A novel bi-component structural health monitoring strategy for deriving global models of operational wind turbines

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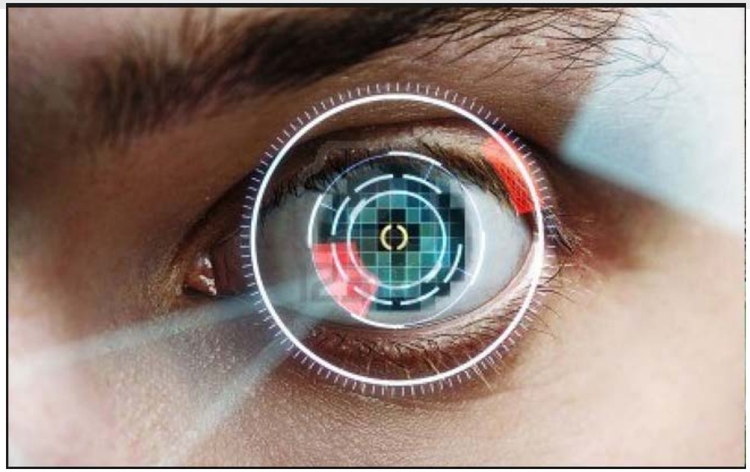
Duration: 02/12/2015 – 23/12/2015

Talk Outline

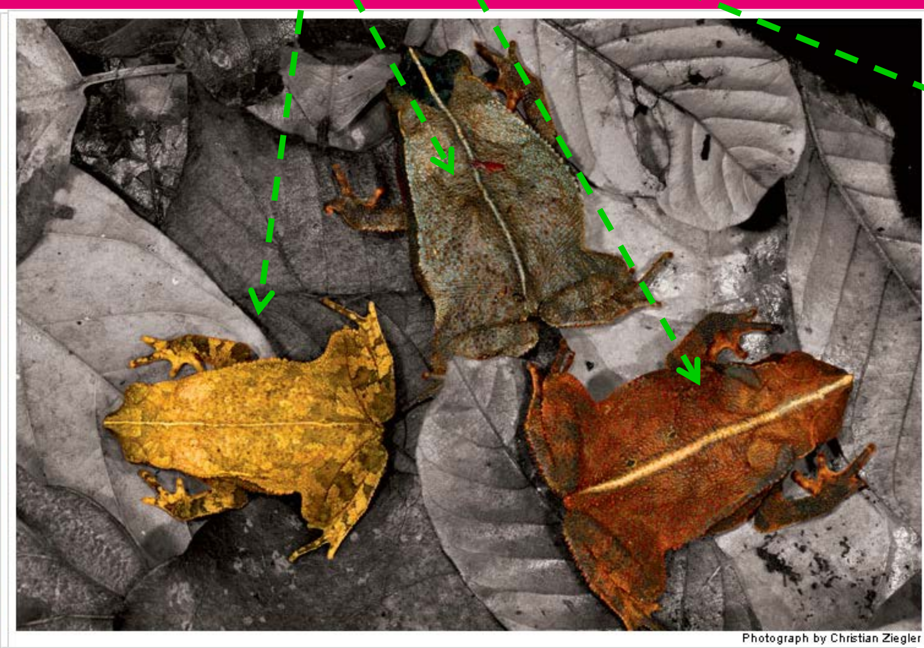
1. Introduction
2. Bi-component framework
   - Short-term variability
   - Long-term variability
3. Application case study
4. Conclusions

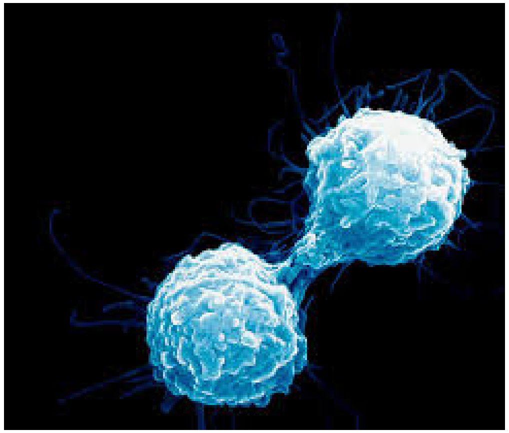
Motivation >> Towards true triggering alarms



