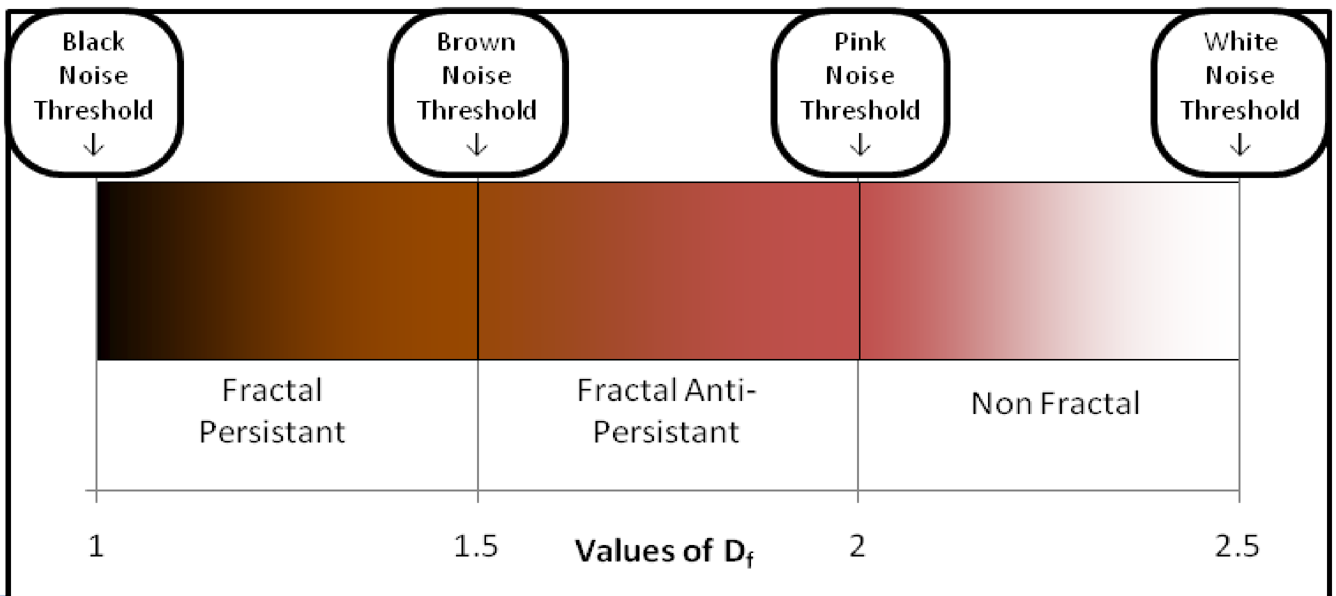
Data Acquisition and Statistical Summarisation

From this industrial standard 10 minute bins are drawn based on longitudinal values of mean TI and a proposed new metric T_{Df} This metric essentially measures how noisy a signal is.

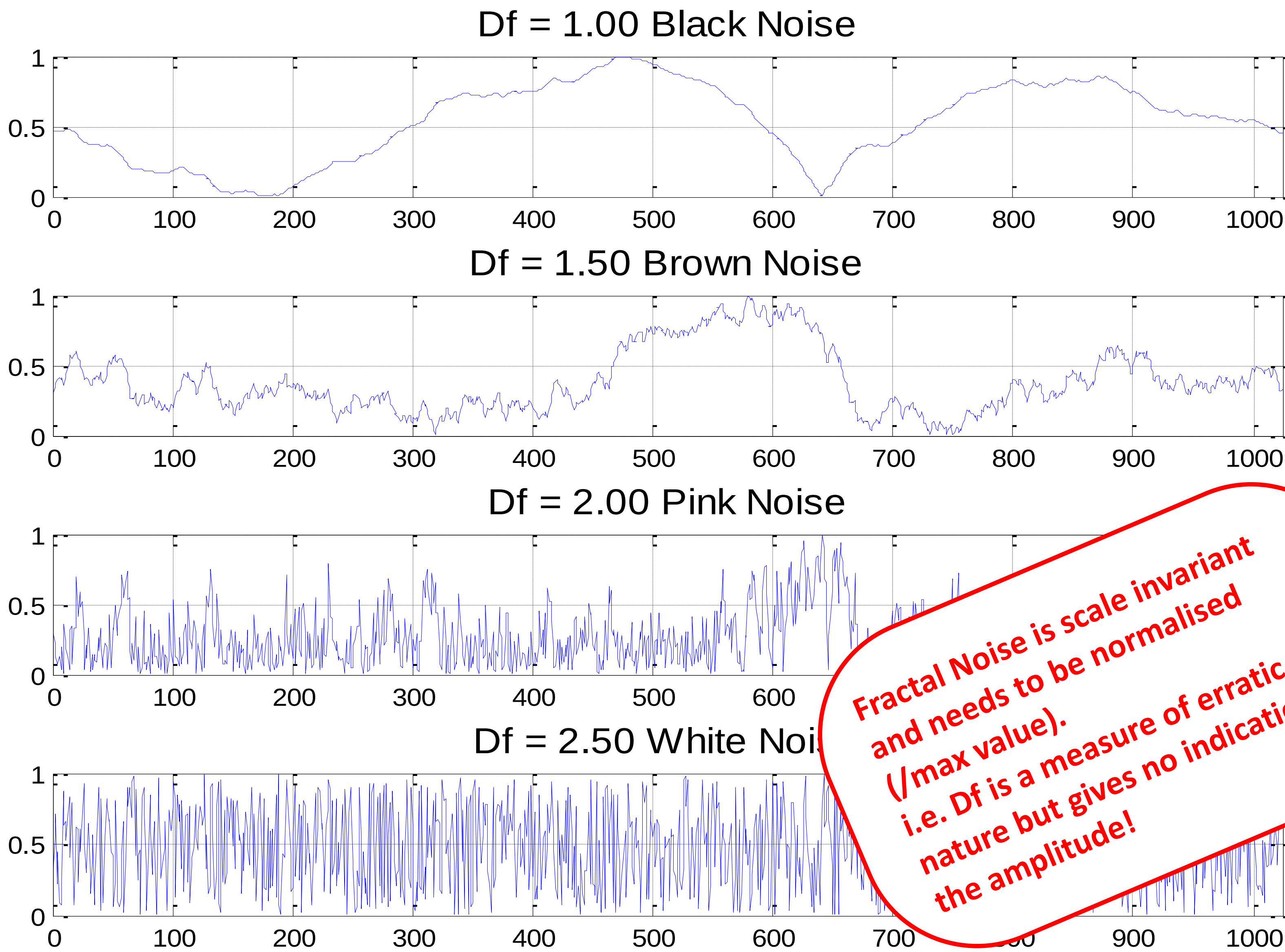
$$\left\{ \begin{array}{l} \bar{u} = mean\ wind\ speed \\ TI = \dfrac{standard\ deviation}{mean\ wind\ speed} \end{array} \right\}$$

