

Drivers and predictability of extreme summer Arctic sea ice conditions with rare event simulation methods

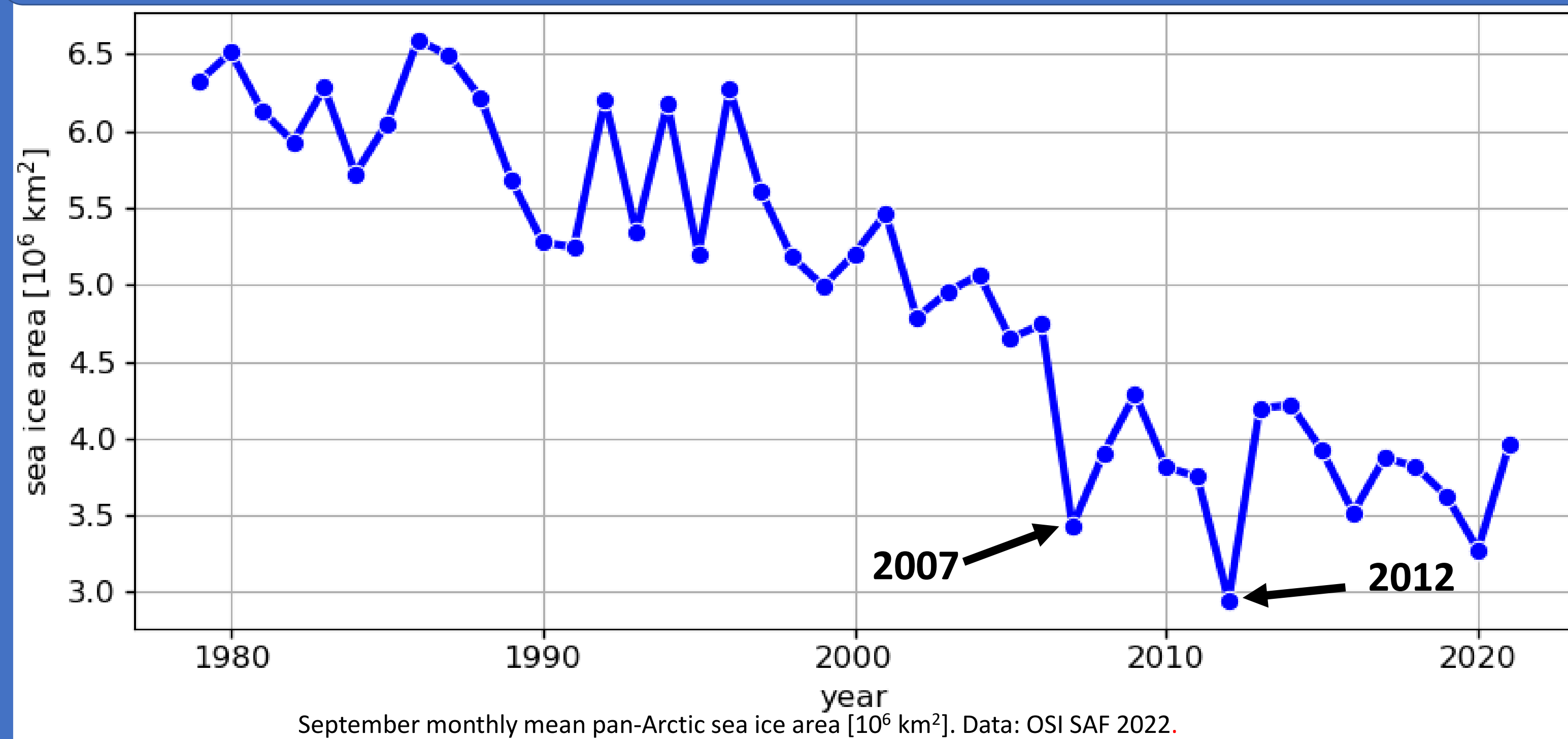
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PhD project 2022 - 2026

