Assessing the probability of extremely rare wind production in Europe at seasonal time scales

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Abstract:

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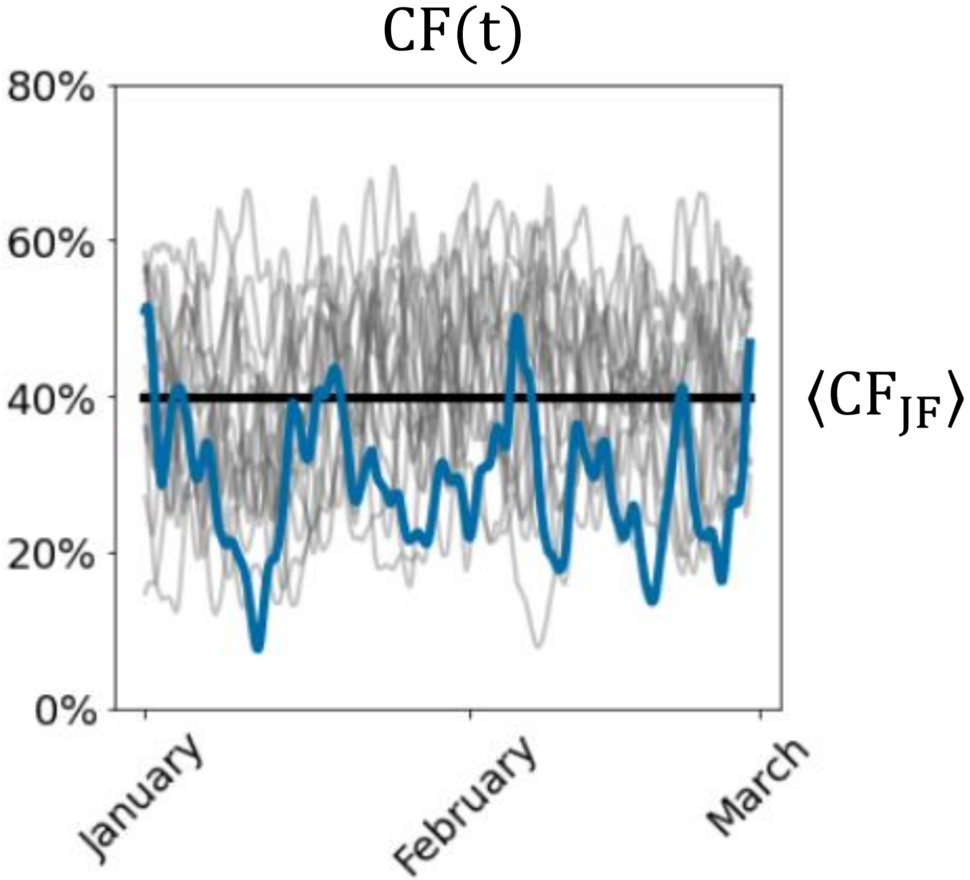
Extreme seasonal low wind production

- Future power systems will be more dependent on weather variability
- **Extreme events**: low seasonal wind production
- **1000 years** climate simulation (CESM)
- Simple wind energy model: **European** capacity factor $\mathrm{CF_{JF}}$ in **January-February**
- **5 scenarios** of installed capacity



