Virtual energy storage-gain due to spatiotemporal coordination of hydropower over Europe

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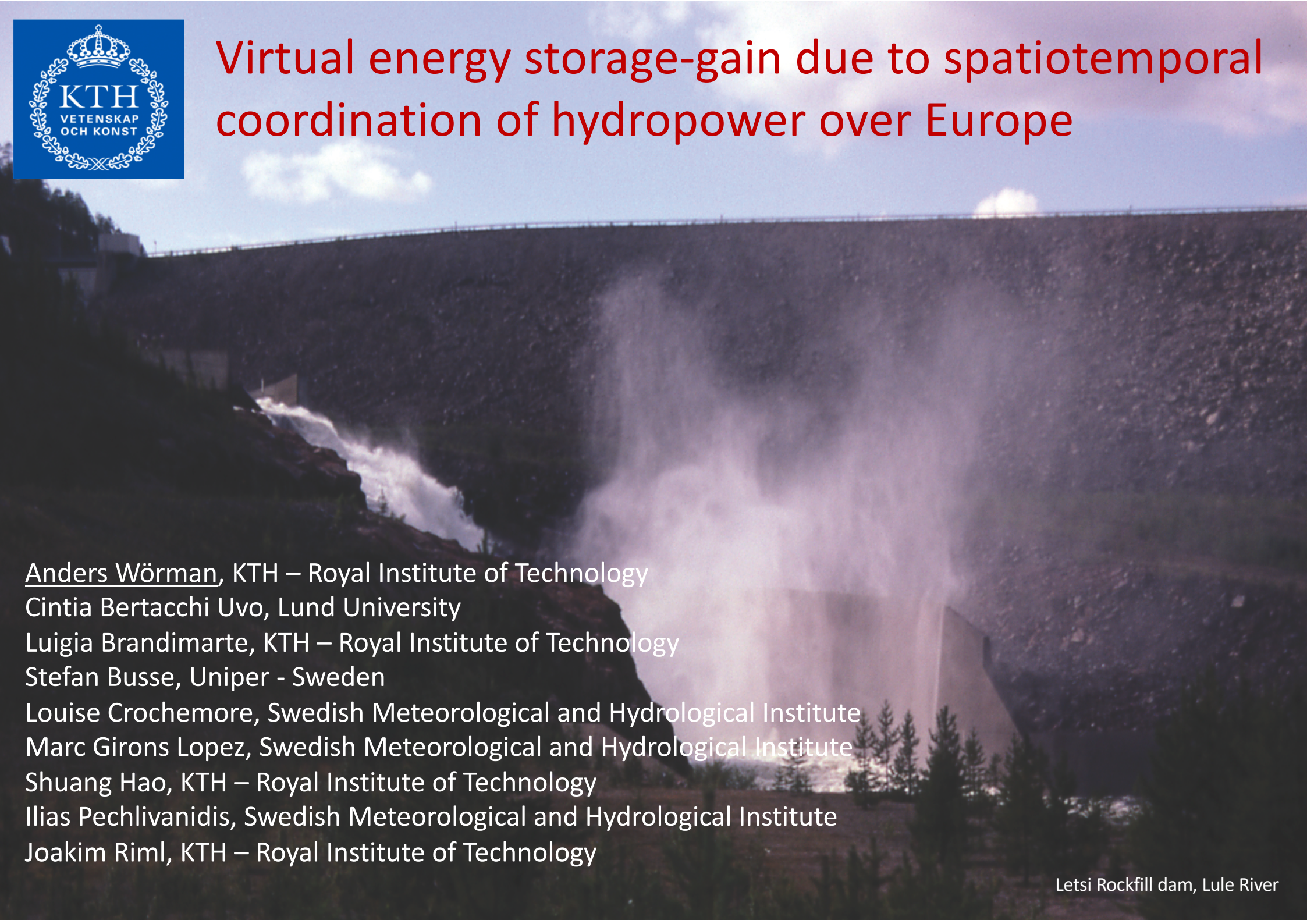
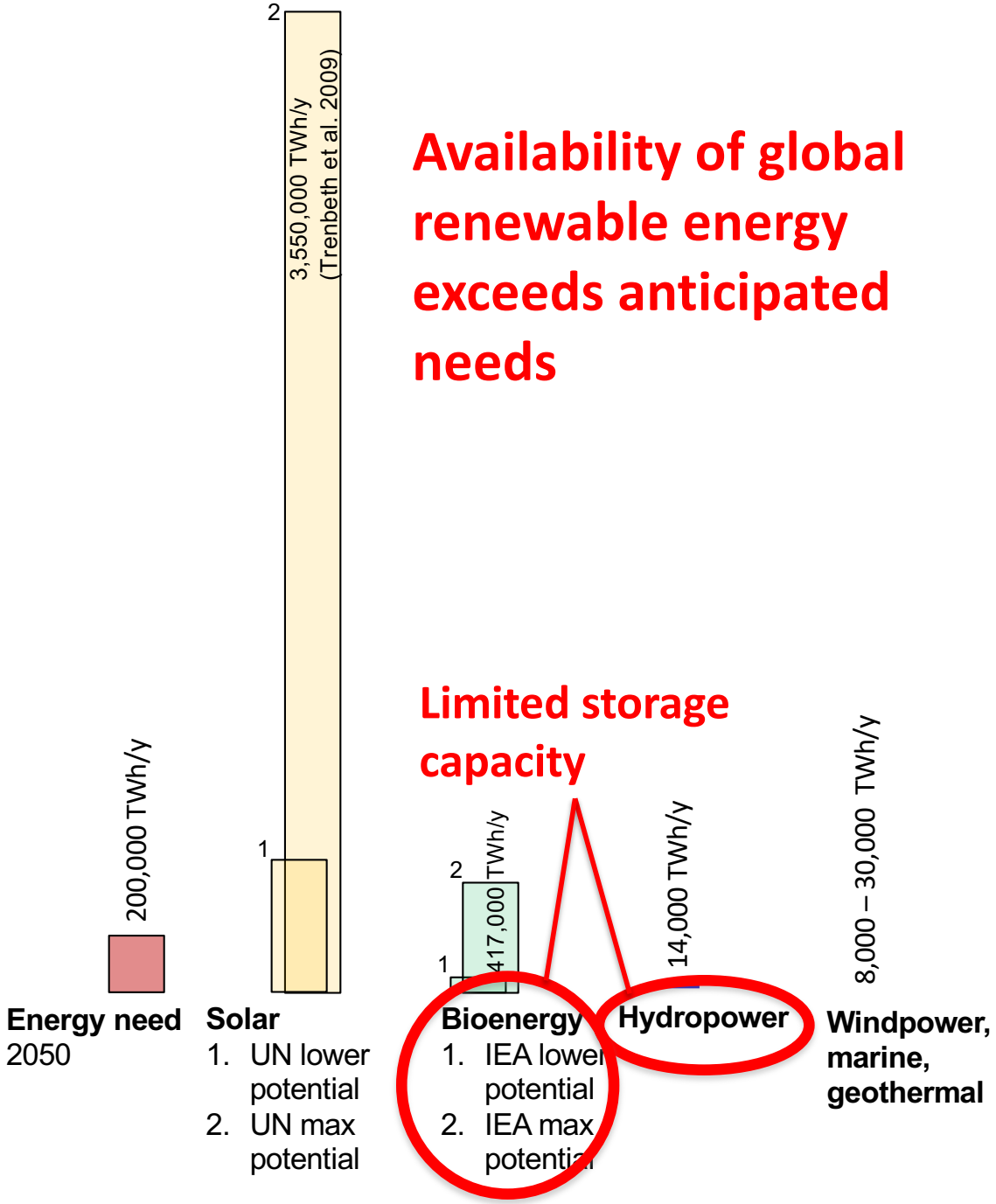


