STOCHASTIC DYNAMICS OF POWER SYSTEMS OVERVIEW FOR R. TEMPONE AND E. HALL

19.2.2019 I DIRK WITTHAUT

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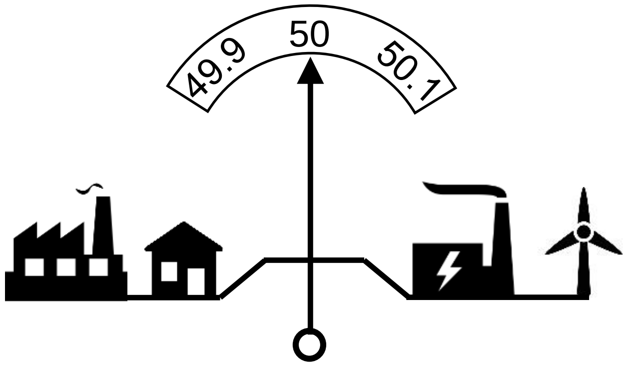
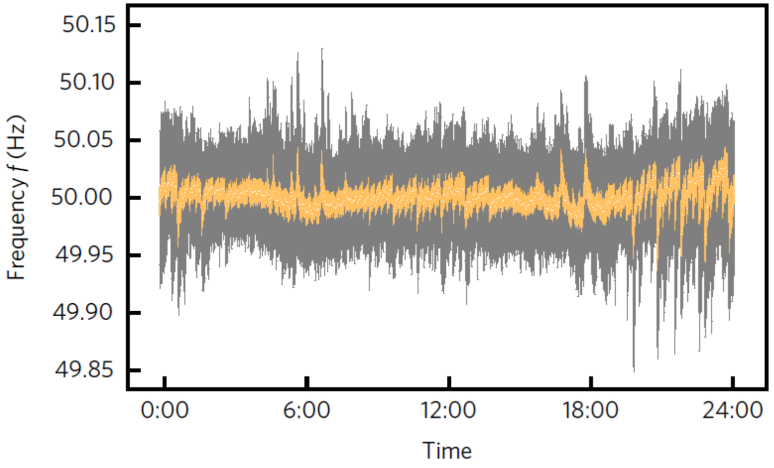
FREQUENCY DYNAMICS IN POWER SYSTEMS

Why study power system frequency data?

- The mains frequency is the central observable in power system control: It measures the *power balance* in the grid.
- The frequency is readily measured at any plug (in contrast to power), so data is easy to obtain.
- What can we learn about power system dynamics and stability?





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FREQUENCY DYNAMICS IN POWER SYSTEMS

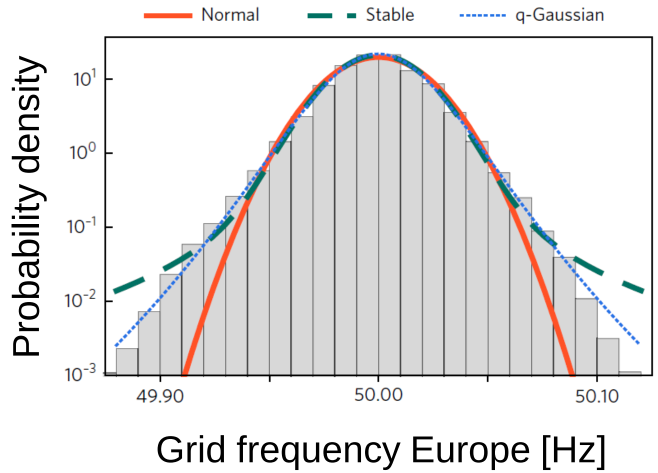
Aggregate statistics for frequency time series

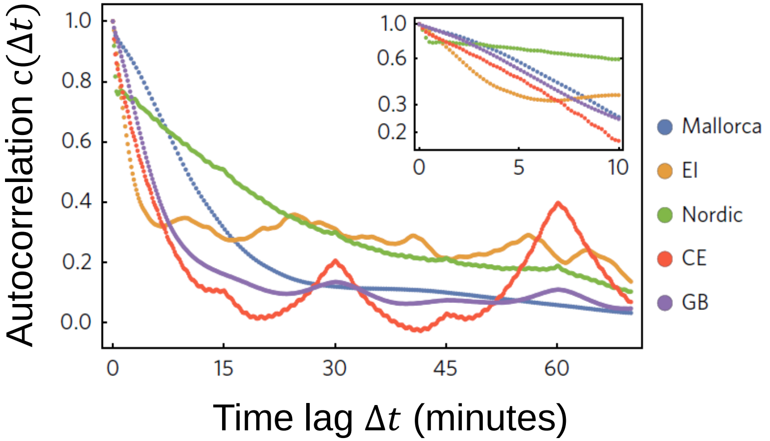
A first look at the frequency time series as a whole:

