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

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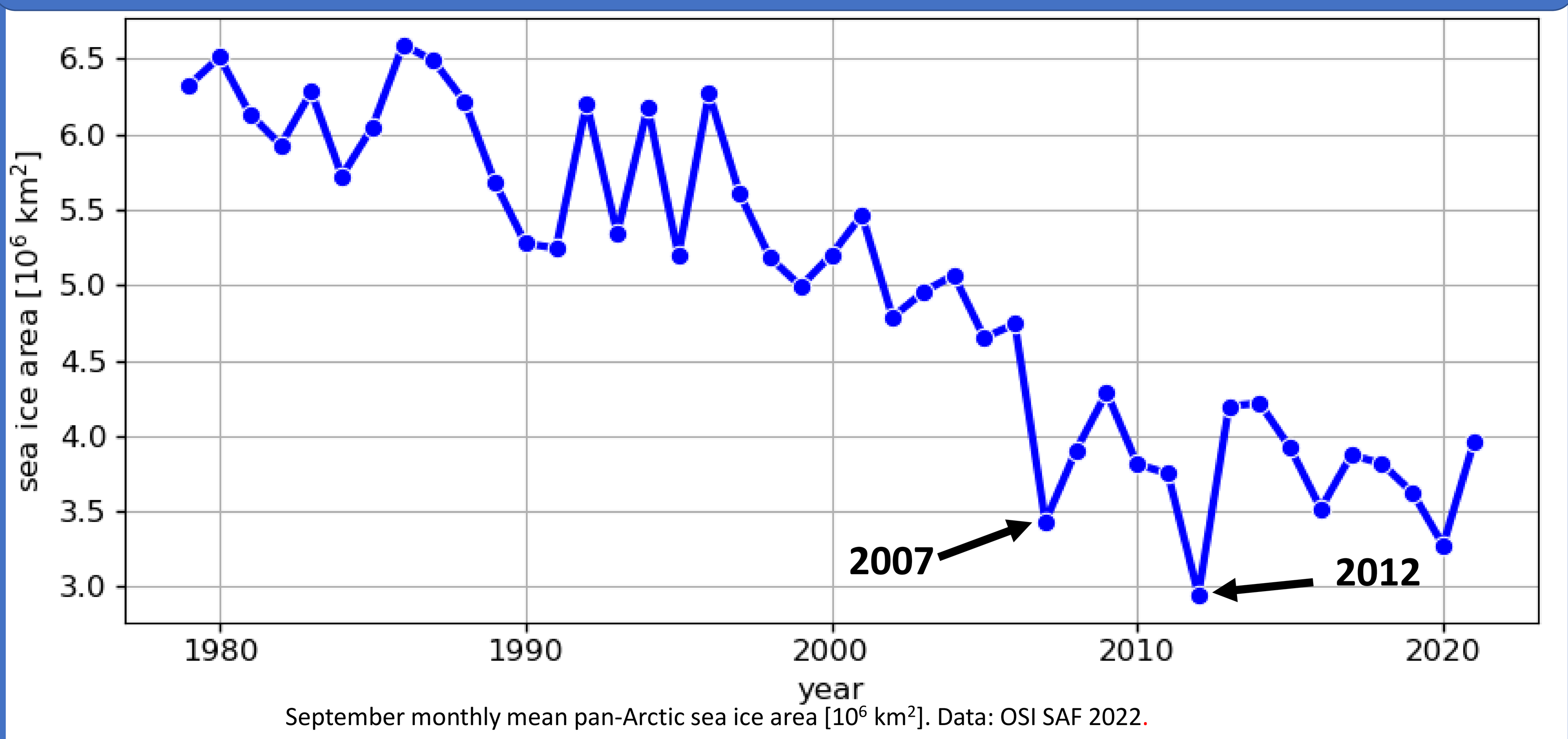
Extreme events in summer Arctic sea ice cover