Letsi Rockfill dam, Lule River

Transition to a renewable energy system

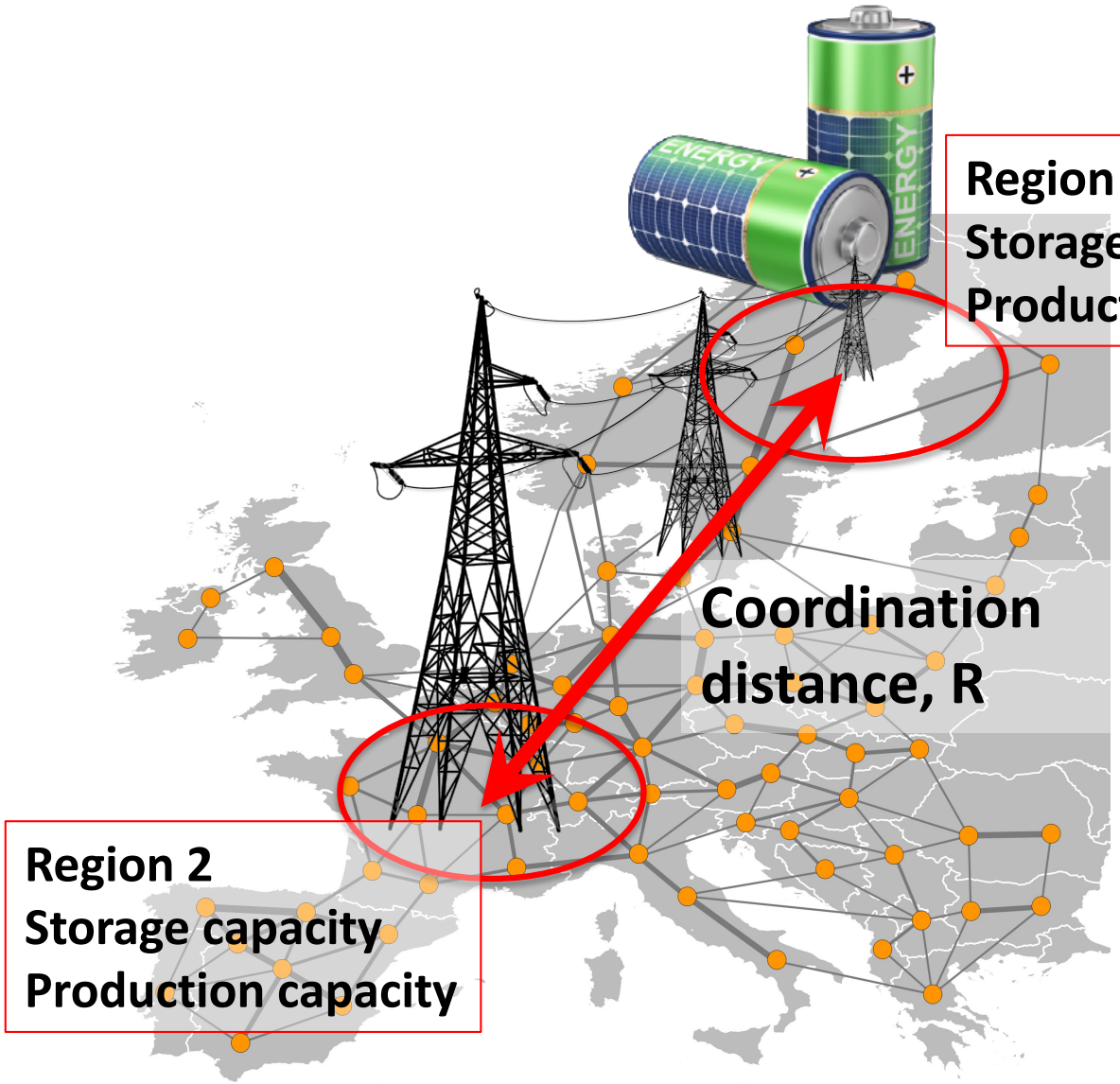


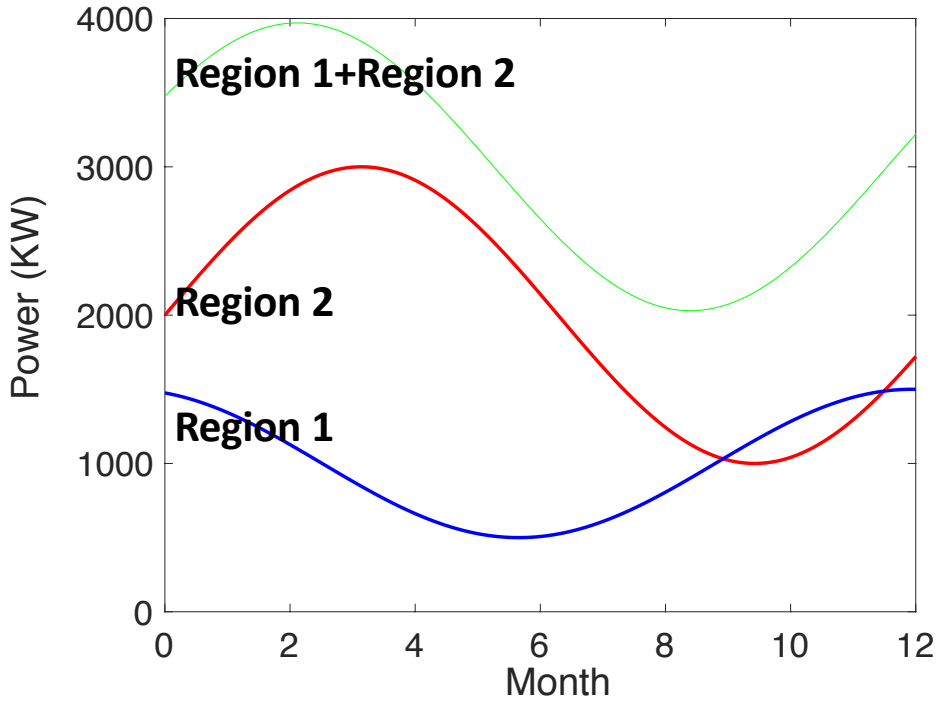
Availability of global renewable energy exceeds anticipated needs

Important constraints

- Climate-driven fluctuations and intermittency of renewabe energy
- Spatially uneven energy distribution
- Technical capacities for energy storage and transmission

Coordination potential for renewable energy systems





How is production coordination over a distance R reducing the variance in production capacity and energy storage demand?

