# A systematic approach for estimating loads in off-shore wind farms

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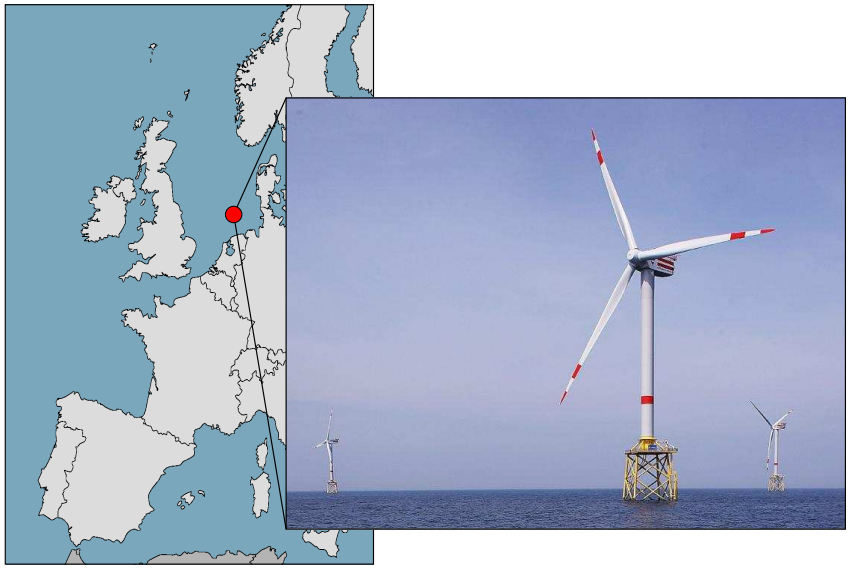
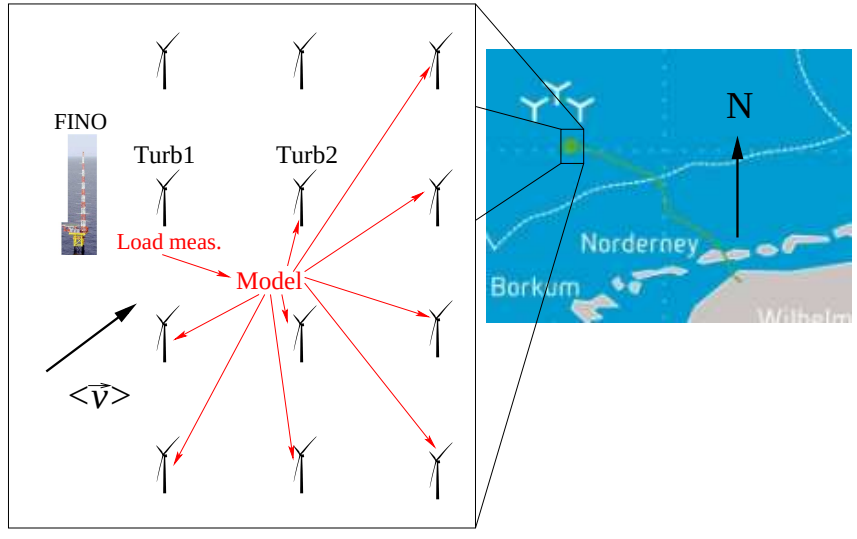
ForWind Zentrum für Windenergieforschung Bremen Hannover Oldenburg

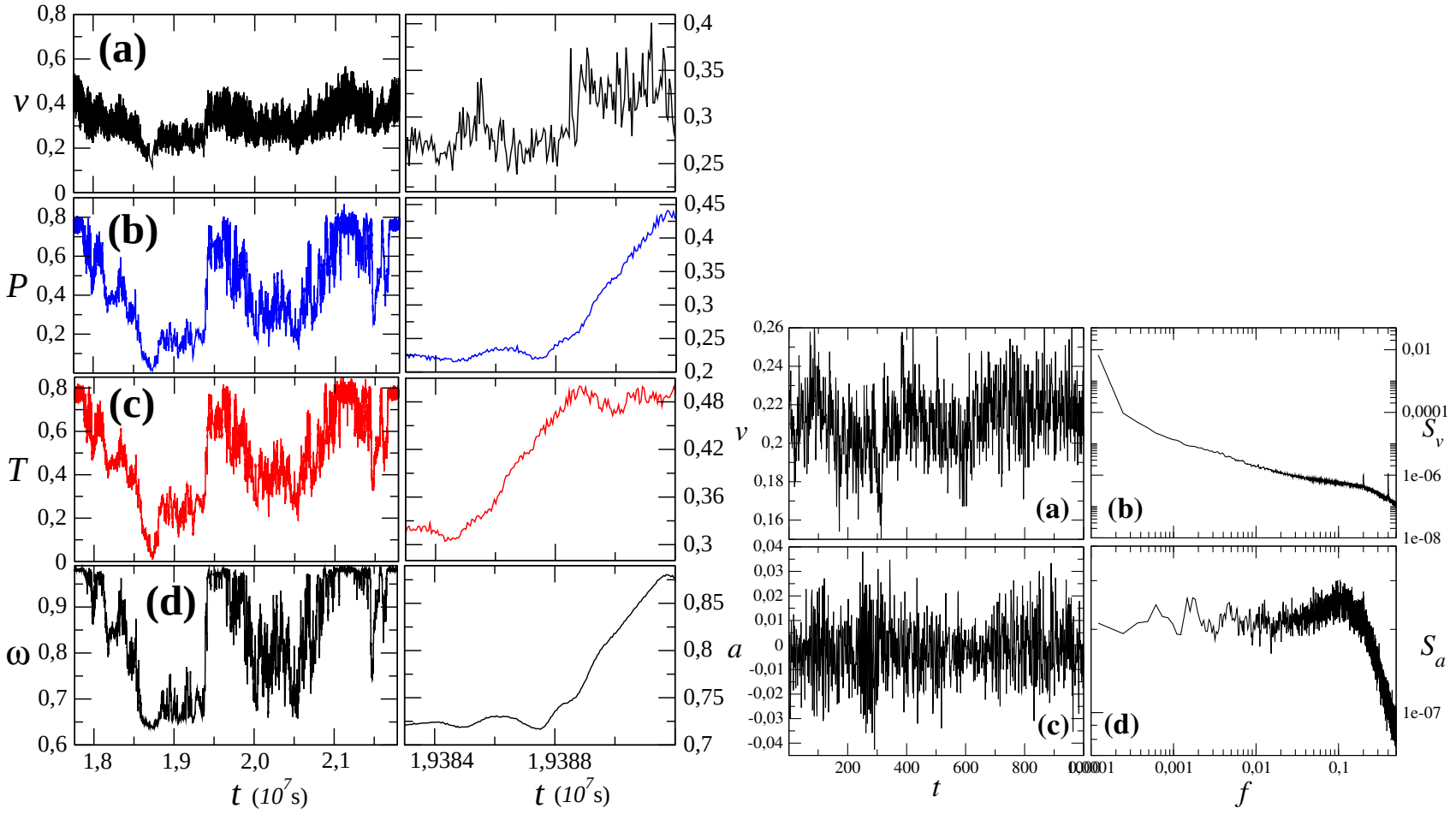
# Looking for models to reproduce measurement series