- A histogram of the mains frequency f reveals *heavy tails* not compatible with Gaussian statistics

- Data is best described by described Levy-stable or q-Gaussians distributions

- Auto-correlation of time series $f(t)$ reveals:
  - effective damping γ
  - high impact of electricity trading in intervals of 15,30,45,60,… minutes





Schäfer, Beck, Aihara, DW, Timme, Nature Energy 3, 119 (2018)

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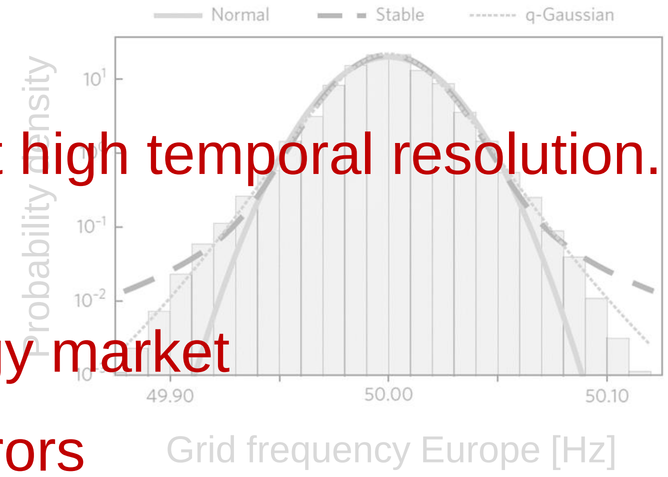
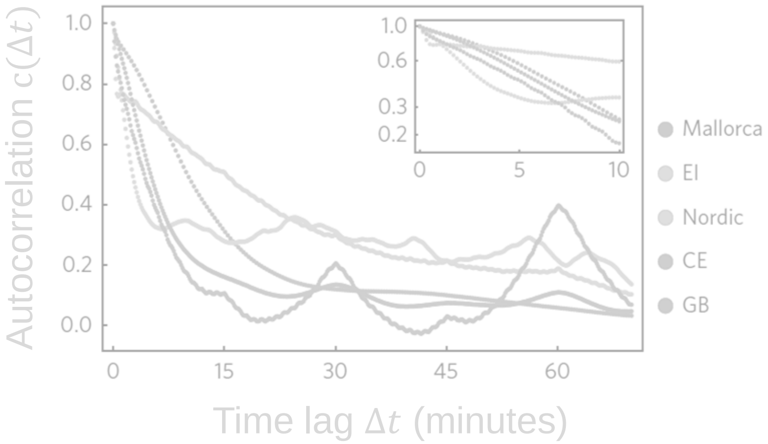
We should have a more detailed view on the data at high temporal resolution.

Then we might learn a lot about:

- The scheduling of power generation on the energy market
- The impact of renewables including prognosis errors
- The problem of decreasing grd inertia
- Potential sytemic risk for the grids





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KRAMERS-MOYAL COEFFICIENTS

Constructing an stochastic model

- Let us assume that the frequency dynamics can be modeled by an SDE:

$$df = a(f,t)\,dt + b(f,t)\,dW$$

- Kramers-Moyal coefficients:

$$a(f,t) = \lim_{\Delta t \to 0} E\big([f(t+\Delta t) - f(t)] \;\big| f\big)$$

$$b(f,t) = \frac{1}{2} \lim_{\Delta t \to 0} E\big([f(t+\Delta t) - f(t)]^2 \big| f\big)$$

