Étude de saisons caniculaires extrêmes en Asie du Sud à l'aide d'un algorithme d'événement rares

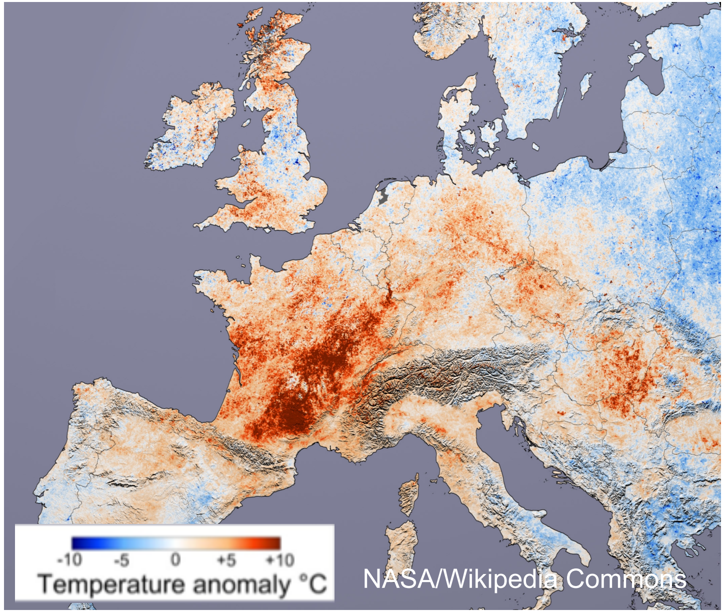
Clément Le Priol[1,2],
with Joy M. Monteiro[3,4], Freddy Bouchet[2]

Journées du GDR « Défis théoriques pour les Sciences du Climat », Grenoble, 27 mai 2024

[1] Laboratoire de Physique à l'ENS de Lyon, Lyon, France
[2] Laboratoire de Météorologie Dynamique, IPSL, ENS-PSL, CNRS, Paris, France
[3] Department of Earth and Climate Science, IISER Pune, Pune, India
[4] Department of Data Science, IISER Pune, Pune, India

Extremely rare events matter

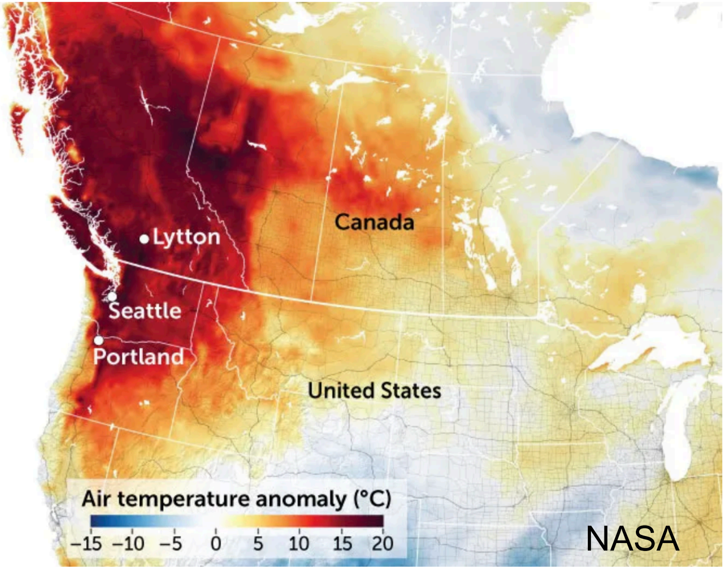
2003 West European heatwave



July 20 - August 20
temperature anomaly

2021 Pacific Northwest heatwave

June 29, 2021 temperature compared with the 2014–2020 average for that day



NASA

Extremely rare events matter

An event that has a **return time** of **1000 years** has:

- **1/1000** chance to occur in any year

$$\mathrm{rt}(x) = 1/\mathbb{P}(X \geq x)$$

- **6%** chance to occur in the next **60 years**.