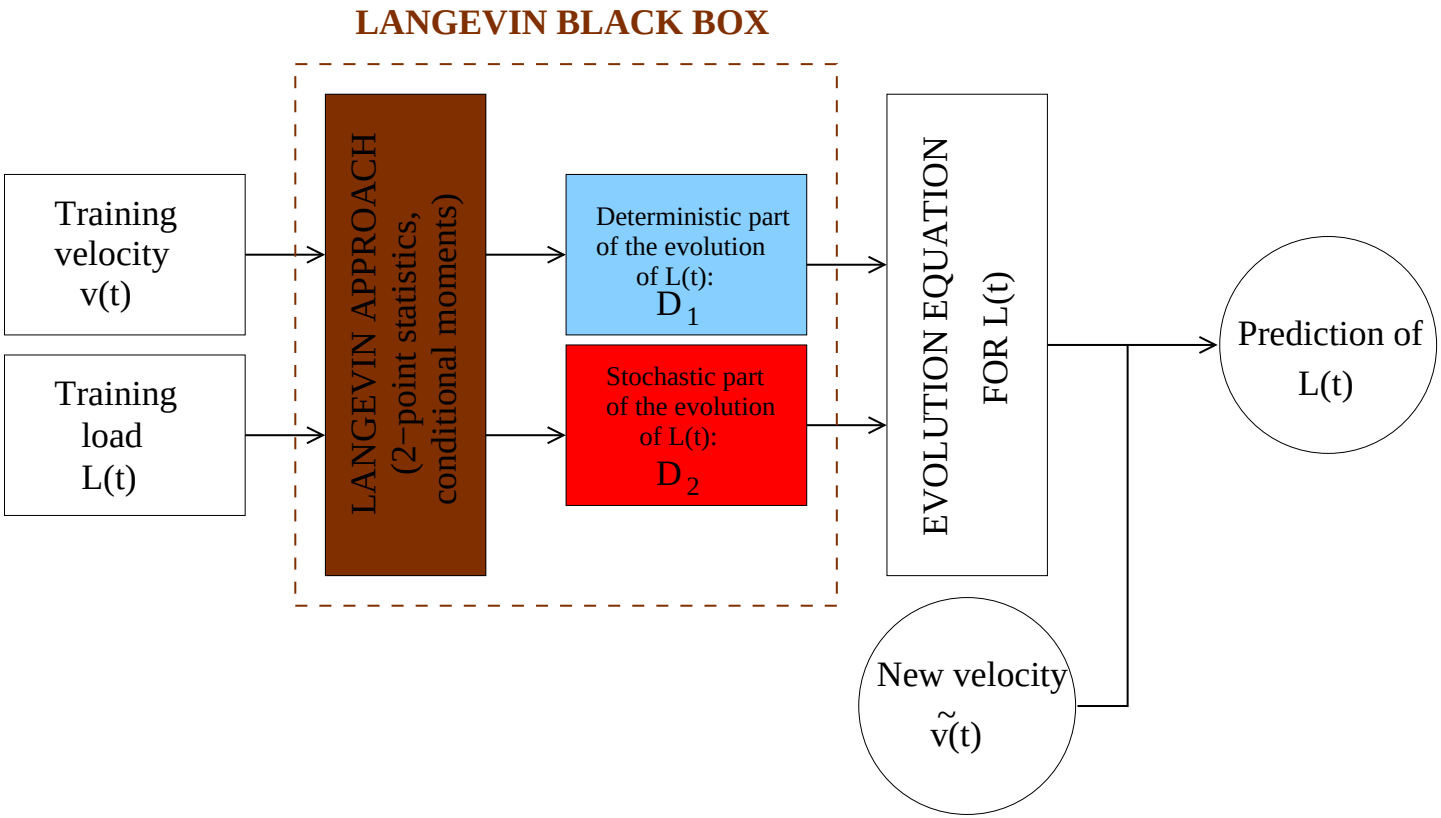
# Data from single wind turbines

Control and monitoring: how to reconstruct such signals?



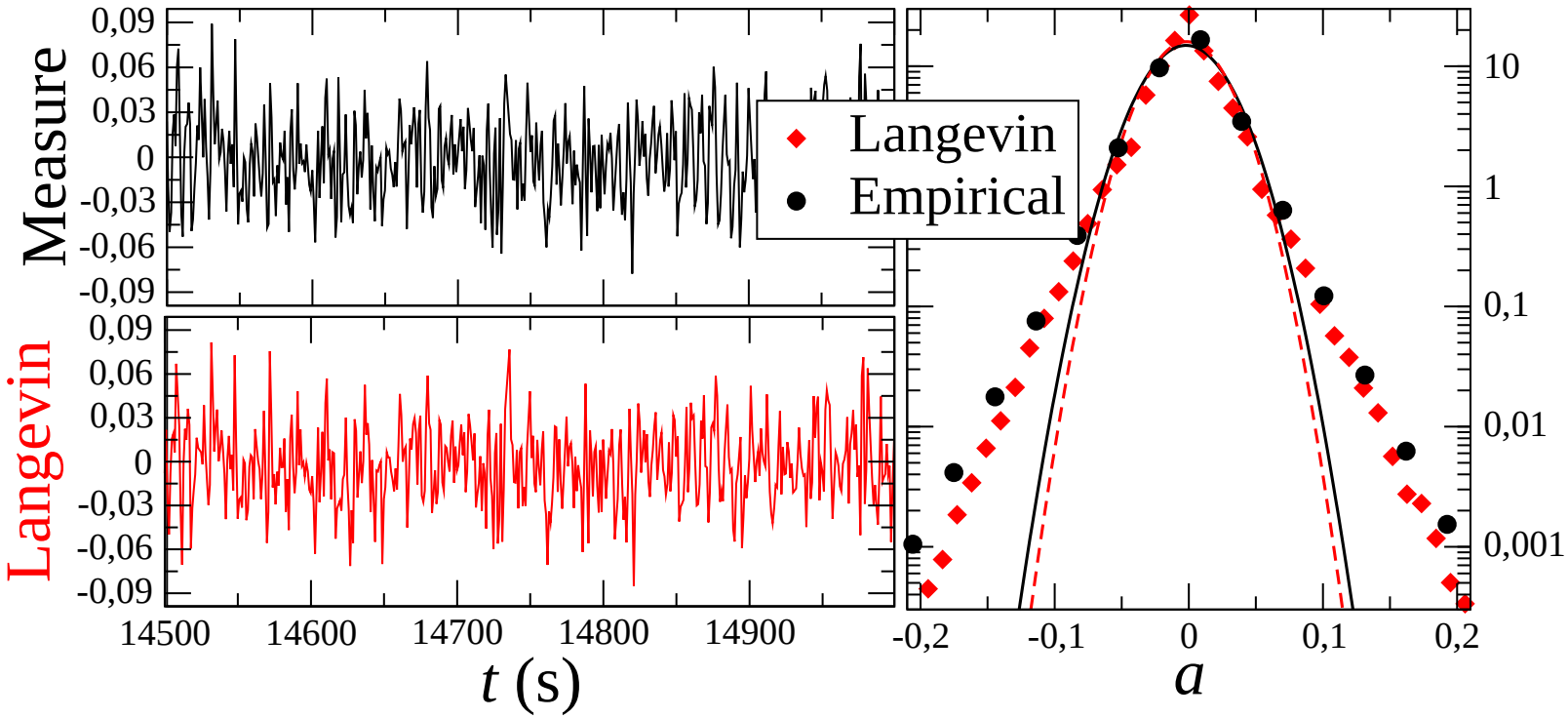
# An alternative way to reconstruct signals (loads)