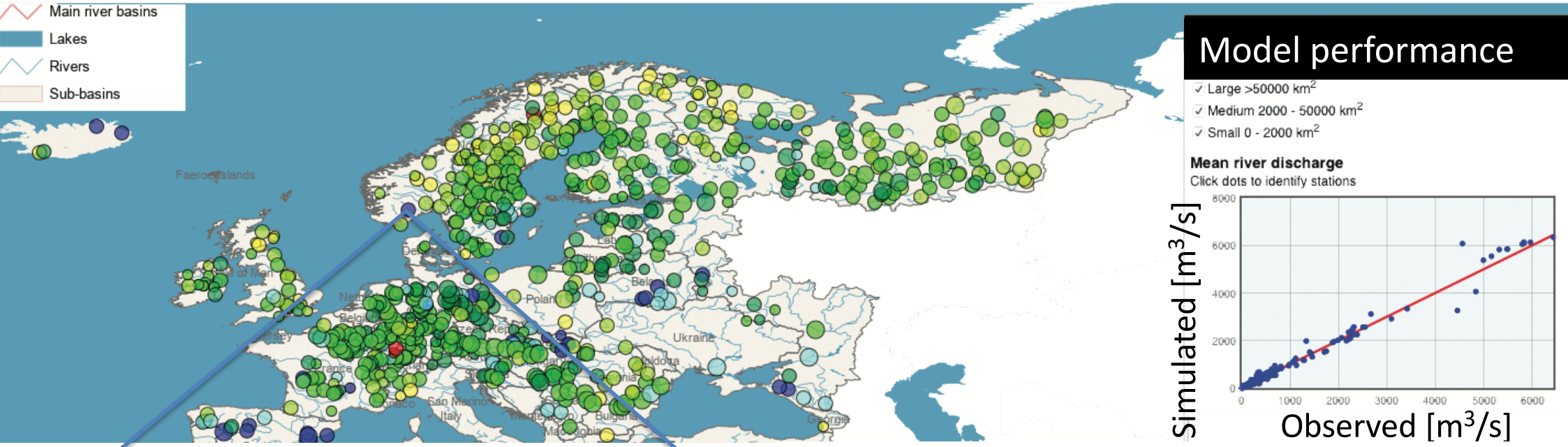
Project aims

1. Analyses of the coupling of climate fluctuations and hydropower availability
    a. Spatio-temporal statistics, including spatial covariation and control of climate indicators
    b. Seasonal forecast methods

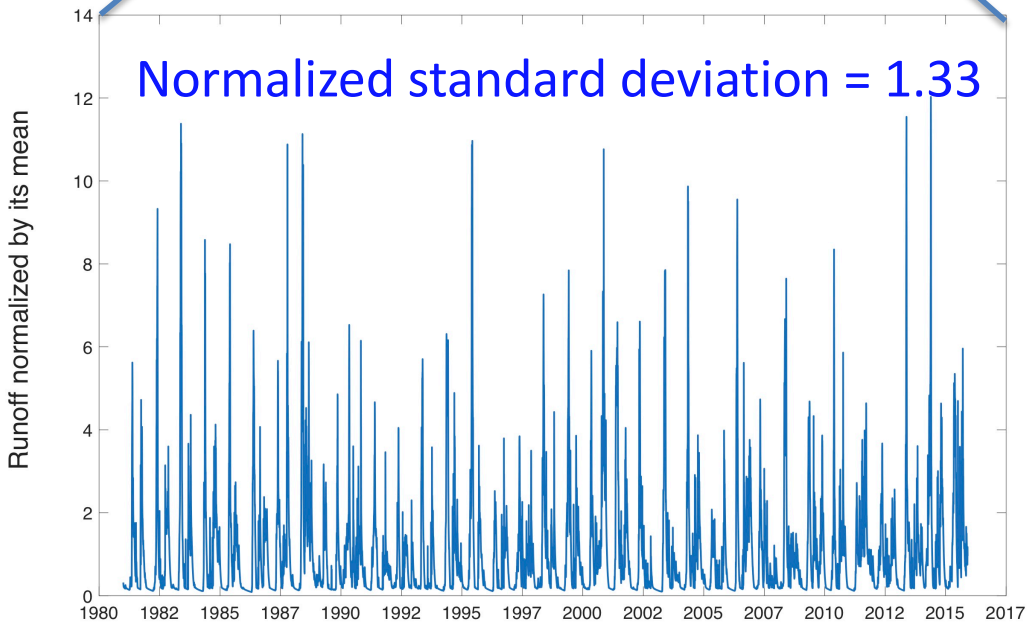
2. Implications of spatiotemporal coordination
    a. Quantify virtual energy storage gain due to production coordination
    b. Identify incentives in production management models