(In a stationary climate)

Difficulties in studying extremely rare events

- **Observational records** (60-150 years)**: Too short** for observing most events but **useful for GEV/GPD fits**

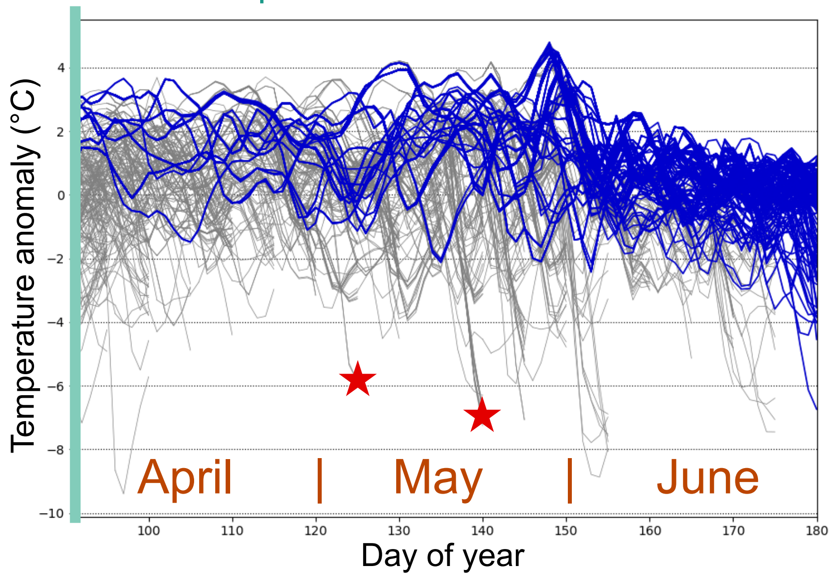
- **Climate models:** Obtaining **good statistics** on events that have a **return time of centuries** using direct simulations requires **millennia of simulation** -> extremely **large computation cost** with the best models

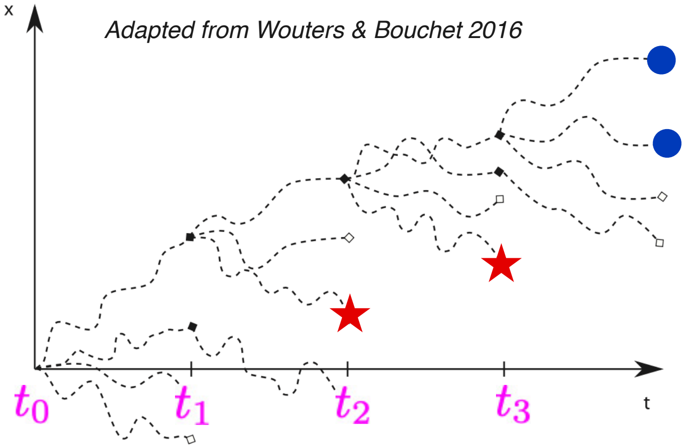
- **How to sample extremely rare events in climate models?**
—> Rare event algorithms

Rare event algorithm's principle

Duplicate the trajectories most likely to produce the desired event, **eliminate** the others (*resampling step*).

Initialization April 1st





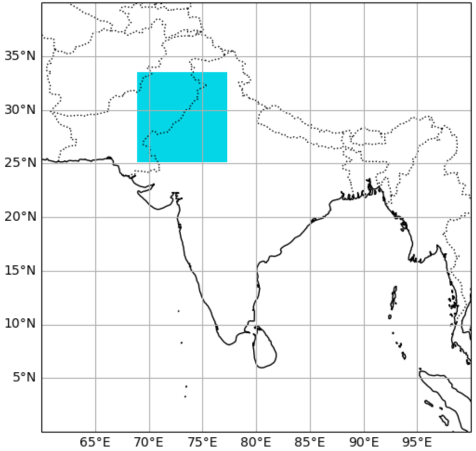
N=200 trajectories (constant)

Resample every 5 days

Total integration time: 90 days (3 months)

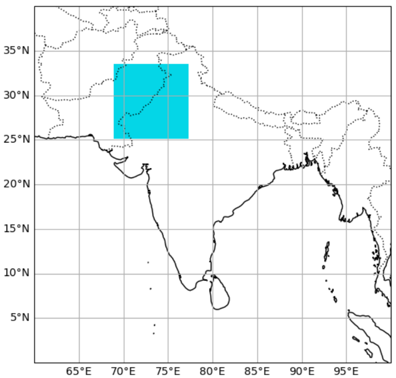
Application: extreme heatwave seasons in South Asia

- Heatwave season = pre-monsoon season (March to June)
- We want to sample extrema of April-May-June (AMJ) averaged temperature



Choice of the score function

- We resample according to weights W_n assigned to each trajectory
- The computation of the weights relies on a **score function** $W\left(\{x(t)\}\right)$
- A good score function, tailored to the events of interest, is **crucial** to the effectiveness of the algorithm.