Industry Standard

$$T_{Df} = unbounded\ Fractal\ Dimension\ by\ Fourier\ means$$



Data Acquisition and Statistical Summarisation



Fractal Noise is scale invariant and needs to be normalised (/max value).
i.e. Df is a measure of erratic nature but gives no indication to the amplitude!

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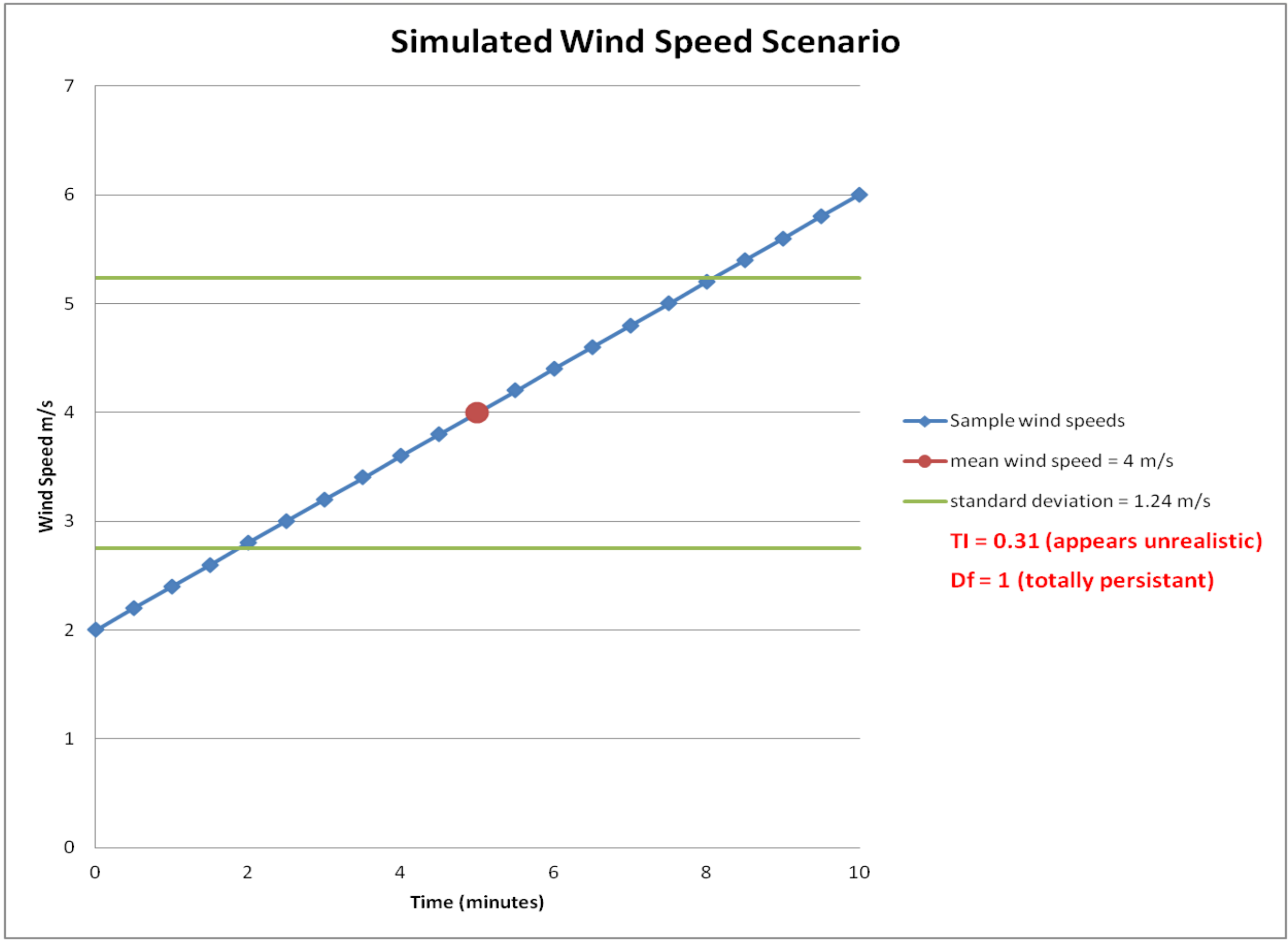
Data Acquisition and Statistical Summarisation

- Df =1 is effectively 0% turbulence by the T_{Df} metric

- However the current TI metric would classify this sample as having 31% turbulence

- **The current TI metric does not allow for trends within the wind speed sample**

- **N.B. the T_{Df} metric does not cater for the spread of the erratic signal**



- **Therefore there is a need for both metrics when describing a wind speed signal**

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Artificial Wind Speeds

Generation of Artificial wind speed signals based on TI, T_{Df} and mean speed

If we consider a 10 minute bin of 10Hz data summarised to mean, TI and T_{Df}

Question:

What can we do with it?

