Intermittency And Wind Energy Production

George Fitton

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Where are we right now?
Linear Models

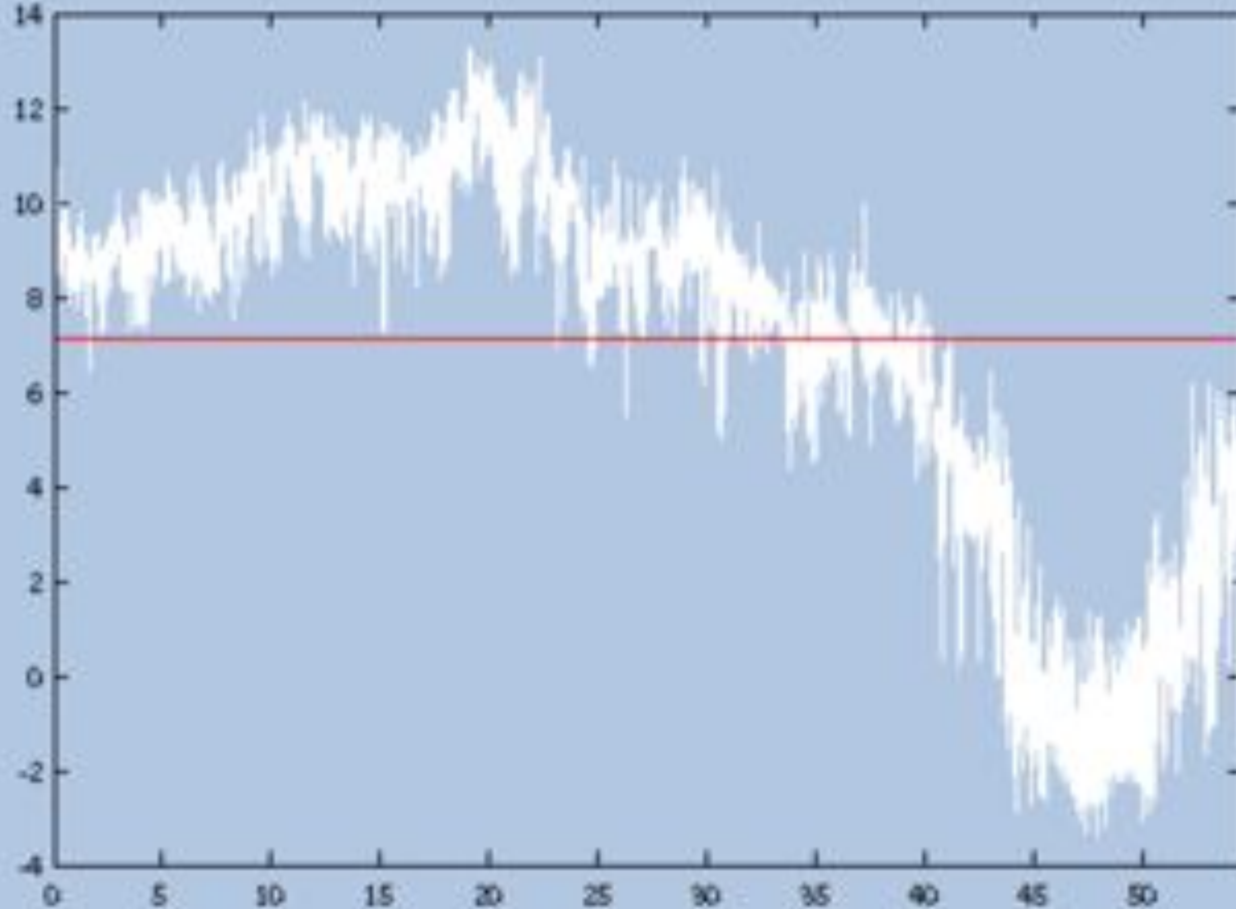
Generating Torque From The Wind

- Power = Money
- However, $P \propto v^3$
- How do we measure and predict the wind?