Question

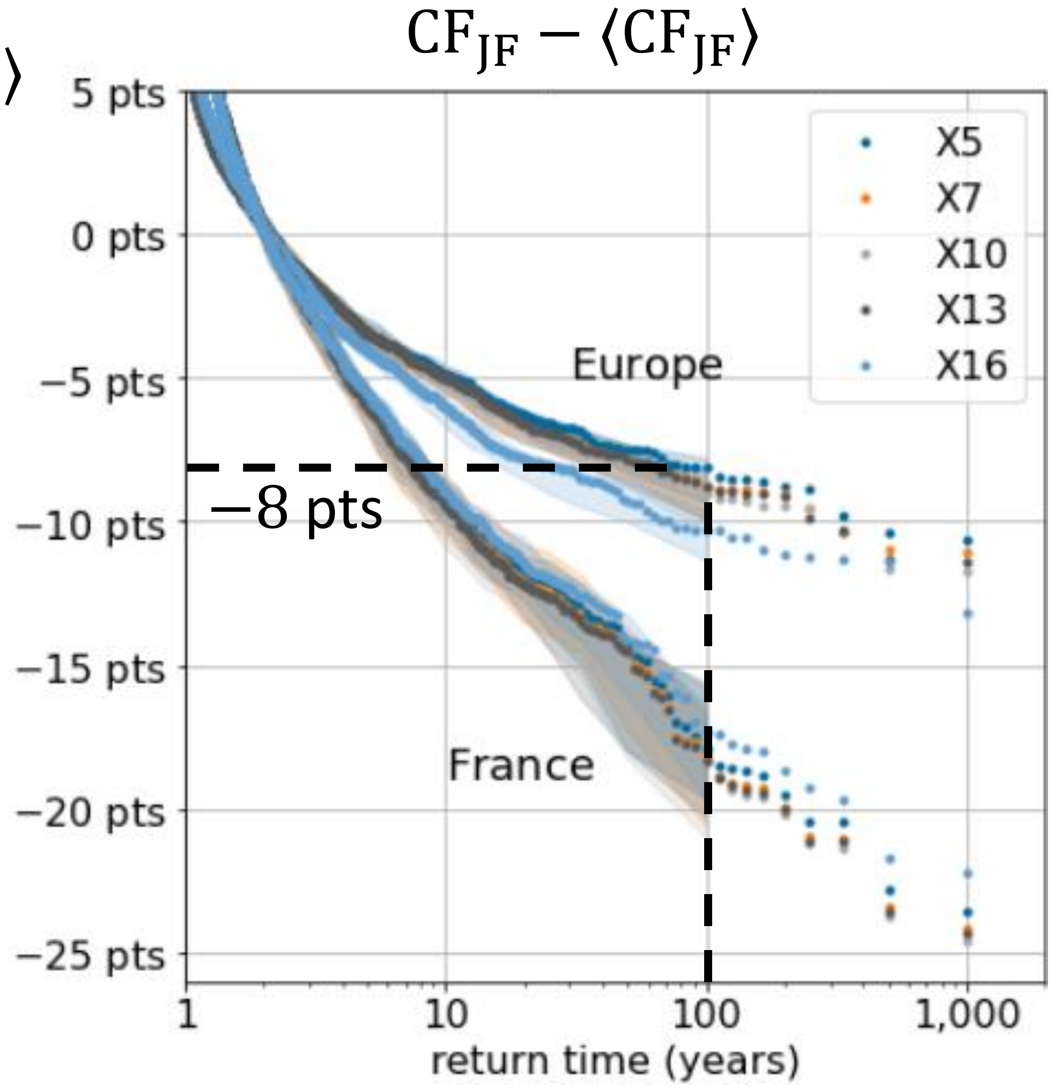
- What is the probability of such an event?

Return times for seasonal wind production

- Seasonal anomaly of capacity factor : $\mathrm{CF_{JF}} - \langle \mathrm{CF_{JF}} \rangle$

- $\langle \mathrm{CF_{JF}} \rangle = 40\ \%$

- Interpretation:
  « European production is 8 points below the seasonal average once every 100 years »



