Defining climate by means of an ensemble: why it is possible

Gábor Drótos, Tamás Bódai, Mátyás Herein, Tamás Tél

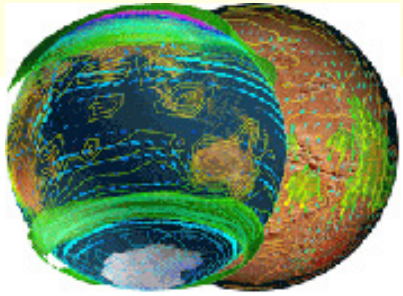
IFISC (UIB-CSIC), Palma de Mallorca, Spain,
and
MTA–ELTE Theoretical Physics Research Group, Eötvös University, Budapest, Hungary

EGU General Assembly
Vienna, 10 April 2019

Motivation

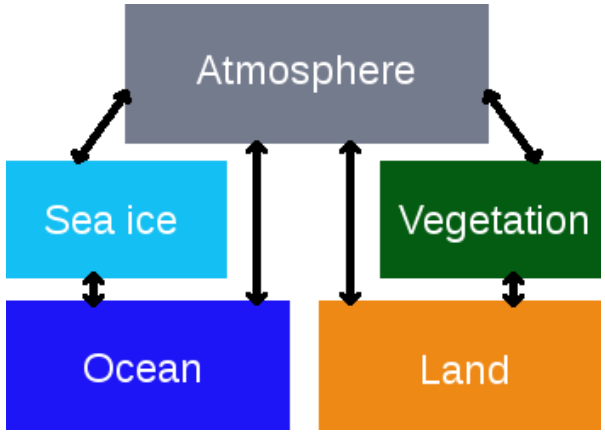
Let us define climate

A model Earth



Planet Simulator, University of Hamburg

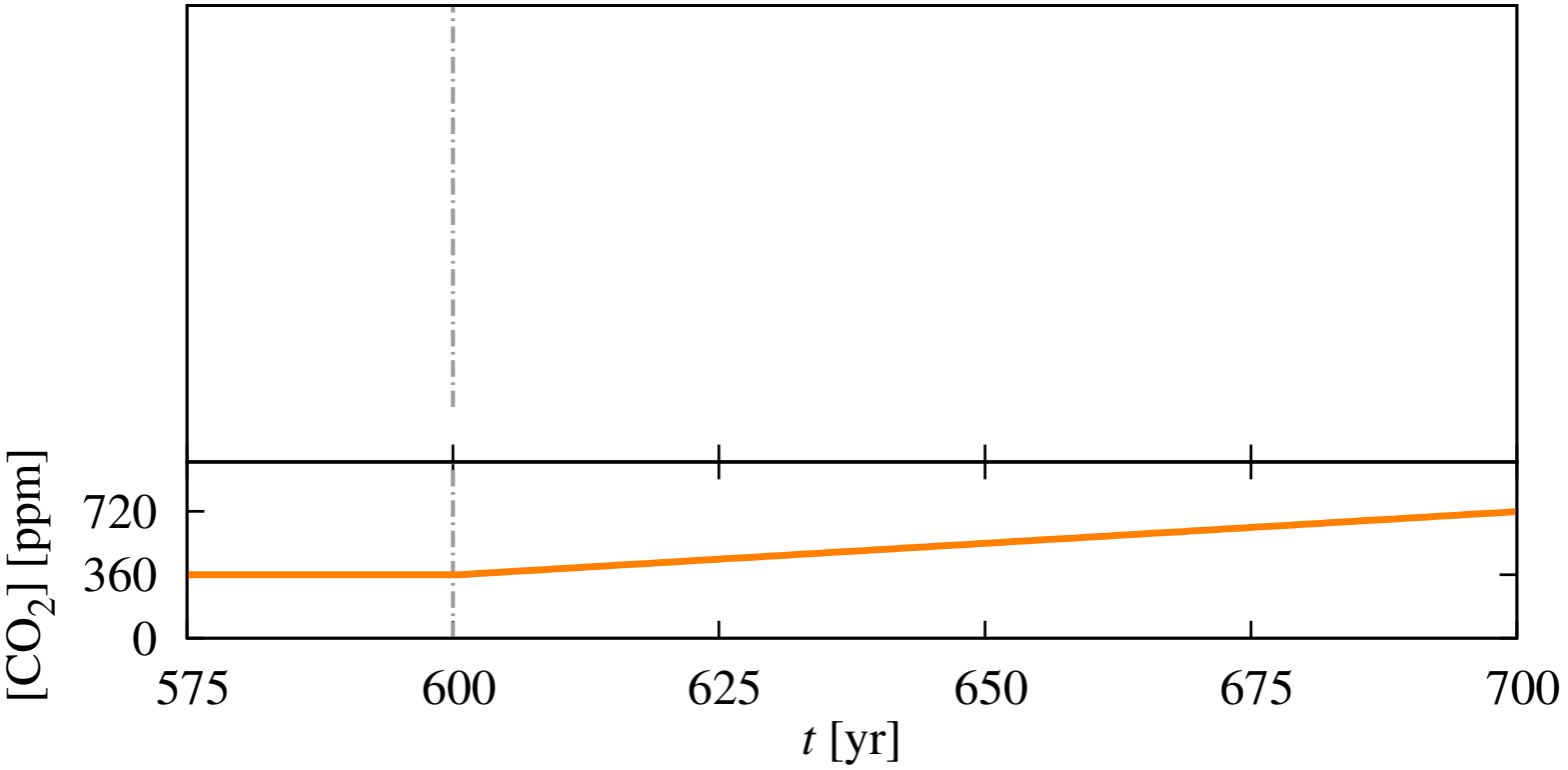
- Atmosphere: PUMA:
  conservation laws and parameterizations
- Mixed-layer ocean:
  heat and water reservoir, no fluid dynamics



