Mesoscale wind power generation + two-dimensional multifractal fractional Brownian motion + impact of synthetic climate change on future electricty networks

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Mesoscale Wind Turbulence

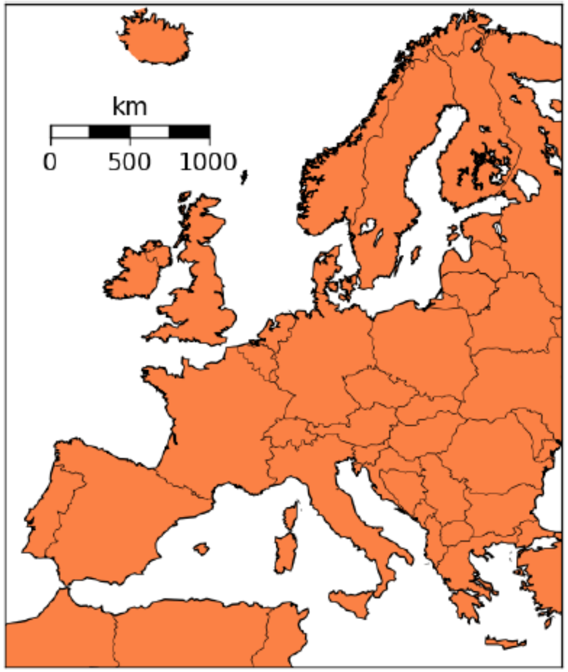
$$\mathrm{E}(k) \sim k^{-5/3}$$

$$\Delta v_l \sim l^{1/3}$$

$$\eta = 5km \ \leq l \ \leq L = 600km$$

$$\mu \approx 0.36$$

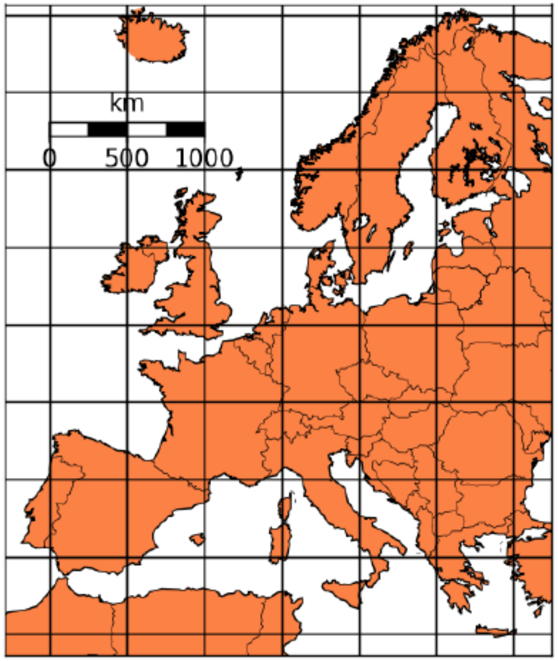
$$\left\langle \Delta v_\eta^2(x+d)\, \Delta v_\eta^2(x) \right\rangle \sim d^{-\mu}$$



R Baïle + J Muzy: *Spatial Intermittency of surface layer wind fluctuations at mesoscale range*, **Phys.Rev.Lett. 105 (2010) 254501**. **P Milan, M Wächter + J Peinke:** *Turbulent character of wind energy*, **Phys.Rev.Lett. 110 (2013) 138701**. **R Calif, F Schmitt + Y Huang:** *Multifractal description of wind power fluctuations using arbitrary order Hilbert spectral analysis*, **Physica A 392 (2013) 4106-20**. **J Apt:** *The spectrum of power from wind turbines,* **J. Power Sources 169 (2007) 369-74.**

2dim multifractal fBm

$$\mathrm{v}(\mathbf{x}) = \mathrm{v}_{typ} + \frac{\sqrt{m(\mathbf{x})}}{\langle\sqrt{m}\rangle}\mathrm{v}_{fBm}(\mathbf{x})$$