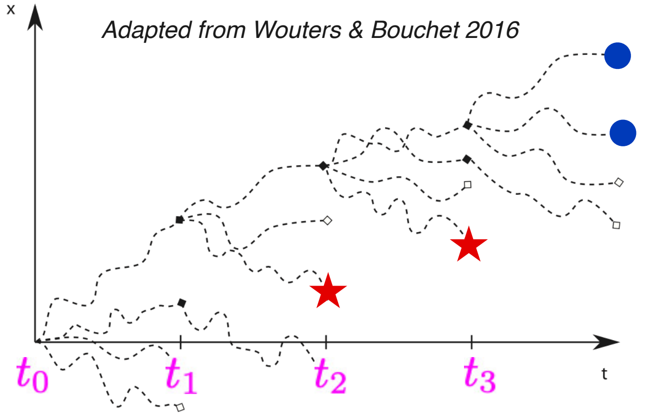


We want to sample extremes of $\tilde{A}\left(\{x(t)\}\right) = \frac{1}{T}\int_{\mathrm{AMJ}} A(x(t))dt\,,\; T = 90\text{ days}$

where $A\left(x(t)\right) = \frac{1}{\mathcal{A}}\int_{Area} T_{2m}(\mathbf{r},t)\mathbf{dr}$

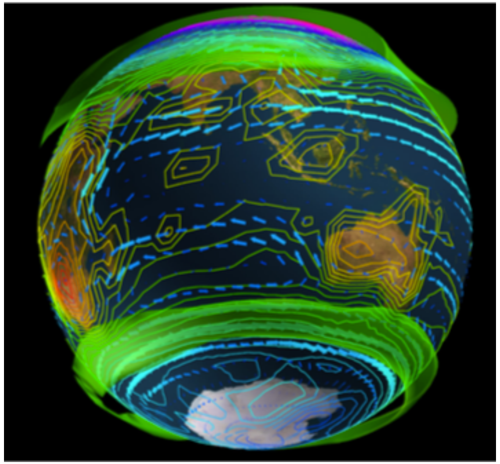
Score function suited for long-lasting extremes:

$$W\left(\{x(t)\}_{t_i \le t \le t_{i+1}}\right) \propto \exp\left(k\int_{t_i}^{t_{i+1}} A\left(x(t)\right)dt\right)$$