Illustrative purposes

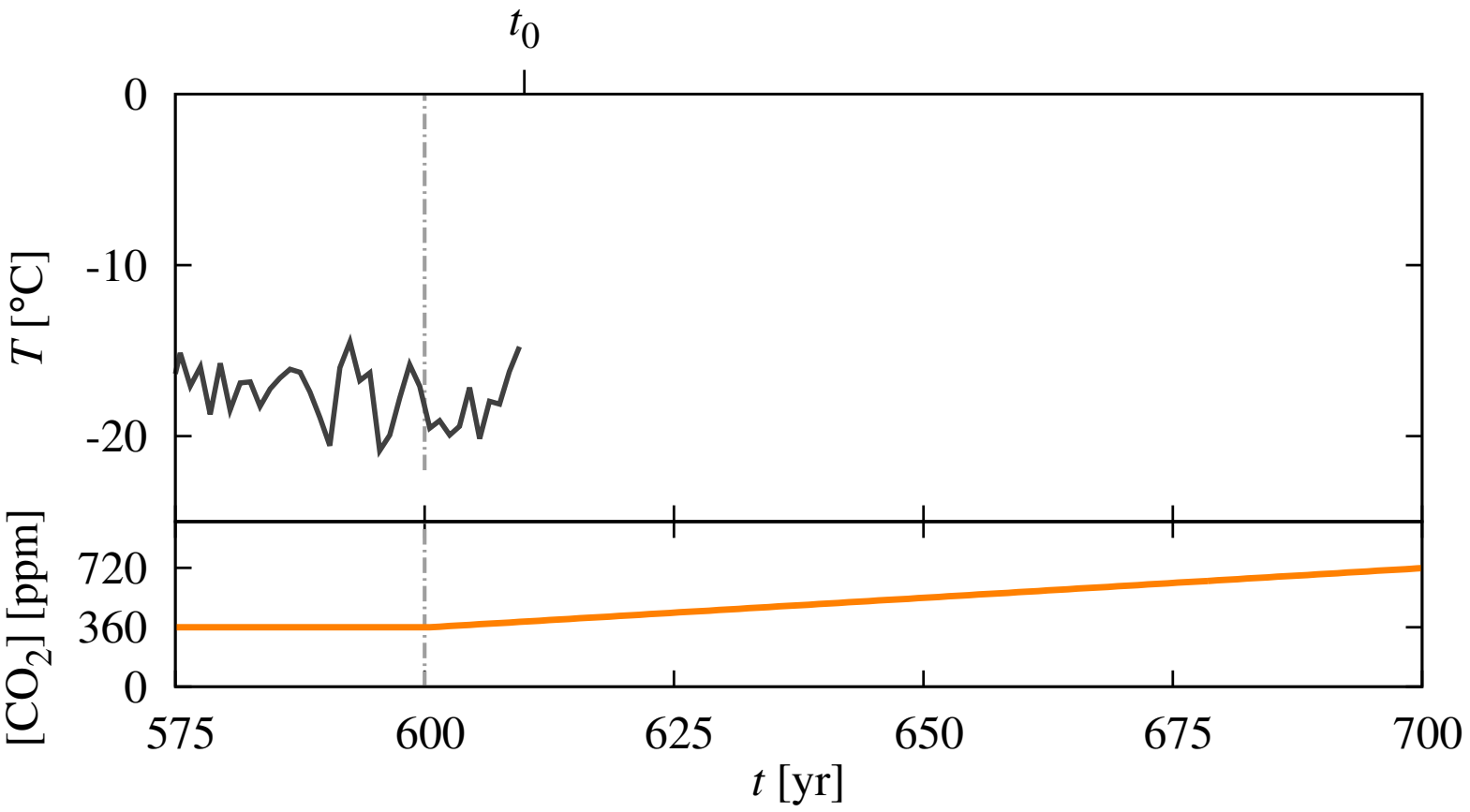
CO_2 forcing

Fixed forcing scenario



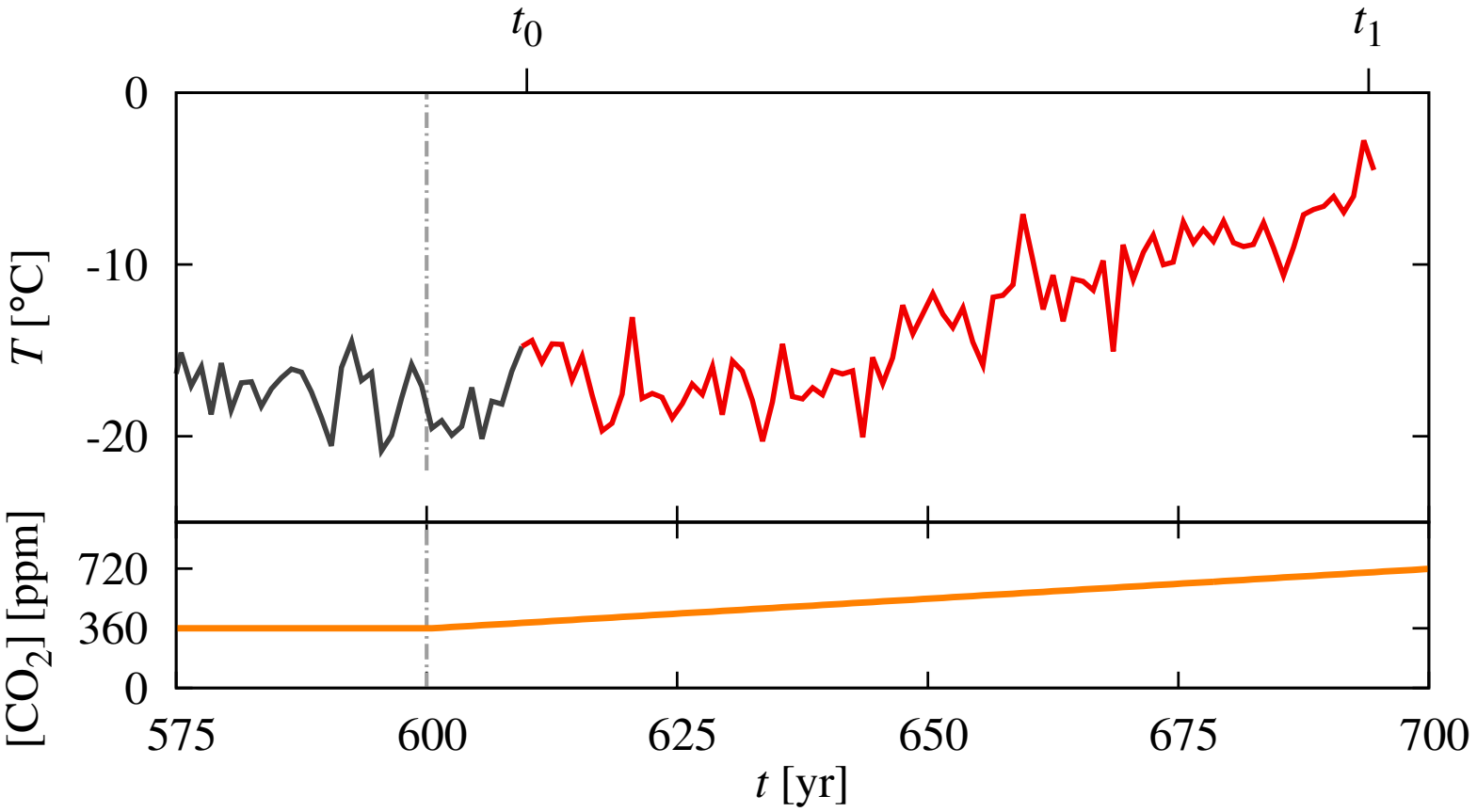
"Instrumental records"