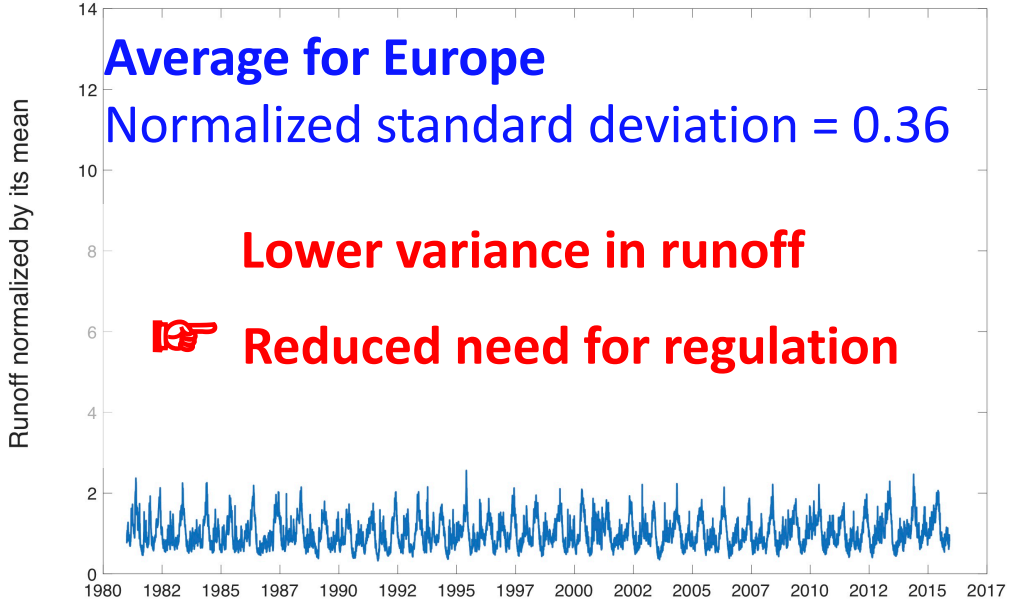
Simulated runoff data for Europe

35 years (1981 – 2015) using E-HYPE

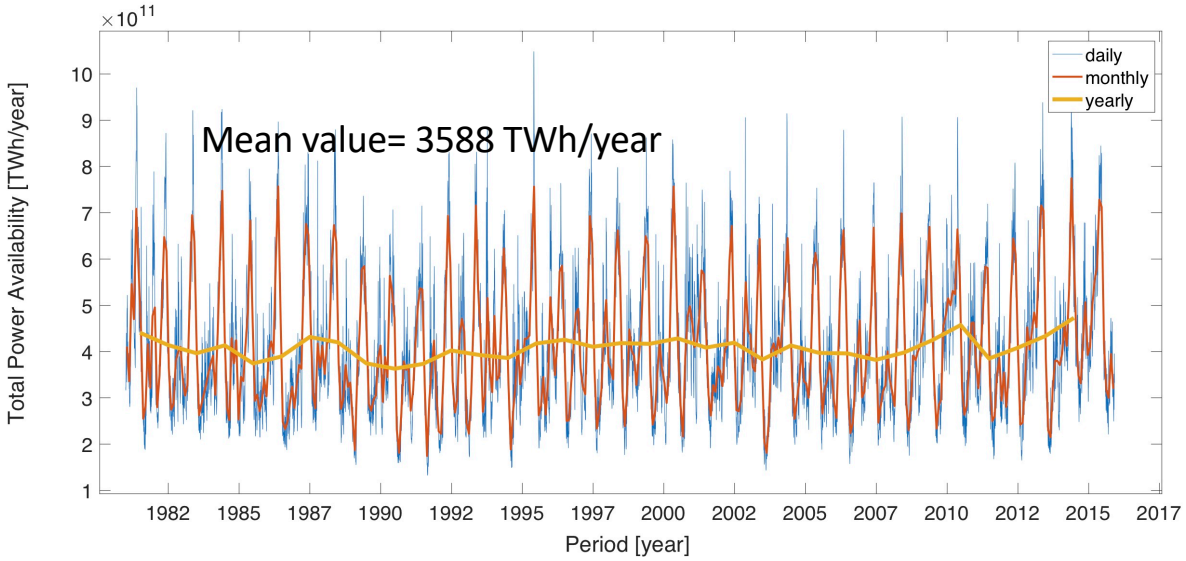


Model performance



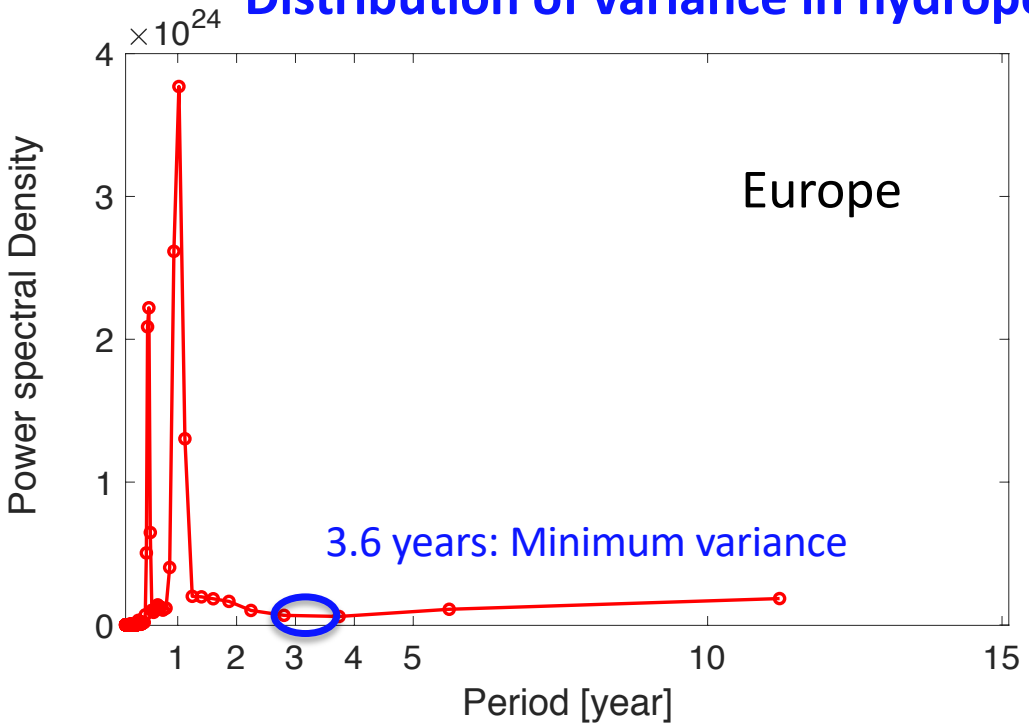


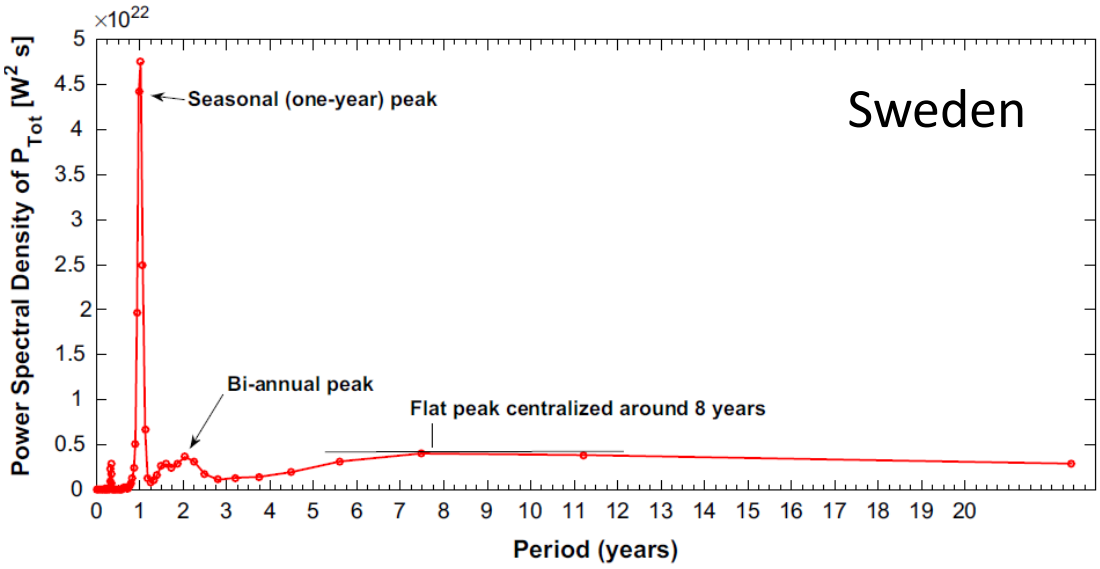
Potential energy of runoff in Europe



Coeficient of variation, CV	Sweden	Europe 35,408 watersheds
Daily time-series CV(P)	146%	36%
Annual time-series CV(P)	16%	5.9%
5-year time-series CV(P)	8.0%	2.4%