It is pointless in proposing a new metric (T_{Df}) unless it has some practical application!

So lets consider mixing Gaussian statistics with non Gaussian statistics!

Artificial Wind Speeds

Consider a series of 600 random numbers (n_x) between 0-1 subjected to the following convolution ($\otimes$) in the frequency domain.

$$[u_x(t)] = \frac{1}{t^{1-q/2}} \otimes \mathrm{t}\,[n_x(t)]$$

Where: T_{Df} (Turbulent Fourier Dimension)=(5-q)/2

Frequency domain equivalent with *i* indexing filter

$$[U_x(\omega)] = \frac{1}{(i\omega)^{q/2}}\,[n_x(\omega)]$$

For this example lets take a T_{Df} of 1.8, a TI of 0.45 (45%), and a u mean of 7.5 m/s

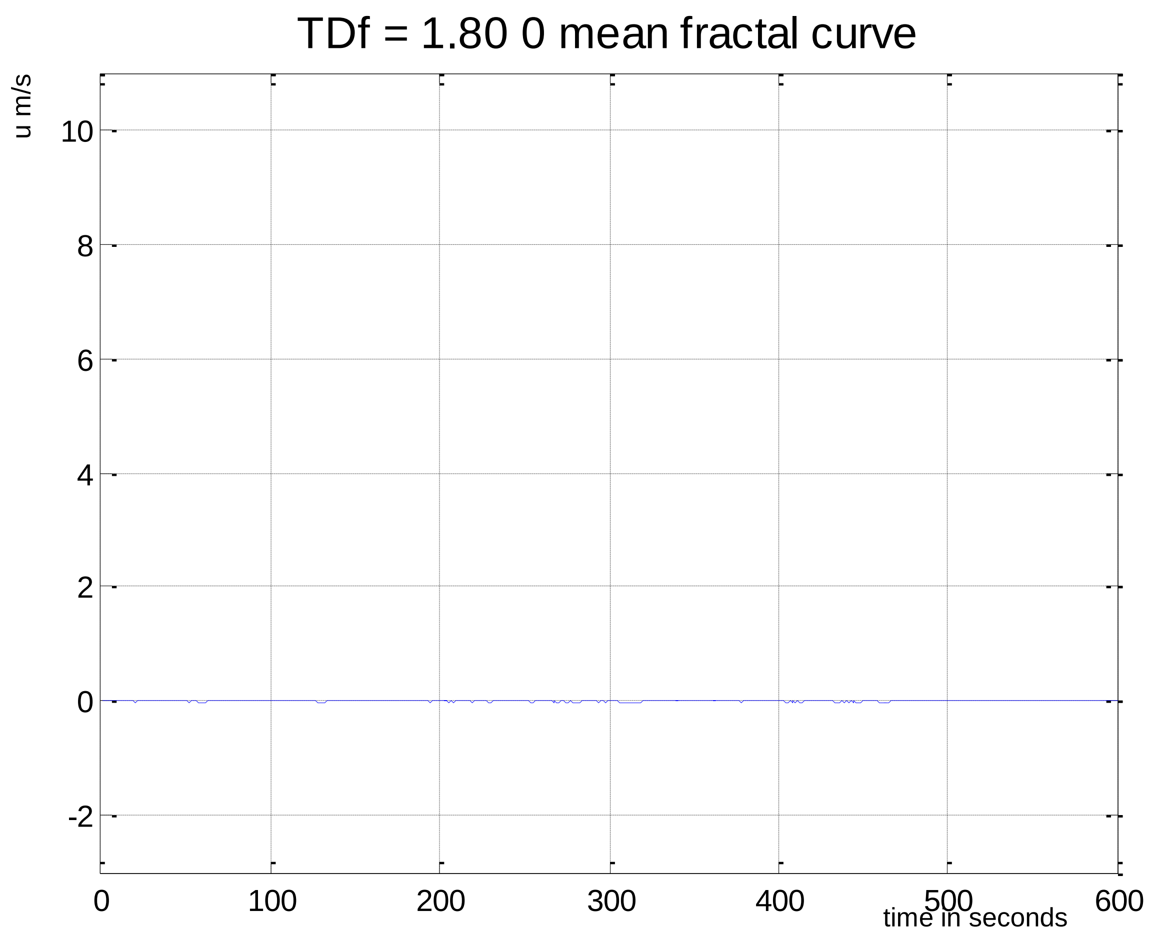
Artificial Wind Speeds

Generating a fractal curve of known T_{Df} gives the following graph.

Fractal noise is scale invariant and as such has the same fractal properties at any scale.

Note the amplitude is not defined!

If we zoom in the concept becomes clearer!