The temperature of a grid point in the Southern Pacific

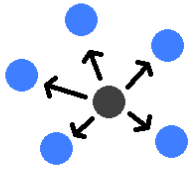


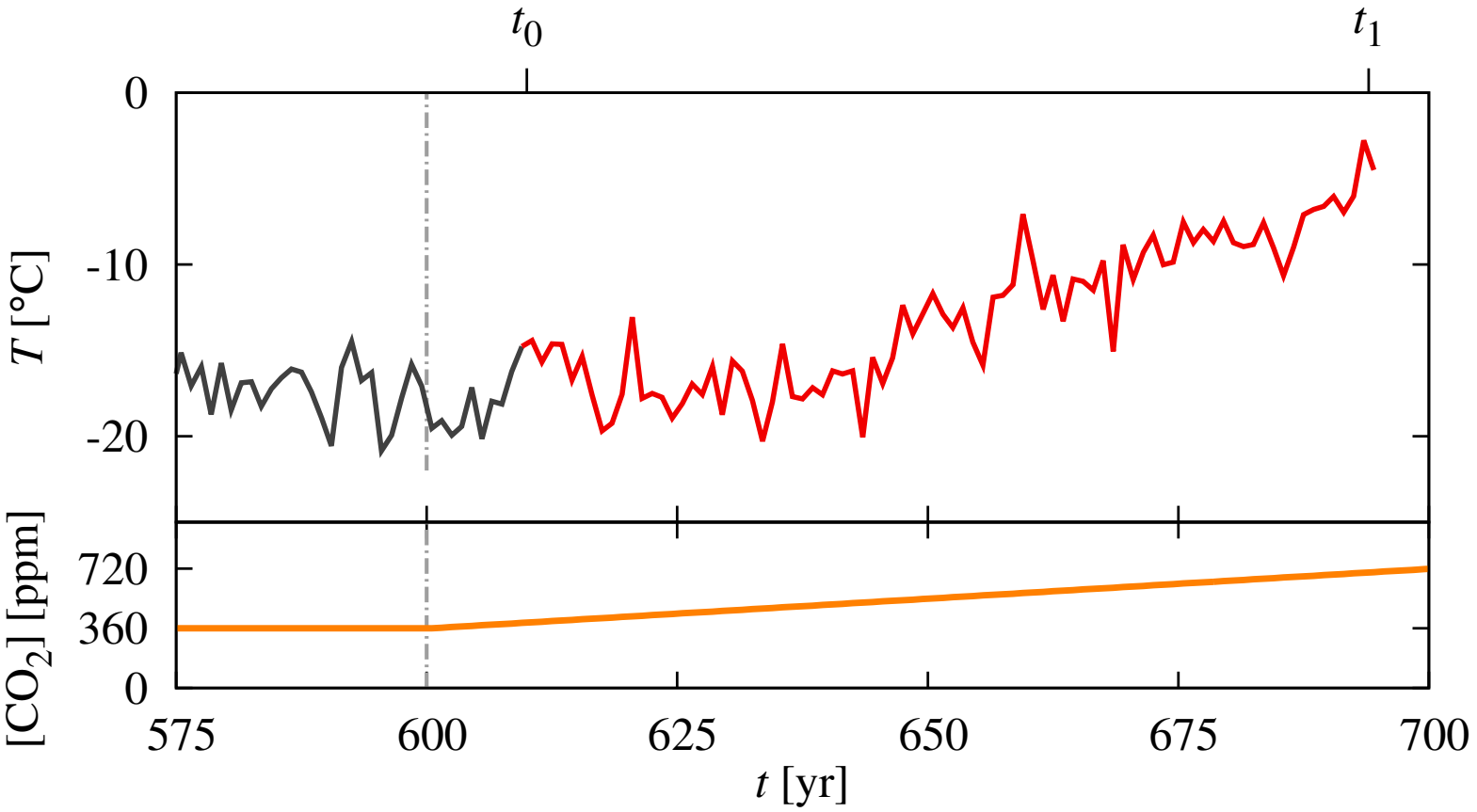
Prediction