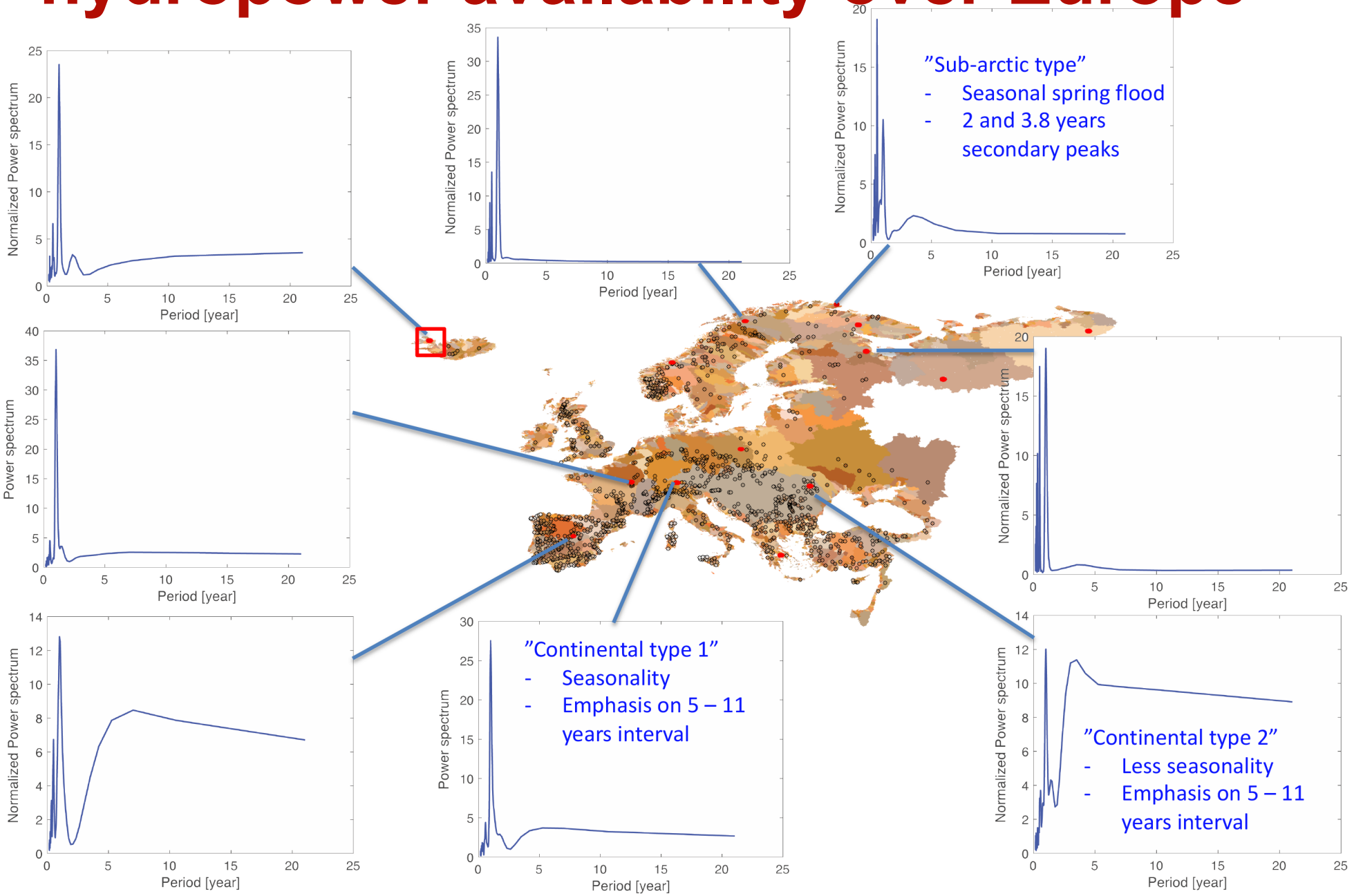
Distribution of variance in hydropower potential on periods





Wörman, Lindström and Riml, 2017. J. Hydrol.

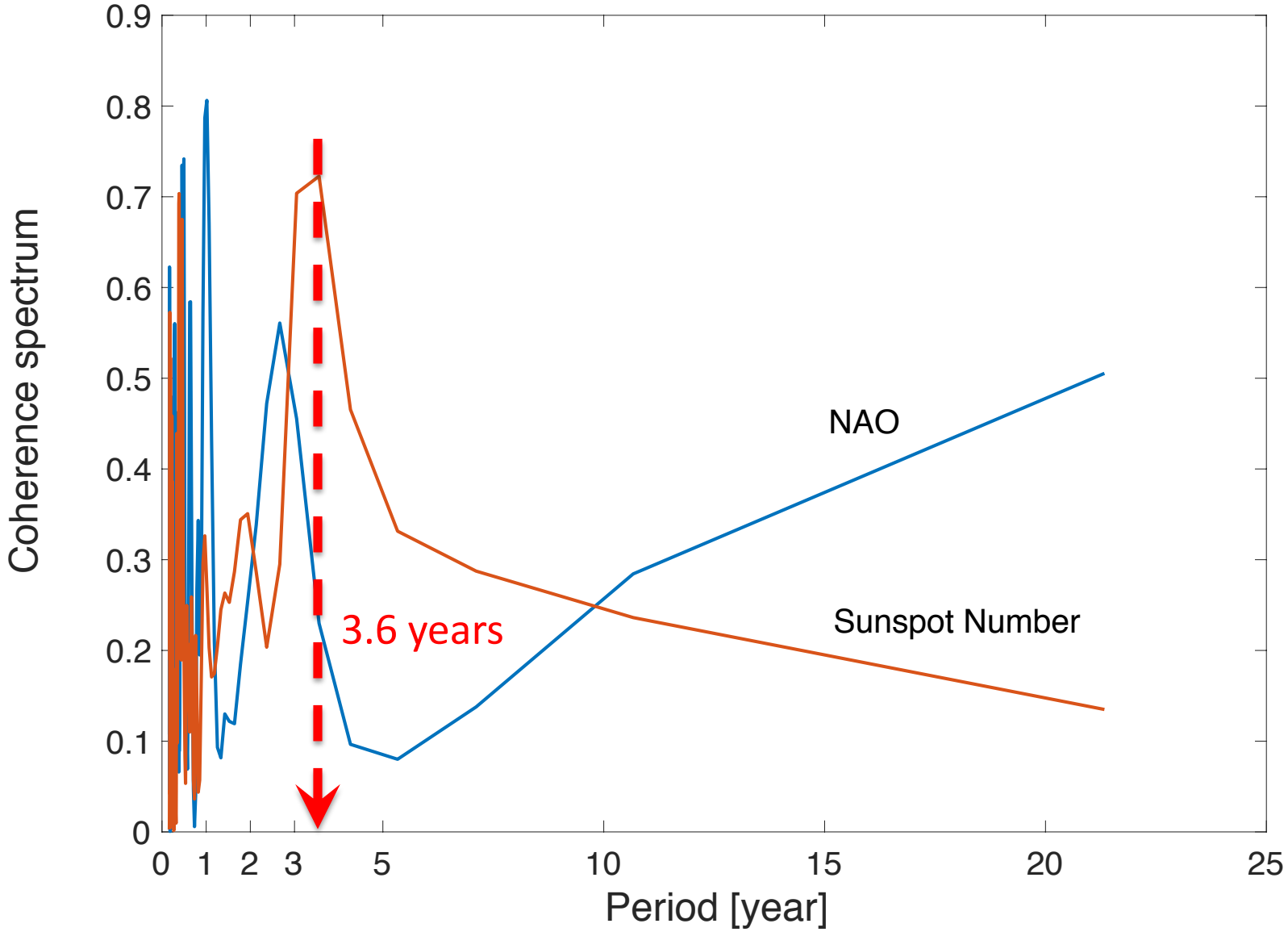
Differences in temporal pattern of hydropower availability over Europe