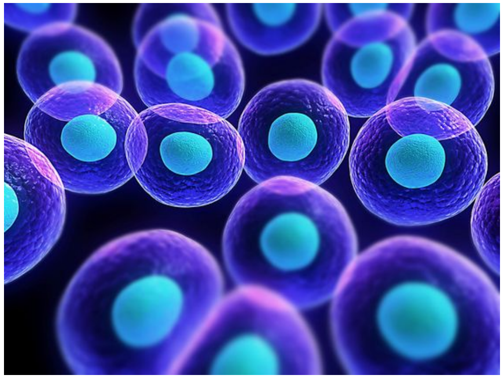
Influencing agents

Systems

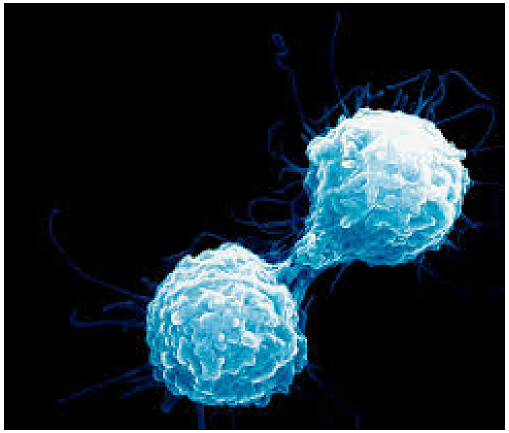




Filtering out the influence



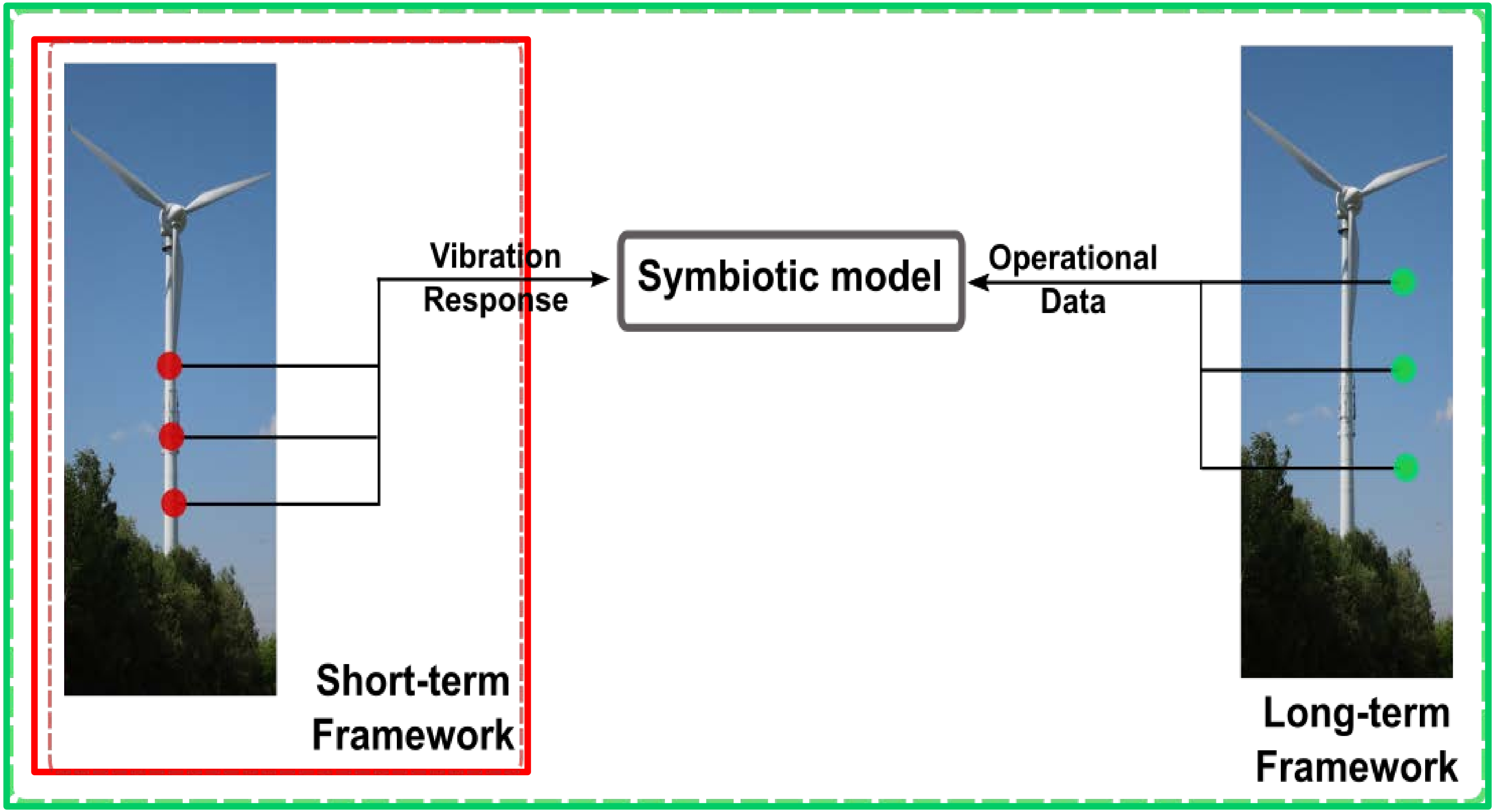
Merging the influence



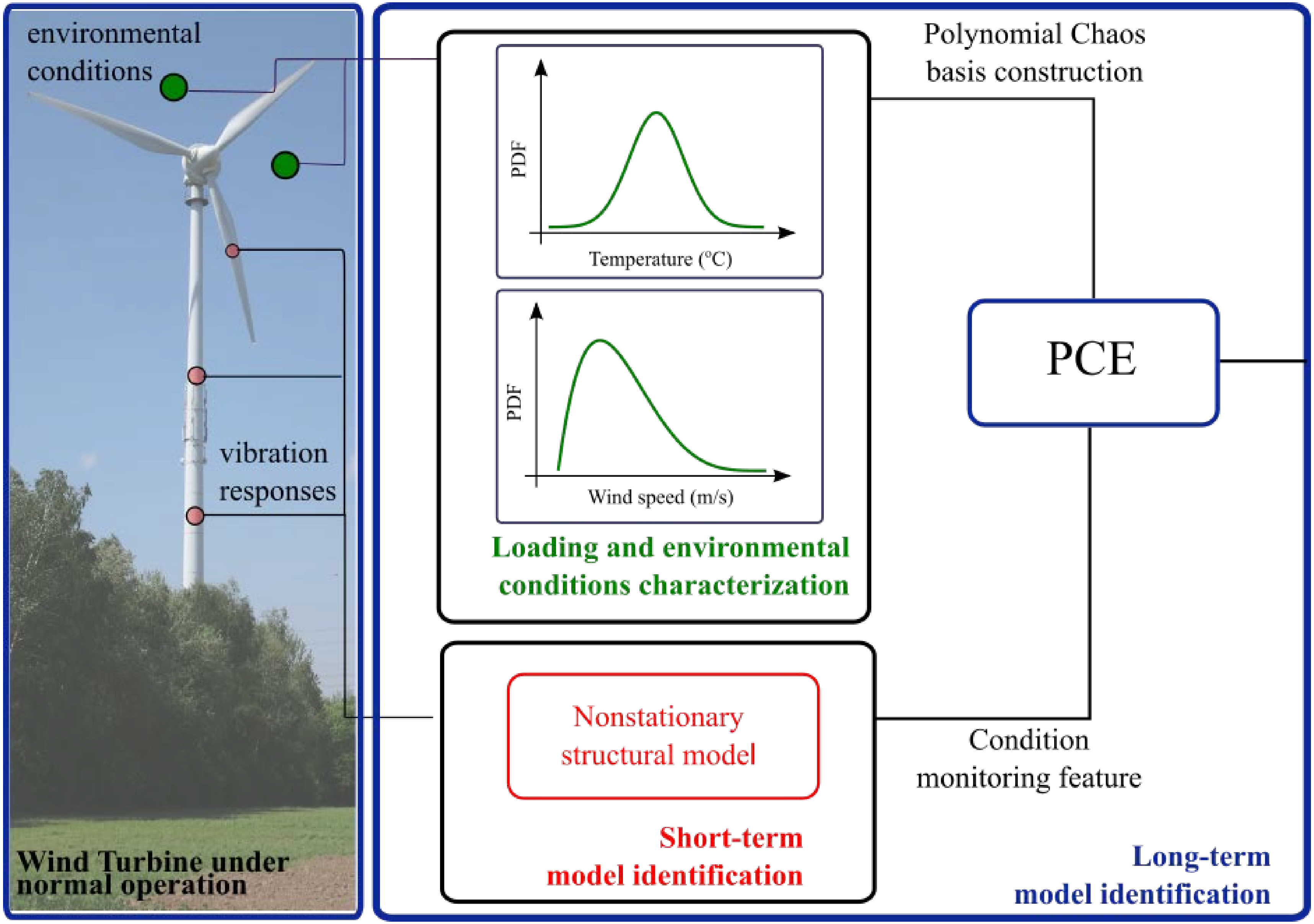
Filtering out the influence

A genetic code
with encrypted effects

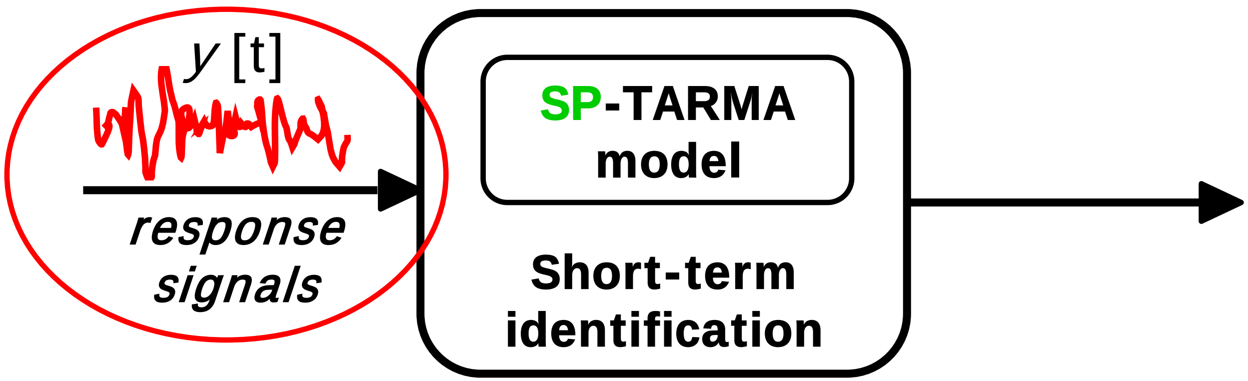
Holistic SHM strategy >> concept



2. Bi-component framework >> methodology



2.1. Short-term modeling >> model description



Smoothness Priors Time-varying ARMA model *(Kitagawa & Gersch 1996)*

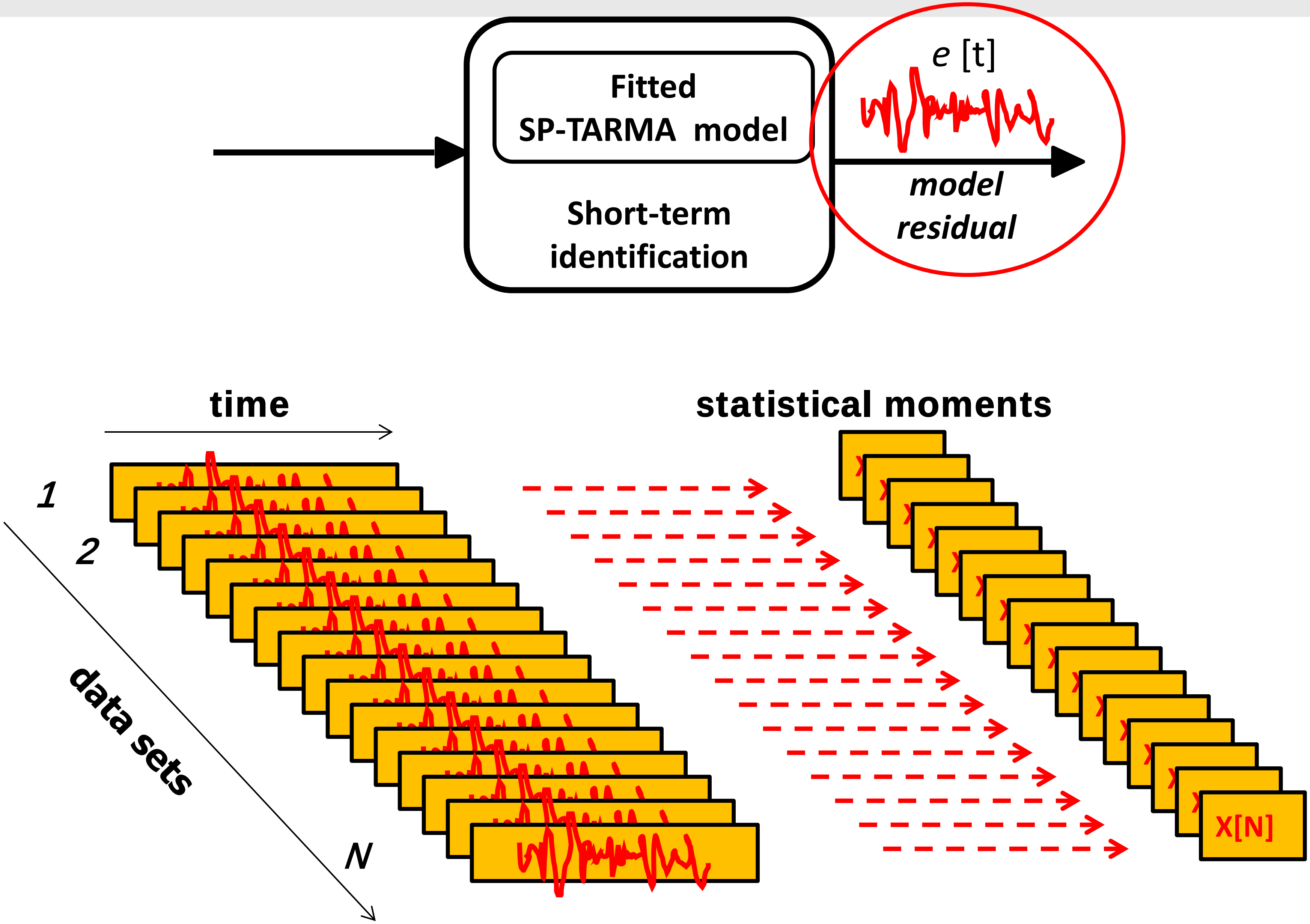
(1) $$y[t] + \sum_{i=1}^{n_a} a_i[t]\, y[t-i] = e[t] + \sum_{i=1}^{n_c} c_i[t]\, e[t-i], \qquad e[t] \sim \mathrm{NID}(0, \sigma_e[t]^2)$$