The temperature of a grid point in the Southern Pacific

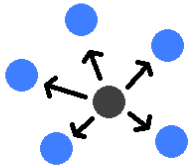


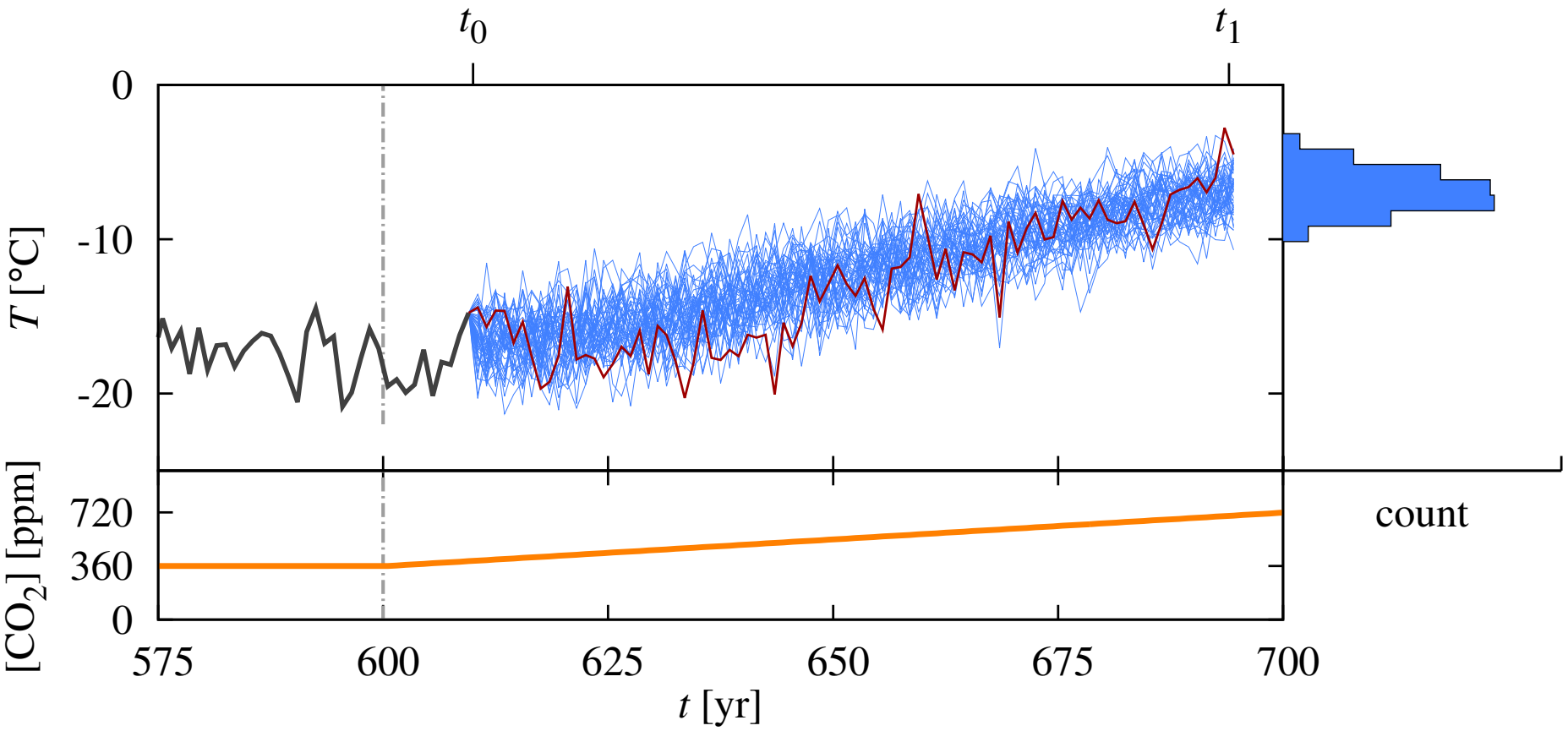
Prediction from perturbed initial conditions