Langevin Approach: Evolution = Tendency + Fluctuations

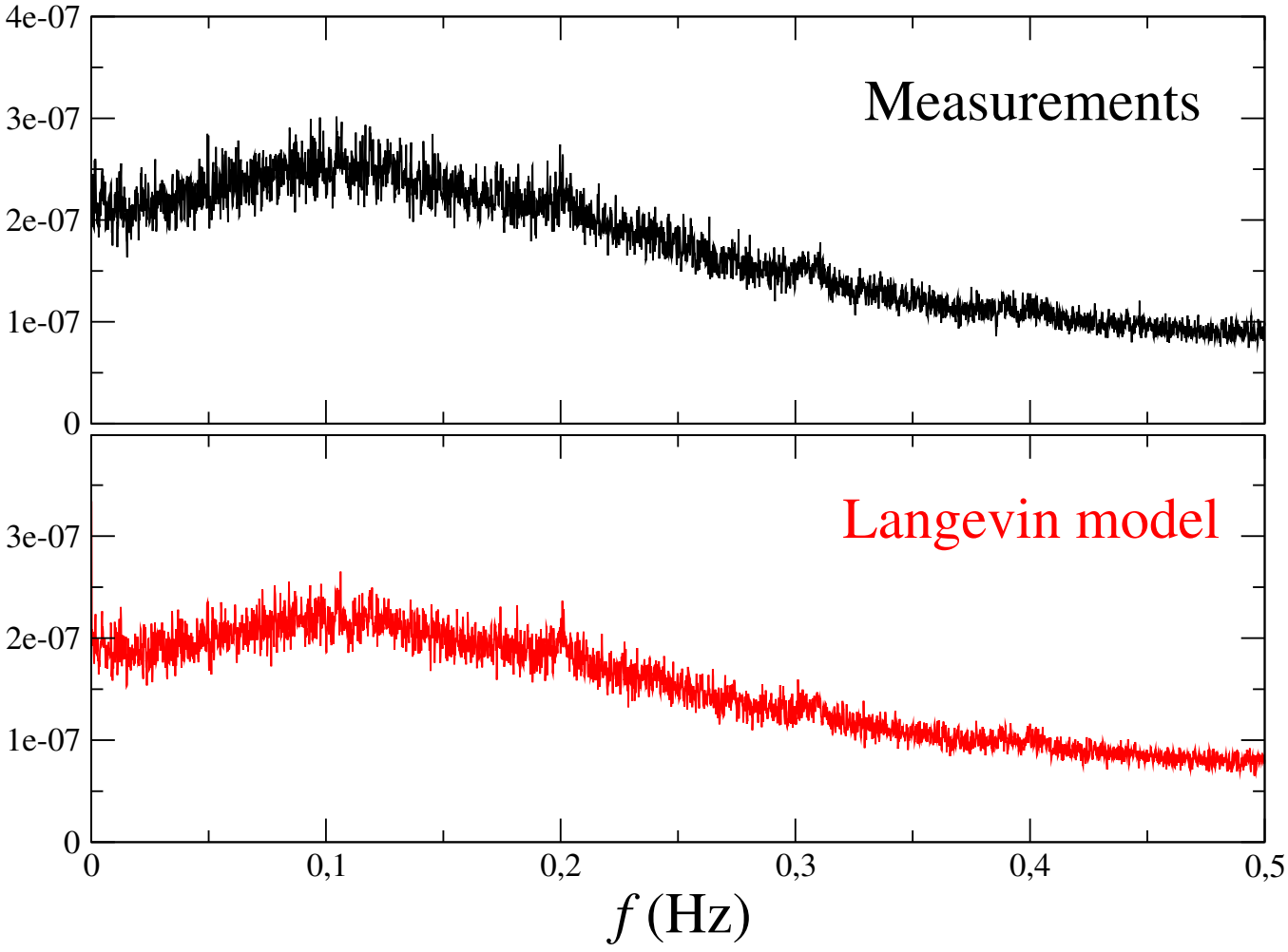



https://cran.r-project.org/web/packages/Langevin/

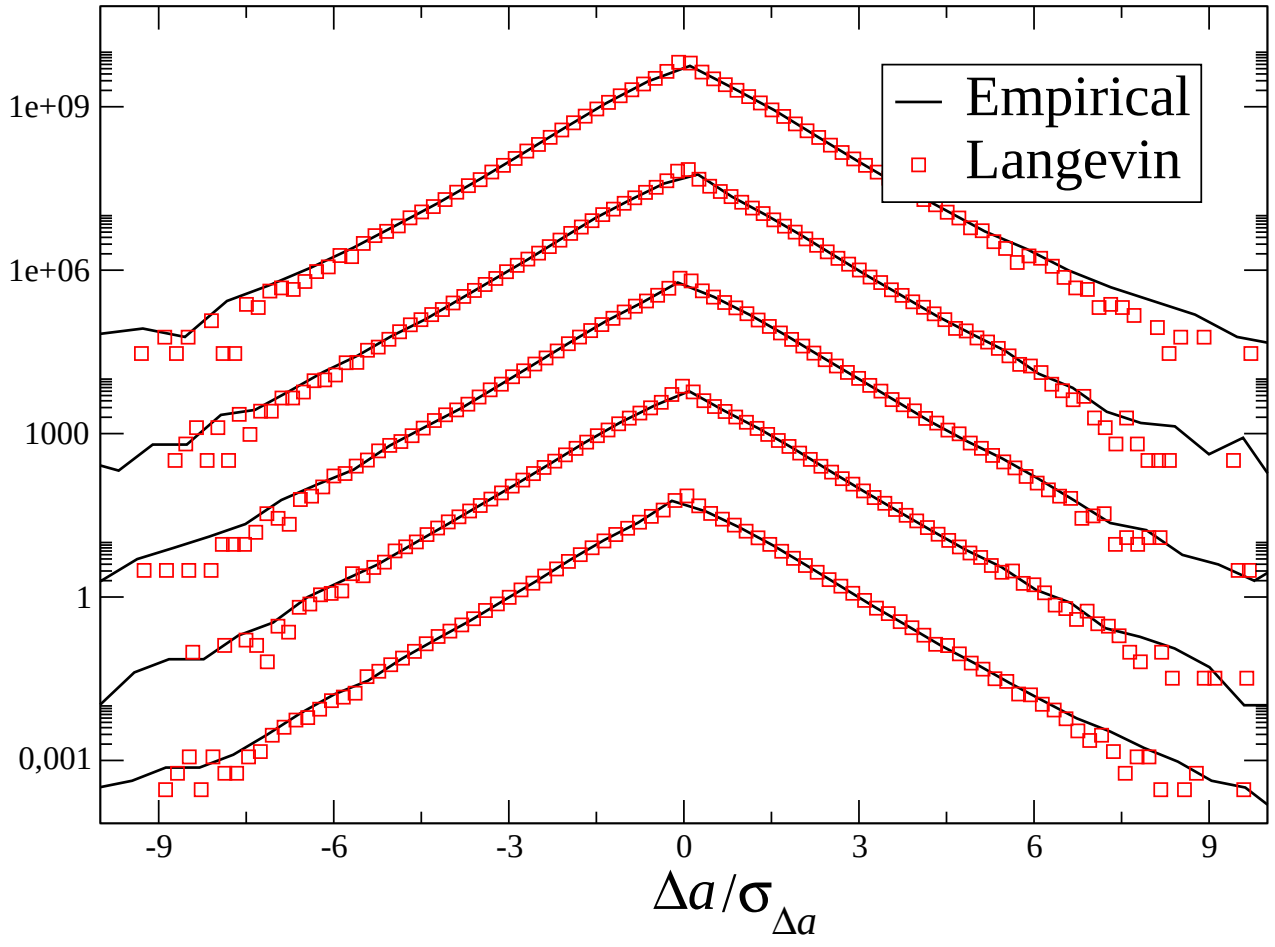
# Tower acceleration (AV4, November 2014)