(2) $$(1-B)^{\kappa} a_i[t] = w_{a_i}[t], \qquad w_{a_i}[t] \sim \mathrm{NID}(0, \sigma_{w_a}^2[t])$$

(3) $$(1-B)^{\kappa} c_i[t] = w_{c_i}[t], \qquad w_{c_i}[t] \sim \mathrm{NID}(0, \sigma_{w_c}^2[t])$$

user-defined parameters: n κ $\nu = \sigma_w^2[t]/\sigma_e^2[t]$

2.1. Short-term modeling >> feature extraction



Polynomial Chaos Expansion (PCE) model *(Ghanem & Spanos 1991)*

Modeling of the way that uncertainty, related to a number of random input variables, propagates through a system

random system output

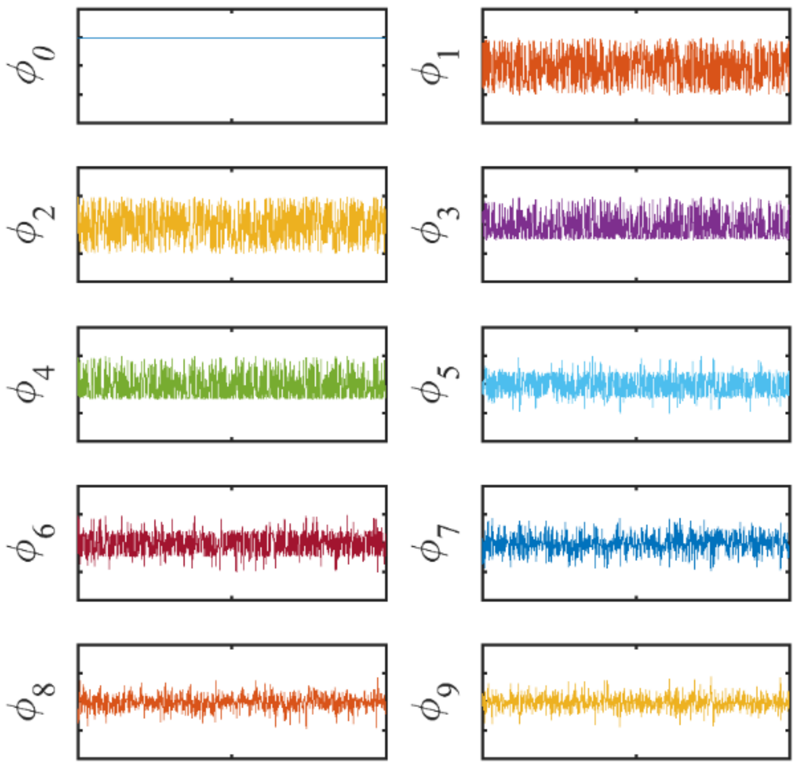
Polynomial Basis Functions orthonormal to $p_{\Xi}(\xi)$

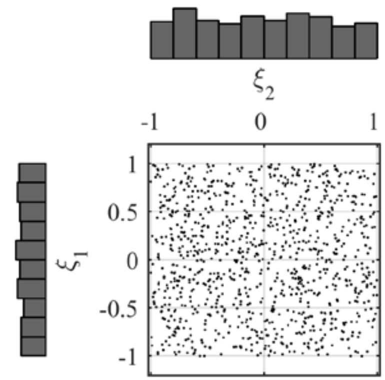
$$Y = \mathrm{S}(\boldsymbol{\Xi}) = \sum_{\boldsymbol{d} \in \mathrm{N}^M} \theta_{\boldsymbol{d}} \varphi_{\boldsymbol{d}}(\boldsymbol{\Xi})$$