Extreme events in summer Arctic sea ice cover



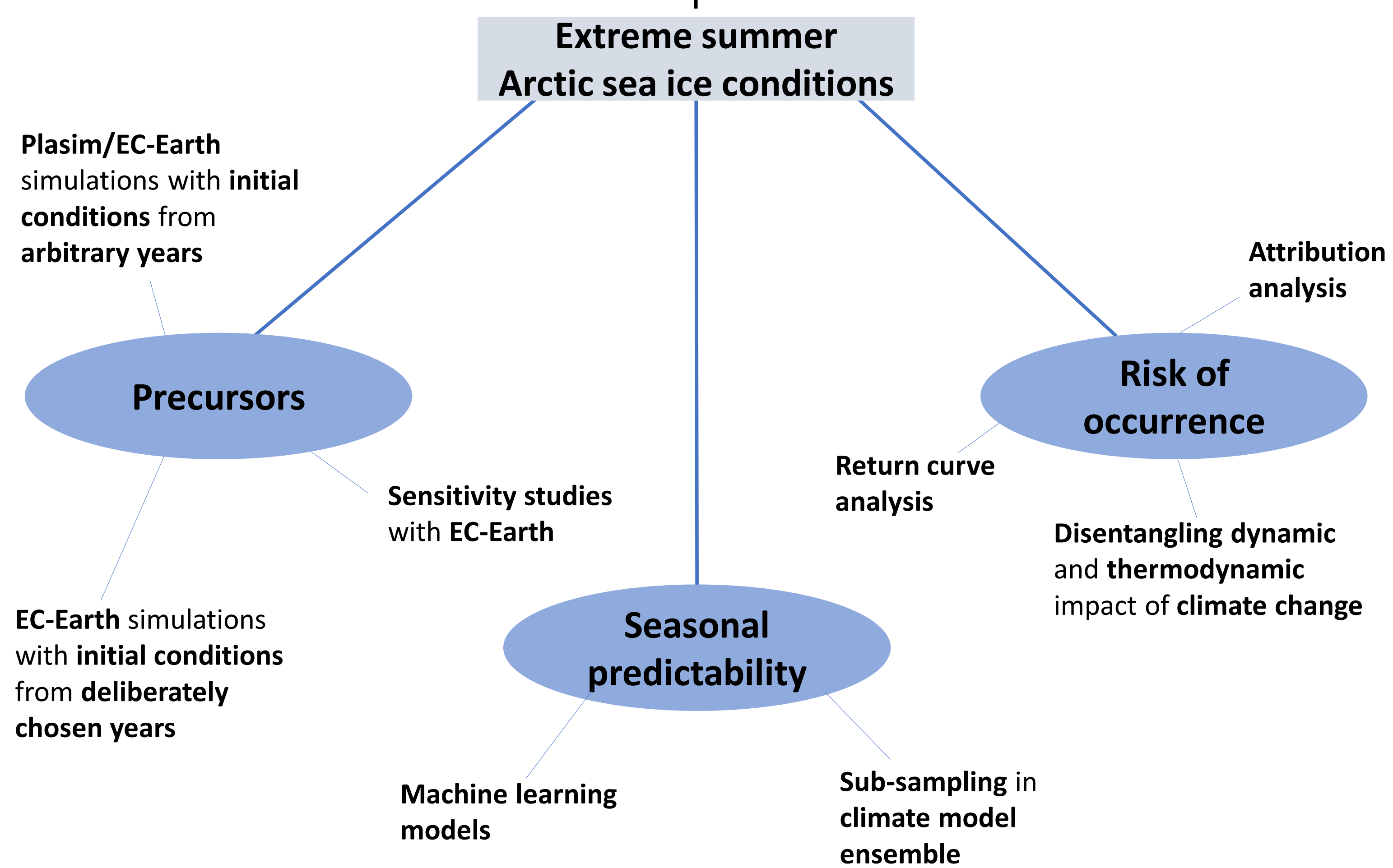
- Due to **climate change**, summer Arctic sea ice cover is **decreasing**
- On top of the **downward trend**, **internal climate variability** contributes to the **year-to-year variations** and associated **extremes** of the annual Arctic sea ice minimum
- Three problems** complicate **robust statistical** and **dynamical studies** about **extreme events** in summer Arctic sea ice cover:
 - 1) **lack of observational data**
 - 2) **poor sampling** of rare events in **computationally expensive climate models**
 - 3) **reliability of climate models**
- What is the **relative contribution** of different **atmospheric** and **oceanic drivers** and of **natural** and **forced variability** to **extremes** in summer Arctic sea ice cover?

Project overview

Phase 1: Coupled atmosphere-ocean configuration of Plasim with stationary pre-industrial climate