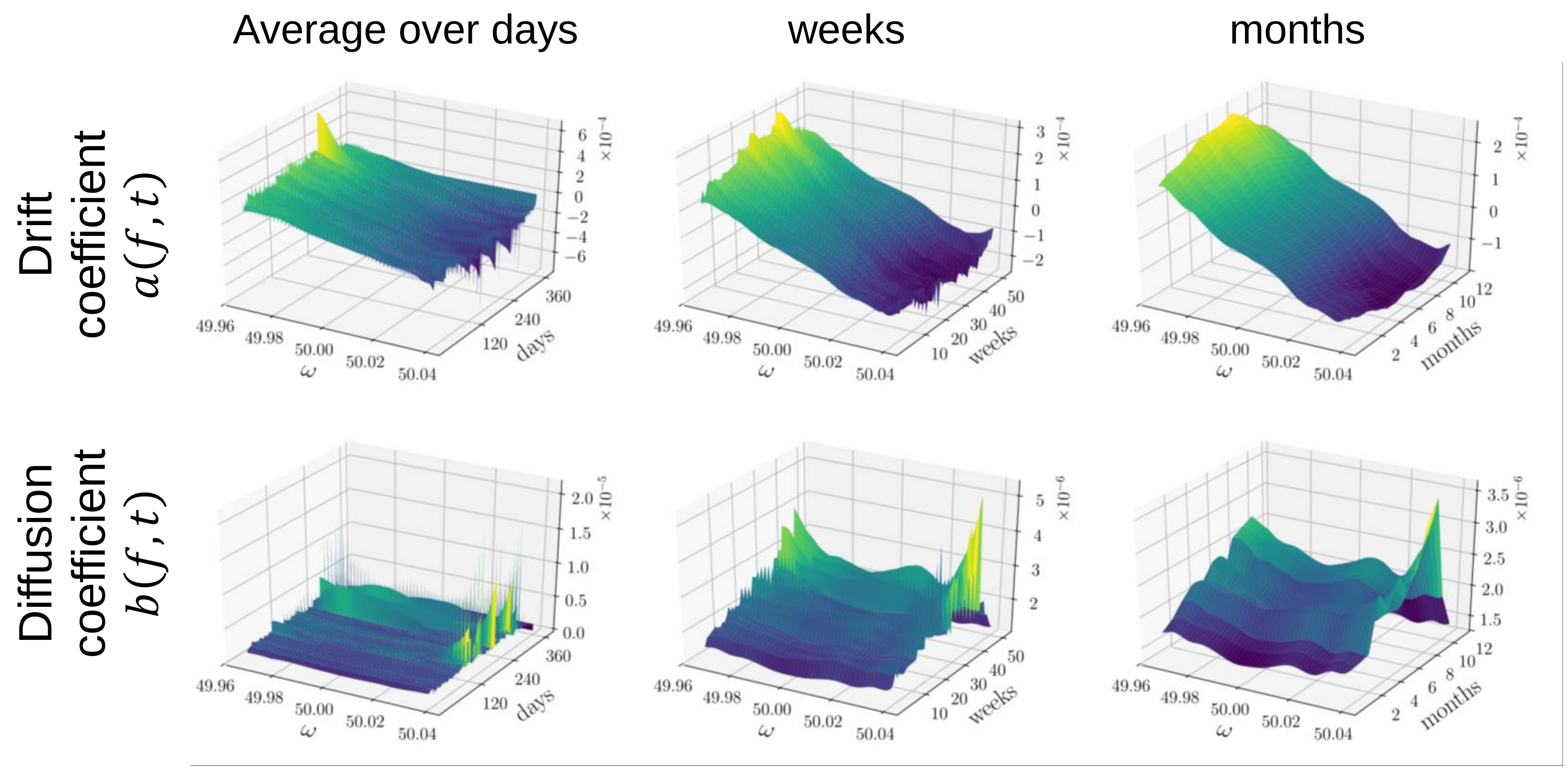
- In practice we cannot take the like and we do not know the expected value.

➢ Use a finite Δt, replace expected value E by time average…

KRAMERS-MOYAL COEFFICIENTS

Results for the Central European Power Grid

Results for the Central European Grid 2016: $df = a(f,t)\,dt + b(f,t)\,dW$



This is dominated by primary control:
$a(f,t) \approx -\frac{\gamma_2}{M} f$

Higher in summer and for large f. Why?

MAXIMUM LIKELIHOOD APPROACH

Constructing an stochastic model

- The mains frequency just follows the power imbalance in the grid:

  $M\, df = \Delta P\, dt,$ $\qquad$ M: inertia, f: frequency relative to 50 Hz

- We can decompose the power balance ΔP into four contributions:

  1. Mismatch of the power generation ΔP_{gen}
  2. Rapid, irregular changes of the generation and load → treated as noise $D\, dW$
  3. Action of primary control: $\Delta P_1 = -\gamma_1 f \times H(f - 10\, mHz)$
  4. Action of secondary control: ΔP_2

  ➢ $M\, df = (\Delta P_{gen} + \Delta P_2)\, dt - \gamma_1 f \times H(f - 10\, mHz) dt + D\, dW$