independent input random variables with known joint pdf $p_{\Xi}(\xi)$

unknown deterministic coefficients

3.2. Long-term modeling >> model description





$$L_0 = 1$$
$$L_1 = x$$
$$L_2 = 0.5(3x^2 - 1)$$
$$L_3 = 0.5\,(5x^3 - 3x)$$

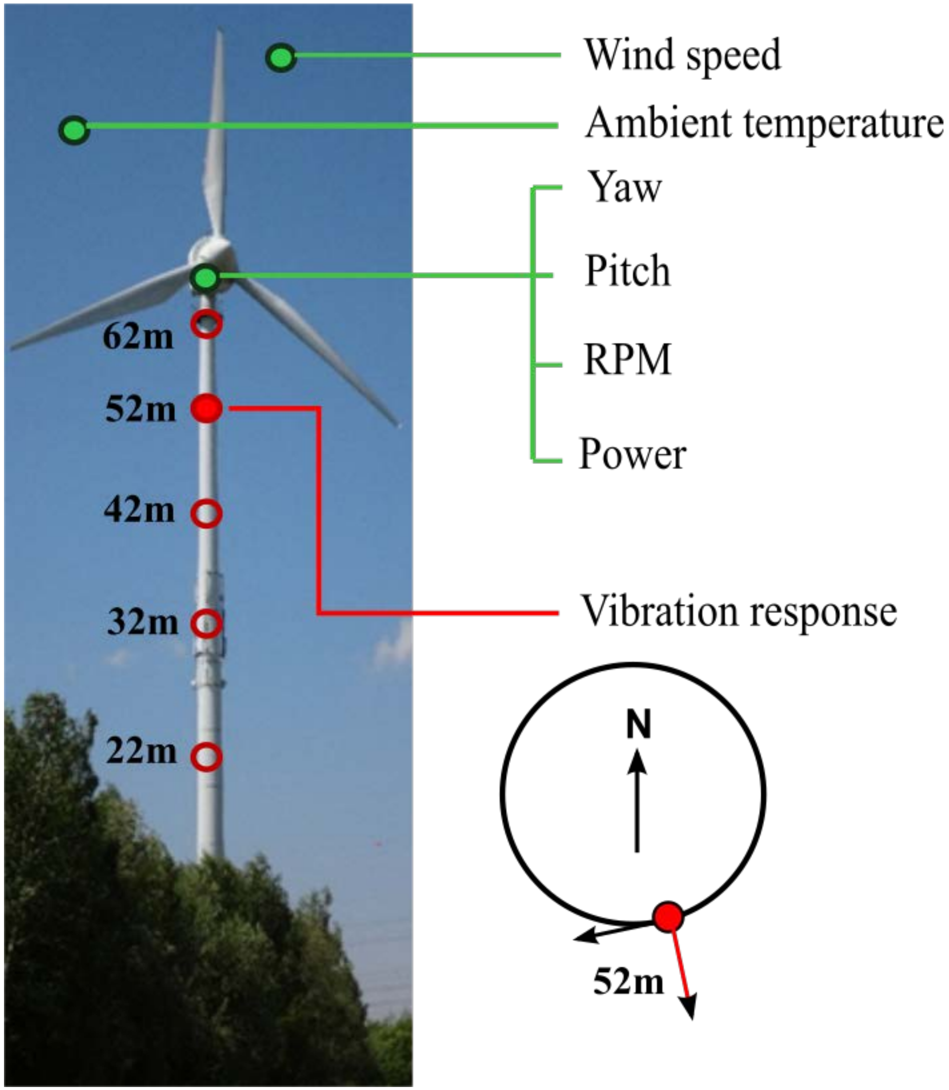
total degree P=3
total terms T=10

$$\tilde{Y} \equiv \sum_{j=0}^{9} \theta_j\, \varphi_j = \theta_0 + \theta_1 \xi_1 + \theta_2 \xi_2 + \theta_3 \frac{1}{2}(3\xi_1^2 - 1) + \theta_4 \xi_1 \xi_2 + \theta_5 \frac{1}{2}(3\xi_2^2 - 1) + \theta_6 \frac{1}{2}(5\xi_1^3 - 3\xi_1)$$
$$+\theta_7 \frac{1}{2}(3\xi_1^2 - 1)\xi_2 + \theta_8 \frac{1}{2}(3\xi_2^2 - 1)\xi_1 + \theta_9 \frac{1}{2}(5\xi_2^3 - 3\xi_2)$$

3. Application case study >> Operating Wind Turbine

Basic parameters of the wind turbine	
Location	Dortmund, Germany
Power	500 kW
Tower height	63 m
Height of the rotor center	65 m
Number of blades	3
Length of blade	19.13 m
Diameter of the rotor	40.66 m
Rotation area	1298 m^2
Rotor speed	variable, 18-36 rpm
Blade material	GRP
Tower material	steel
Construction year	1997

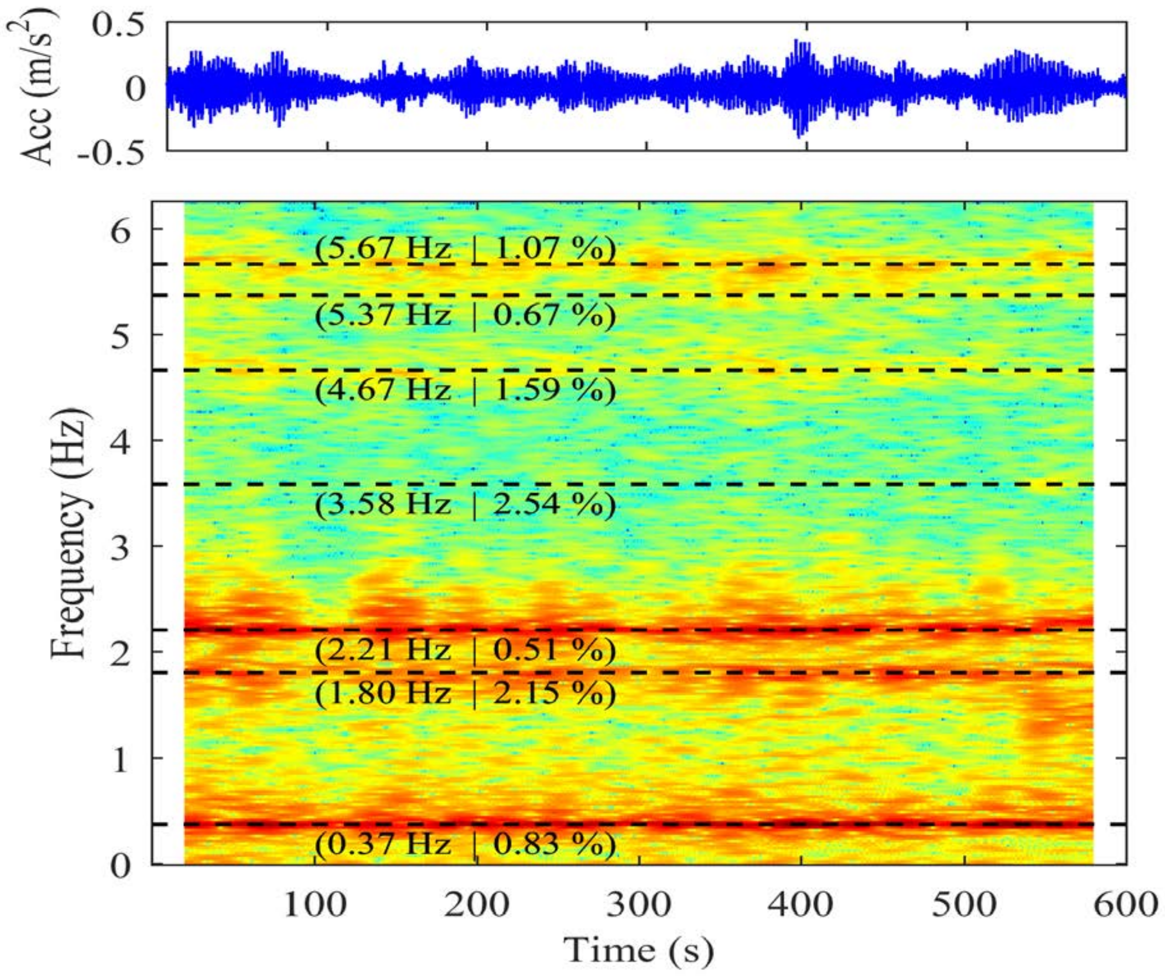
In collaboration with Ruhr University in Bochum, Germany