$L\ ,\ \sigma_0\ ,\ \mathrm{H}\ ,\ \mu$

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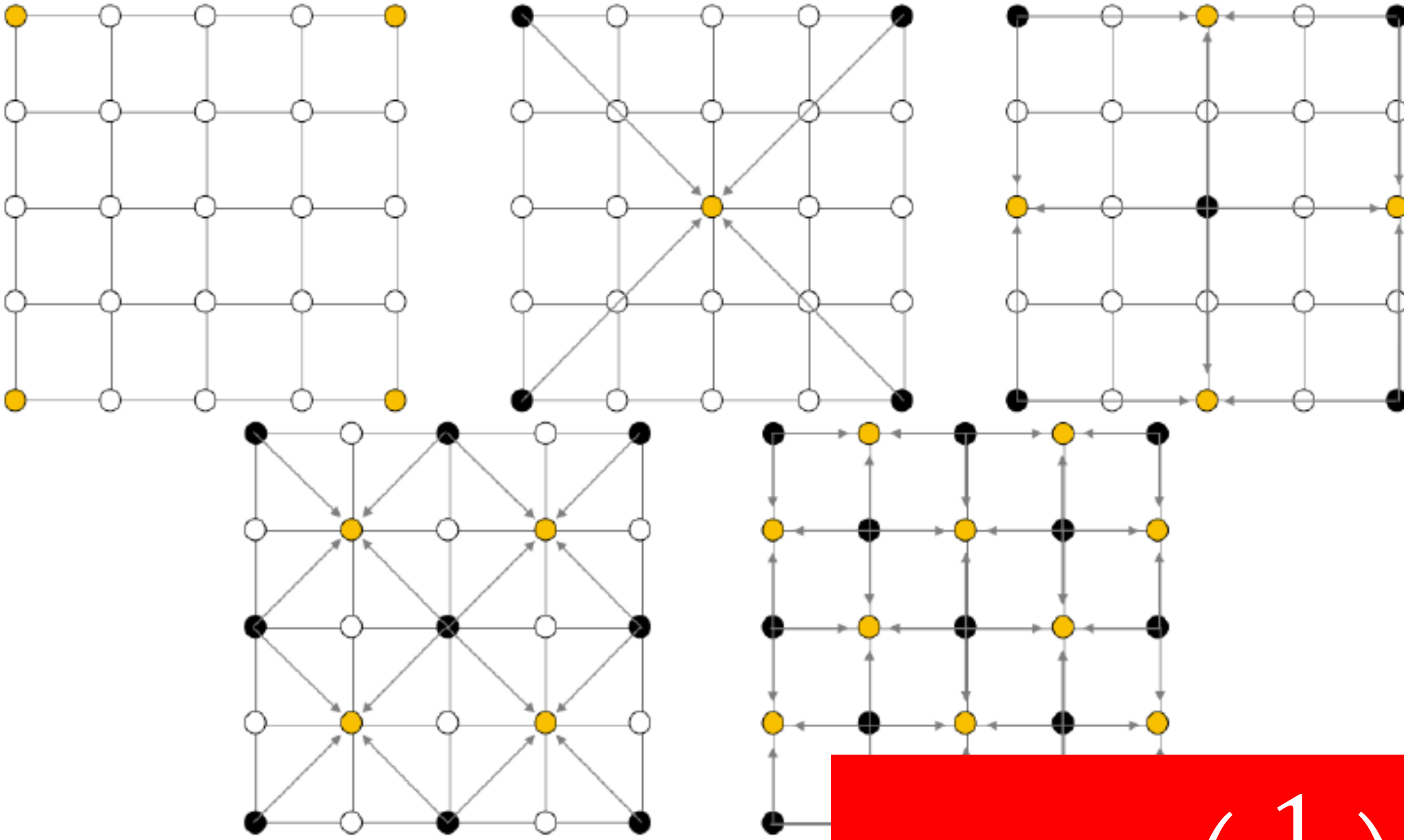
2dim fBm: midpoint displacement method