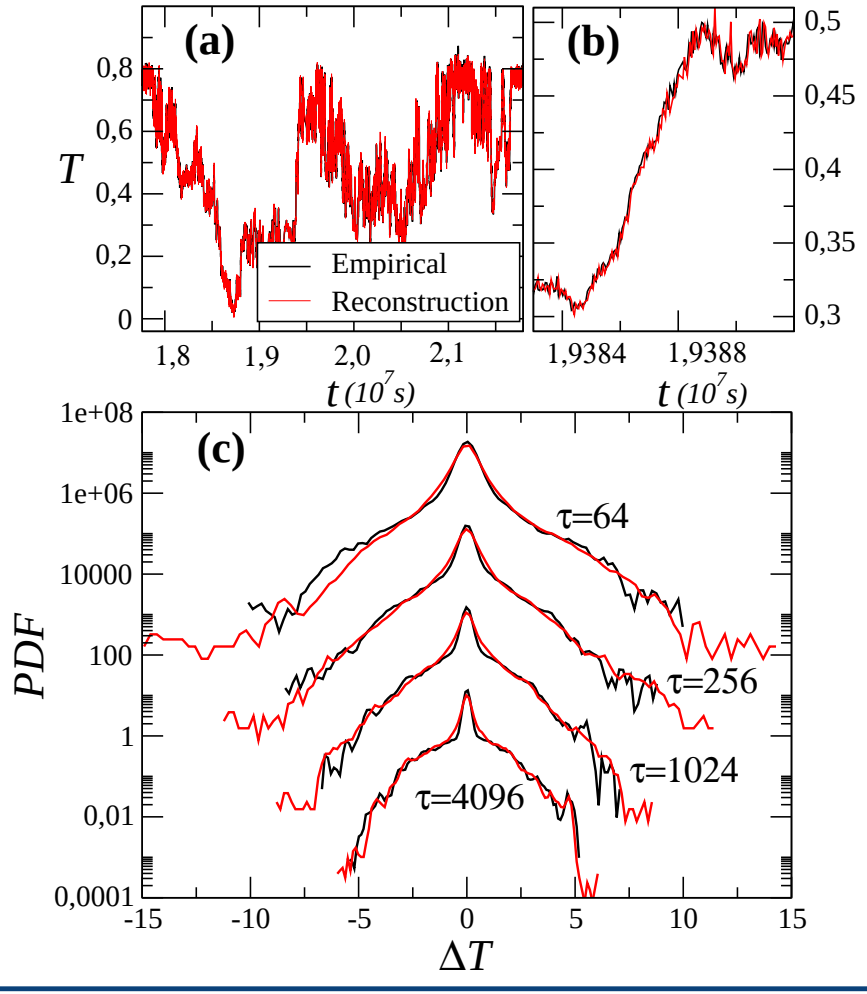
# Power spectra



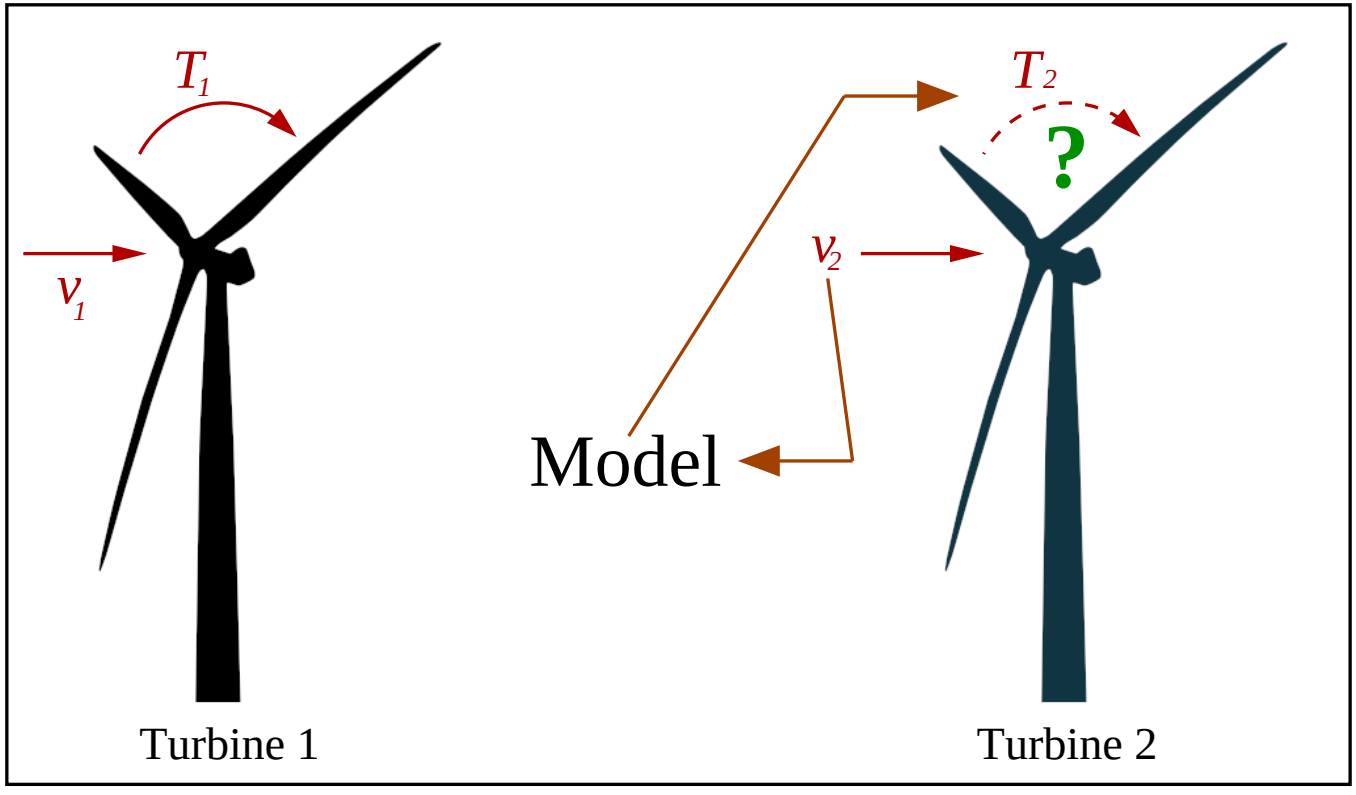
# Increment (2-point) statistics