Linear Models

- WAsP (Wind Atlas Analysis and Application Program)
- Based on interpolation and extrapolation

v [m/s]



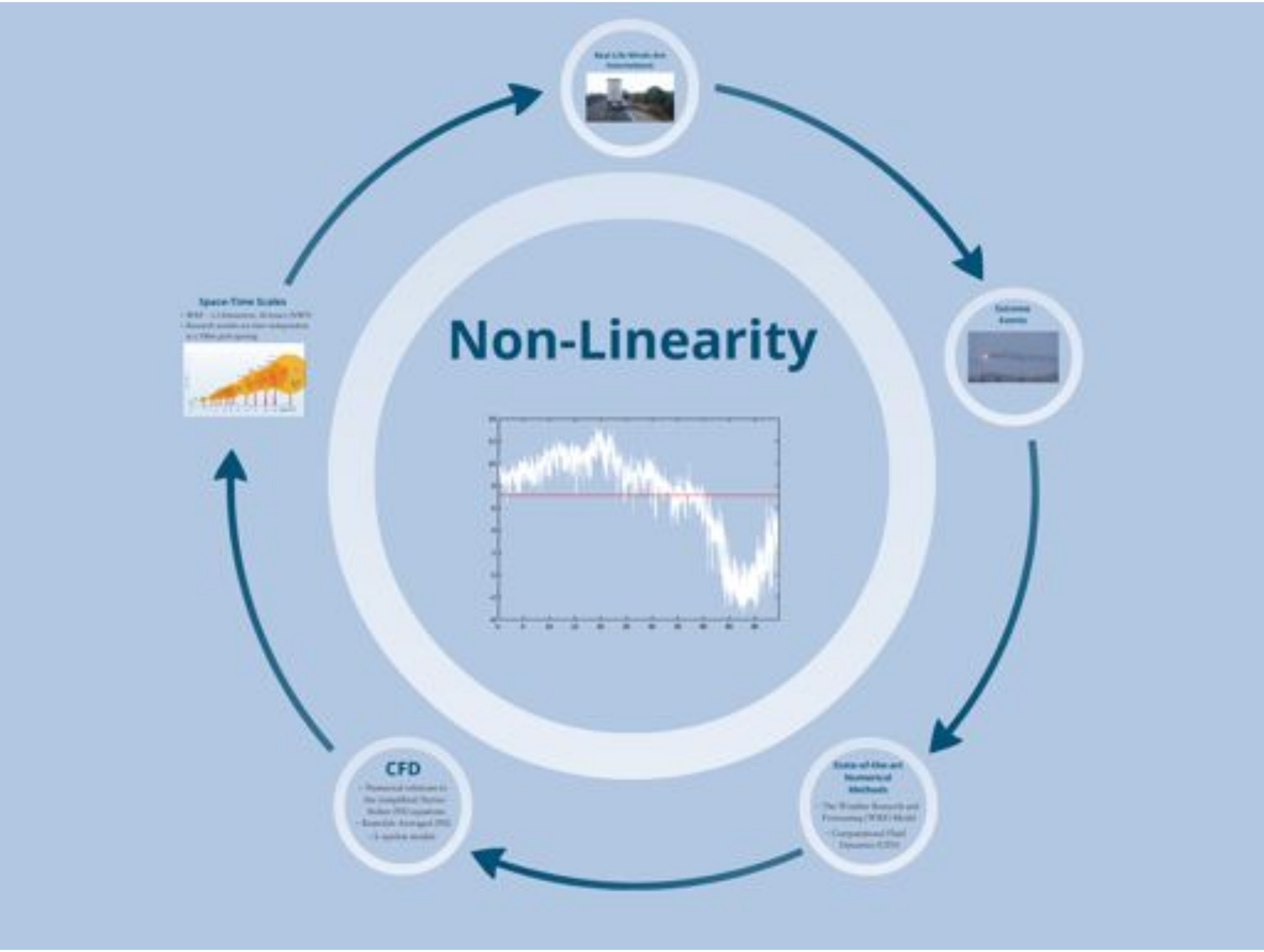
t [mins]