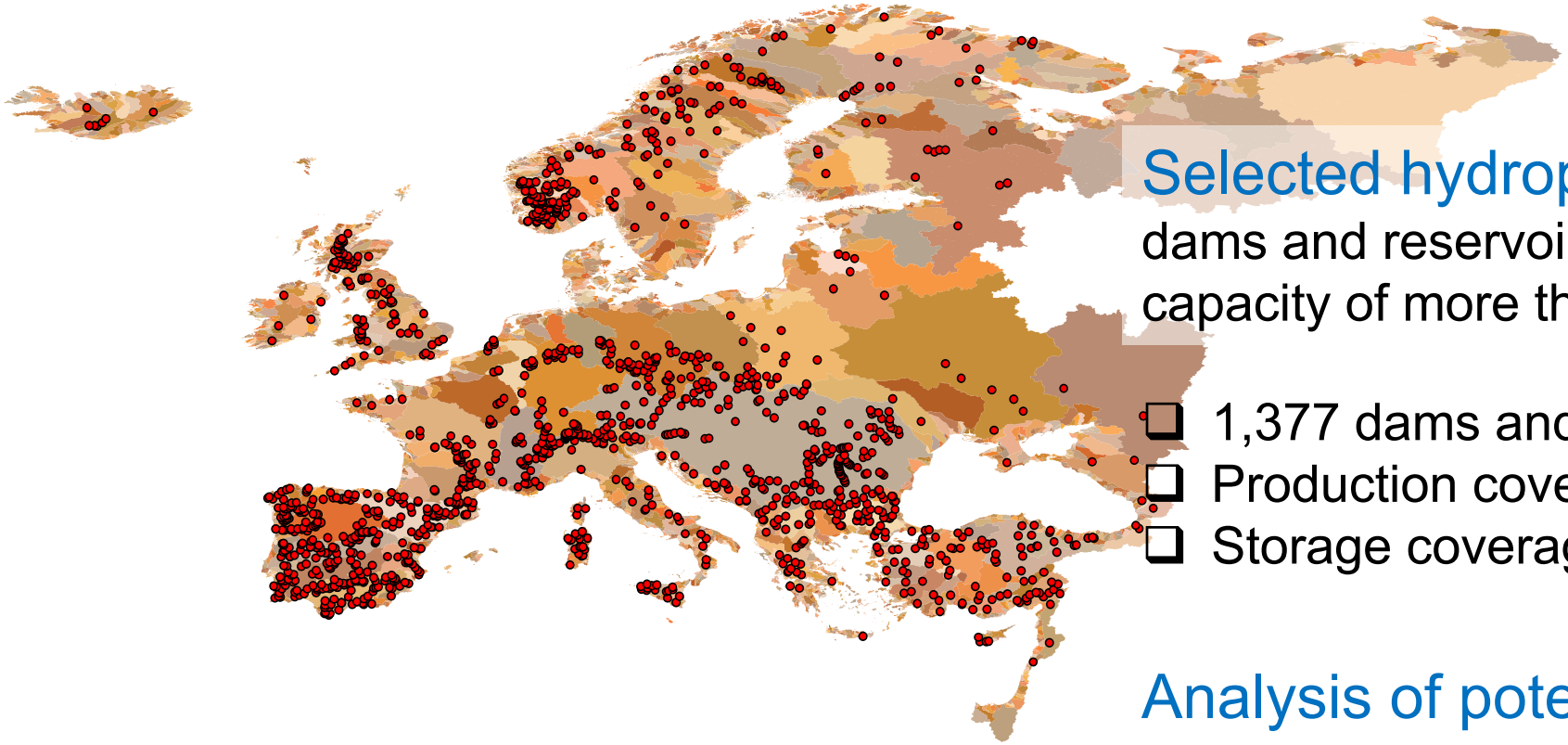
Wörman, et al.. 2020. Under revision

Climatic control on hydropower availability

Coherence between power of all runoff in Europe and climate indicators



Global Reservoir and Dam (GRanD) Database



Selected hydropower system

dams and reservoirs with a storage capacity of more than 0.1 km³

- 1,377 dams and hydropower stations
- Production coverage: 366 TWh/y
- Storage coverage: 81,000 GWh

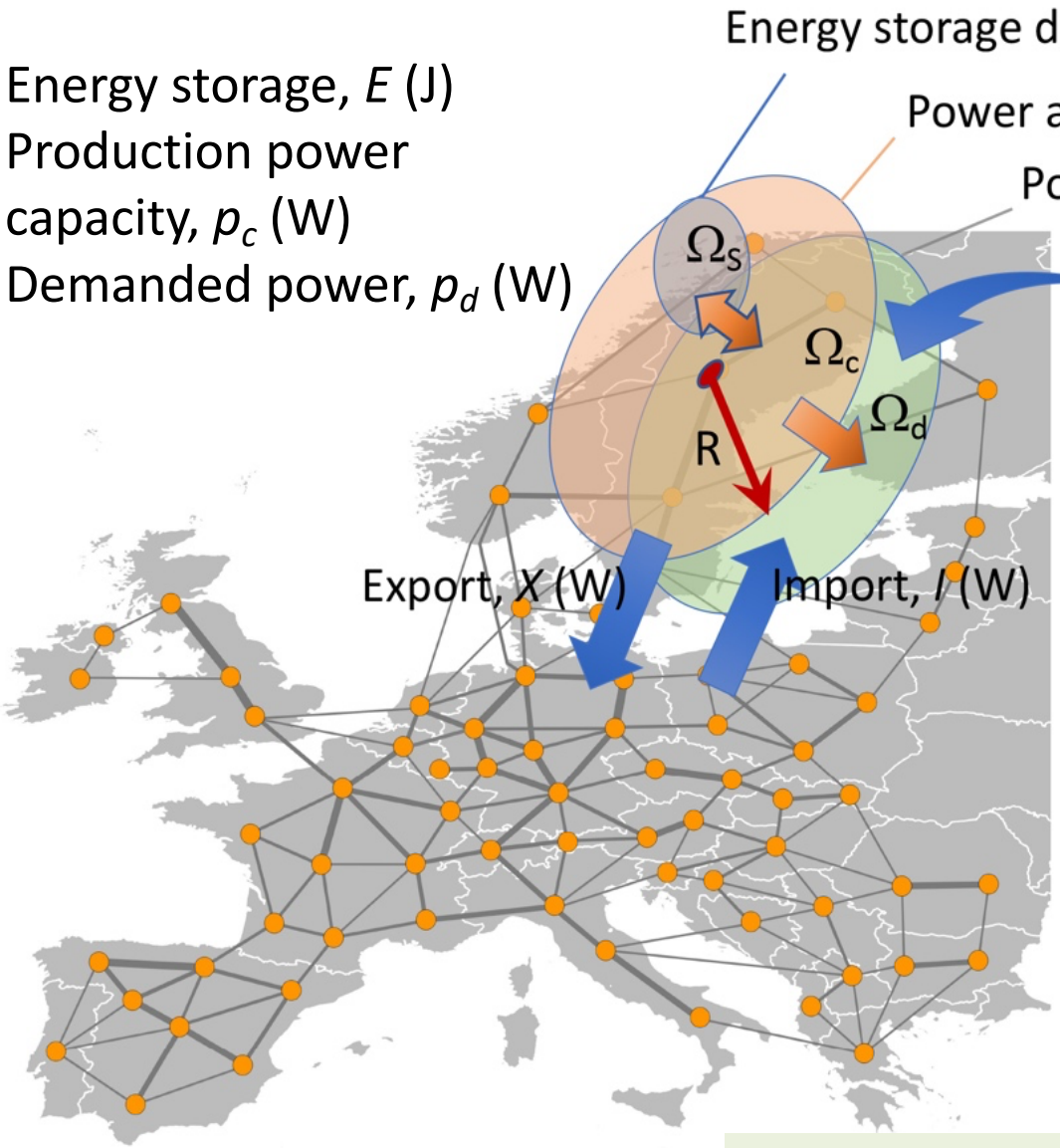
Analysis of potential hydropower availability in main river basins