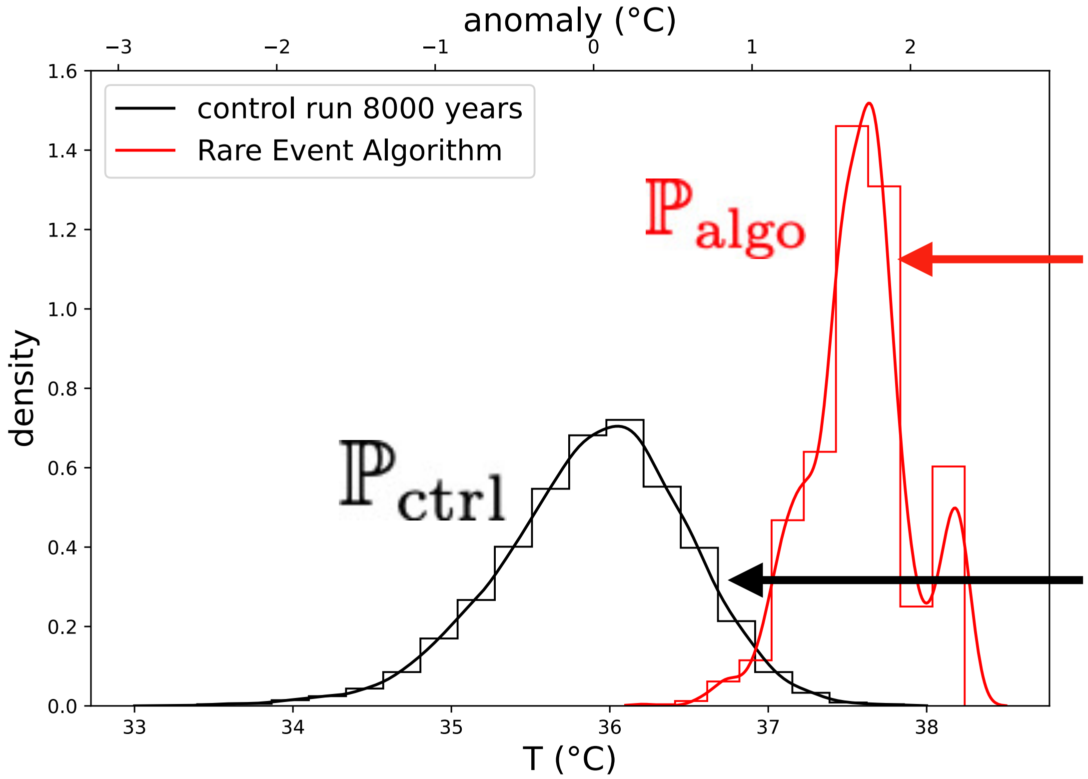
Model used: PlaSim

- **Land-atmosphere coupling configuration.**
- **Runs fast** (less than 1hCPU/year)
- **A control run of 1200 years** (1990's climate) provides **initial conditions** for the algorithm
- Independent **8000-year long control run**
- **Goal:** Compare the algorithm extreme event statistics with the long control run statistics.