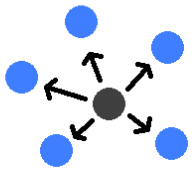


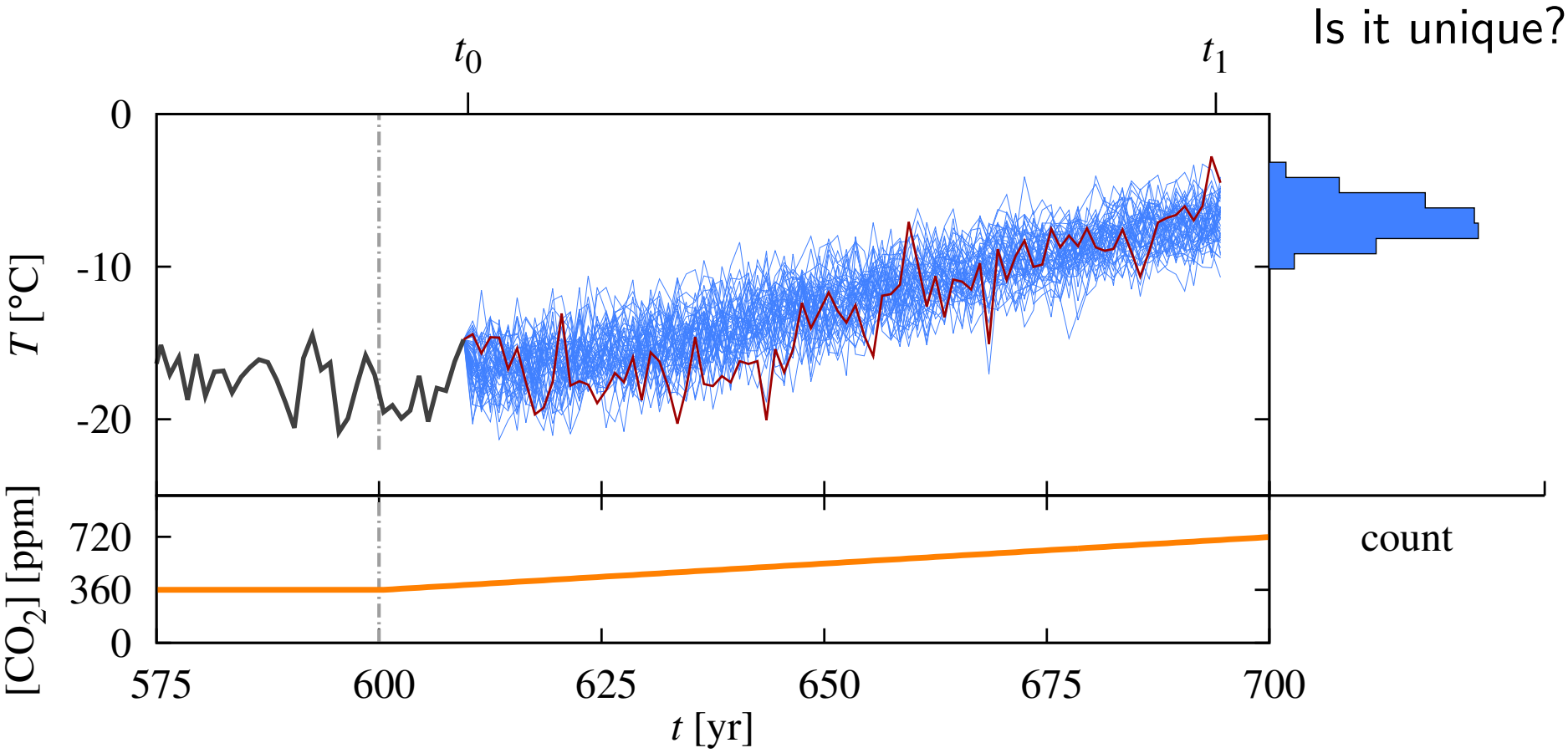
Prediction from perturbed initial conditions



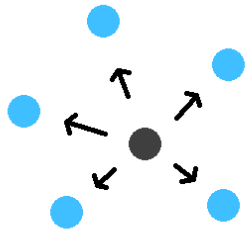


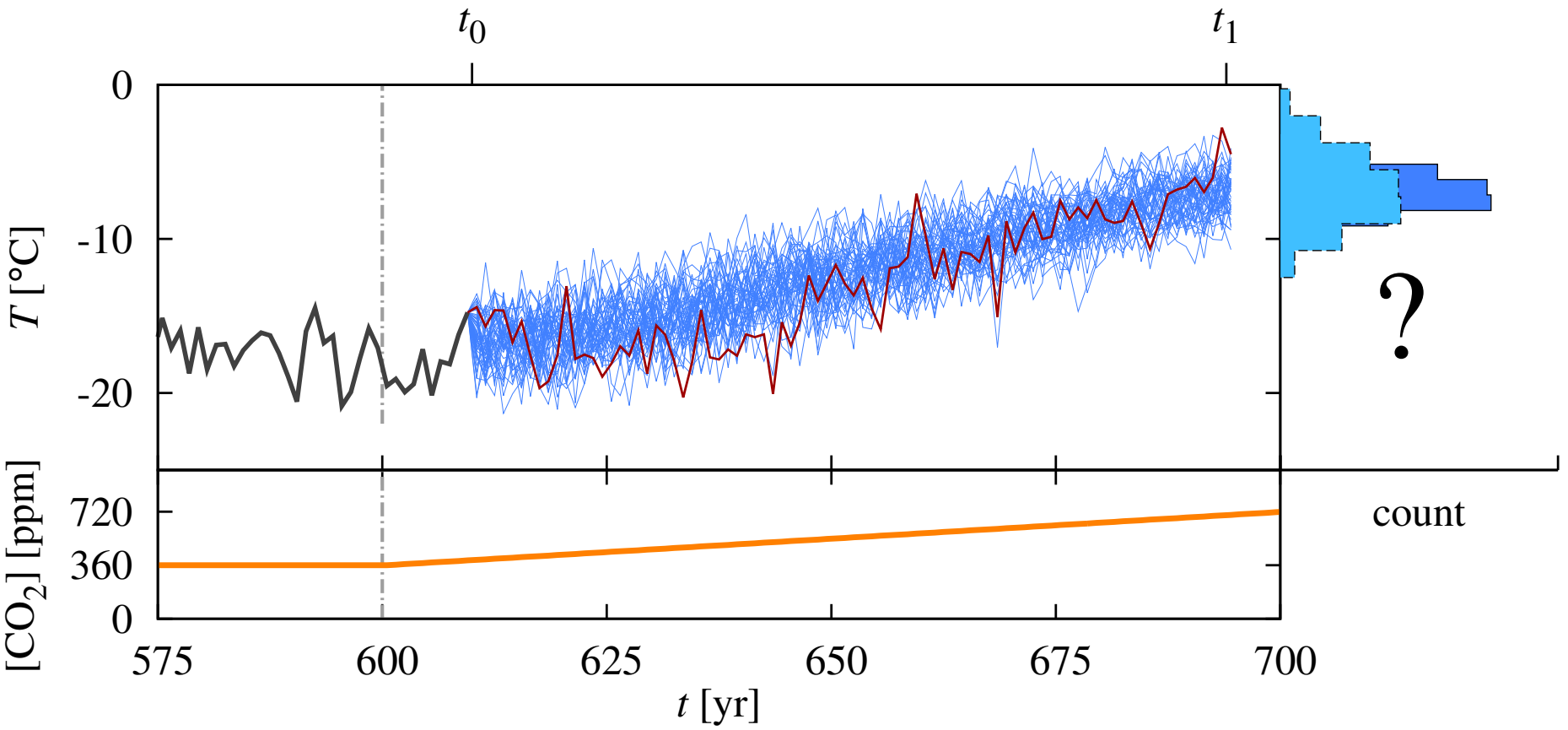
Prediction from perturbed initial conditions