Wind Maps

Parameterisation

- Turbulence Intensity (TI)
- Wind speed up
- 10 minute SCADA data


Where are we right now?
Linear Models
Wind speed up



Space-Time Scales
Non-Linearity
CFD
State-of-the-art
Numerical
Methods

Real Life Winds Are Intermittent

Extreme Events

State-of-the-art Numerical Methods

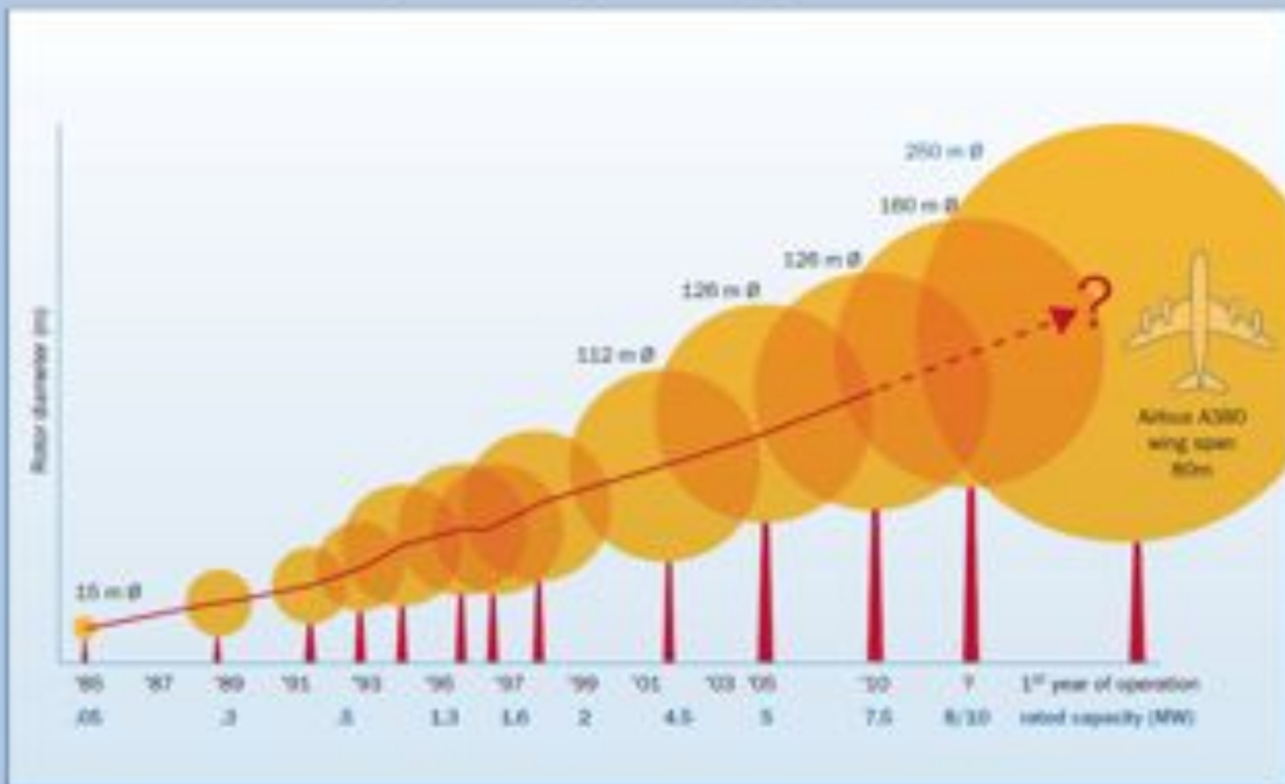
- The Weather Research and Forecasting (WRF) Model
- Computational Fluid Dynamics (CFD)