Outcome: Sampling of extremely rare heatwave seasons

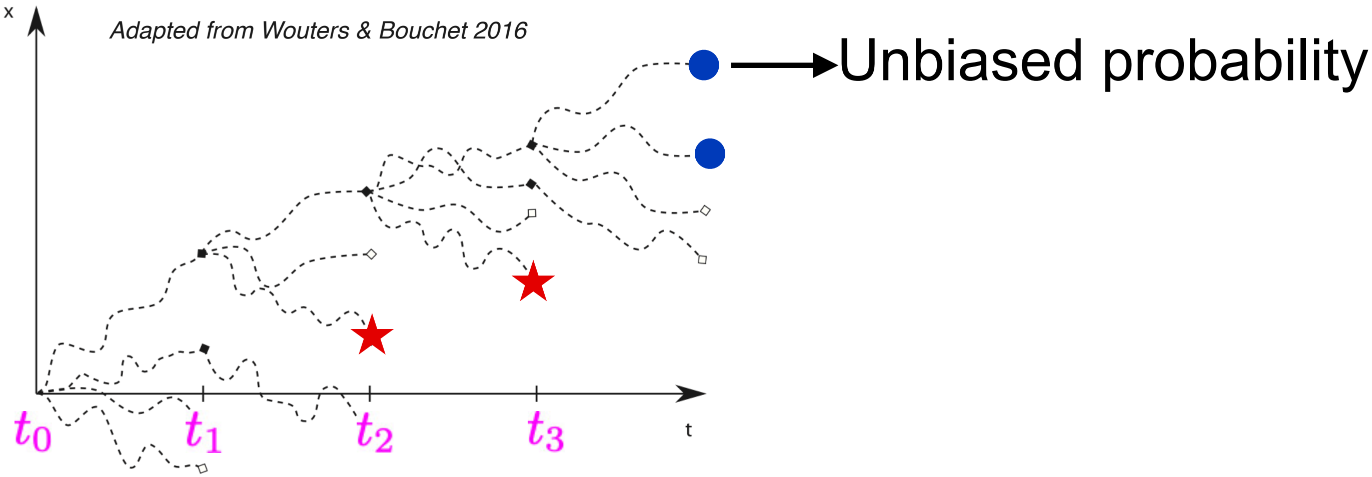
PDF of AMJ averaged temperature



Computation cost:
300 years

Computation cost:
8000 years

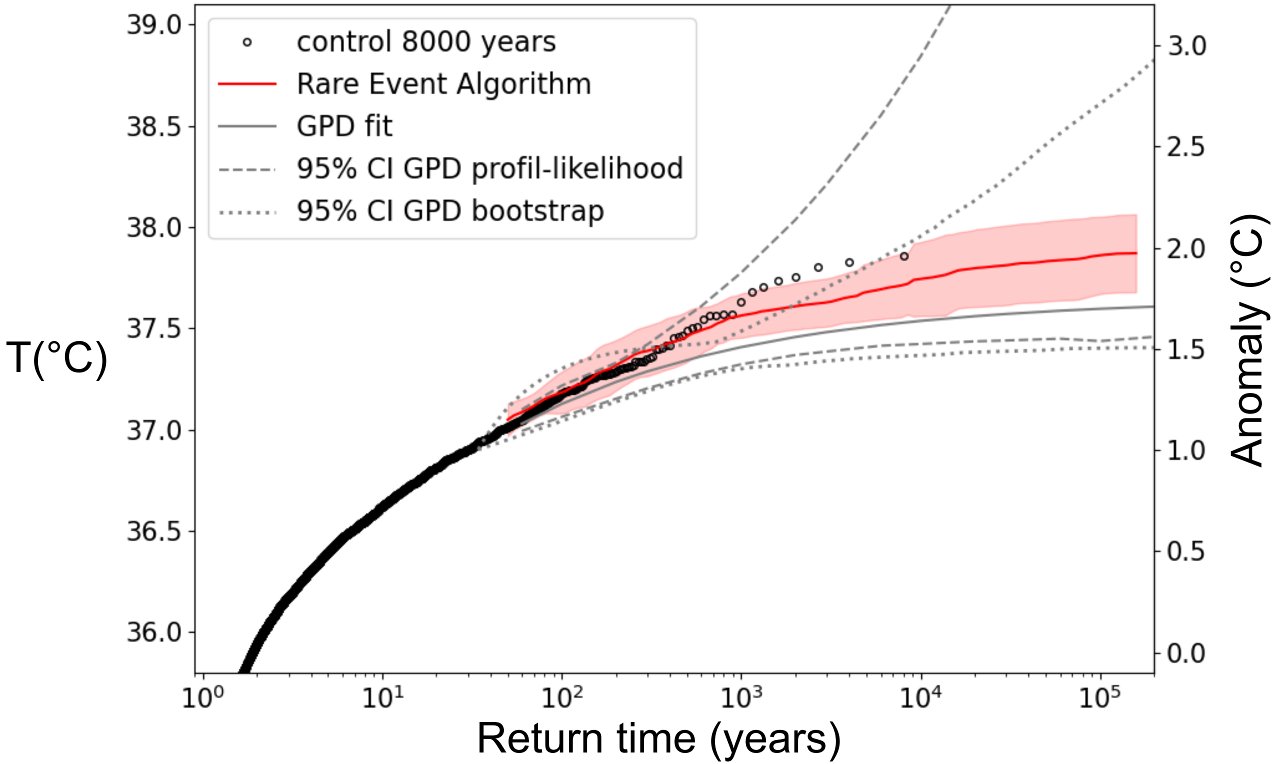
We can recover the unbiased probability of each trajectory.



The knowledge of the trajectories probabilities is crucial to compute return time curves and any other statistics