Conclusions

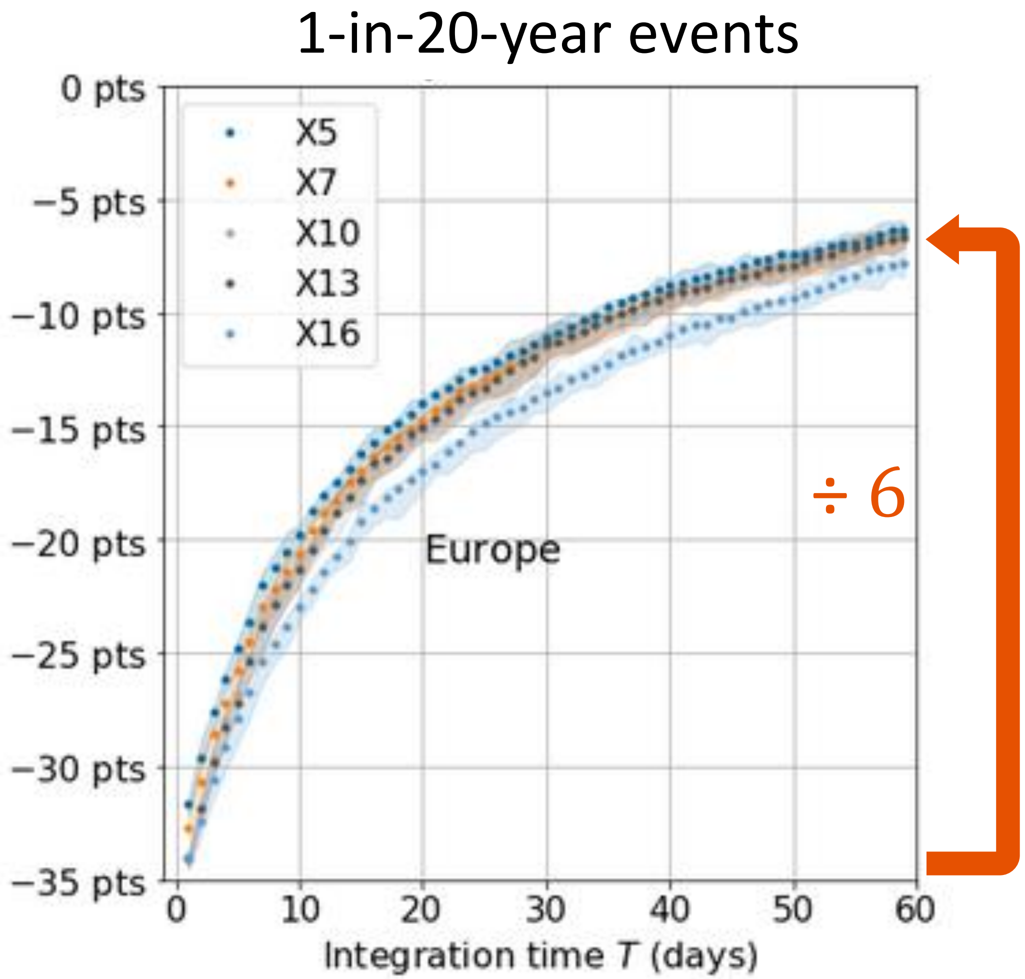
- We estimate return times up to 1000 years
- Return time curves depend very weakly on the scenario
- The aggregation at the scale of Europe strongly reduces the amplitude of the most rare events

Return level for sub-seasonal wind production

- Amplitude of 1-in-20-year events
- Different durations: from $T = 1$ day to 60 days

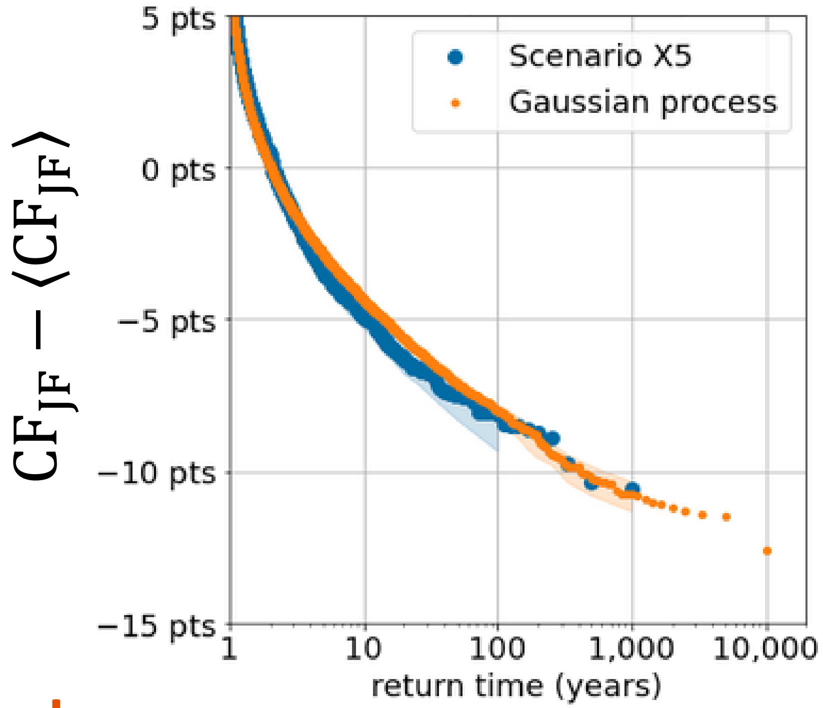
Conclusions

- The amplitude of extreme events are strongly reduced when we aggregate in time.