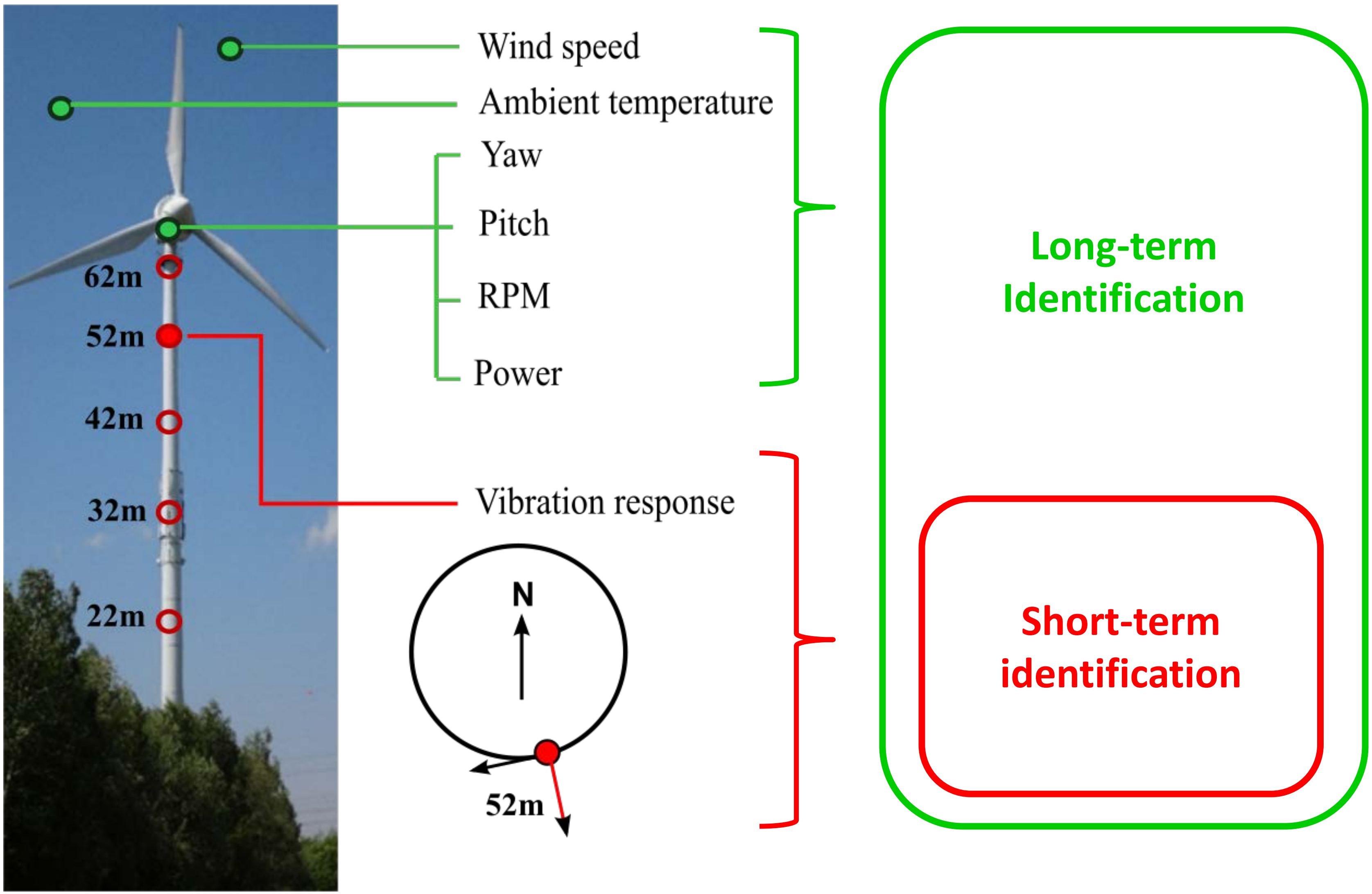
Monitored data characteristics	
Monitoring period	2010/01/08 - 17:00 2013/09/10 - 21:00
Recording frequency	Continuous
Data set length	1 hour
Total datasets	30 560
Sampling frequency	100 Hz

Vibration data preprocessing	
Downsampled	12.5 Hz
Lowpass cutoff freq.	6 Hz

Model structure selection	
ARMA	(na = nc = 18)

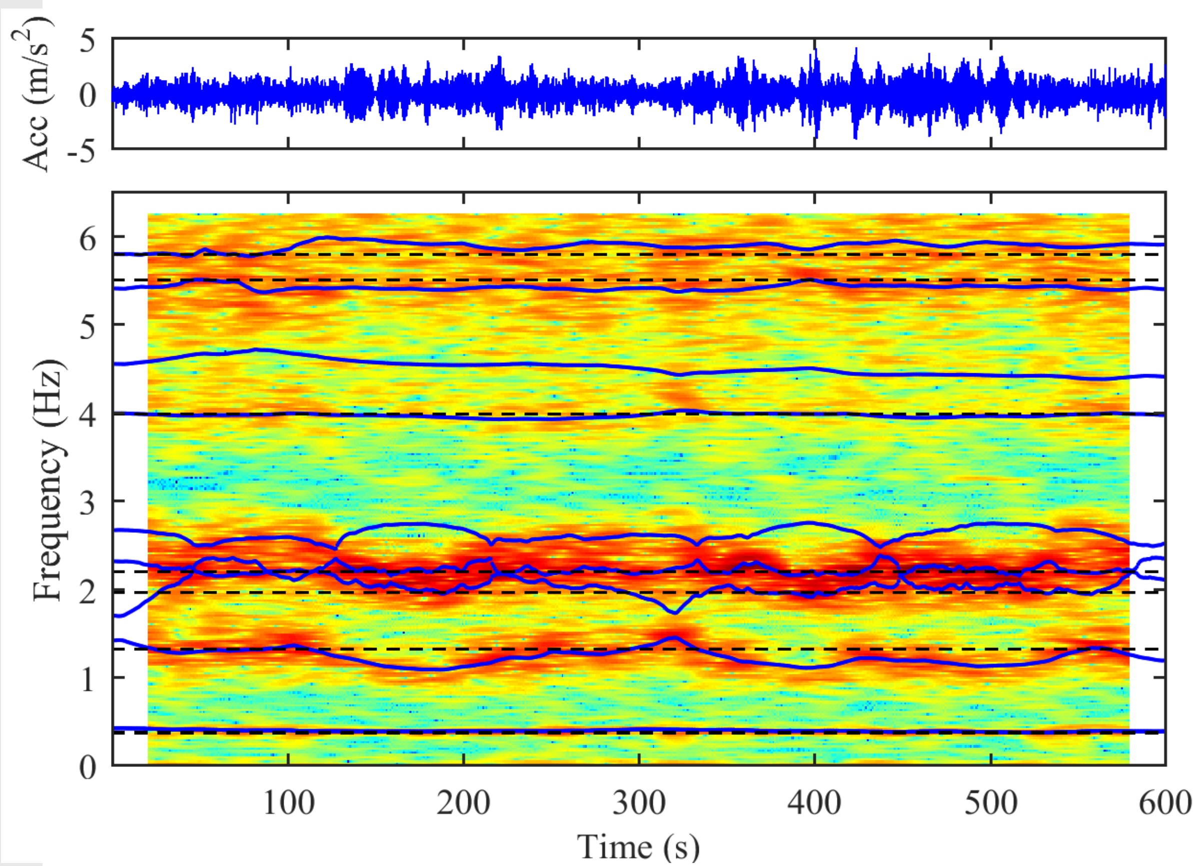


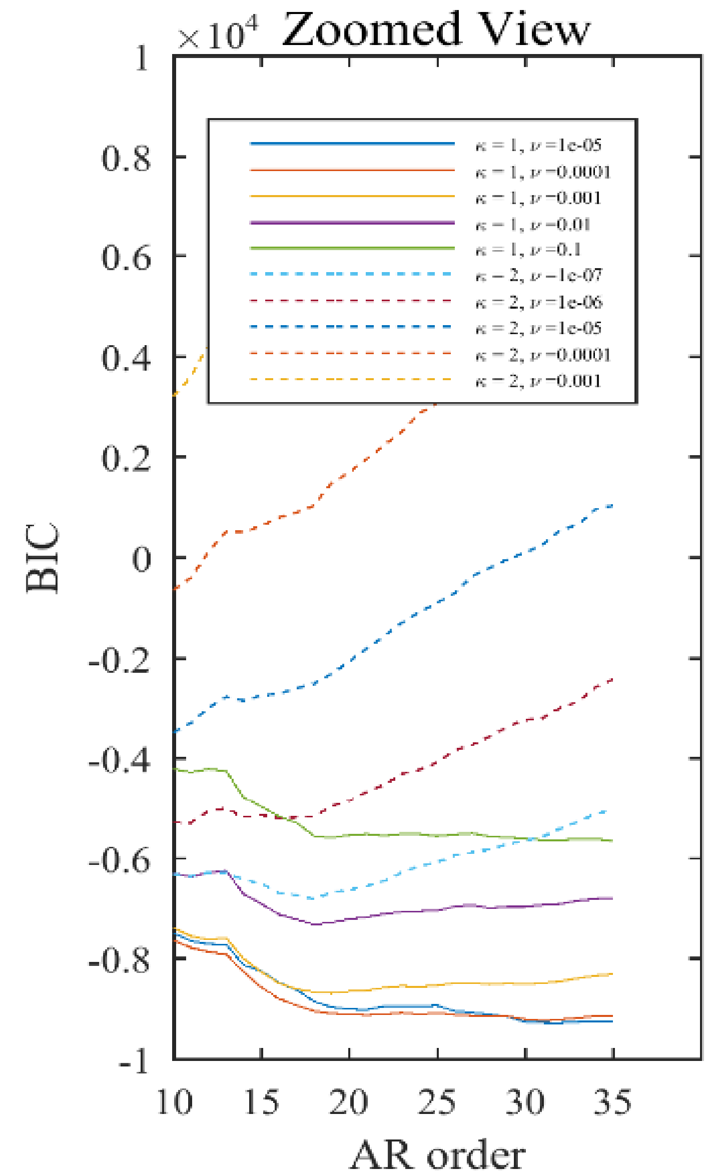
3. Application case study >> Framework setting