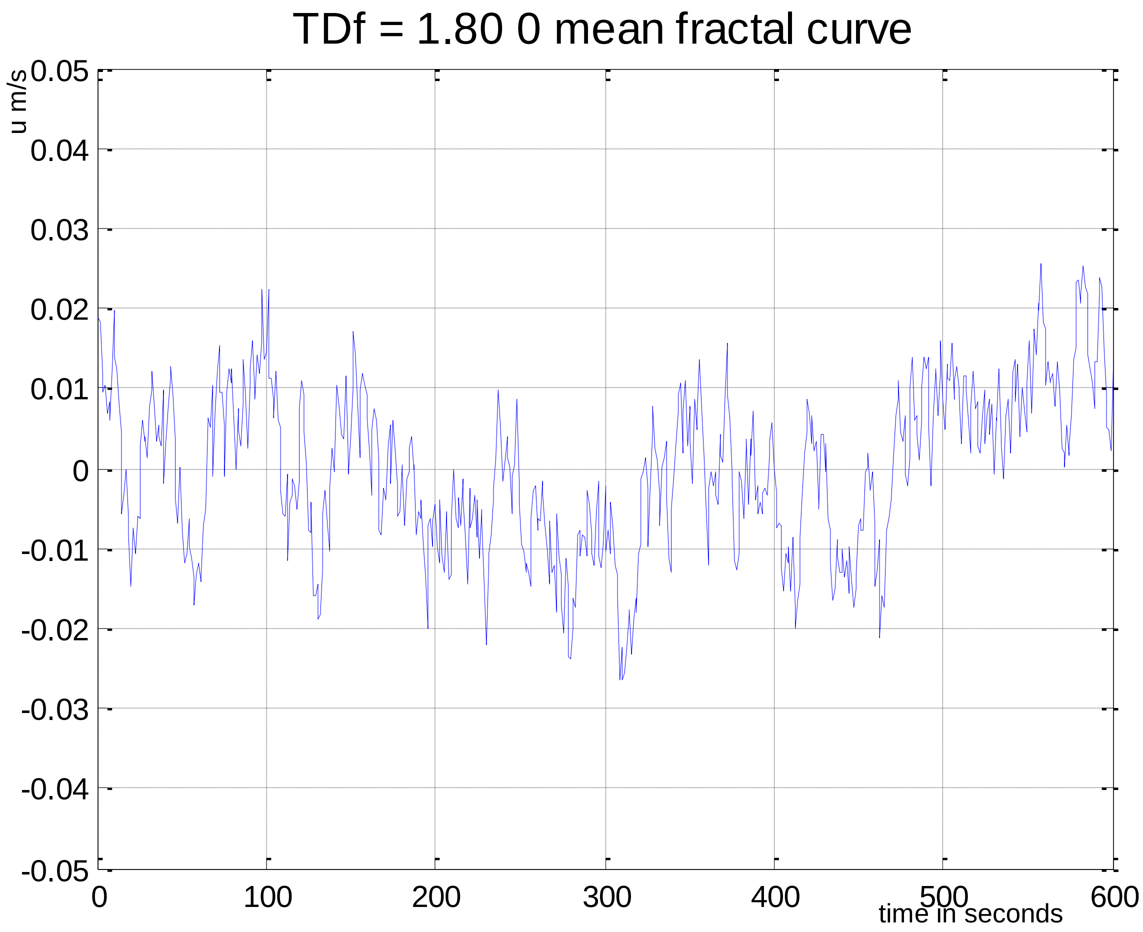


Artificial Wind Speeds

Zooming in shows the fractal self symmetry within the curve.

However this is not scaled and as such is of no use on its own.

If we normalise to unit standard deviation (divide by standard deviation) uniform scaling is maintained giving;