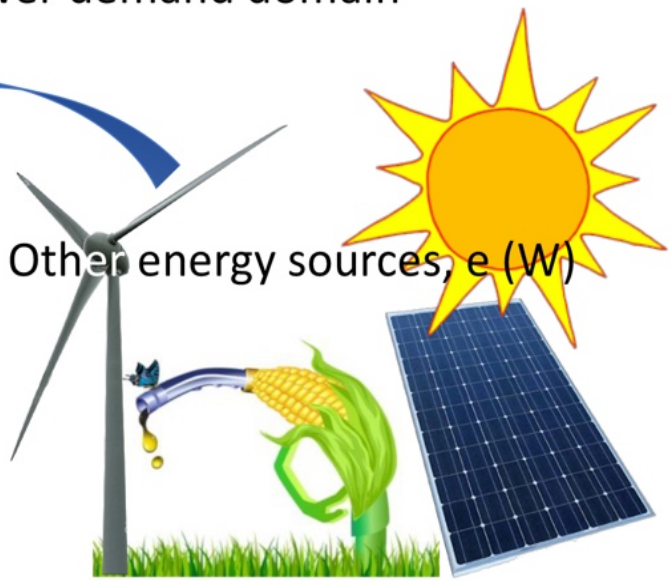
- 3,032 of main river basis with effluence to the sea
- Coordination benefits across main river basins

Beames at al., 2019. http://globaldamwatch.org

Spatio-temporal analysis of hydropower balancing

- Energy storage, E (J)
- Production power capacity, p_c (W)
- Demanded power, p_d (W)





Energy balance equation

$$\left(\frac{\partial E}{\partial t} - P_c\right)\Big|_{\Omega} = \varepsilon$$

Frequency-domain energy balance

$$f^2 S(E) = \sum_{i=1}^{N} S(P_{c,i}) + \sum_{i \neq j}^{N} \mathrm{Re}\{S(P_{c,i}; P_{c,j})\}$$

f = frequency (1/T)
T = 1/f= period
S(…) = power spectral density
N = number of watersheds
ε = Energy balance term (considered as constant)

Cross-spectral densities considered within coordination reach R

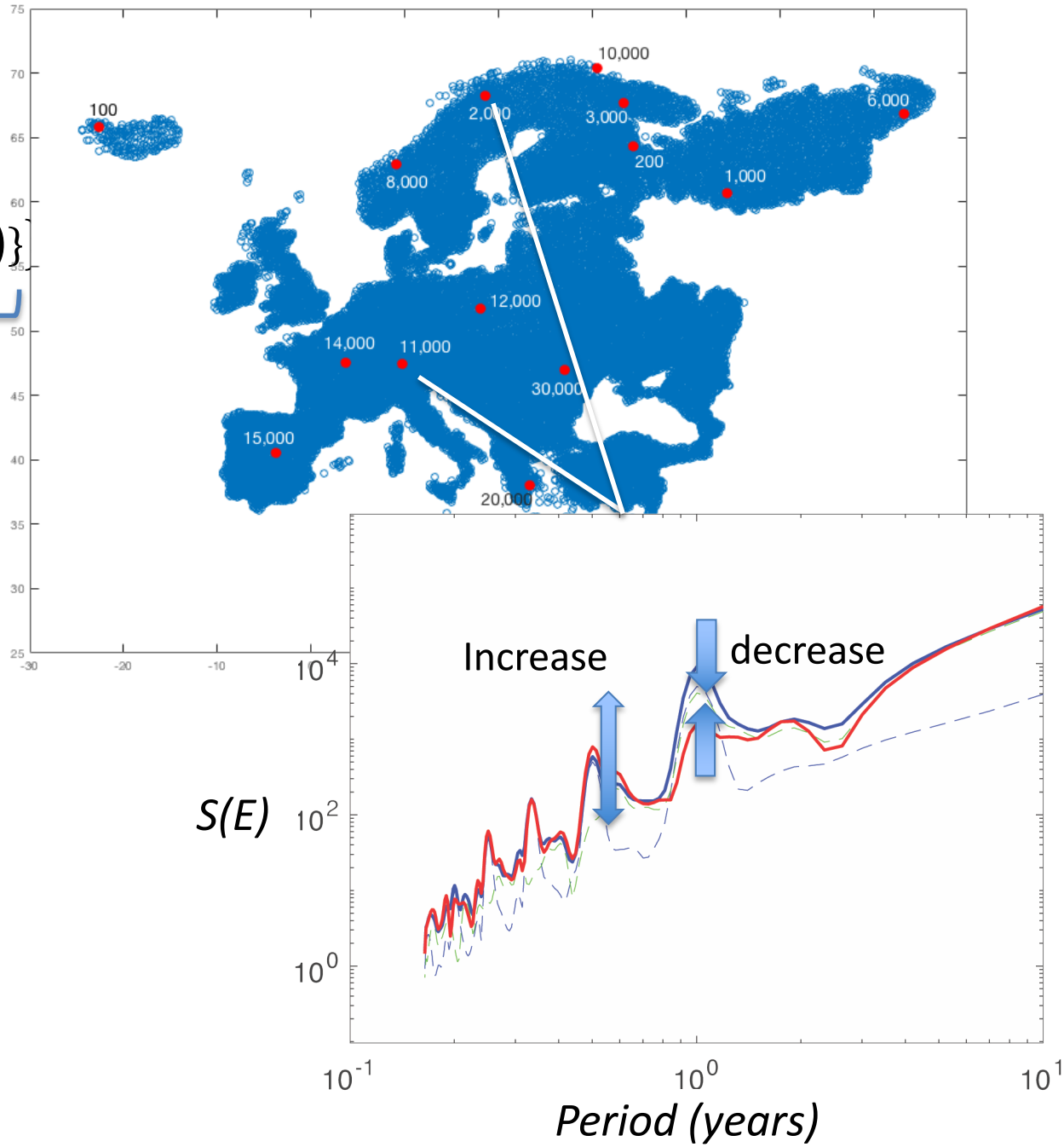
Example for pairwise spectra:
Storage requirement and availability spectra

$$f^2 S(E) = \underbrace{S(P_{C,1}) + S(P_{C,2}) + \mathrm{Re}\{S(P_{c,i}; P_{c,j})\}}$$