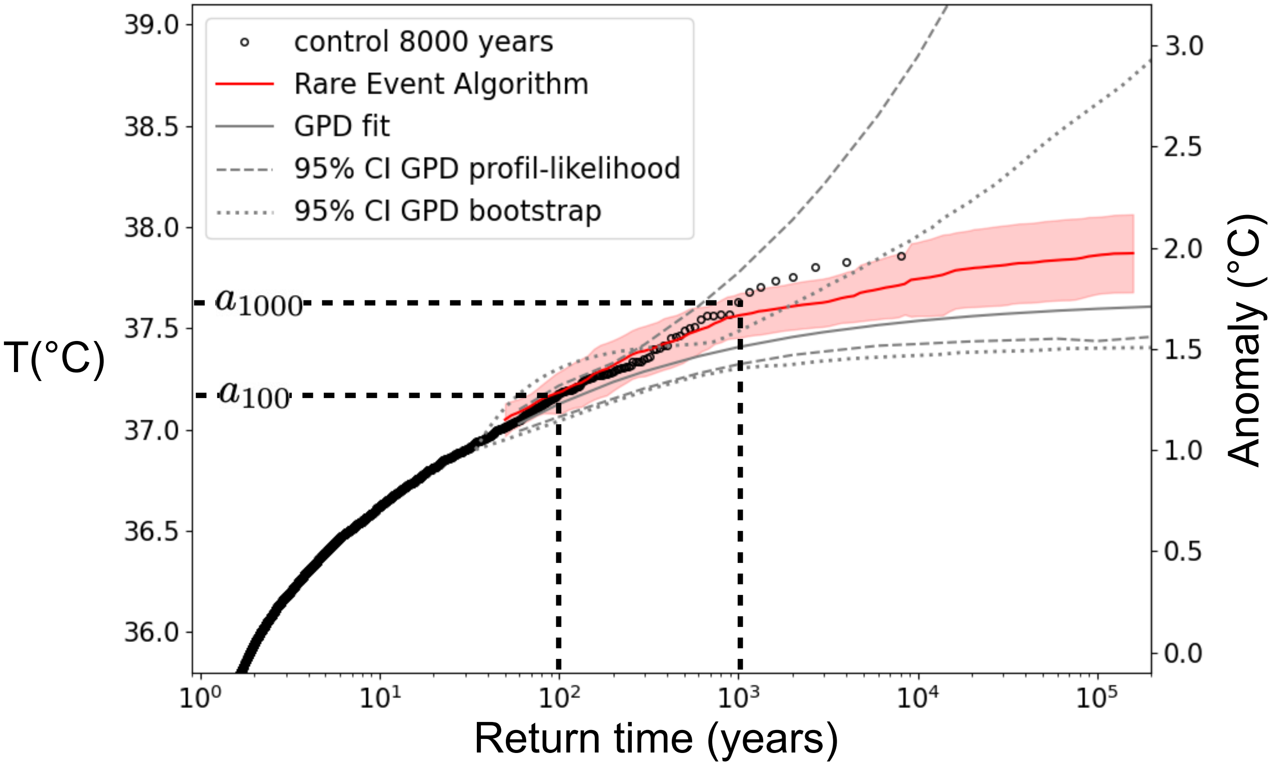
Outcome: Return time curve

AMJ averaged temperature



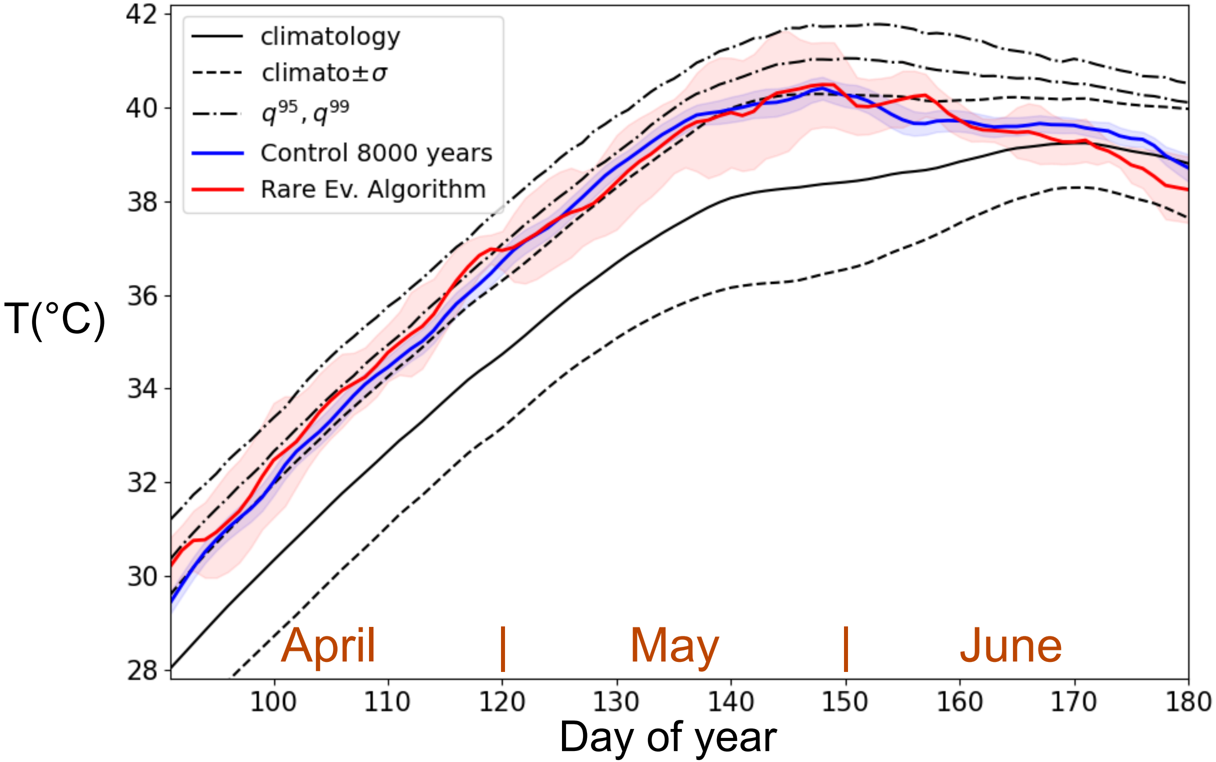
Outcome: Return time curve

AMJ averaged temperature

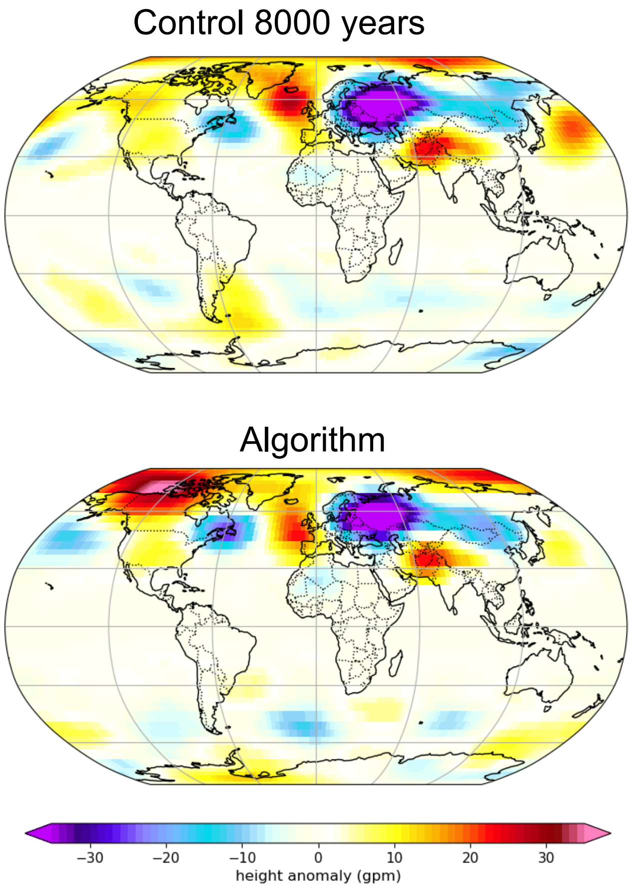