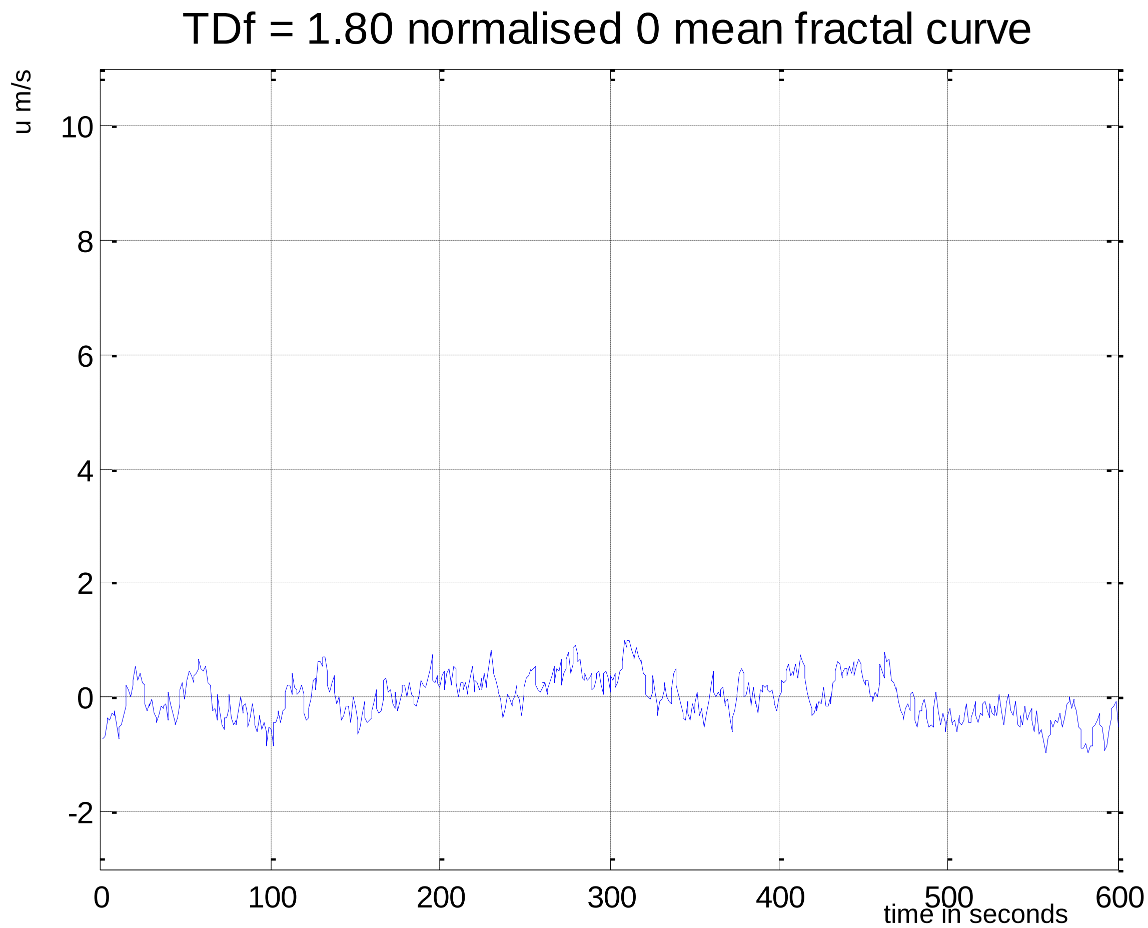


Artificial Wind Speeds

Now that the curve is normalised around zero a known spread can be applied.

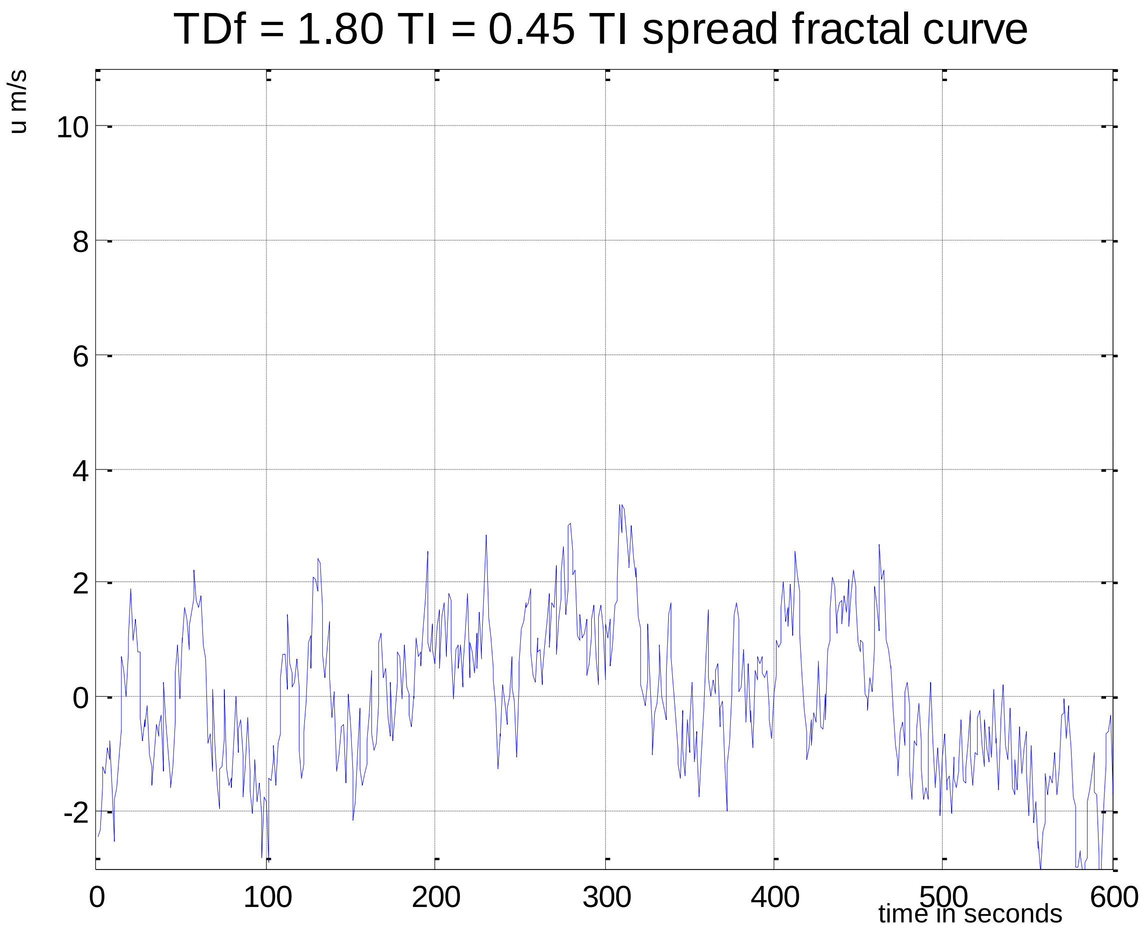
Standard dev is = mean x TI

So multiply across to give the next slide



Artificial Wind Speeds

Now that the curve has a spread indicative of the standard deviation it is now time to add in an average.