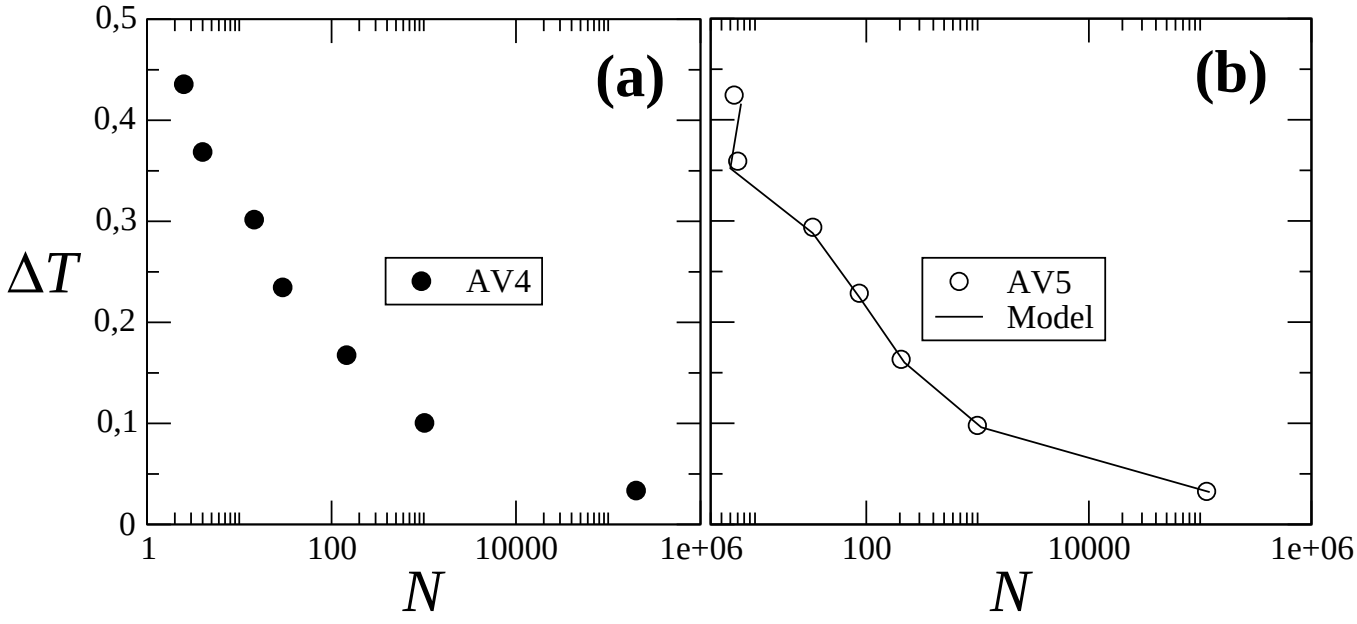
# Other loads: Torque



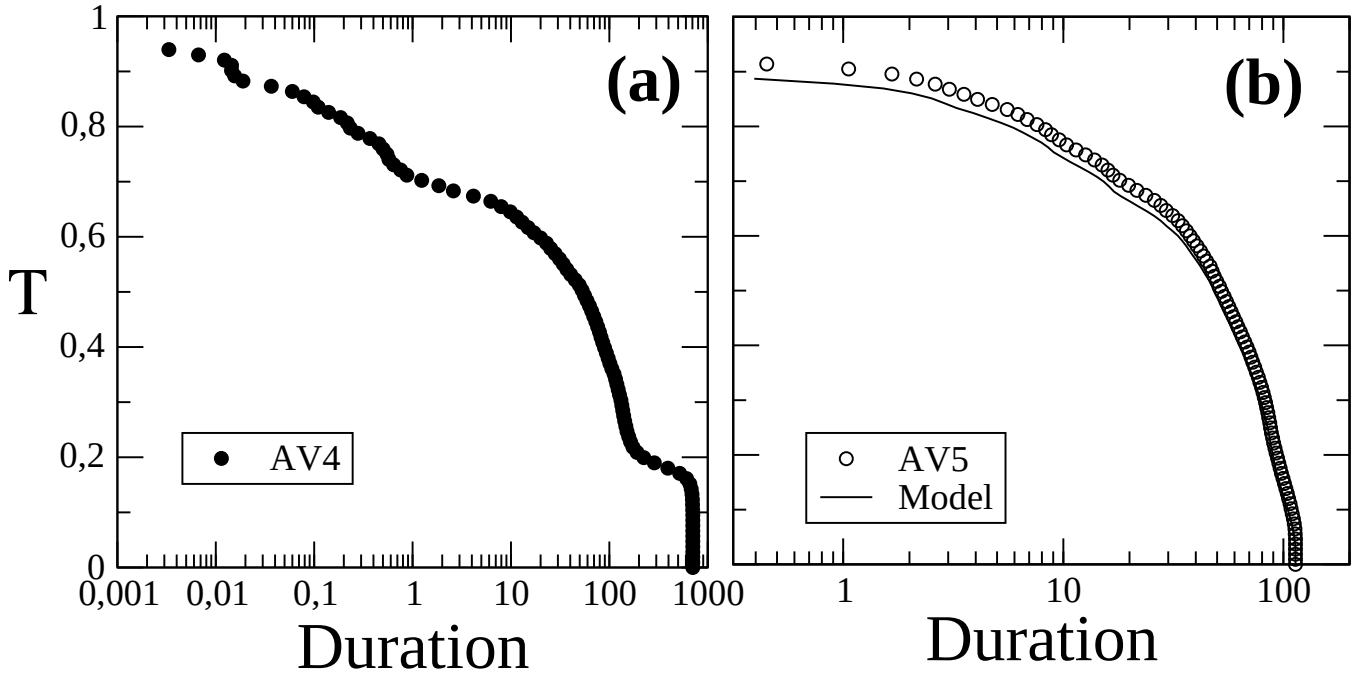
# Using one single turbine to model several other