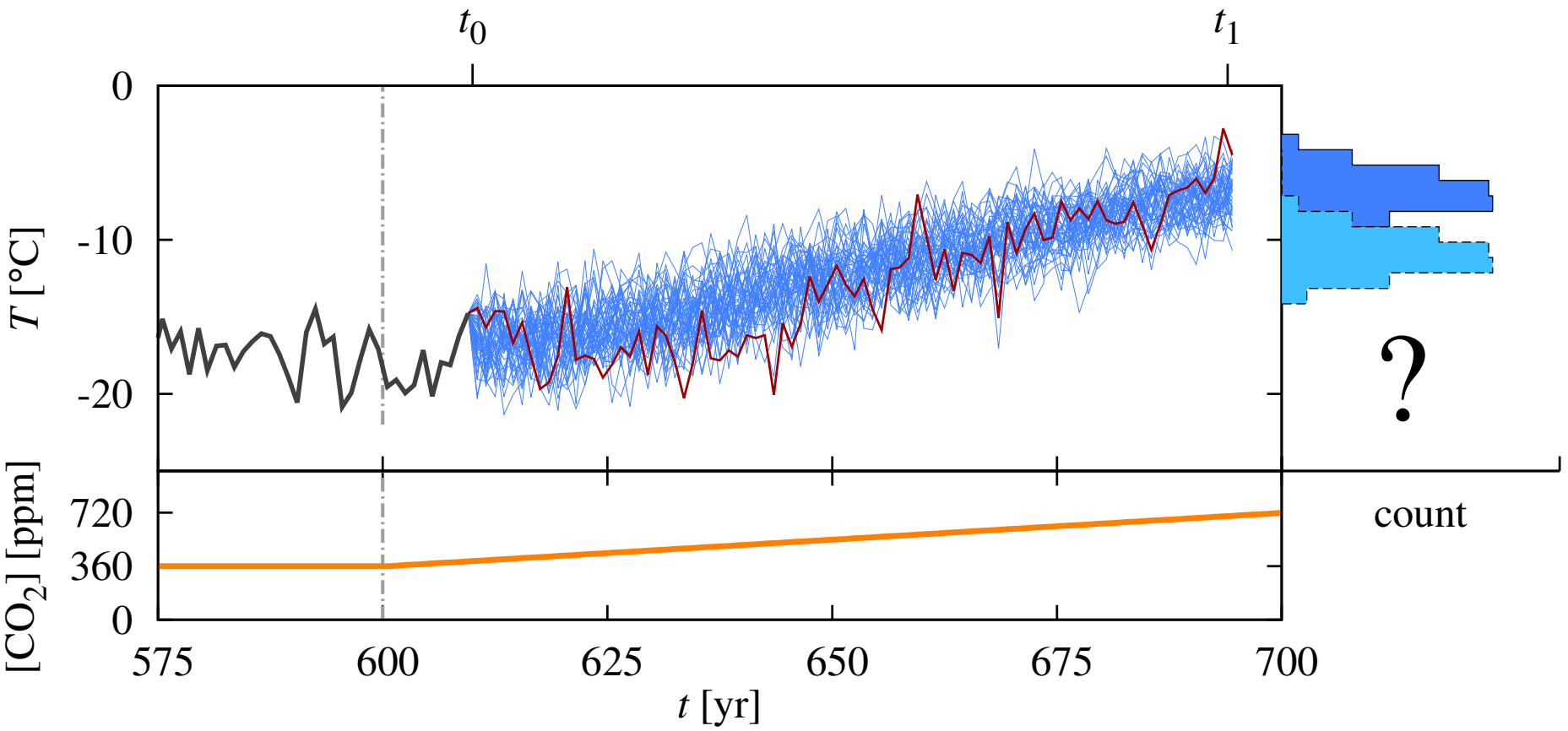


Prediction from perturbed initial conditions

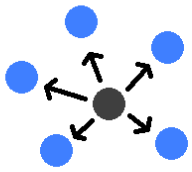


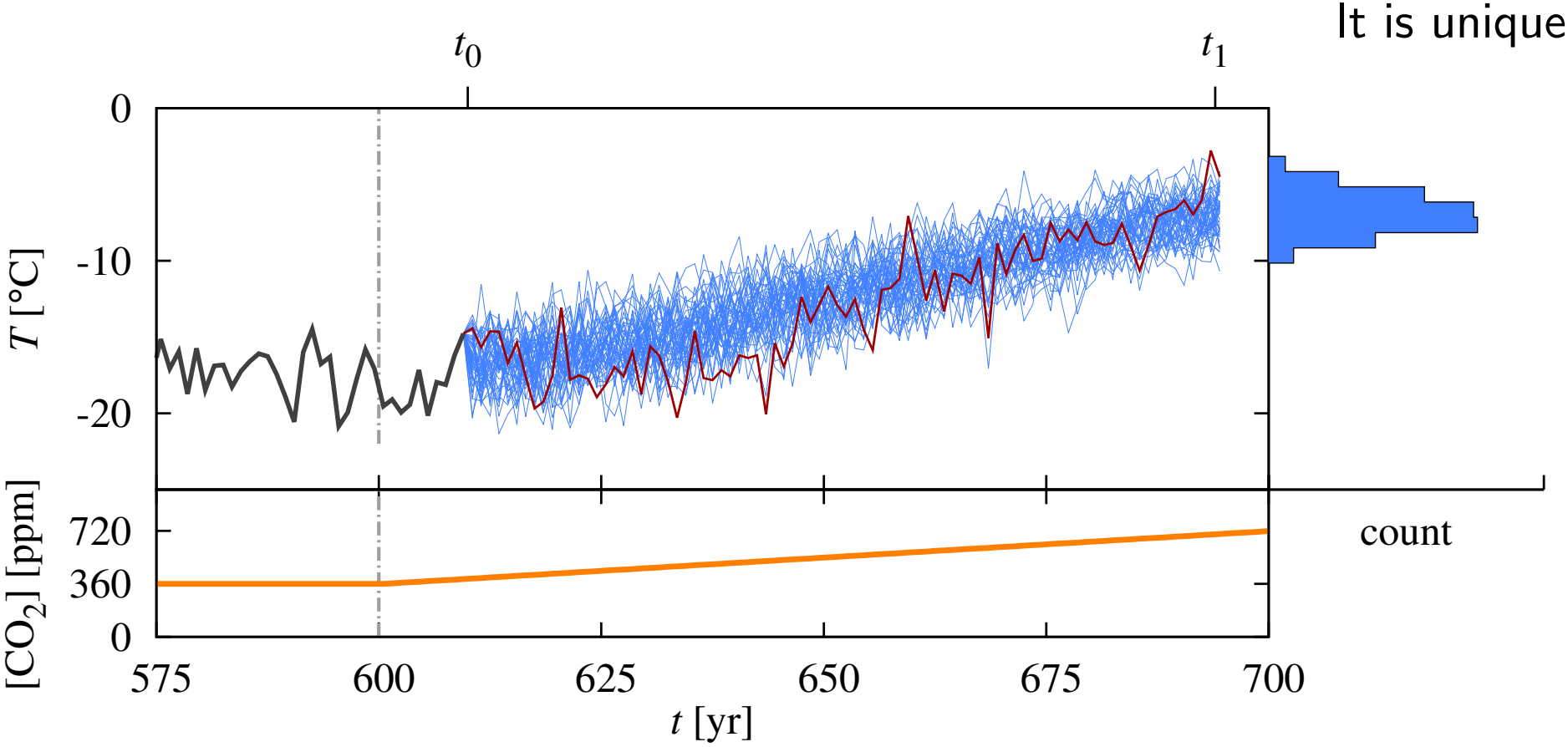


Prediction from perturbed initial conditions