Predicting return time for reanalysis data

- Gaussian process: Simple 1D effective model



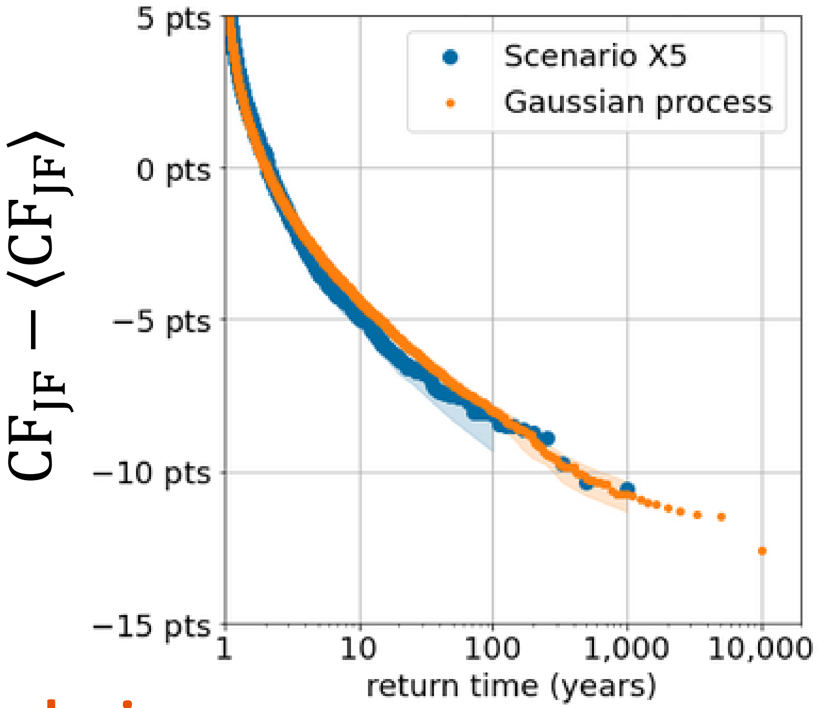
Conclusions

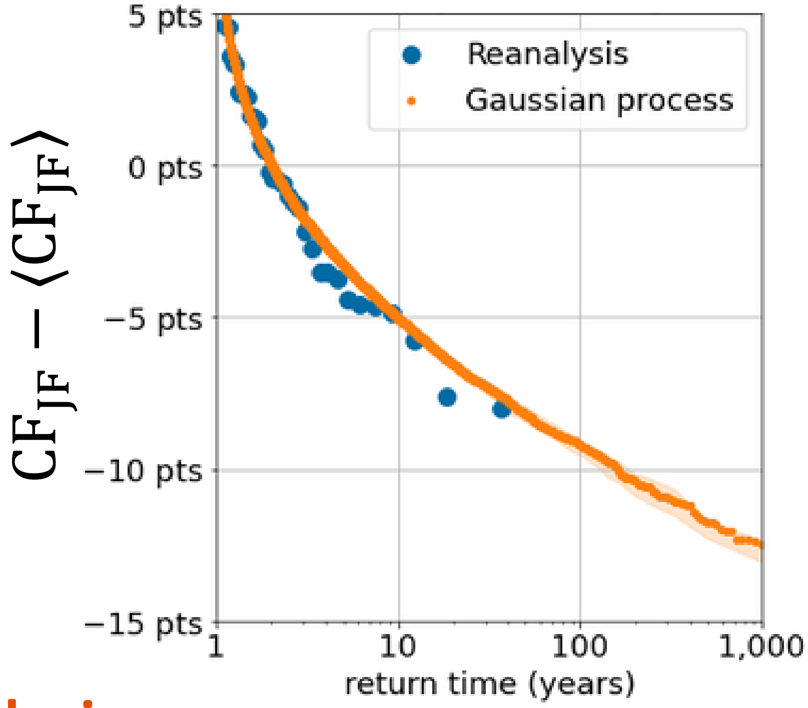
- The Gaussian process gives good estimates of the return time curve

Predicting return time for reanalysis data

- Gaussian process: Simple 1D effective model

Renewables.ninja, Staffell et al. (2016)





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- The amplitude of extreme events are strongly reduced when we aggregate in time

- A Gaussian process allows us to estimate return time curves for reanalysis data