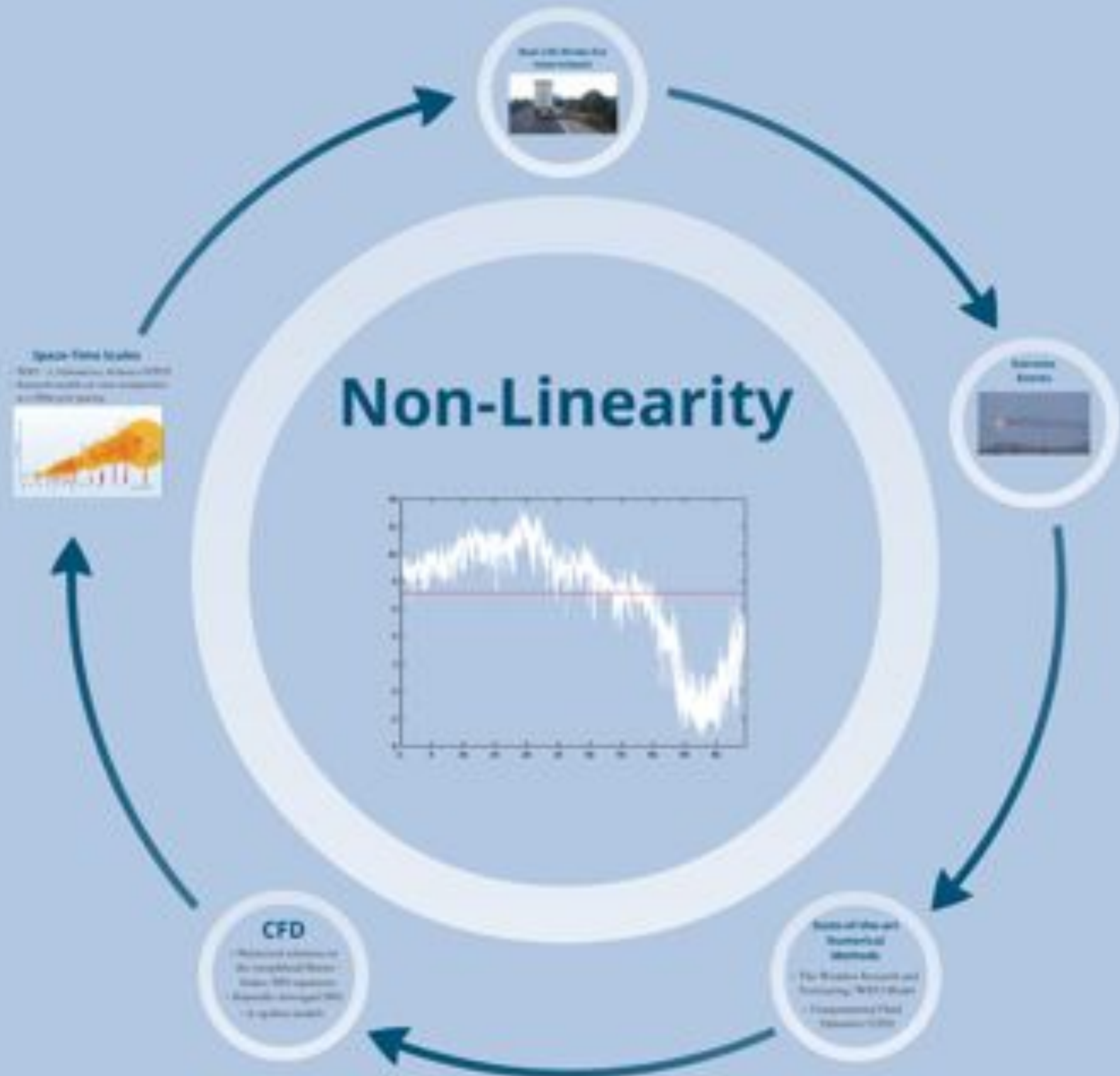
CFD

- Numerical solutions to the (simplified) Navier-Stokes (NS) equations
- Reynolds-Averaged (NS)
- k-epsilon models