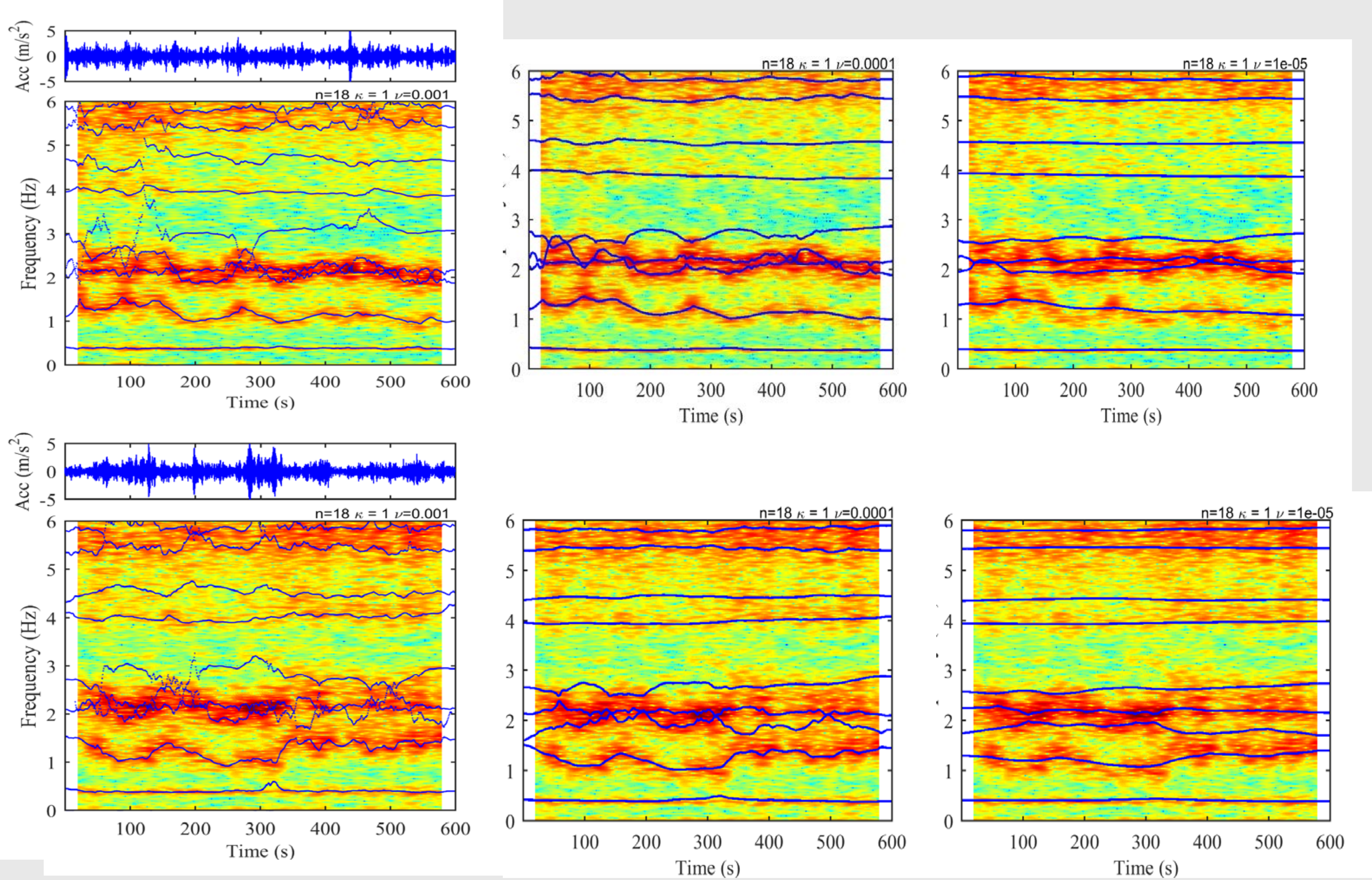
3. Application case study >> Short-term modeling

Model structure selection	
ARMA	BIC, stabilization (na = nc = 18)
SP-TARMA	BIC (na = nc = 18, v = 0.0001)