Power availability spectrum

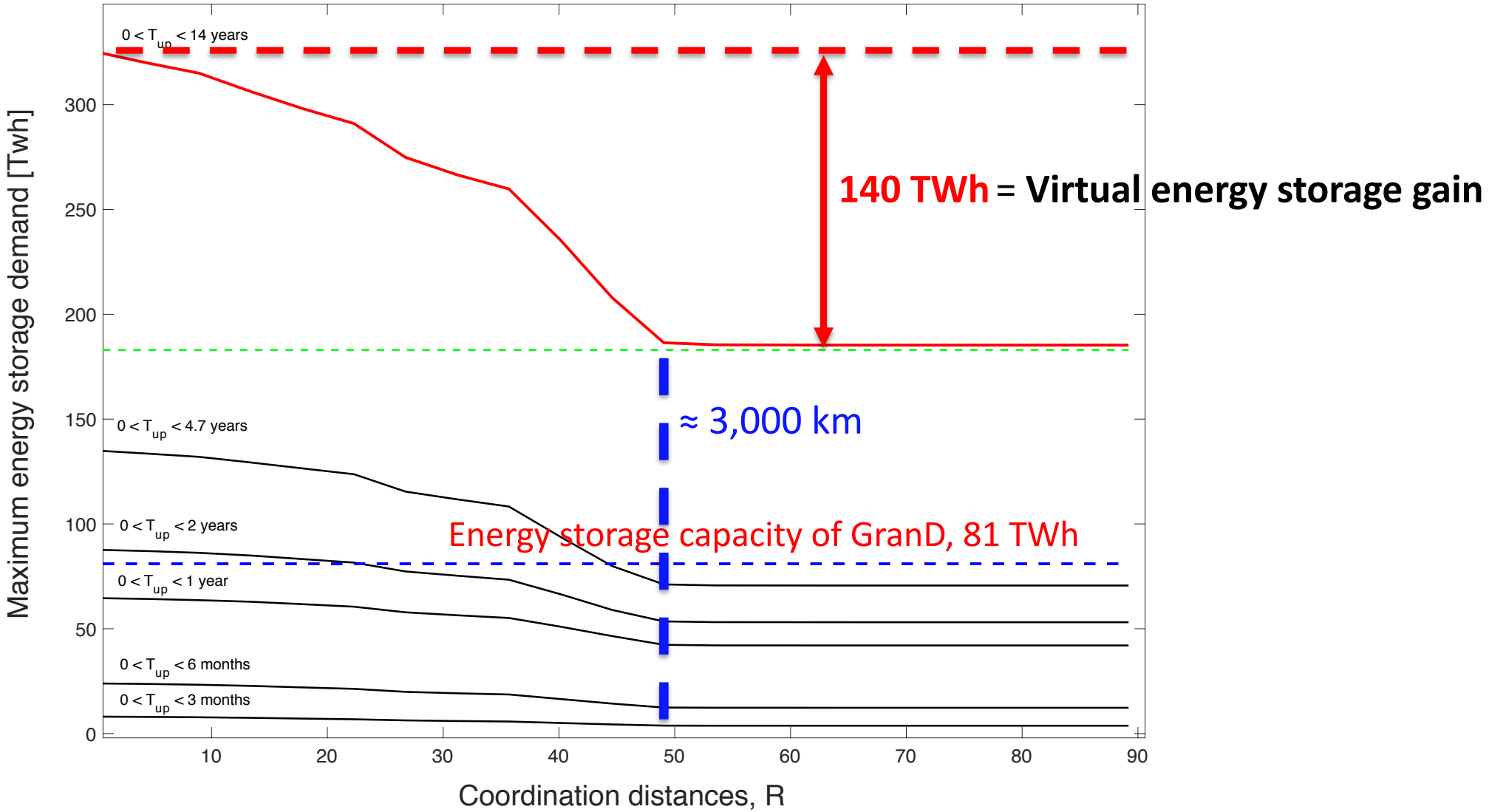
$$S(E) = \frac{S(P_{C,1}) + S(P_{C,2}) + \mathrm{Re}\{S(P_{c,i}; P_{c,j})\}}{f^2}$$

Storage requirement spectrum



Wörman, et al.. 2020. Under revision

Energy storage demand for all main river basins with account taken to the coordination distance, R

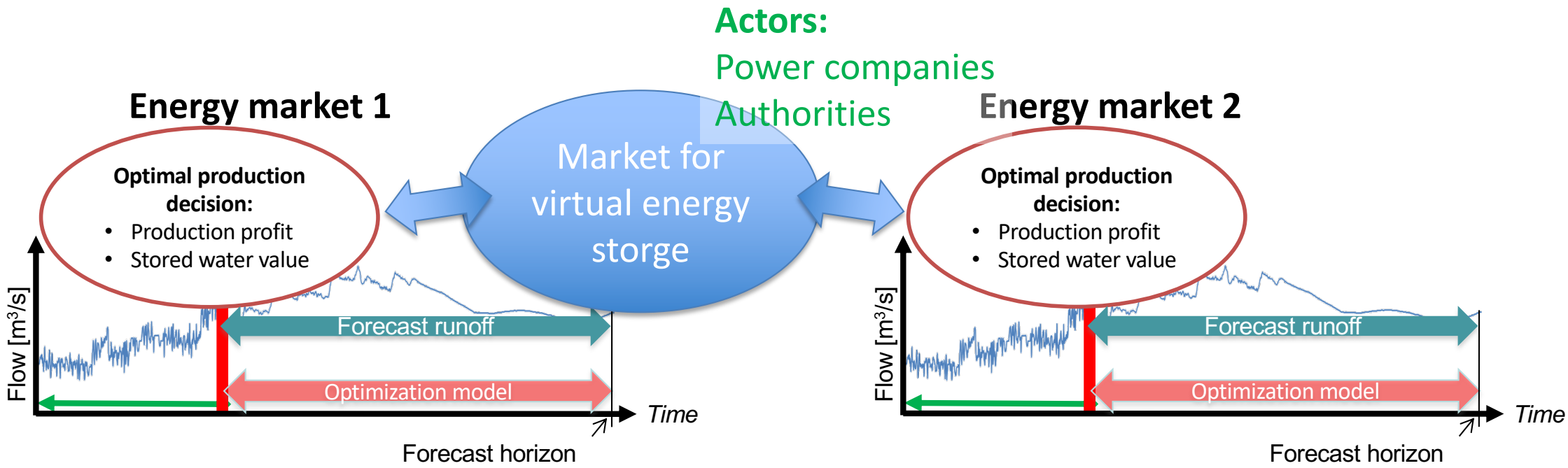


DD = Decimal degrees (43.5 - 78.7 km between 67 N to 45 N)

Possible acknowledgement of “virtual energy storgage” in production optimization models

- Virtual energy storage can give higher profit, and
- Higher flexibility and safety against energy droughts
- Not used in current production management models
- ”Sub-optimization” within main river basins, but the energy market connects production across main river basins

New incentives (objectives) for virtual energy storage?



Conclusions

- Hydropower availability varies in Europe on typical periods of 2, 3,6 och 8 – 11 år
- Climat indeces can explain the variation, but the pattern varies between different regions
- Spatiotemporal coordination of hydropower production can result in a virtual energy storage gain (VESG) twice the capacity of existing hydropower reservoirs
- Largest VESG is obtained upto distances of 3,000 km, i.e. on the continental scale
- A spectral method that can quantify VESG has been developed

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