Phase 2: EC-Earth with different forcing scenarios

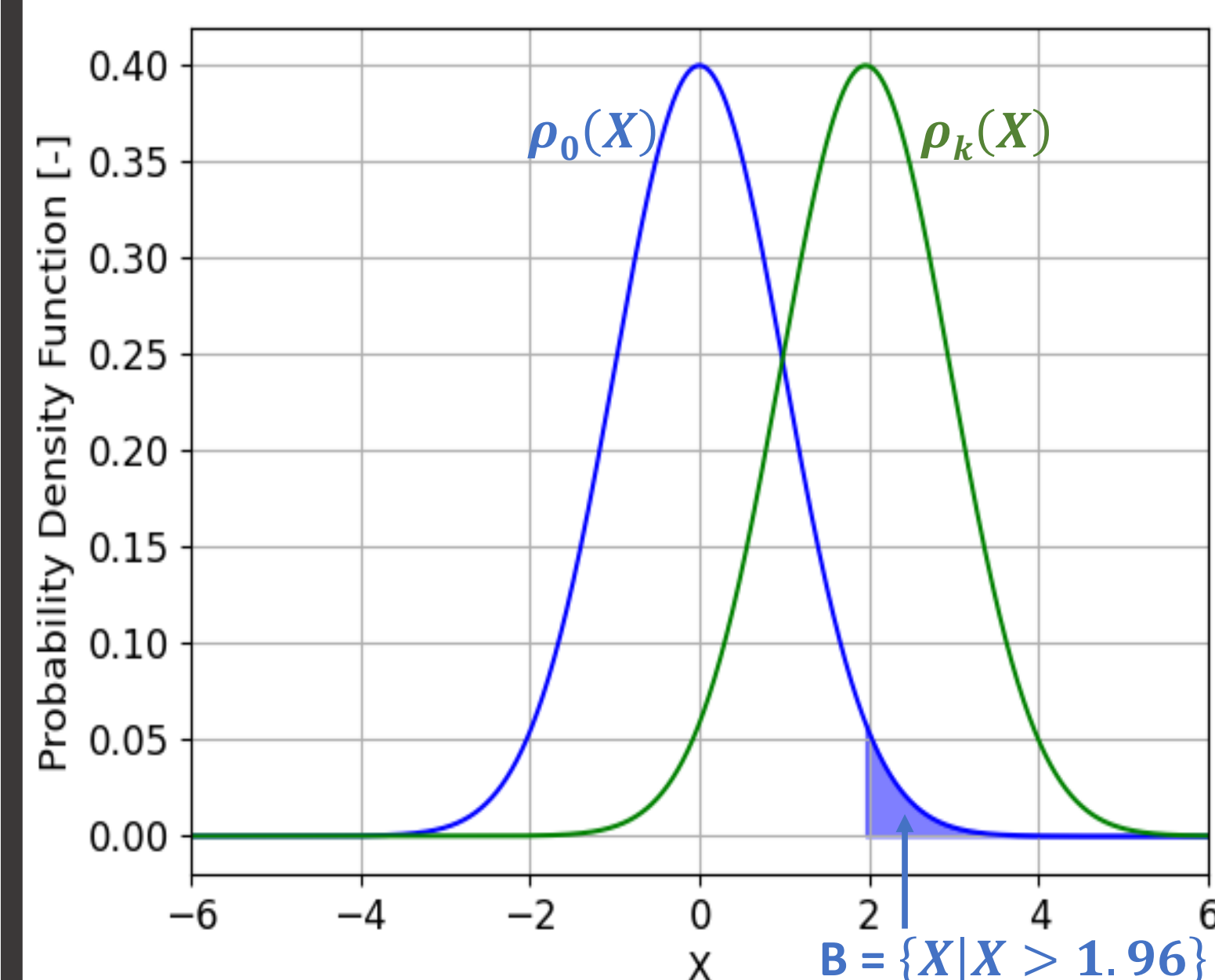
Rare event algorithm to oversample rare dynamical trajectories leading to extreme events



Rare event algorithm

Importance sampling

- Make rare events more common to reduce the uncertainty of an estimator



- Example:** Estimate

$$P(B) = \int \mathbf{1}_B(X) \cdot \rho_0(X) dX$$

by drawing data from ρ_k instead of ρ_0 according to

$$P(B) = \int \mathbf{1}_B(X) \cdot \frac{\rho_0(X)}{\rho_k(X)} \rho_k(X) dX \approx \frac{1}{n} \sum_{k=1}^n \mathbf{1}_B(X_k) \cdot \frac{\rho_0(X_k)}{\rho_k(X_k)}$$