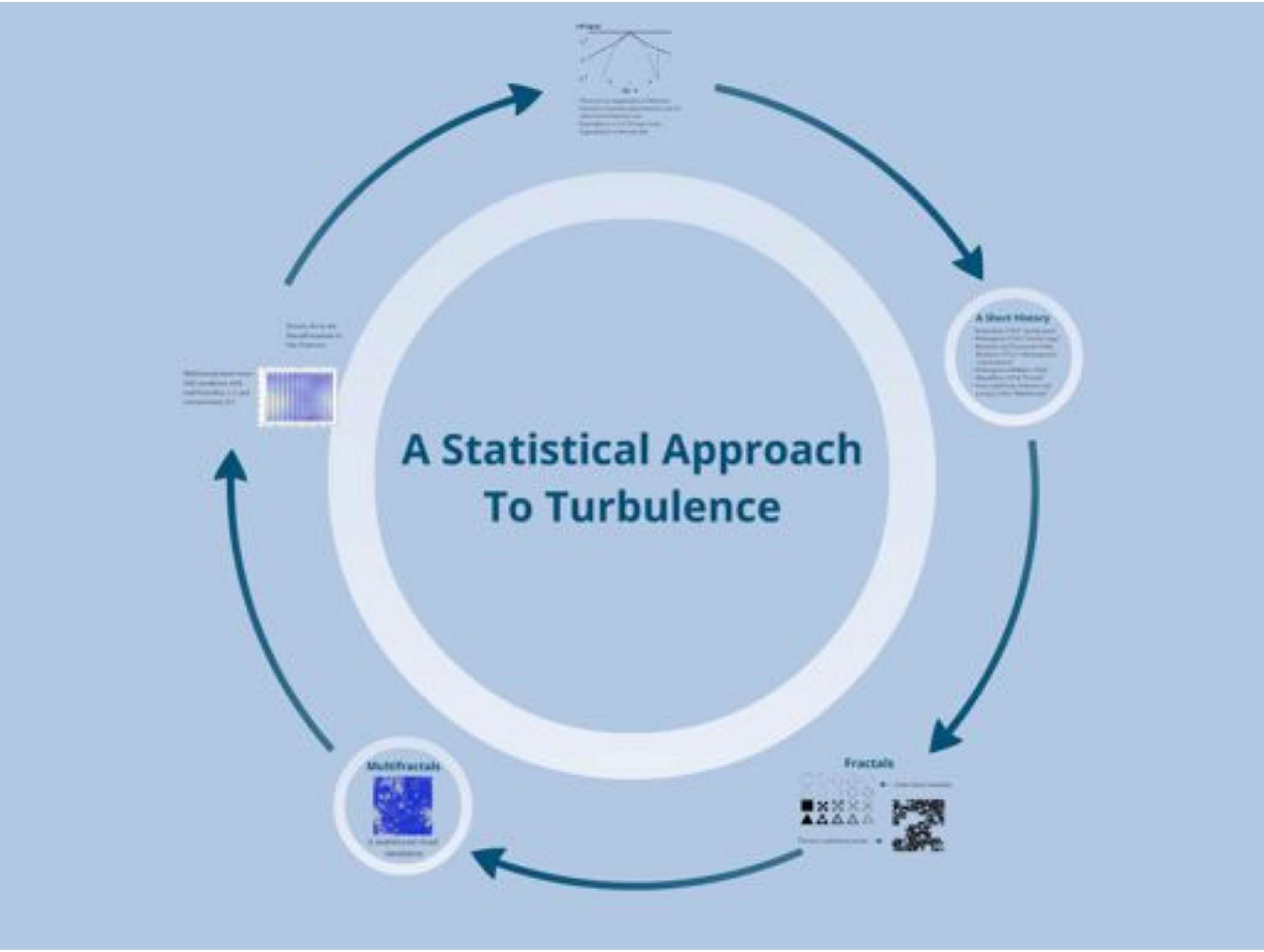
Space-Time Scales

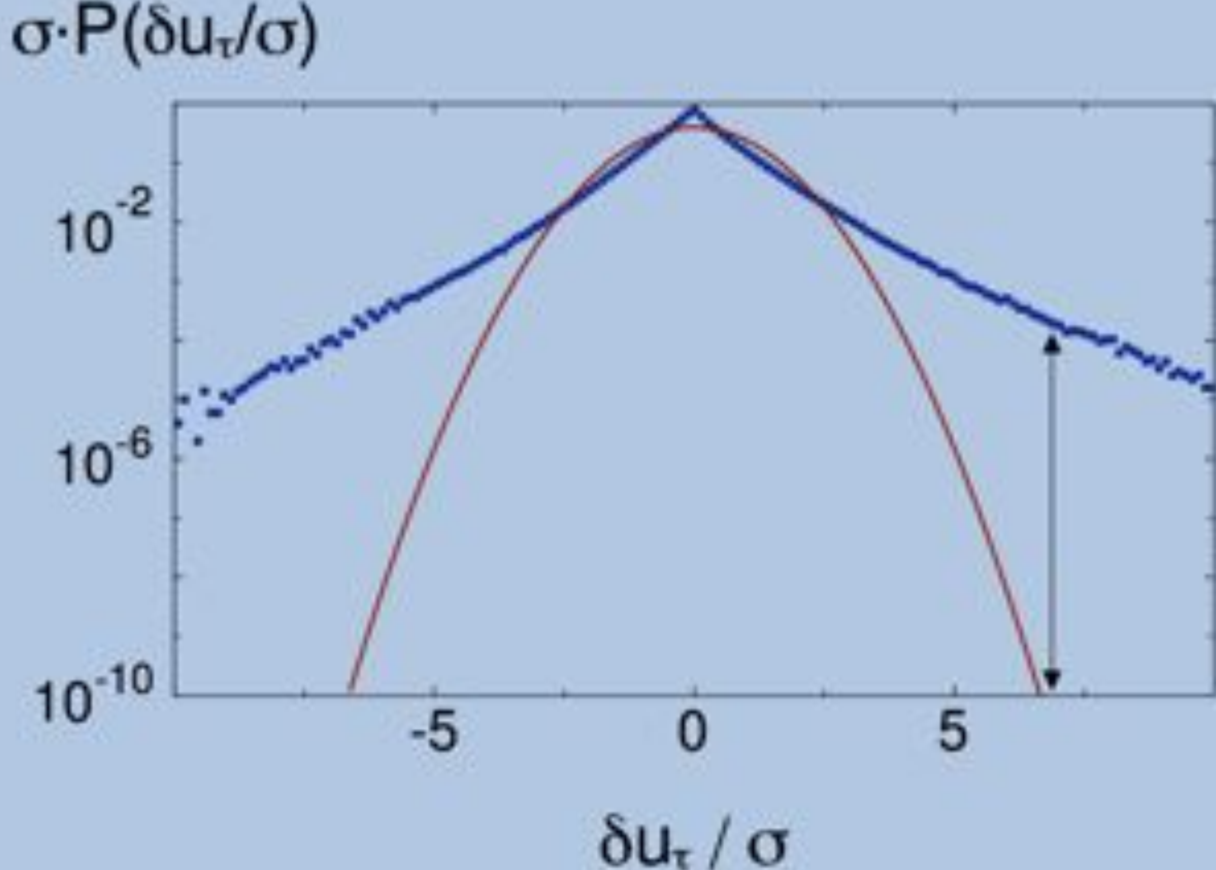
- WRF - 3.3 kilometres, 48 hours (NWP)
- Research models are time-independent at a 100m grid-spacing