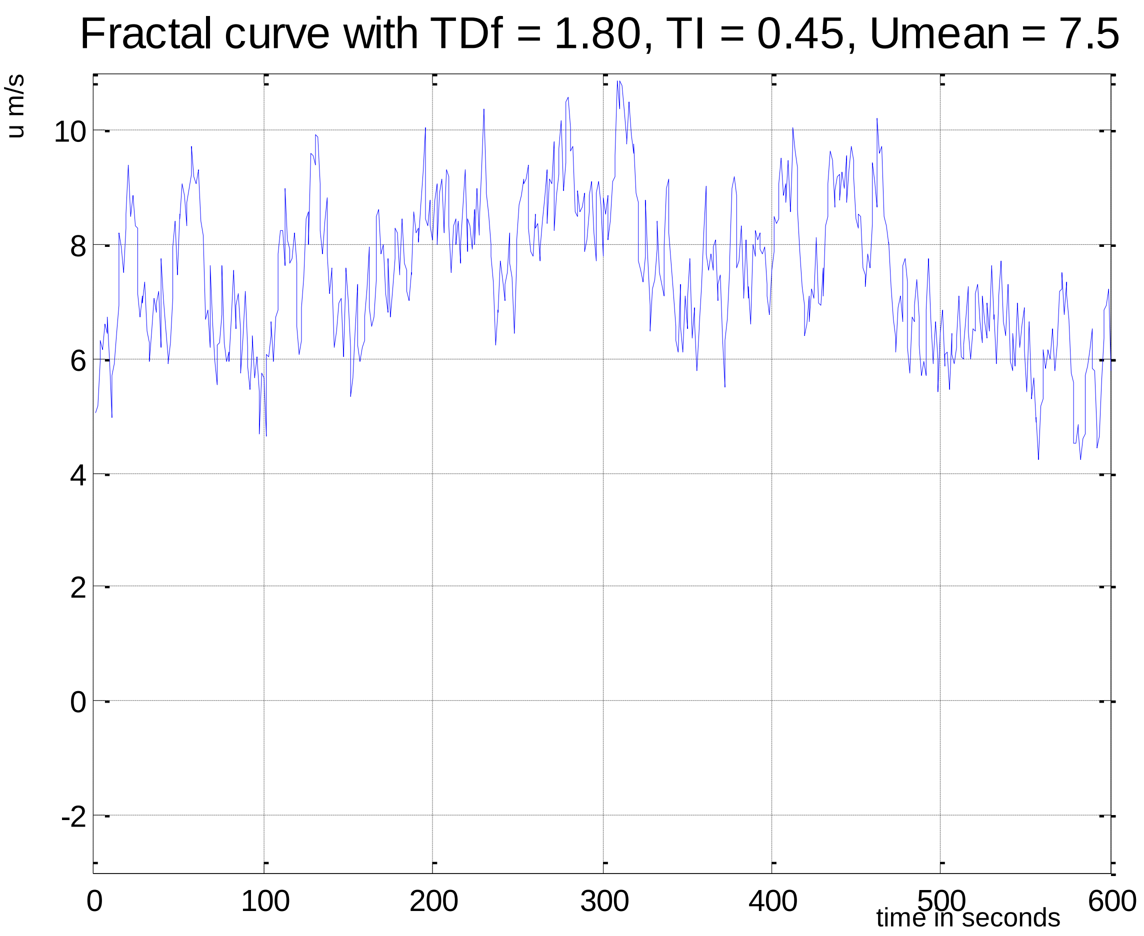


Artificial Wind Speeds

This artificial wind speed has the same statistical properties as an original recording of T_{Df}, TI and u mean.

Early comparisons have shown this model to have a 97% statistical accuracy compared to a frequency bin equivalent.

However this is not over the full data set



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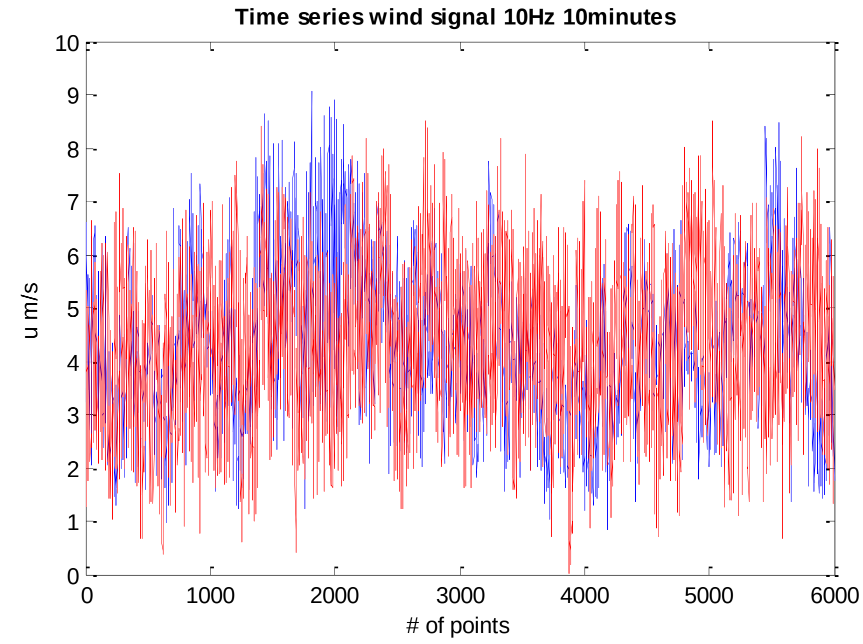
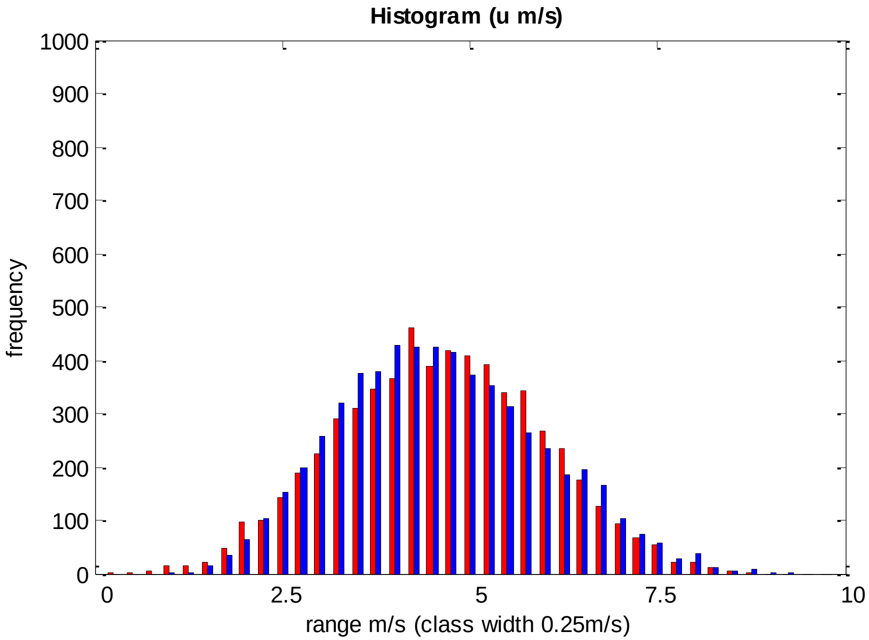
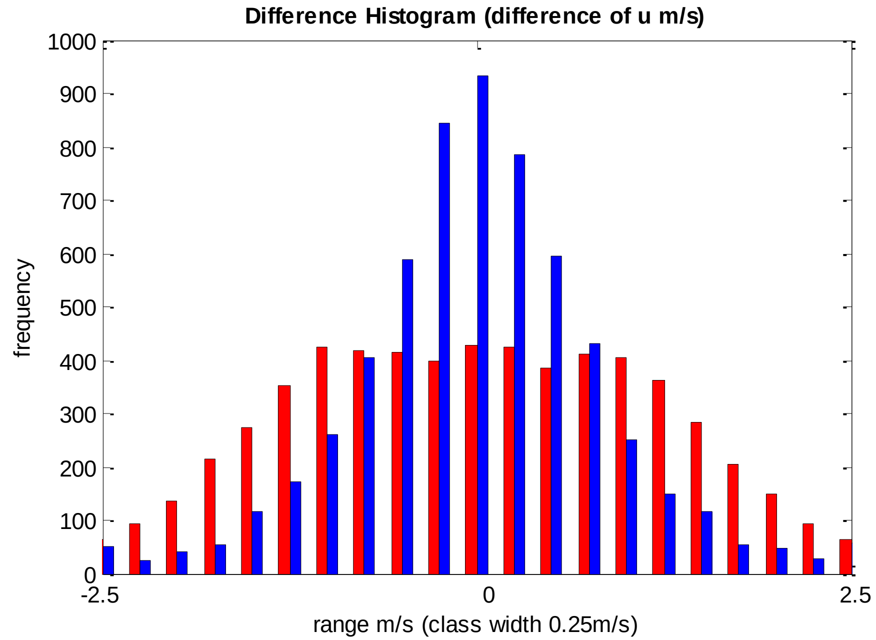
Statistical Sample Results TOA5_3515-2012-04-05 20