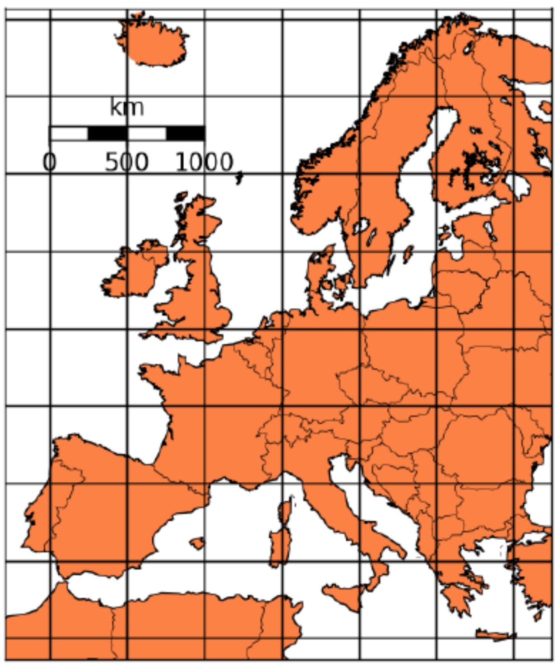
L , σ_0 , H



$$\sigma_{i+1} = \left(\frac{1}{\sqrt{2}}\right)^{H} \sigma_i$$

2dim multifractal fBm

$$\mathrm{v}(\mathbf{x}) = \mathrm{v}_{typ} + \frac{\sqrt{m(\mathbf{x})}}{\langle\sqrt{m}\rangle}\mathrm{v}_{fBm}(\mathbf{x})$$



L , σ_0 , H , μ

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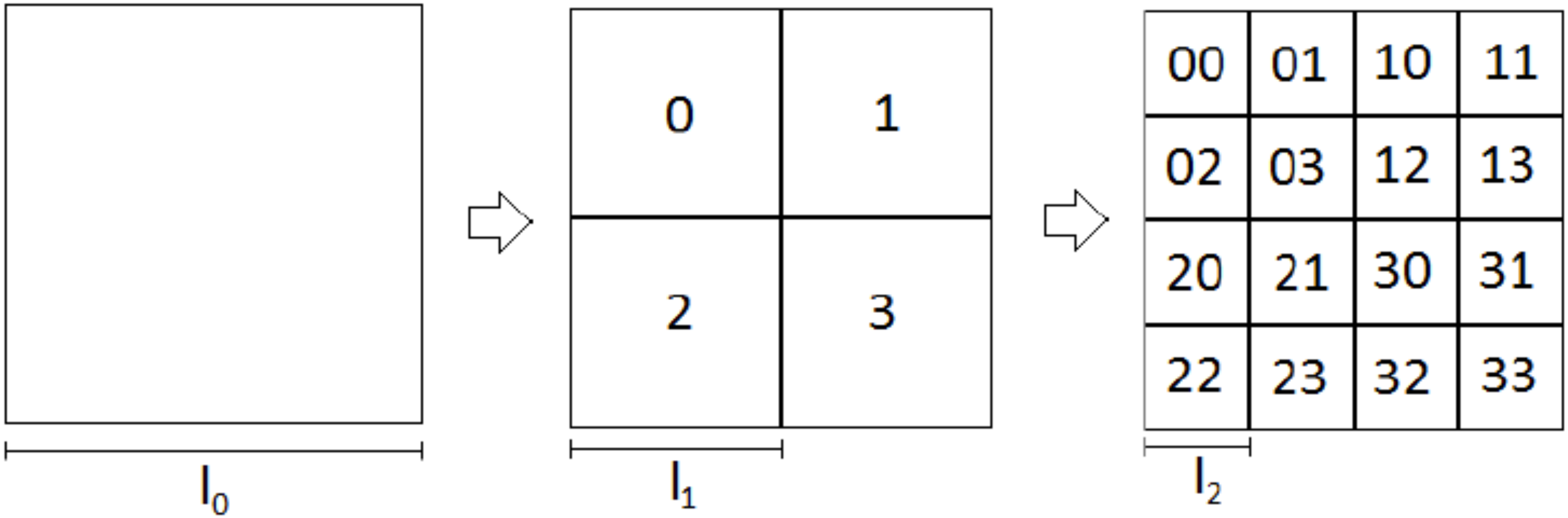
2dim multifractality: random multiplicative cascade