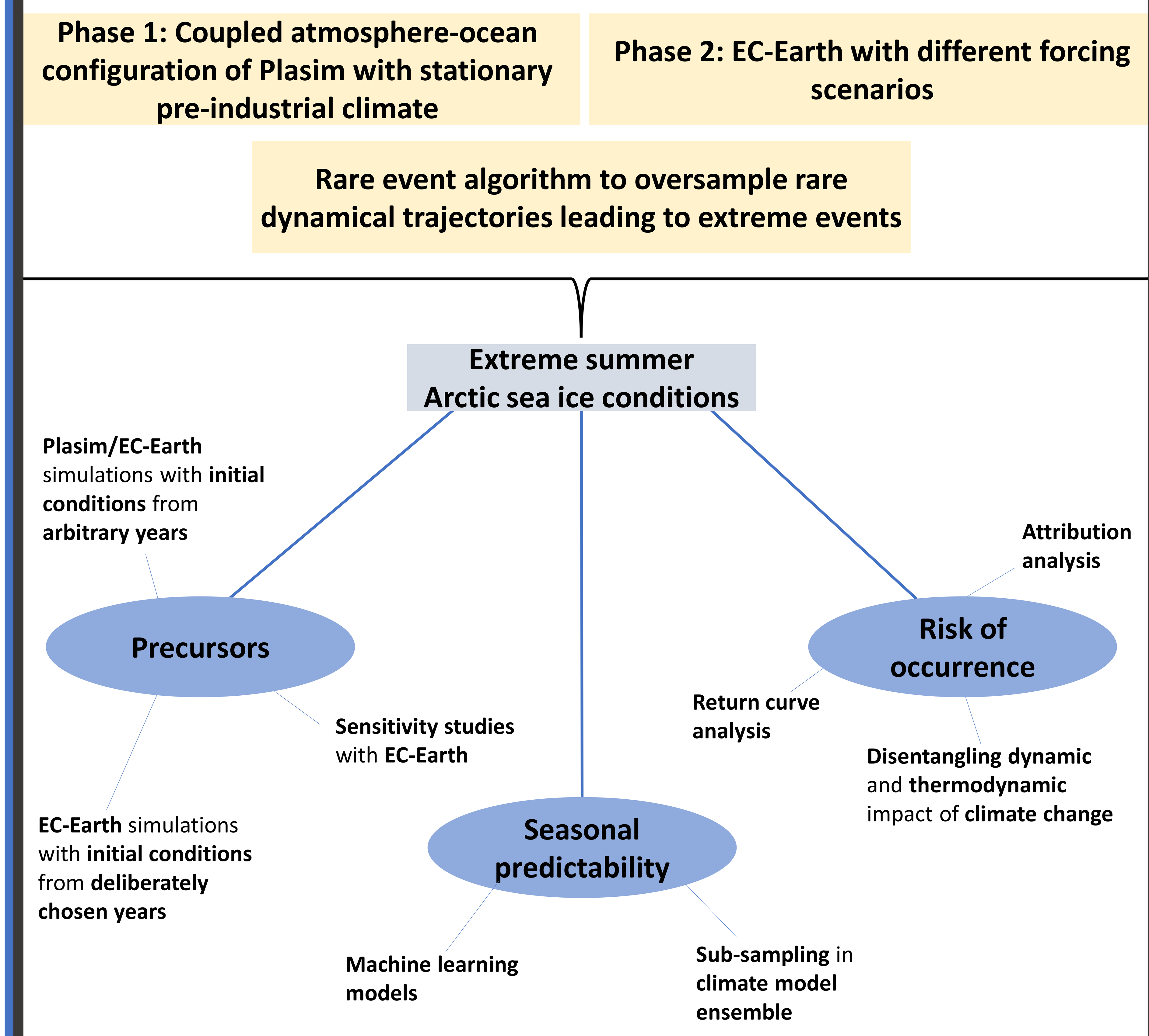
September monthly mean pan-Arctic sea ice area [10^6 km^2]. Data: OSI SAF 2022.

- 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?**

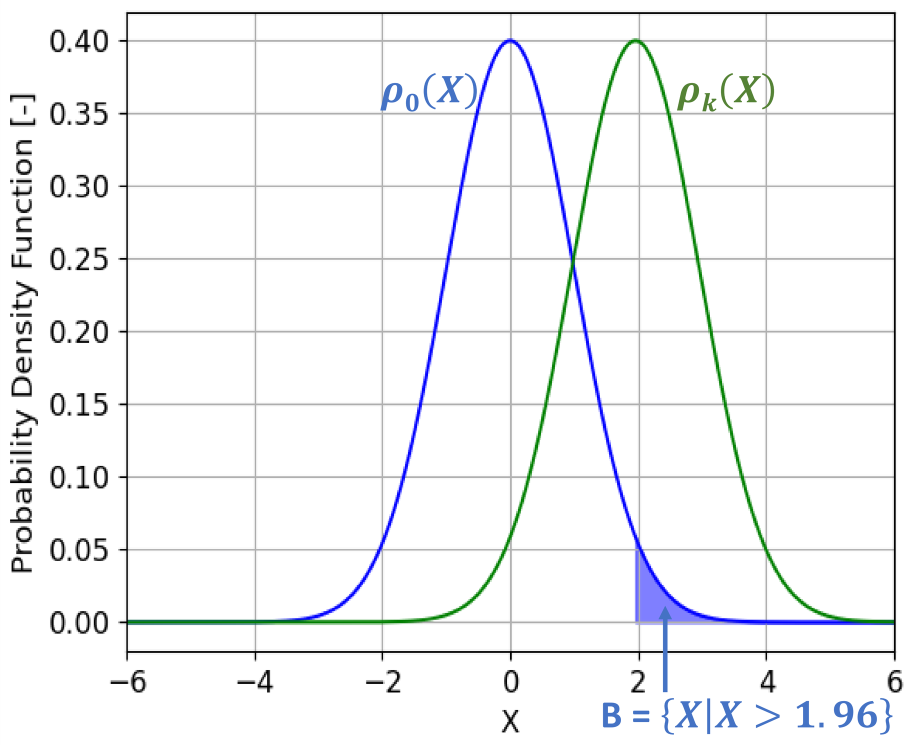
Project overview



Rare event algorithm

Importance sampling

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



- **Example:** Estimate

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

by drawing data from ρ_k instead of ρ_0 according to

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

$$\approx \frac{1}{n} \sum_{k=1}^{n} 1_B(X_k) \cdot \frac{\rho_0(X_k)}{\rho_k(X_k)}$$