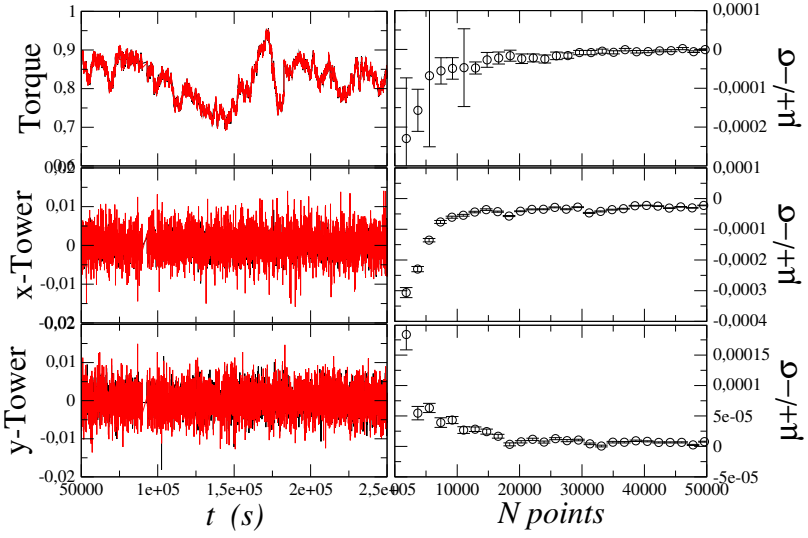
# Other loads: Fatigue loads

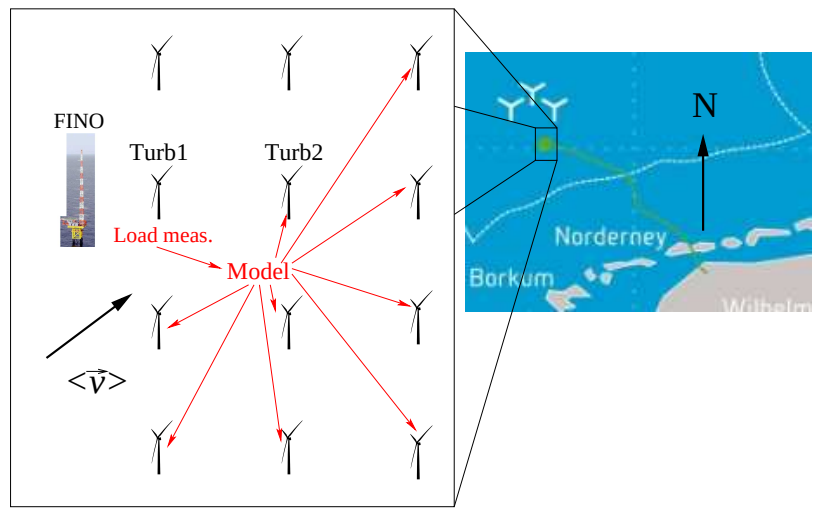


# Other loads: Fatigue loads

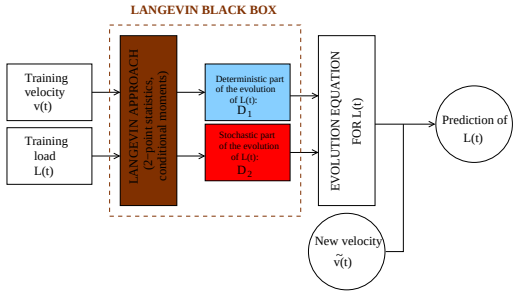


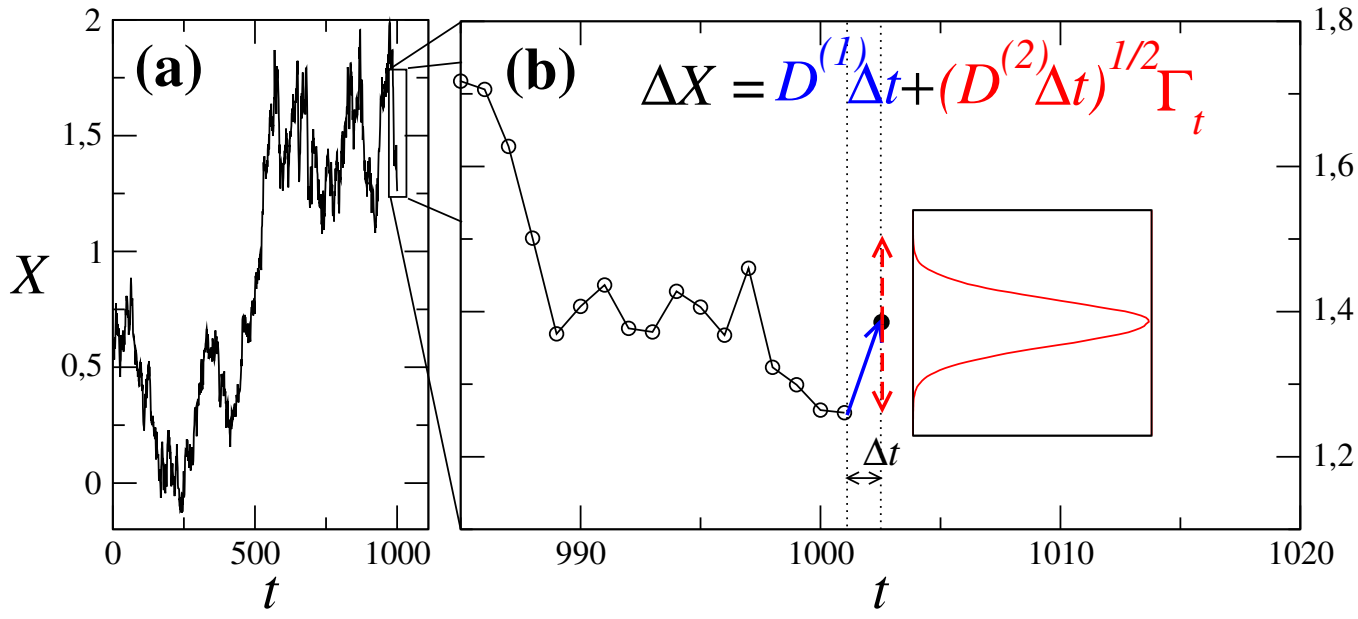
# From one single turbine to a wind farm