L , μ



$$m_{i+1}(\mathbf{x}) = q_{i+1}(\mathbf{x})\, m_i(\mathbf{x})$$

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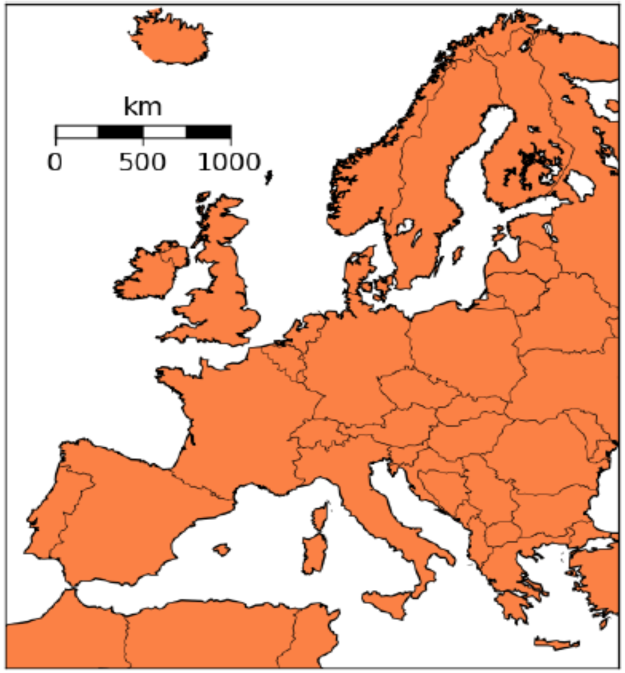
Mesoscale wind power generation

$$\mathrm{v}(\mathbf{x}) = \mathrm{v}_{typ} + \frac{\sqrt{m(\mathbf{x})}}{\langle\sqrt{m}\rangle}\mathrm{v}_{fBm}(\mathbf{x})$$



$$\mathrm{v}(\mathbf{x}) \rightarrow G_n^W(t)$$

$$\langle G_n^W \rangle = \langle L_n \rangle$$

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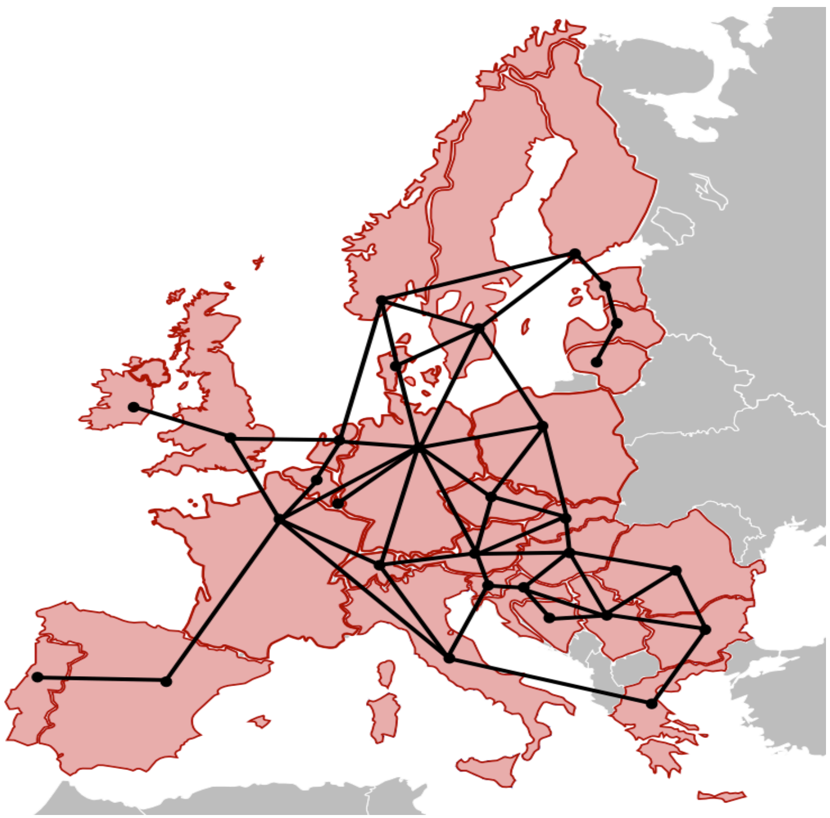
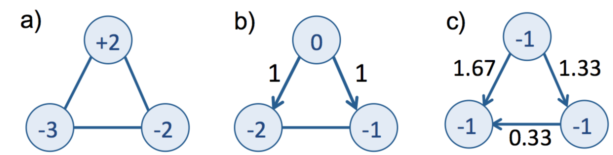
Simplified future electricty network:

$$G_n^W(t) - L_n(t) = B_n(t) + P_n(t)$$





$$G_n^B(t) = \left(B_n(t)\right)_-$$

$$C_n(t) = \left(B_n(t)\right)_+$$

$$\sum_n P_n(t) = 0$$

$$\langle G_n^W \rangle = \langle L_n \rangle$$

$$F_l(t) = \sum_n PTDF_{ln} P_n(t)$$

Infrastructure measures

backup energy $E_n^B = \langle G_n^B \rangle$

backup capacity $K_n^B = max_q(G_n^B)$

transmission capacity $K_l^T = max_q|F_l| \cdot d_l$

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Impact of synthetic climate change

L [km]	300	600	1200
E^B [$\langle L \rangle$]	0.0701 ± 0.0018	0.073 ± 0.003	0.086 ± 0.004
$\mathcal{K}^B$ [$\langle L \rangle$]	0.362 ± 0.007	0.396 ± 0.013	0.471 ± 0.010
$\mathcal{K}^T$ [GW]	160.0 ± 1.1	233.2 ± 1.1	334 ± 2
$\mathrm{Var}(\mathbf{B})$ [$\langle L \rangle^2/100$]	0.240 ± 0.005	0.275 ± 0.004	0.387 ± 0.007
$\mathrm{Var}(\mathbf{P})$ [$\langle L \rangle^2/100$]	0.197 ± 0.0019	0.401 ± 0.002	0.719 ± 0.011
$\mathrm{Cov}(\mathbf{B}, \mathbf{P})$ [$\langle L \rangle^2/100$]	0.0115 ± 0.0007	0.0185 ± 0.0007	0.0372 ± 0.0014
LCOE [€/MWh]	7.85 ± 0.19	9.1 ± 0.2	11.3 ± 0.7

σ_0 [v_{typ}]	0.1	0.2	0.3
E^B [$\langle L \rangle$]	0.069 ± 0.002	0.073 ± 0.003	0.079 ± 0.002
$\mathcal{K}^B$ [$\langle L \rangle$]	0.357 ± 0.006	0.396 ± 0.013	0.414 ± 0.015
$\mathcal{K}^T$ [GW]	151.8 ± 0.9	233.2 ± 1.1	278.1 ± 1.5
$\mathrm{Var}(\mathbf{B})$ [$\langle L \rangle^2/100$]	0.238 ± 0.008	0.275 ± 0.004	0.302 ± 0.004
$\mathrm{Var}(\mathbf{P})$ [$\langle L \rangle^2/100$]	0.1727 ± 0.0018	0.401 ± 0.002	0.591 ± 0.007
$\mathrm{Cov}(\mathbf{B}, \mathbf{P})$ [$\langle L \rangle^2/100$]	0.0123 ± 0.0008	0.0185 ± 0.0007	0.0236 ± 0.0010
LCOE [€/MWh]	7.93 ± 0.3	9.1 ± 0.2	9.8 ± 0.3