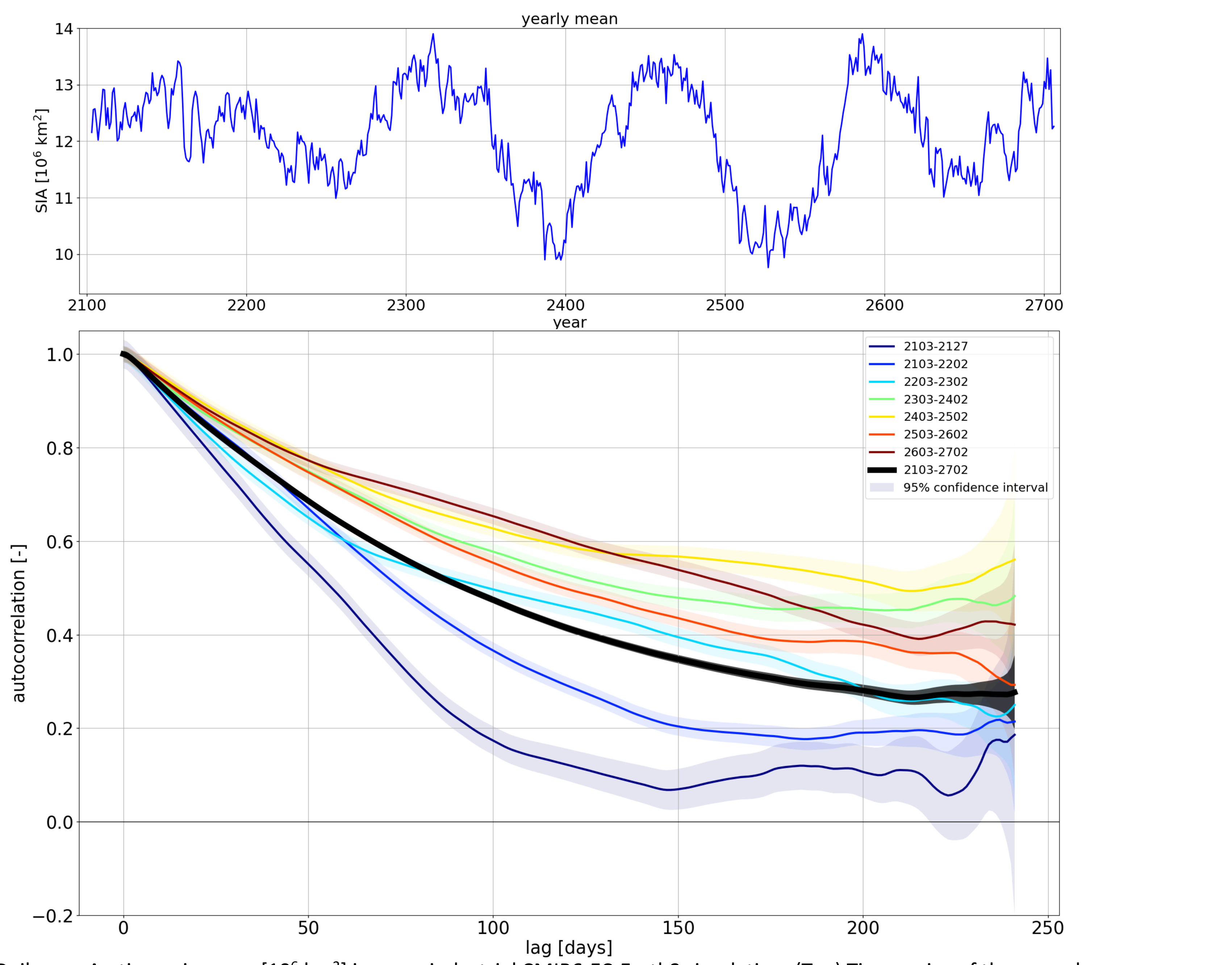
Application to climate model ensemble

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

$$P_k(\{X(t)_{0\le t \le T_a}\}) \underset{N \to \infty}{\sim} \frac{e^{k\int_0^{T_a} A(X(t))dt}}{E_0[e^{k\int_0^{T_a} A(X(t))dt}]} \mathbf{P_0}(\{\mathbf{X(t)}\}_{0 \le t \le T_a})$$

- **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 variabiltiy** in the data

References

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