Prediction from perturbed initial conditions





The attractor and its natural probability distribution

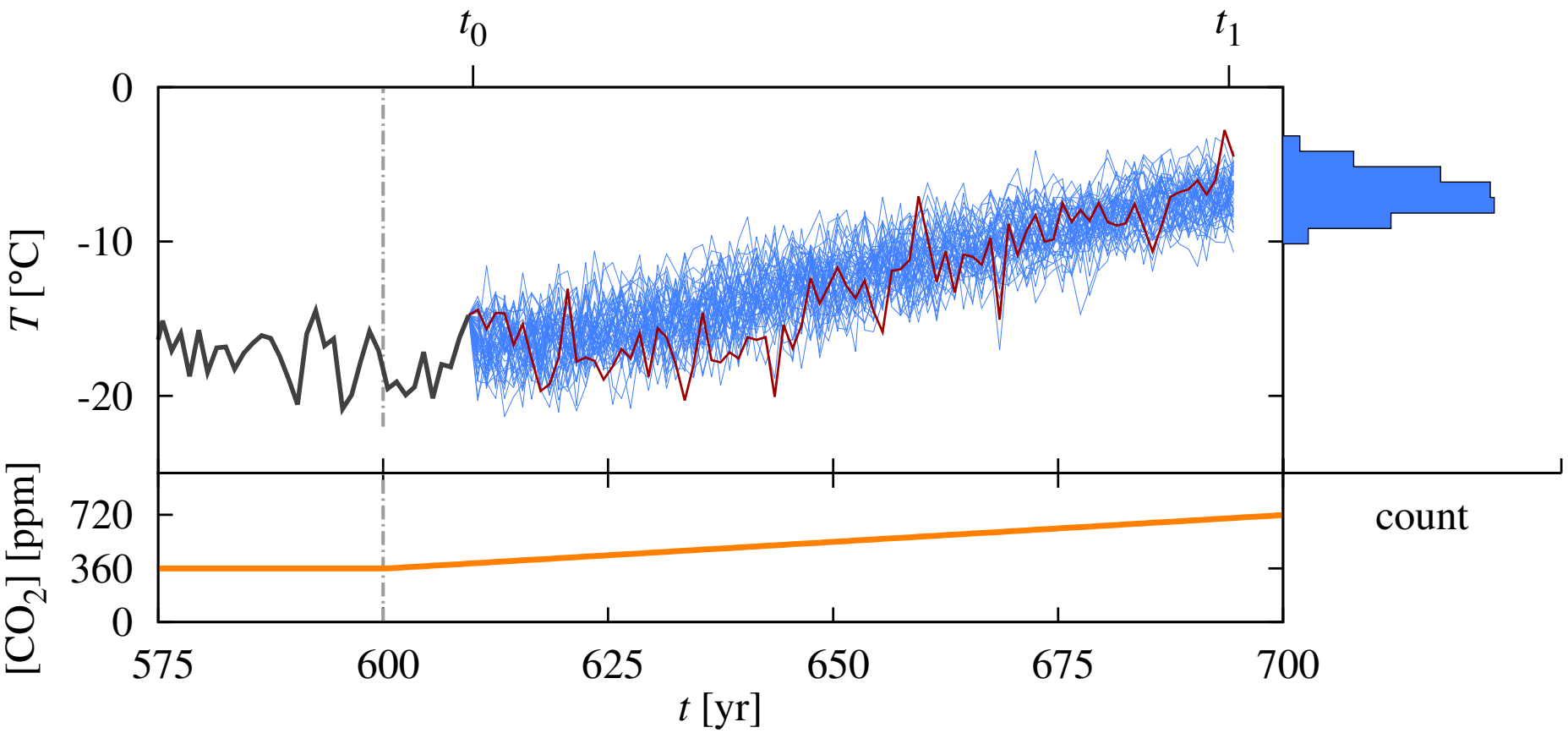
If $t_0 \to -\infty$ (and $N \to \infty$):