# A little deeper into the model...




$$X(t+\Delta t) = X(t) + \text{"Tendency"} + \text{"Fluctuation"}$$

# *Conclusions:* ***Reproducing loads from wind***

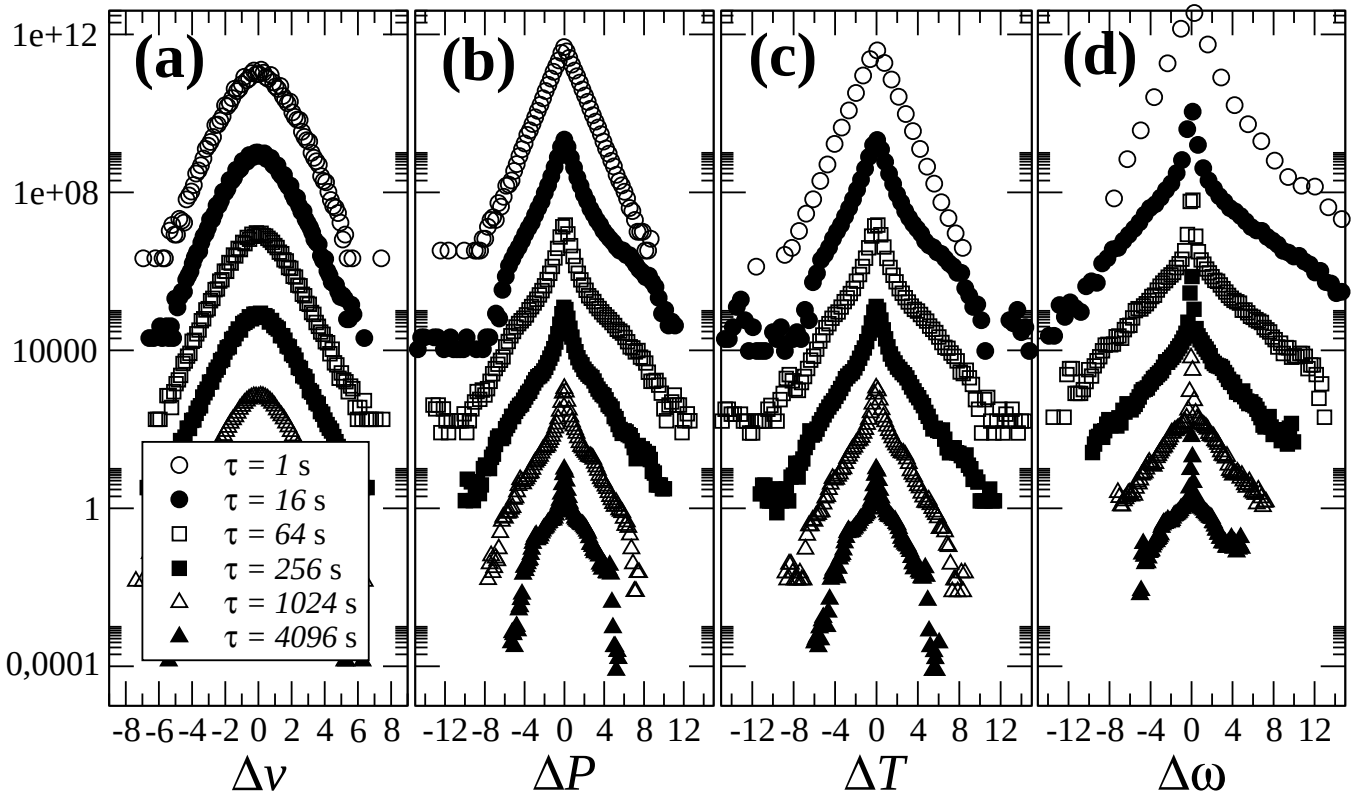
- Model incorporating (deterministic) tendencies and (stochastic) fluctuations.
- Good estimate of instantaneous and fatigue loads.
- Possible cost reduction when modelling load measurements for other identical wind turbines at the same wind park.
- Software available at `https://cran.r-project.org/web/packages/Langevin/`.
- Comparison with other approaches?
  Talk by Luís Vera-Tudela (tomorrow).

Thank you!

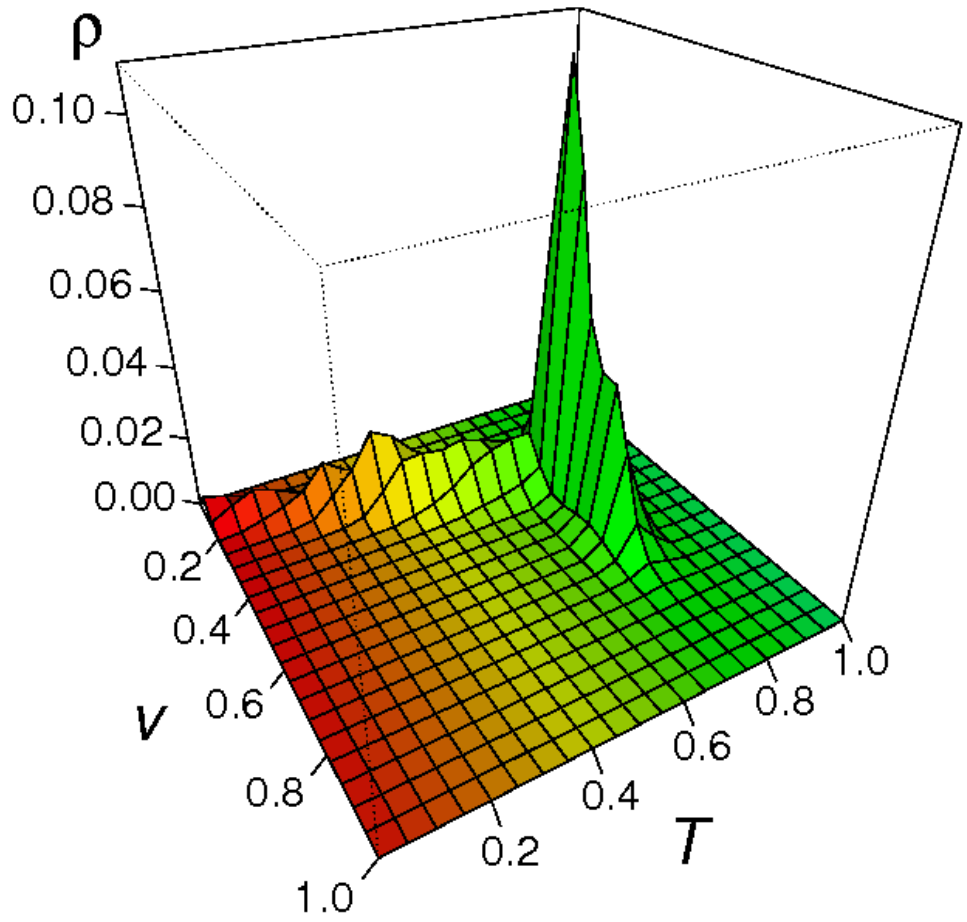
**Acknowledgements:**

- **Senvion**, for providing the data here analyzed.
- **Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety**, for funding research project *Probabilistic loads description, monitoring, and reduction for the next generation offshore wind turbines (OWEA Loads)* under grant number 0325577B.