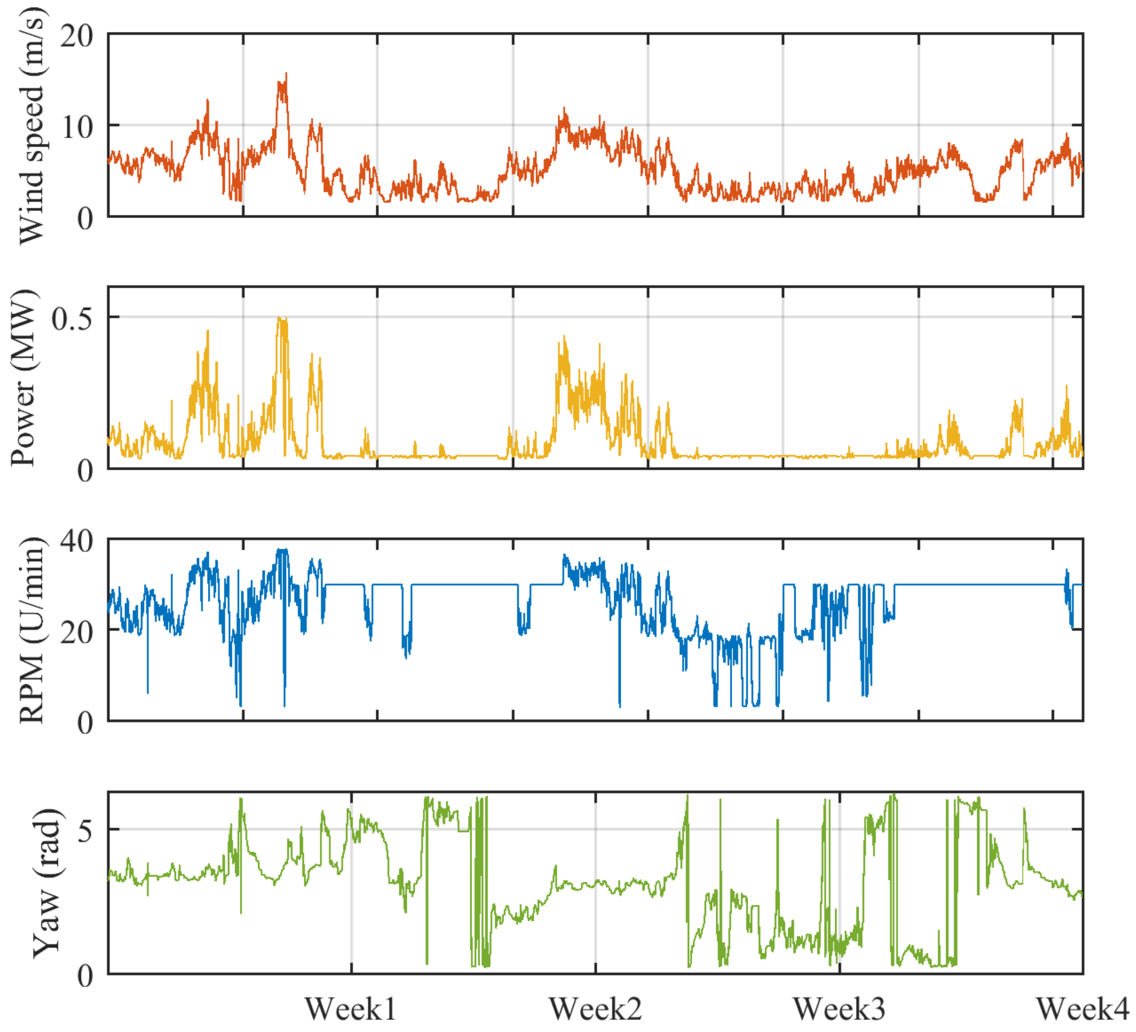




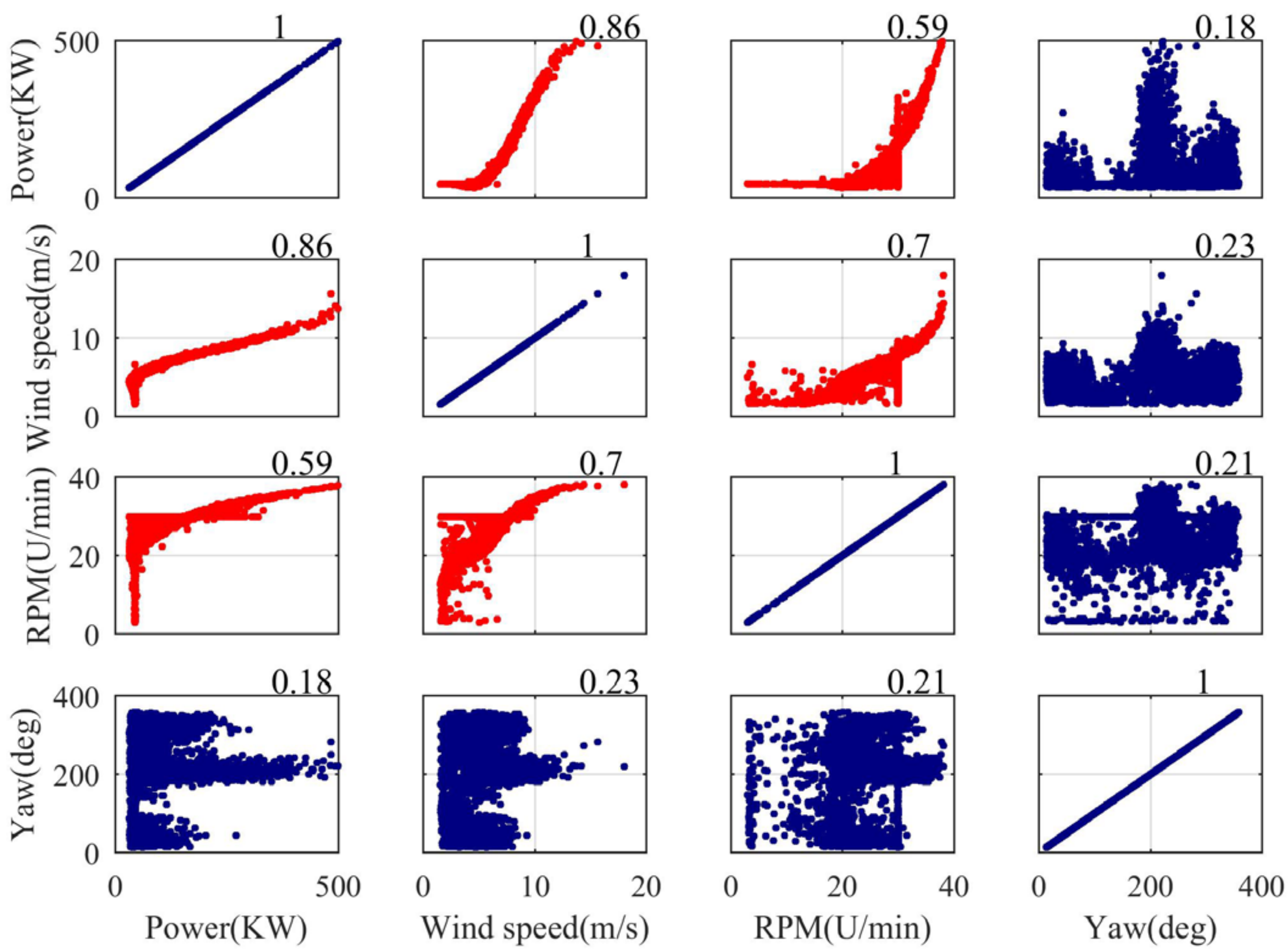
3. Application case study >> SP-TARMA Tuning

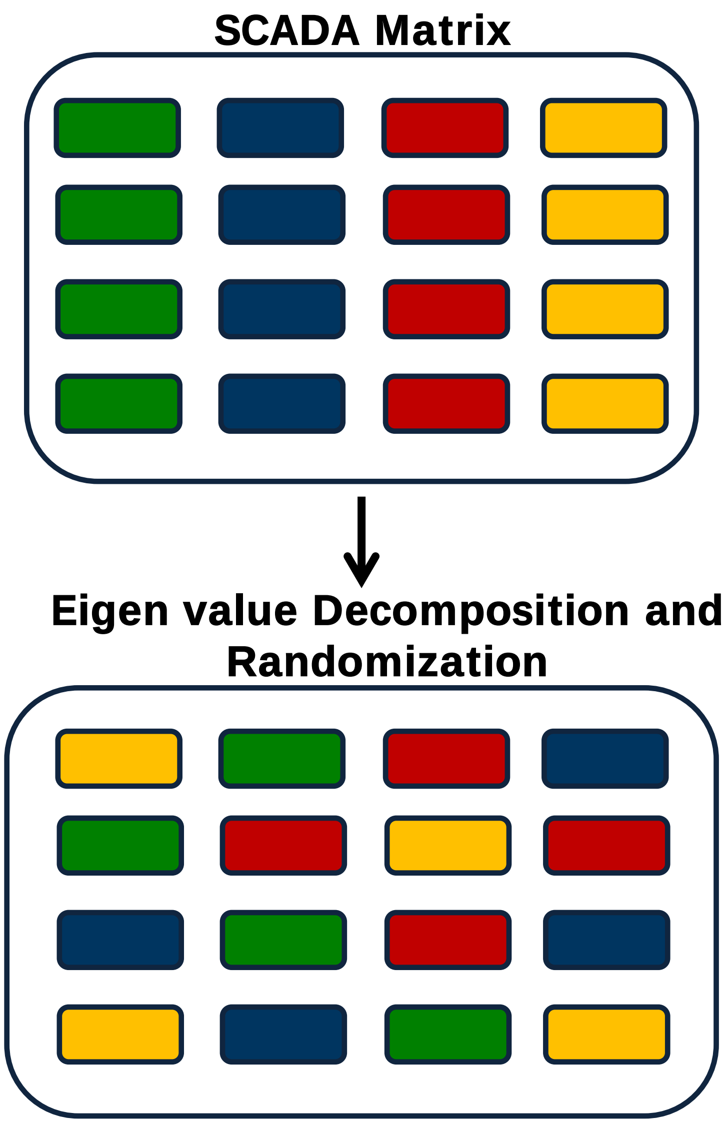


Selected input parameters:



PCE prerequisite not fulfilled:

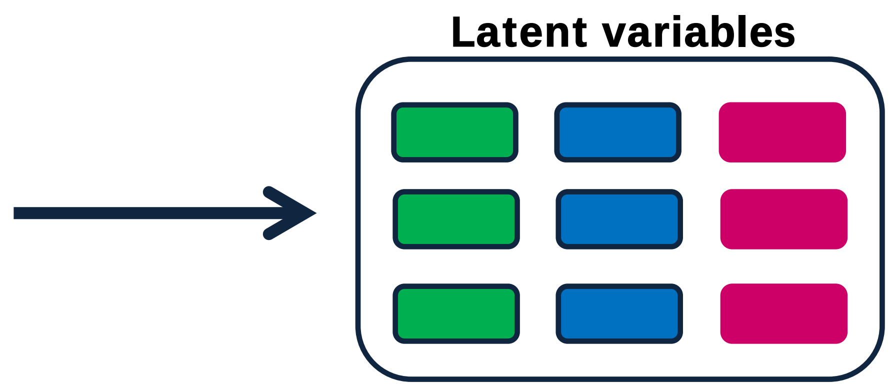




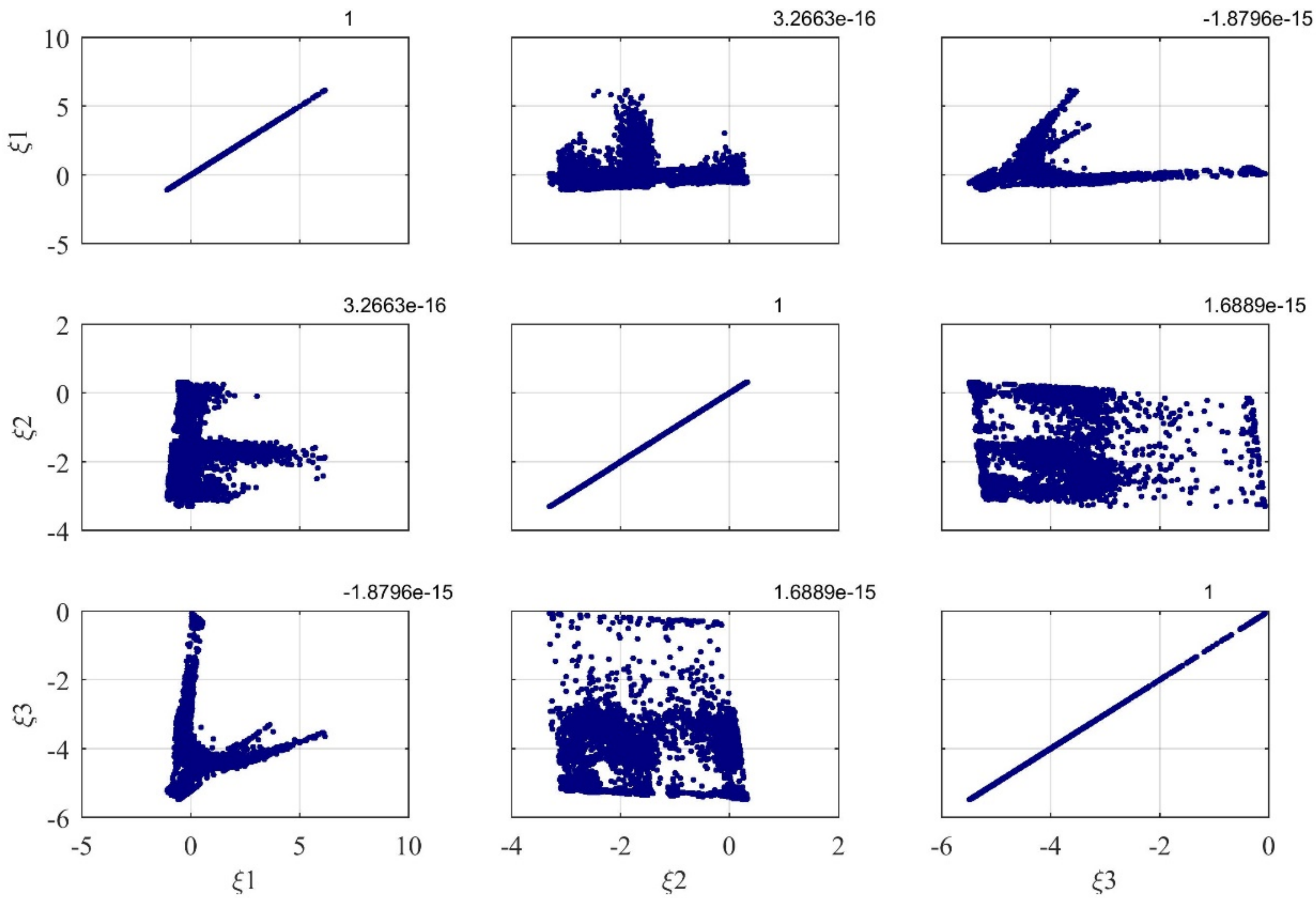
Independent Component Analysis

$$s = Wx$$

the maximization of the non-Gaussianity of each one of the latent variables ***s***



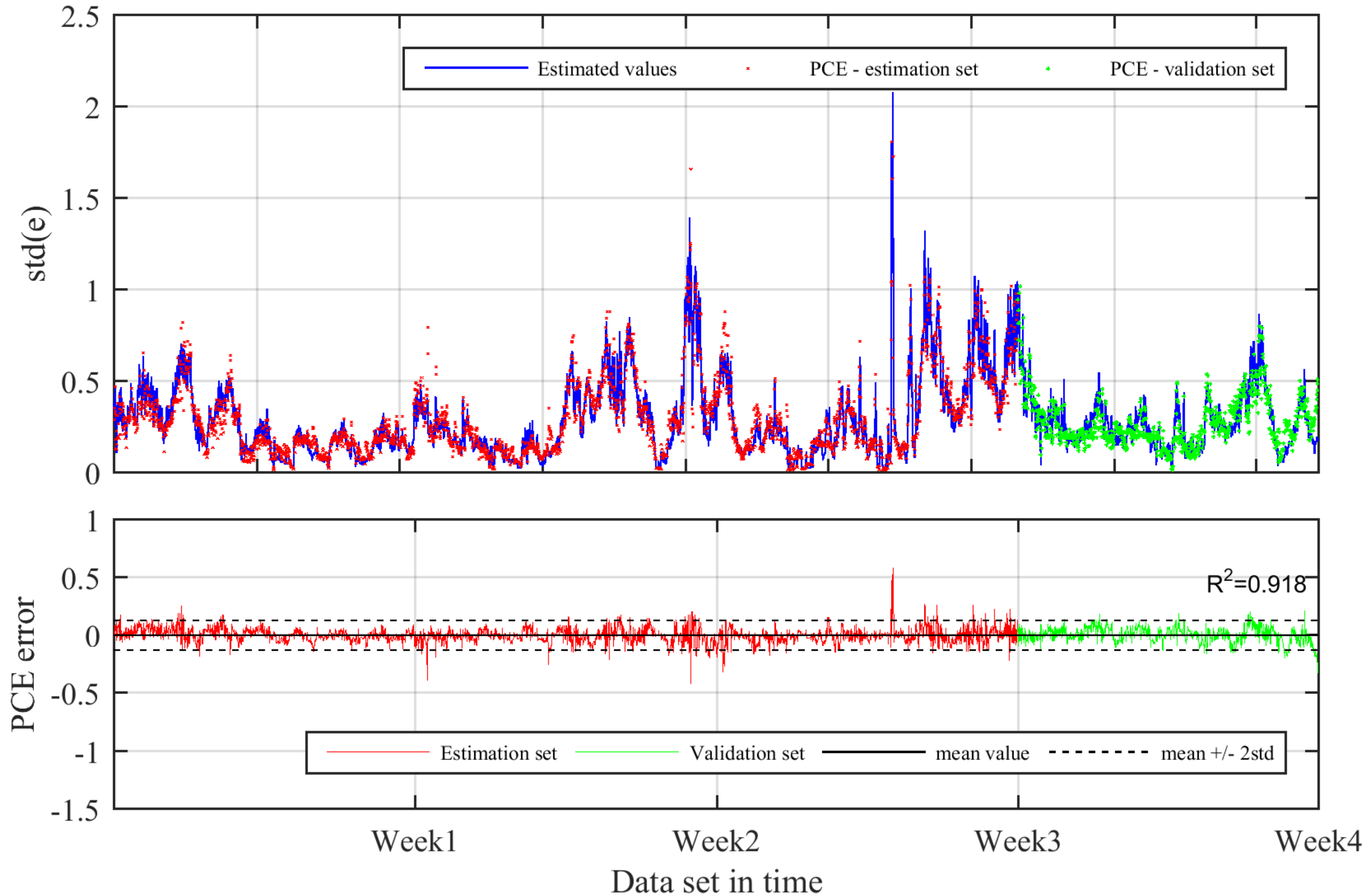
ICA-based **input variables**



Random input variables	
1	Wind direction [deg]
2	Power [kW]
3	RPM [U/min]
4	Yaw [rad]

Output variables	
1	Standard deviation of the SP-TARMA model residuals

Polynomial Chaos basis
Legendre polynomials (maximum total order = 5)



4. Conclusions

1. The proposed framework merges environmental and operational variables into the modeling of vibration response

2. The proposed framework addresses the non-stationarity present in collected response data and the temporal variability of the identified model parameters

3. Successful implementation on an operating WT structure in Dortmund (Germany) verifies the robustness of the approach.

4. The proposed strategy serves as the first step towards automated condition assessment.

5. The outcomes demonstrate the potential for a holistic SHM damage detection framework, further extended via statistical hypothesis testing (to be explored next).

Published work :

1. Bogoevska S., Spiridonakos M., Chatzi E., Dumova-Jovanoska E., Höffer R.; A novel bi-component structural health monitoring strategy for deriving global models of operational wind turbines; European Workshop on Structural Health Monitoring, July 2016 , Bilbao

2. Bogoevska S., Spiridonakos M., Chatzi E., Dumova-Jovanoska E., Höffer R.; A data-driven framework for comprehensive identification of operational wind turbines under uncertainty; International Conference of Uncertainty in Structural Dynamics, September 2016, Leuven

Thank you