Evolution of the temperature during centennial heatwave seasons

Centennial heatwave season

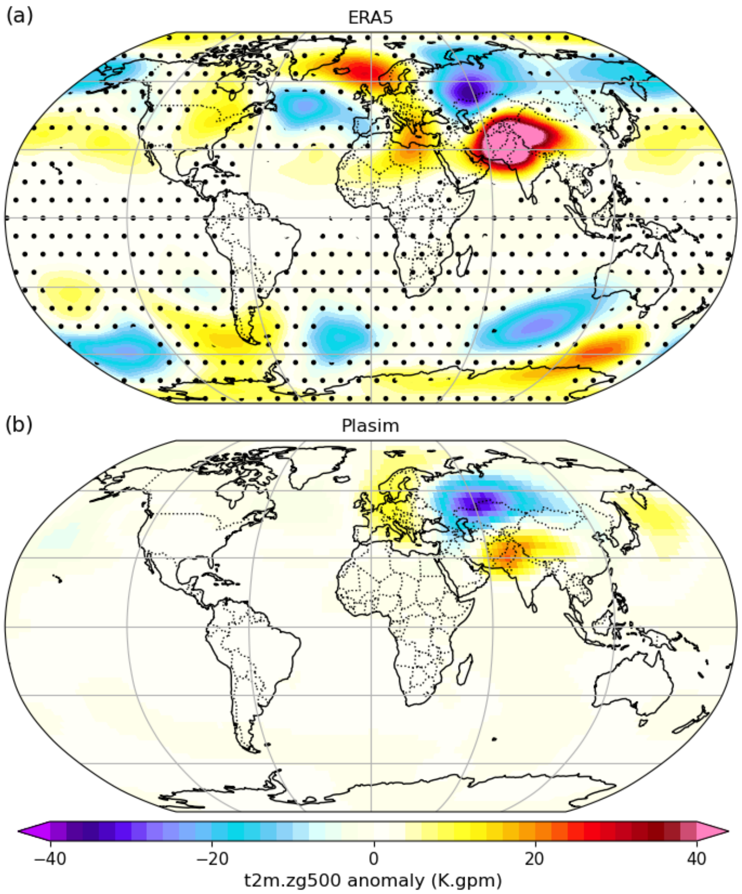


Composite maps of Zg500 AMJ anomaly



1000-year heatwave season: $T_{\mathrm{AMJ}} \geq a_{1000}$

Can we trust the teleconnection pattern of the model ?