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References

- Staffell, Iain and Pfenninger, Stefan (2016). Using Bias-Corrected Reanalysis to Simulate Current and Future Wind Power Output. Energy 114, pp. 1224-1239. doi: 10.1016/j.energy.2016.08.068
- James W. Hurrell et al. (2013). The Community Earth System Model: A Framework for Collaborative Research. Bulletin of the American Meteorological Society, 94(9):1339–1360
- e Highway 2050. Europe's future secure and sustainable electricity infrastructure, 2015.
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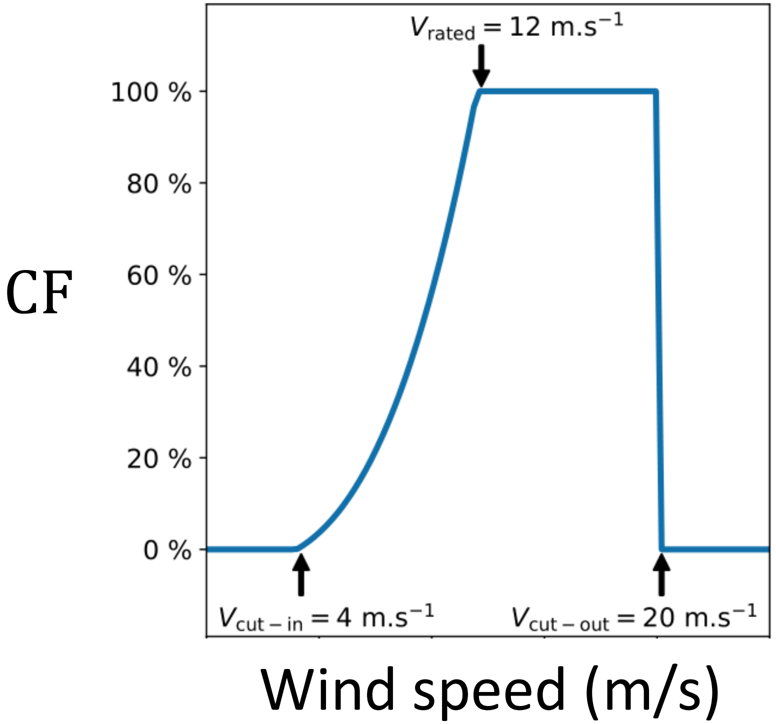
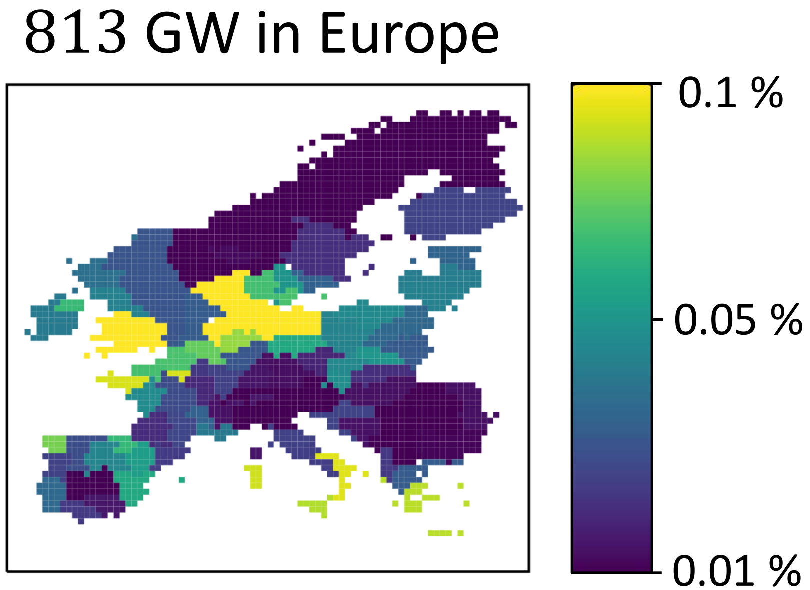
Appendix