Measured Data		Simulated Data	
Mean u	= 4.3580 m/s	Mean u	= 4.3580 m/s
Turb. Inten.	= 0.3102	Turb. Inten.	= 0.3102
TDf	= 2.0796	TDf	= 2.0800
Fractal R2 Corr.	= 0.9719	Fractal R2 Corr.	= 0.9745
Fractal RMS err	= 1.2681	Fractal RMS err	= 1.3064







Results

Q: So just how good a model is it?

A: That is dependant on what you are using the wind speeds for but in general the following can be said based on the 2 urban data sets.

Statistical Marker	Generalisation
Mean	Perfect
TI	Perfect
T_{Df}	Near Perfect
Histogram Shape	Near perfect
Differential Histogram	Some issues in the mid range / insignificant for power prediction
Time series	Seriality is met reasonably well. Generic Shape can be different
Skewness	Near Perfect

N.B. Minimal Data storage as well minimal computation time!

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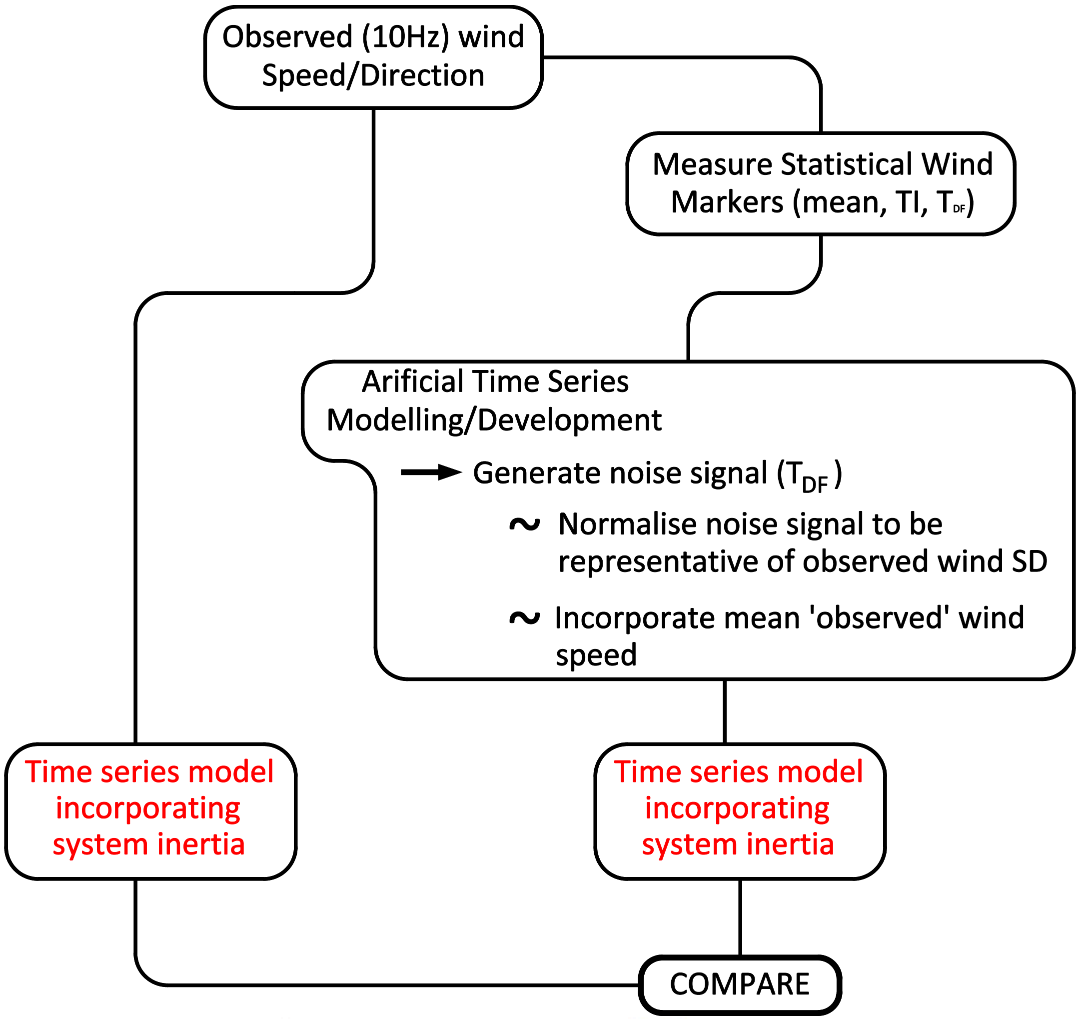
Future Applications