Correlation between T2m over the study region and Zg500. MAMJ average

Perspective

Cost of running the algorithm: 300 years

but

we needed initial conditions: 1200-year long run

Solution:

Draw initial conditions from existing

Single Model Large Ensembles

Key messages

- **Extremely rare events matter**
- **Rare event algorithms can sample a large number of very extreme events**
- The **knowledge** of the trajectories **probabilities is crucial** to **compute any statistics.**
- They provide a **precise estimate** of the (model-dependent) **return time curve.**
- **Rare event simulations** could be combined with **Single Model Large Ensembles** to **explore** extremely rare events in **future warmer worlds**

Our work is on arXiv: **http://arxiv.org/abs/2404.07791**

Appendix

Algorithm experiment and computational cost

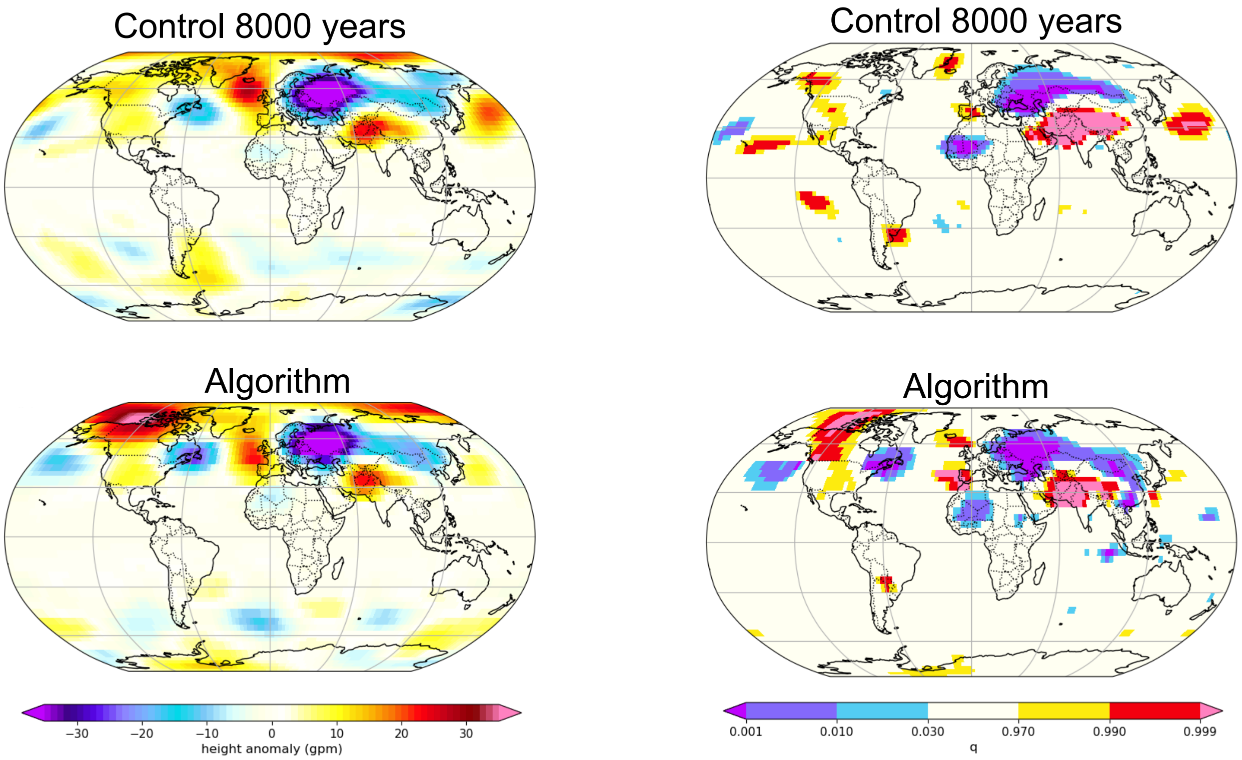
1200 independent initial conditions (April 1st)

6 algorithm experiments with N=200 trajectories running from April to June

Total computational cost: 6*200*3 months = 300 years

Composite maps of Zg500 AMJ anomaly

1000-year heatwave season: $T_{\mathrm{AMJ}} \geq a_{1000}$



Statistical significance (T-test)