Non-Linearity
Space-Time Scales
CFD


A Statistical Approach
To Turbulence
A Short History
Fractals
Multifractals

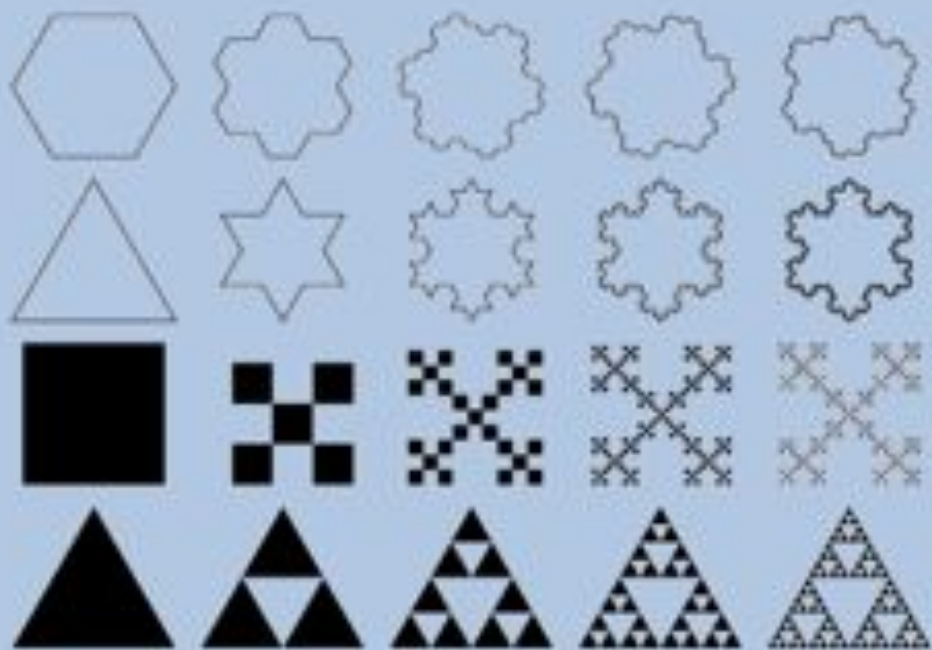


- There are six magnitudes of difference between a Gaussian approximation and the observed intermittent one
- Equivalent to a 1 in 500 year event happening five times per day

A Short History

- Richardson (1922) "cascade poem"
- Kolmogorov (1941) "inertial range"
- Batchelor and Townsend (1949), Batchelor (1953), "inhomogeneity /intermittency"
- Kolmogorov-Obukhov (1962)
- Mandelbrot (1974) "Fractals"
- Parisi and Frisch, Schertzer and Lovejoy (1985) "Multifractals"