Statistical accuracy of the system response model.



Future Applications

$$u_{res} = u_{start} + \Delta_u \left(1 - e^{-\frac{t}{\tau}}\right)$$

Where:

U_{res} = u resultant

U_{start} = initial u at start of transient window

Δ_u = change in u over transient window

As τ increases e.g. larger turbines have greater inertia

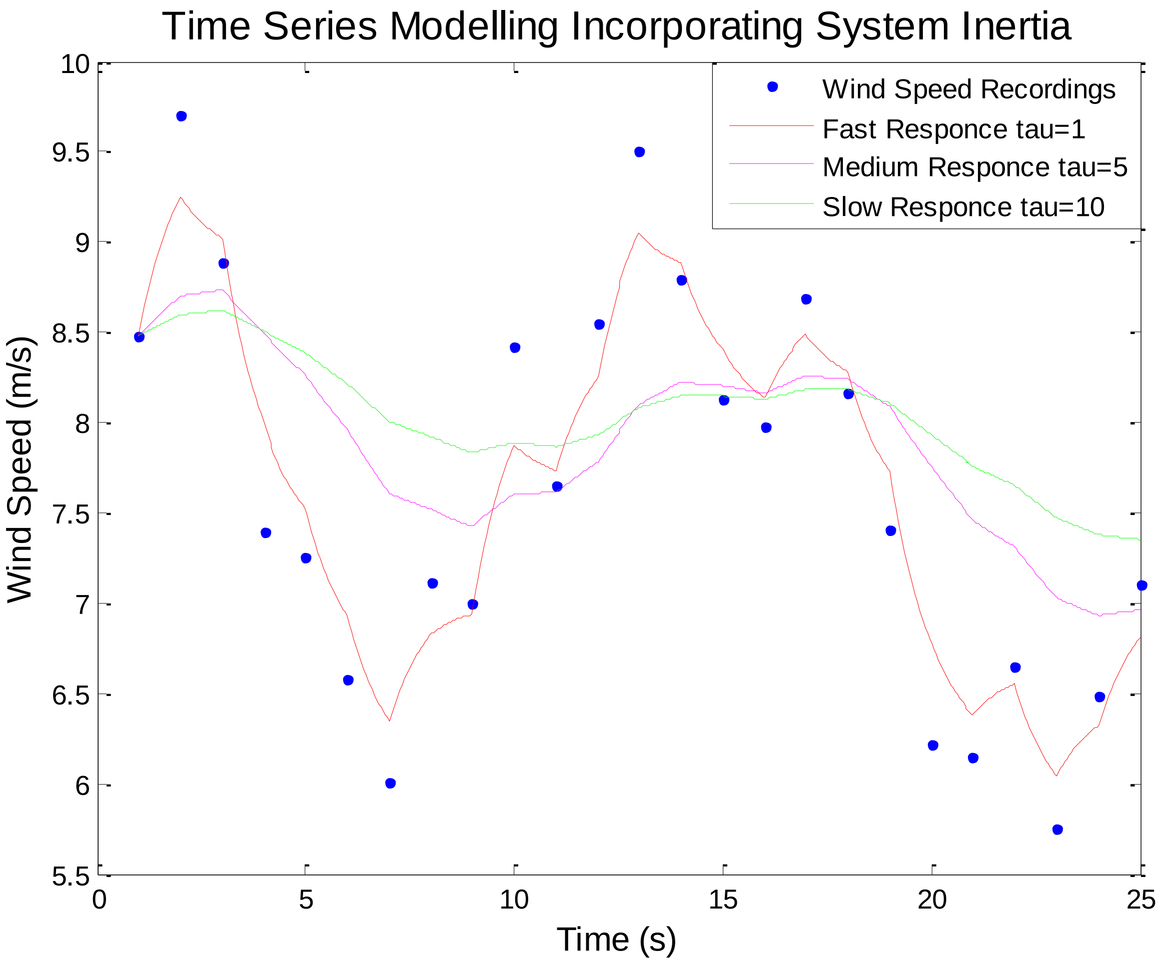


Figure 13 Various system response capabilities based on varying τ .

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Acknowledgements

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Thank you for your time.

Any Questions?

Collaboration
The Author’s of this research would be delighted to share and collaborate on similar projects.

Other Works
For further details on the ongoing work in this area please refer to the author’s research repository stored at;
www.arrow.dit.ie

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