Impact of synthetic climate change

μ	0.18	0.36	0.54
E^B $[\langle L \rangle]$	0.0745 ± 0.003	0.073 ± 0.003	0.075 ± 0.003
$\mathcal{K}^B$ $[\langle L \rangle]$	0.405 ± 0.006	0.396 ± 0.013	0.396 ± 0.004
$\mathcal{K}^T$ [GW]	238.5 ± 0.8	233.2 ± 1.1	224.6 ± 1.6
$\mathrm{Var}(\mathbf{B})$ $[\langle L \rangle^2 /100]$	0.280 ± 0.005	0.275 ± 0.004	0.272 ± 0.007
$\mathrm{Var}(\mathbf{P})$ $[\langle L \rangle^2 /100]$	0.422 ± 0.005	0.401 ± 0.002	0.382 ± 0.003
$\mathrm{Cov}(\mathbf{B}, \mathbf{P})$ $[\langle L \rangle^2 /100]$	0.0193 ± 0.0011	0.0185 ± 0.0007	0.0177 ± 0.0017
LCOE [€/MWh]	9.2 ± 0.4	9.1 ± 0.2	9.0 ± 0.3

H	1/3	1/2	2/3
E^B $[\langle L \rangle]$	0.075 ± 0.003	0.073 ± 0.003	0.0736 ± 0.0014
$\mathcal{K}^B$ $[\langle L \rangle]$	0.402 ± 0.010	0.394 ± 0.007	0.389 ± 0.013
$\mathcal{K}^T$ [GW]	243 ± 2	233 ± 2	224.4 ± 1.9
$\mathrm{Var}(\mathbf{B})$ $[\langle L \rangle^2 /100]$	0.283 ± 0.006	0.276 ± 0.007	0.273 ± 0.006
$\mathrm{Var}(\mathbf{P})$ $[\langle L \rangle^2 /100]$	0.432 ± 0.007	0.400 ± 0.008	0.368 ± 0.005
$\mathrm{Cov}(\mathbf{B}, \mathbf{P})$ $[\langle L \rangle^2 /100]$	0.0194 ± 0.0010	0.0177 ± 0.0009	0.0185 ± 0.0016
LCOE [€/MWh]	9.3 ± 0.2	9.0 ± 0.3	8.85 ± 0.11

Ongoing PhD thesis:

Smail Kozarcanin

Impact of real climate change on the design of future large-scale energy systems

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FunRes

Fundamental Research on Renewable Energy Systems

at the interface between engineering + physics + mathematics

Gorm Andresen + Martin Greiner

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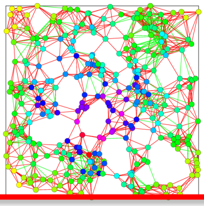
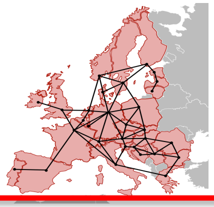
(1) Highly Renewable Energy Networks

(2) Complex Networks





M Schäfer	(Carlsberg PostDoc)
M Dahl	(Master15 + PhD18)
B Tranberg	(Master15 + PhD19)
H Liu	(Master16 + PhD19)
S Kozarcanin	(Master15 + PhD19)
K Zhu	(PhD20)
S Siggaard	(Master17)
M Kofoed	(Master16)
L Schwenk_Nebbe	(Master16)
M Janum	(Master16)
M Raunbak	(Master16)
C Poulsen	(Master16)
N Skou-Nielsen	(Master15)
M Hansen	(Master15)
K Holm	(Master15)
E Eriksen	(Master15)
A Thomsen	(Master14)
B Sairanen	(Master14)
T Jensen	(Master13)
T Zeyer	(Master13)
A Søndergaard	(Master13)
R Rodriguez	(PhD14)
M Rasmussen	(PostDoc11)

D Schlachtberger	(FIAS PhD17)
J Hörsch	(FIAS PhD17)
T Brown	(FIAS PostDoc)
S Schramm	(FIAS)
S Hempel	(FIAS Master16)
S Becker	(FIAS PhD14)
D Heide	(FIAS PhD11)

(3) Wind-farm Modeling + Optimization

(4) Turbulence

B Carlsen	(Master16)
A Huche	(Master16)
E Thorgersen	(Master16)
M Therkildsen	(Master15)
P Nybroe	(Master15)
J Otten	(Master15)
J Bjerre	(Master15)
J Herp	(Master13)
U Poulsen	(Assist Prof)

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