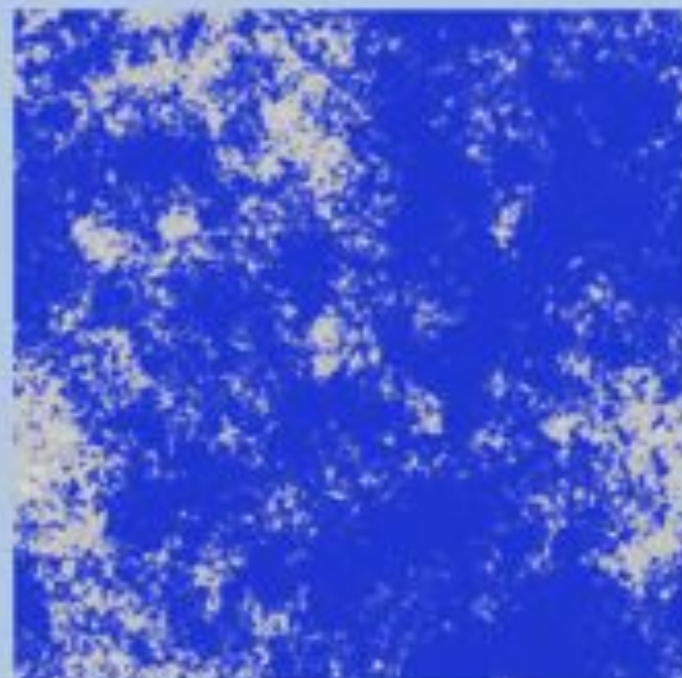
Fractals



Some fractal examples

The beta-turbulence model

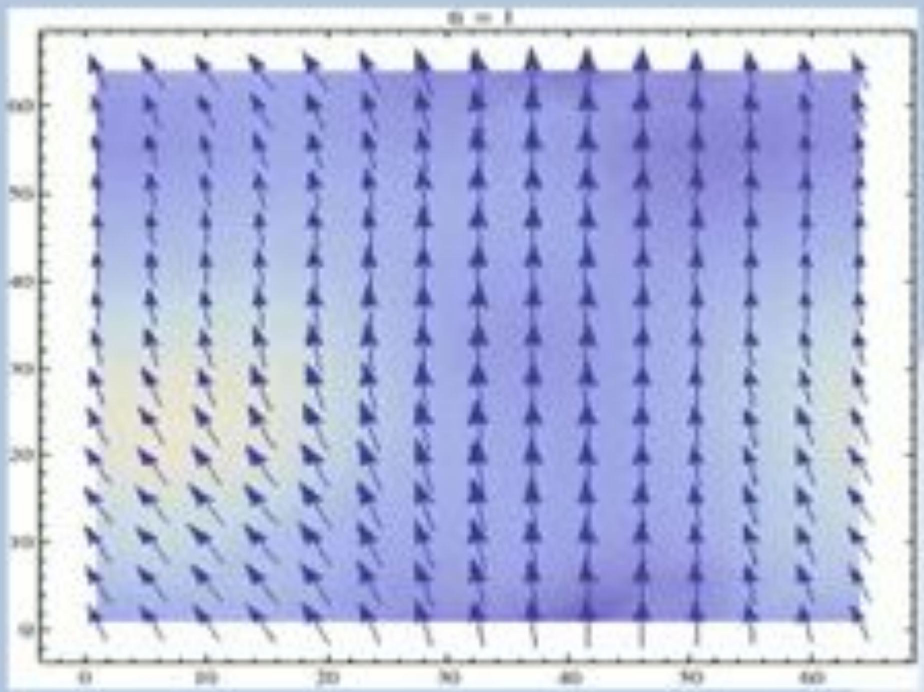
Multifractals



A multifractal cloud simulation

Kinetic Art at the Randall museum in San Francisco

Multifractal wind vector field simulation with multifractality, 1.5, and intermittency, 0.2.




Scaling
Random Processes
Future Input
Our Research

Scaling

- Classical theory dictates that the velocity shears

$$\Delta u_{\lambda} = \varepsilon_{\lambda}^{a} \lambda^{-H}$$

for a and H =1/3

- Homogeneity/Isotropic assumptions

Random Processes

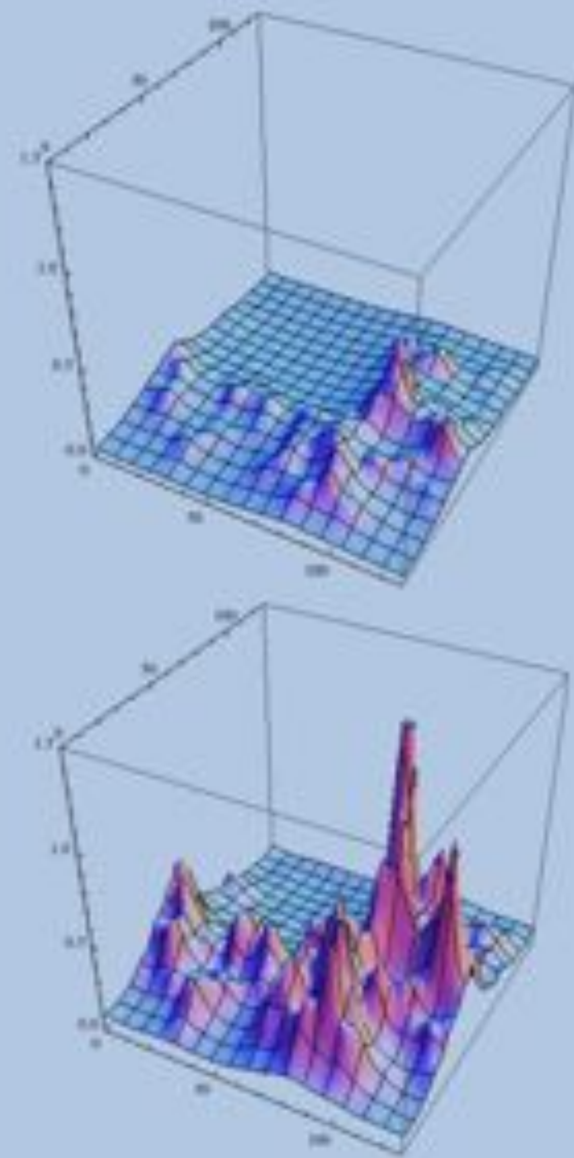
- Stochastic models require the generation of independent and identically distributed (i.i.d.) random variables (multiplicative)
- Their distributions typically have finite variances so that analytic expressions can be defined for the extremes

Velocity Shears

- Velocity shears are correlated (H) and their logarithms are compatible with Lévy stable distributions
- No extreme value theory so empirical parameters (using Weibull for example) are used

The Value of H

- Classical theory dictates H=1/3, our recent studies have shown H=1/7.
- Who cares?
- The value of H (i.e. how correlated the field is) corresponds to how smooth the field is



Future Input

Comparison of non-classical conservation parameters with standard methods such as Kaimal or Von Karman

Final Remarks

- Converting to a sustainable energy infrastructure is forcing us to interact with and understand complex non-linear geophysical processes.
- Understanding is only the start. The future will require both understanding and innovation as means to succeed.