Wind production model

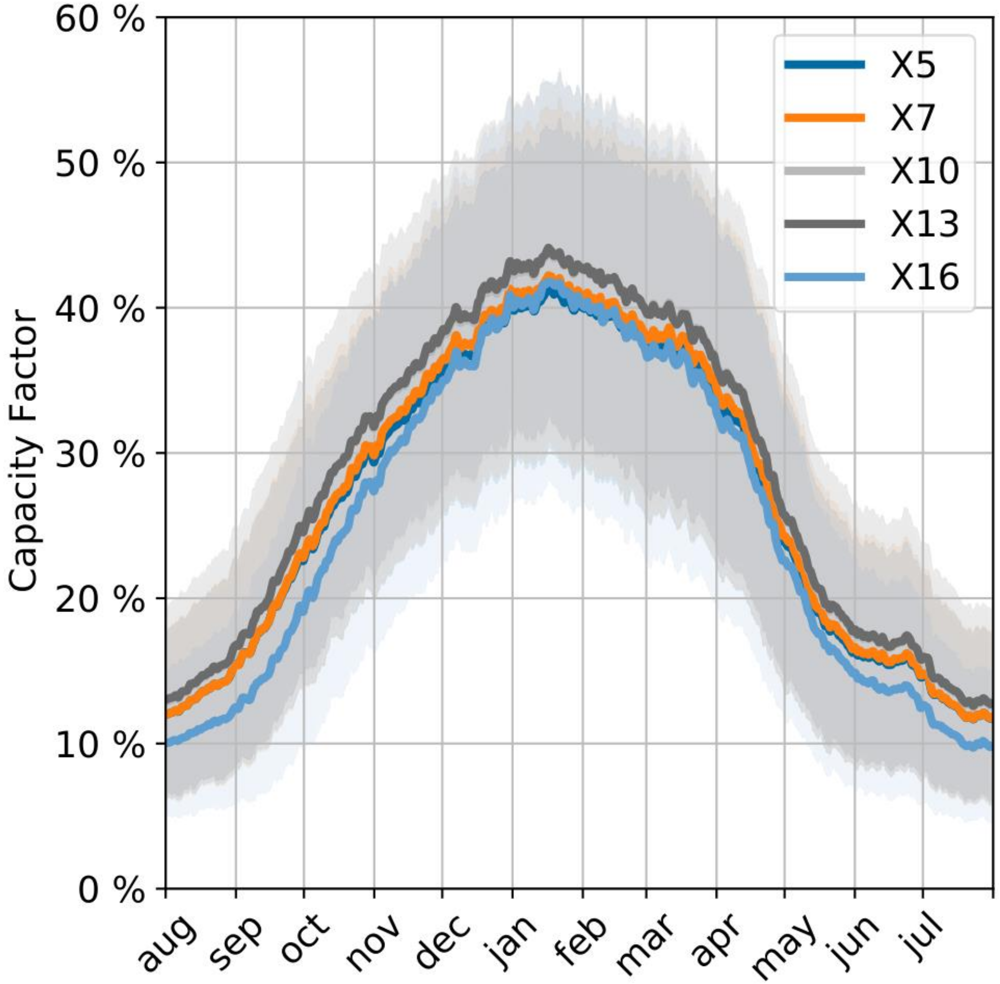




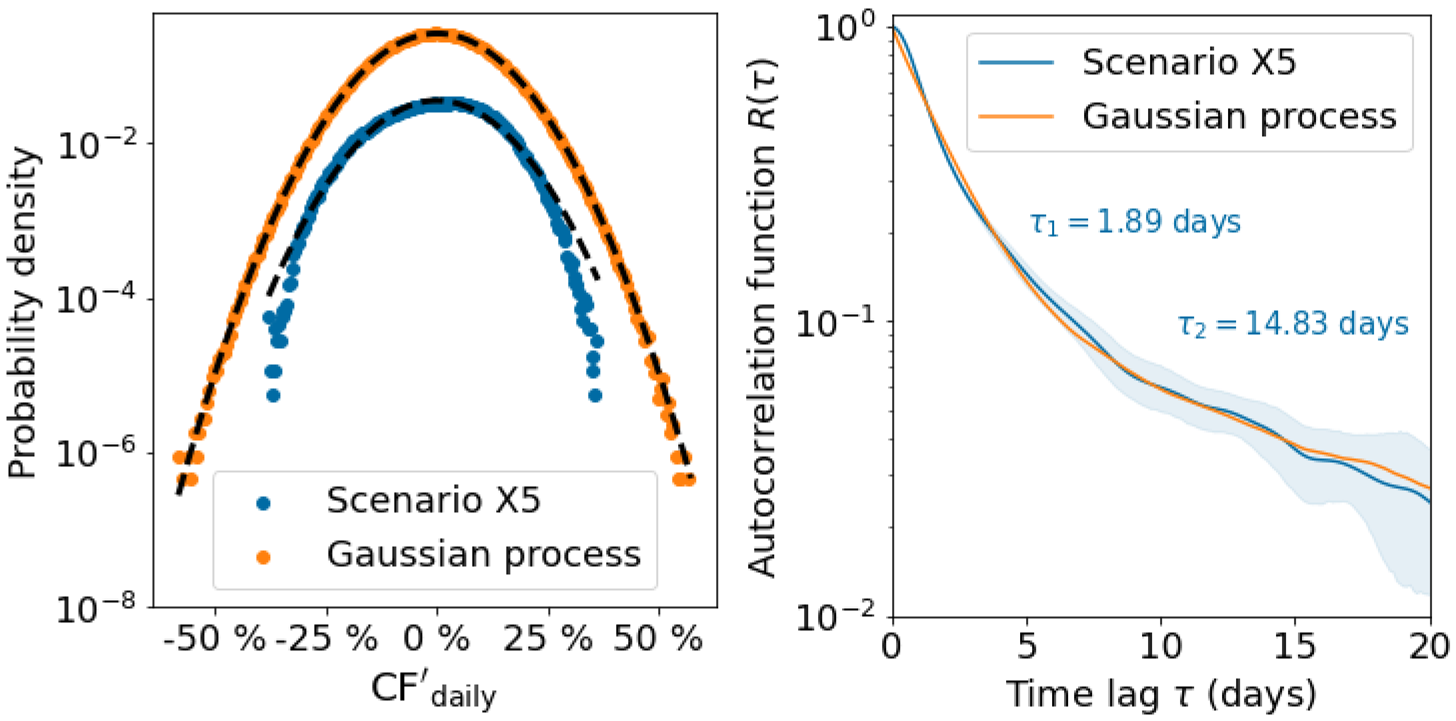
Distribution of installed capacity (scenario e-Highway X5)