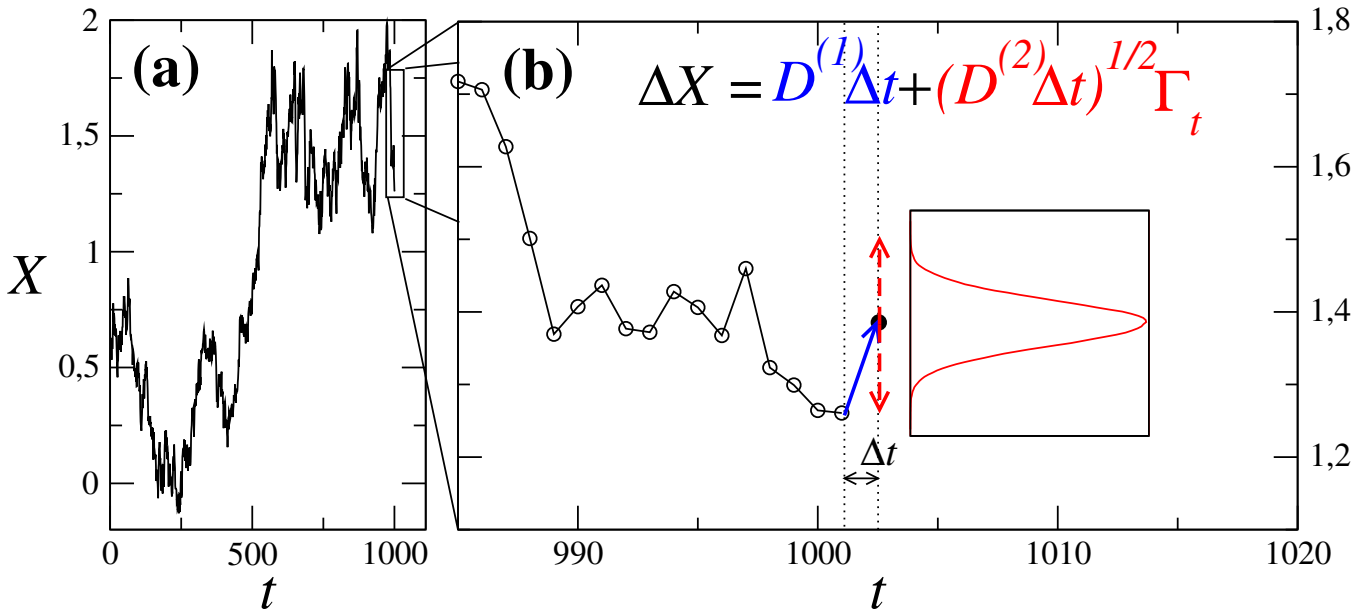
# Starting point: increment statistics



# Starting point: torque $\times$ velocity



# Deriving the model: the Langevin approach




$$L(t + \Delta t) = L(t) + \text{"Tendency"} + \text{"Fluctuation"}$$

Peinke & Friedrich, Phys.Rev.Lett. 78 863 (1997)

Lind et al, Energies 7(12) 8279-8293 (2014)

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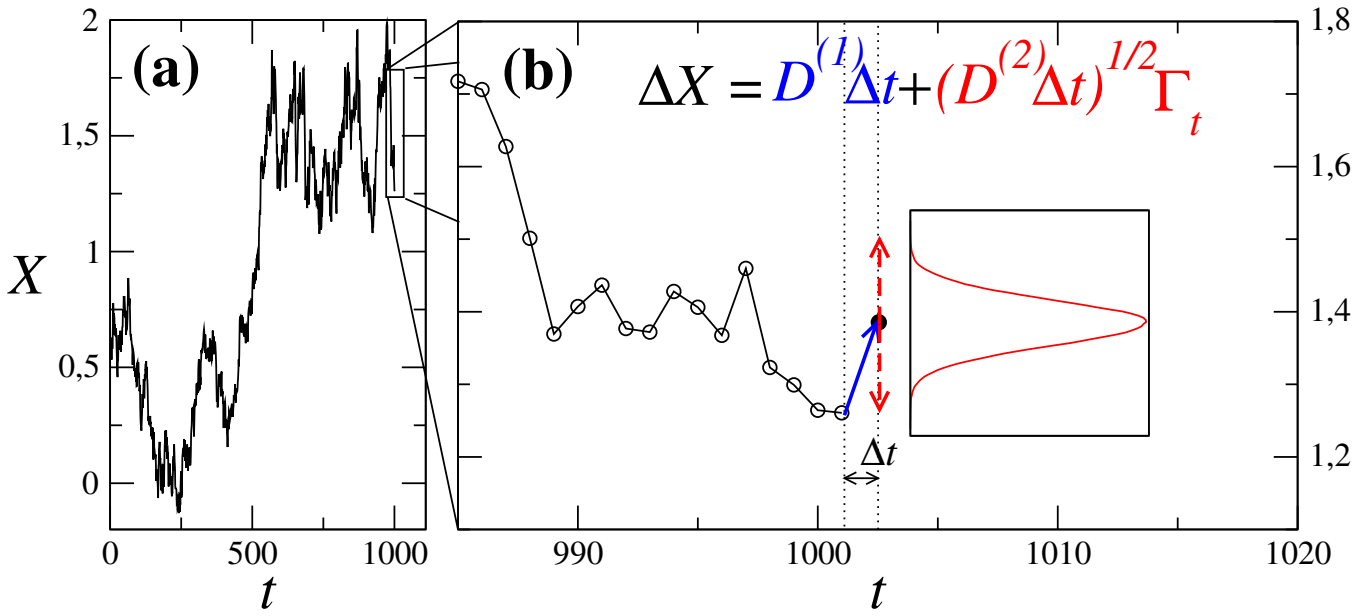
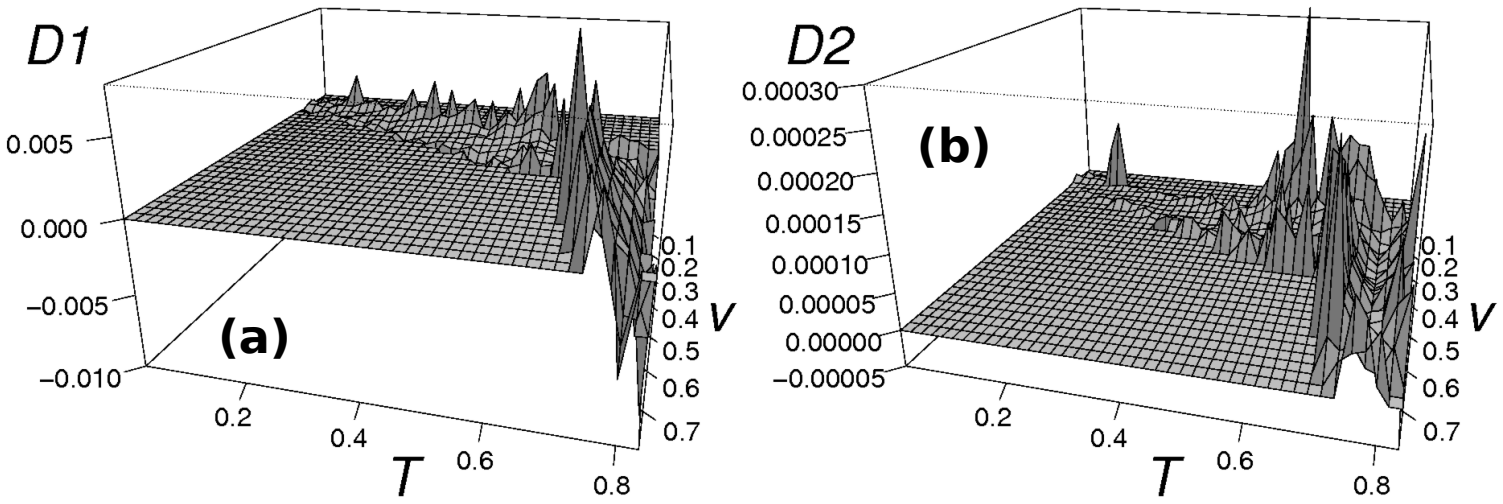



$$D_n(x) = \frac{1}{n!}\lim_{\tau\to 0}\frac{1}{\tau}\underbrace{\langle (X(t+\tau)-X(t))^n\rangle_{X(t)=x}}_{M_n}$$

# Conditional Langevin approach




$$L(t+\Delta t) = L(t) + D^{(1)}(L|v)\Delta t + \sqrt{D^{(2)}(L|v)}\Gamma_t\sqrt{\Delta t}$$

P.Milan et al (2013), Private Communication

Lind et al, J.Phys.Conf.Ser. 524 012179 (2014).

# Drift $D^{(1)}$ and Diffusion $D^{(2)}$