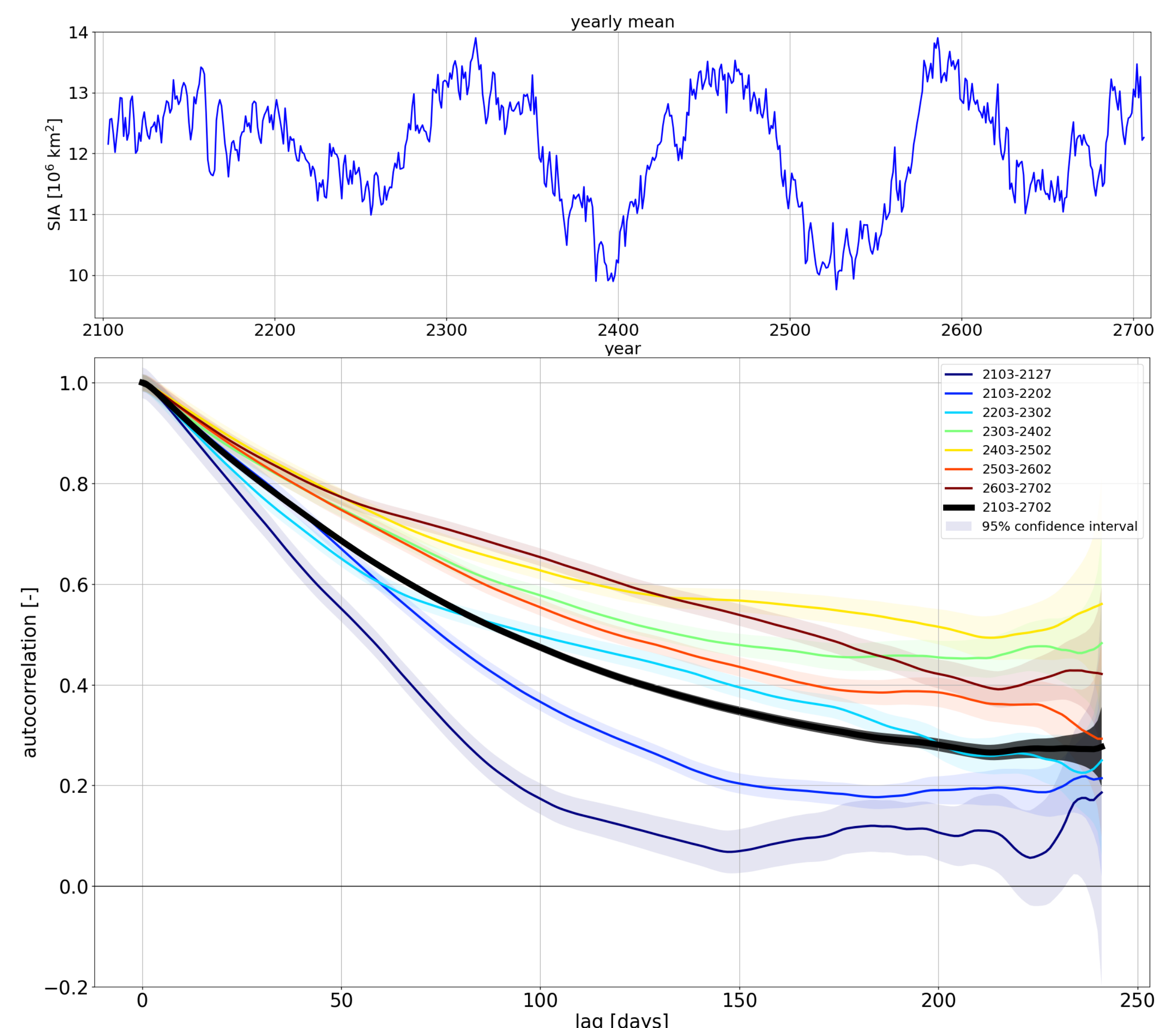
Application to climate model ensemble

- Importance sampling** at the level of **model trajectories** $\{X(t)\}_{0 \leq t \leq T_a}$ with **observable** $A(X(t))$
- The original **trajectory distribution** P_0 is shifted towards a new **distribution** P_k such that **extreme events** become **common**

$$P_k(\{X(t)\}_{0 \leq t \leq T_a}) \xrightarrow{N \rightarrow \infty} \frac{e^{k \int_0^{T_a} A(X(t)) dt}}{E_0[e^{k \int_0^{T_a} A(X(t)) dt}]} P_0(\{X(t)\}_{0 \leq t \leq T_a})$$

- Resampling** of **ensemble trajectories** with **killing-cloning procedure** at **regular intervals** in the order of the **integrated autocorrelation time** of $A(X(t))$

Persistence of pan-Arctic sea ice area anomalies



Daily pan-Arctic sea ice area [10^6 km^2] in a pre-industrial CMIP6-EC-Earth3 simulation: (Top) Time series of the annual averages and (bottom) autocorrelation function applied to the daily data between February and September.

- Autocorrelation function** decays with an **e-folding time scale** of about **140 days**
- The **inherent persistence** of sea ice area anomalies is likely **overestimated** due to a remaining effect of **low-frequency variability** in the data

References

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- Ragone, F., J. Wouters, and F. Bouchet, 2018. Doi: 10.1073/pnas.1712645115
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