- Capacity factor: $\mathrm{CF}(x, y, t) = \dfrac{\text{Wind production}}{\text{Max wind production}} \in [0\%, 100\%]$
- $\mathrm{CF}_{\mathrm{JF}} = \dfrac{1}{T} \displaystyle\int_{\mathrm{Jan-Feb}} \dfrac{1}{D} \int_{\mathrm{Europe}} \mathrm{CF}(x, y, u)\ \mathrm{d}x\mathrm{d}y\mathrm{d}u$

Seasonality of European capacity factor



Simple model : Gaussian process with the same PDF and autocorrelation function



Jan-Feb daily anomaly

$$\mathrm{CF}'_{\mathrm{daily}} = \mathrm{CF}_{\mathrm{daily}} - \langle \mathrm{CF}_{\mathrm{daily}} \rangle$$

Model : sum of 2 Ornstein-Uhlenbeck stochastic processes

- We are able to fit a second time scale τ_2

What is an Ornstein-Uhlenbeck process

- Sum of two Ornstein-Uhlenbeck processes $x_1(t) + x_2(t)$ where

$$\mathrm{d}x_i = -\frac{1}{\tau_i}\mathrm{d}t + \sqrt{2D_i}\,\mathrm{d}W_{i,t}\,, \quad i \in \{1,2\}$$

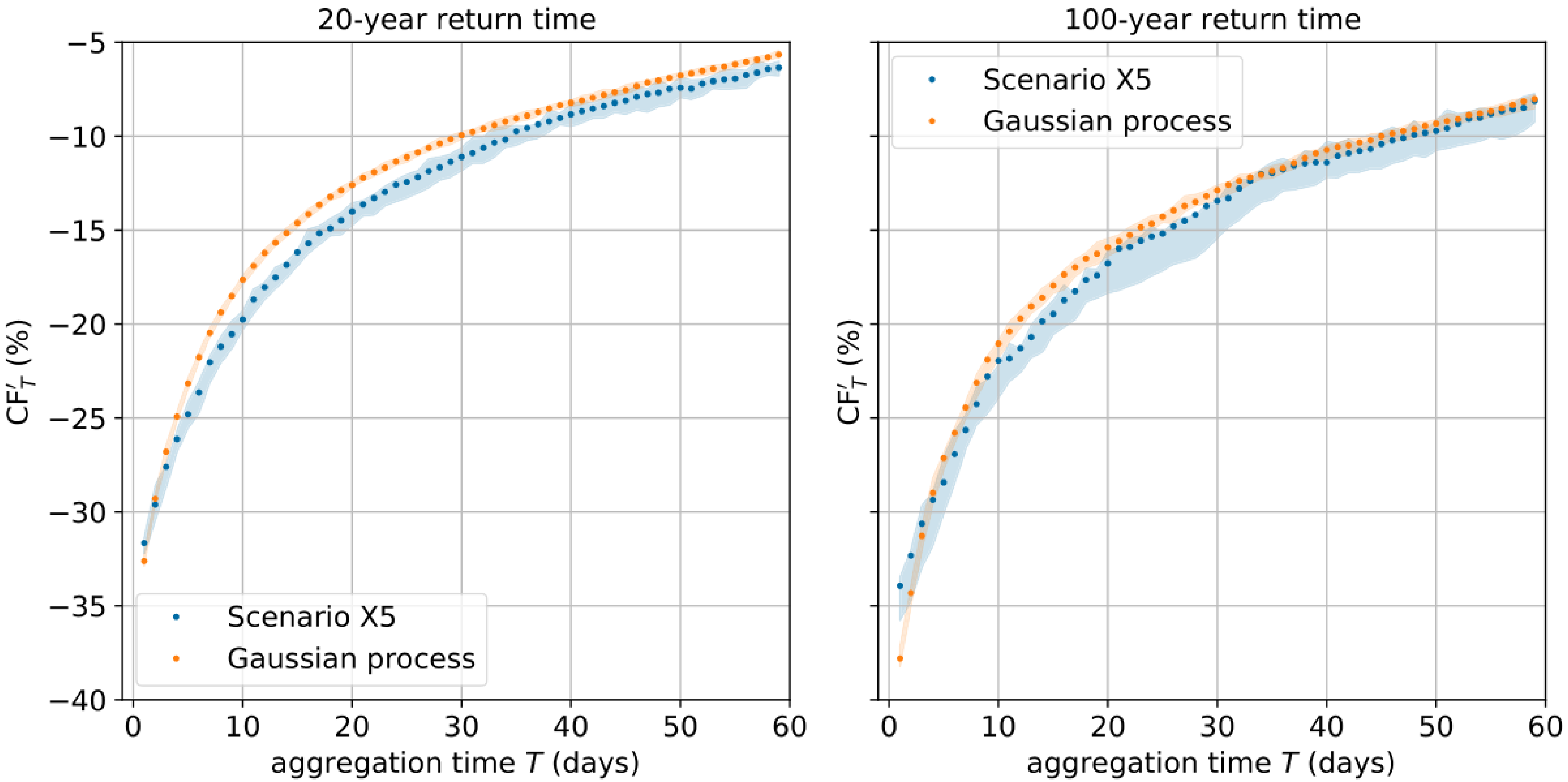
Extreme event definition and return time computation method