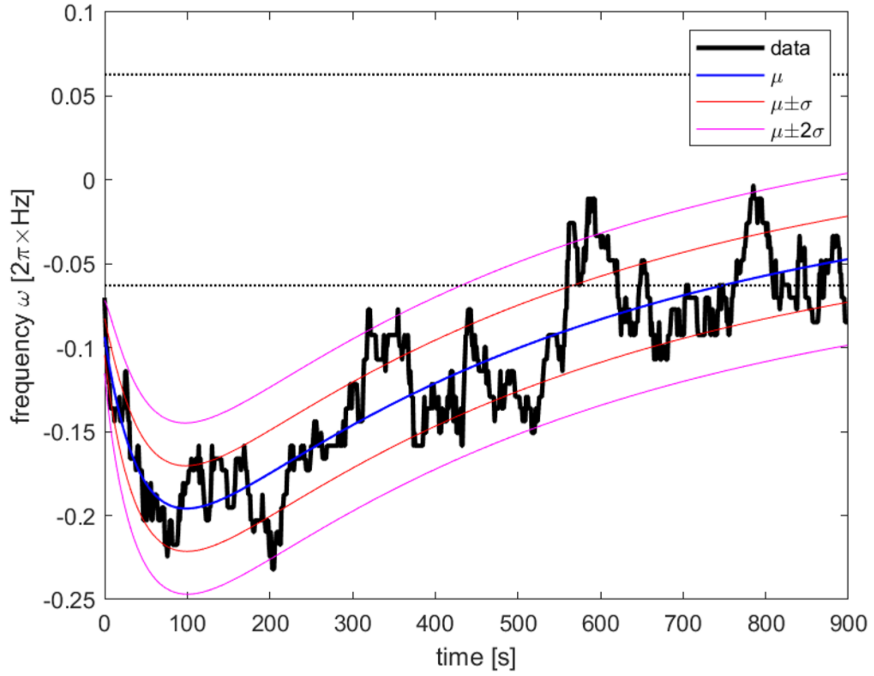
➢ Can we recover parameters such as $\Delta P_{gen}, D, M$ from data?

MAXIMUM LIKELIHOOD APPROACH

Results for a simplified model

- A first attempt with some simplifications:
  - Primary control always on: $\Delta P_1 = -\gamma_1 f$
  - Assume that secondary control brings mismatch to zero at fixed rate: $\Delta P_{gen} + \Delta P_2 = \Delta P_0 e^{-\gamma_2 t}$
  - Assume a Gaussian distribution at all times

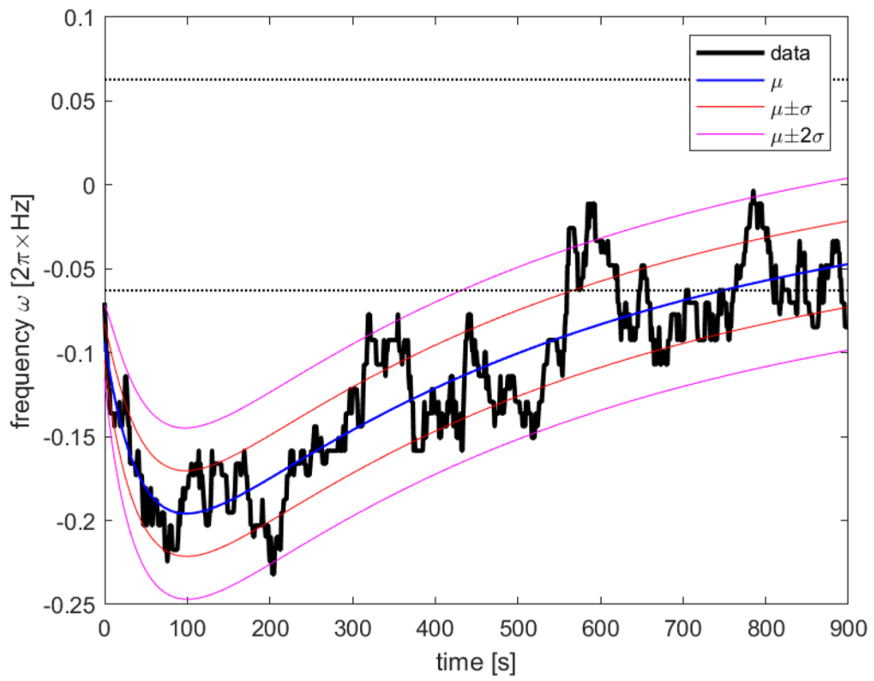
- Fit parameters of model and initial state such that log-likelihood function asummes a maximum
- Results look quite good for the example shown on the right



MAXIMUM LIKELIHOOD APPROACH

Challenges of the maximum likelihood approach

- Challenge 1: overfitting
- There quite a number of parameters in the model and there will be even more if I include a more adequate model for secondary control.
- For instance, it is hard to disentangle the contributions of the two damping factors γ_1,γ_2



MAXIMUM LIKELIHOOD APPROACH

Challenges of the maximum likelihood approach

- Challenge 2: dead bands
- Let‘s proceed with the same model to the next 15 minute interval
- Result: The results look far worse and the reconstructed parameters are very strange.
- That shows that we cannot assume that primary control is always on. We have to include it explictly. But then we have to deal with a nasty discontinuous function…