- Minimum capacity factor fluctuation at year k: $a_T = \min_{t\in[T_1,T_2-T]} \left\{\frac{1}{T}\int_t^{t+T} \mathrm{d}u \, \mathrm{CF}'(u)\right\}$

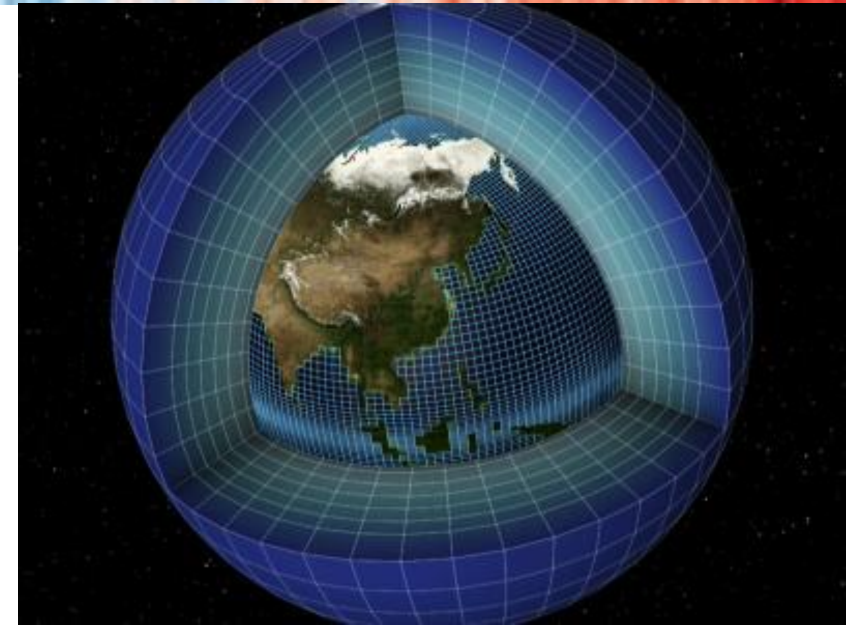
- Return time of a : $r(a) = \frac{1}{\mathrm{P}(a_T<a\,)}$,
  with $\mathrm{P}(a_T < a\,)$ the cumulative density distribution

- In practice, we rank $\widehat{a_T}^1 < \widehat{a_T}^2 < \cdots < \widehat{a_T}^N$ and we plot $\left\{\widehat{a_T}^k\right\}_k$ as a function of $\left\{\frac{N}{k}\right\}_k$.

How amplitude depends on duration

- 

Description of the climate model



- *Community Earth System Model* 1.2.2 (NCAR): The model used by NCAR, USA, for the CMIP experiments (IPCC).

- Full atmospheric model: represents wind, water vapour, rain, radiation, clouds, land surface physics.

- Resolution: $0.9° \times 1.2°$ $(\sim 100\ km)$. Time step: $dt = 3h$.

- **1000 years** of climate data in stationary conditions (2000s climate)