no dependence on initialization,

natural probability distribution of a dynamical attractor

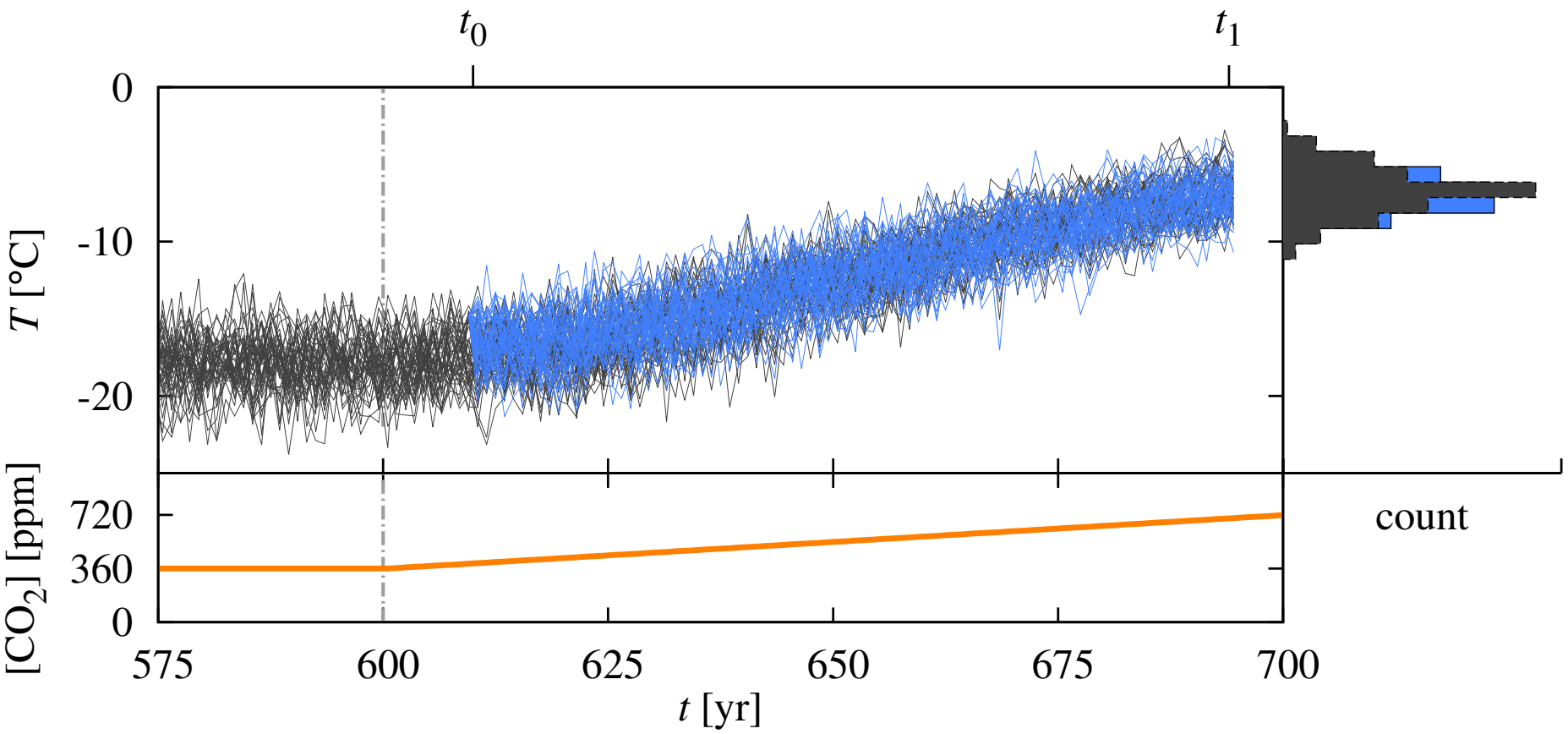
Romeiras, Grebogi and Ott, Phys. Rev. A **41**, 784 (1990)
Ghil, Chekroun and Simonnet, Physica D **237**, 2111 (2008) and **240**, 1685 (2011)

Numerically: do we see the natural probability distribution?



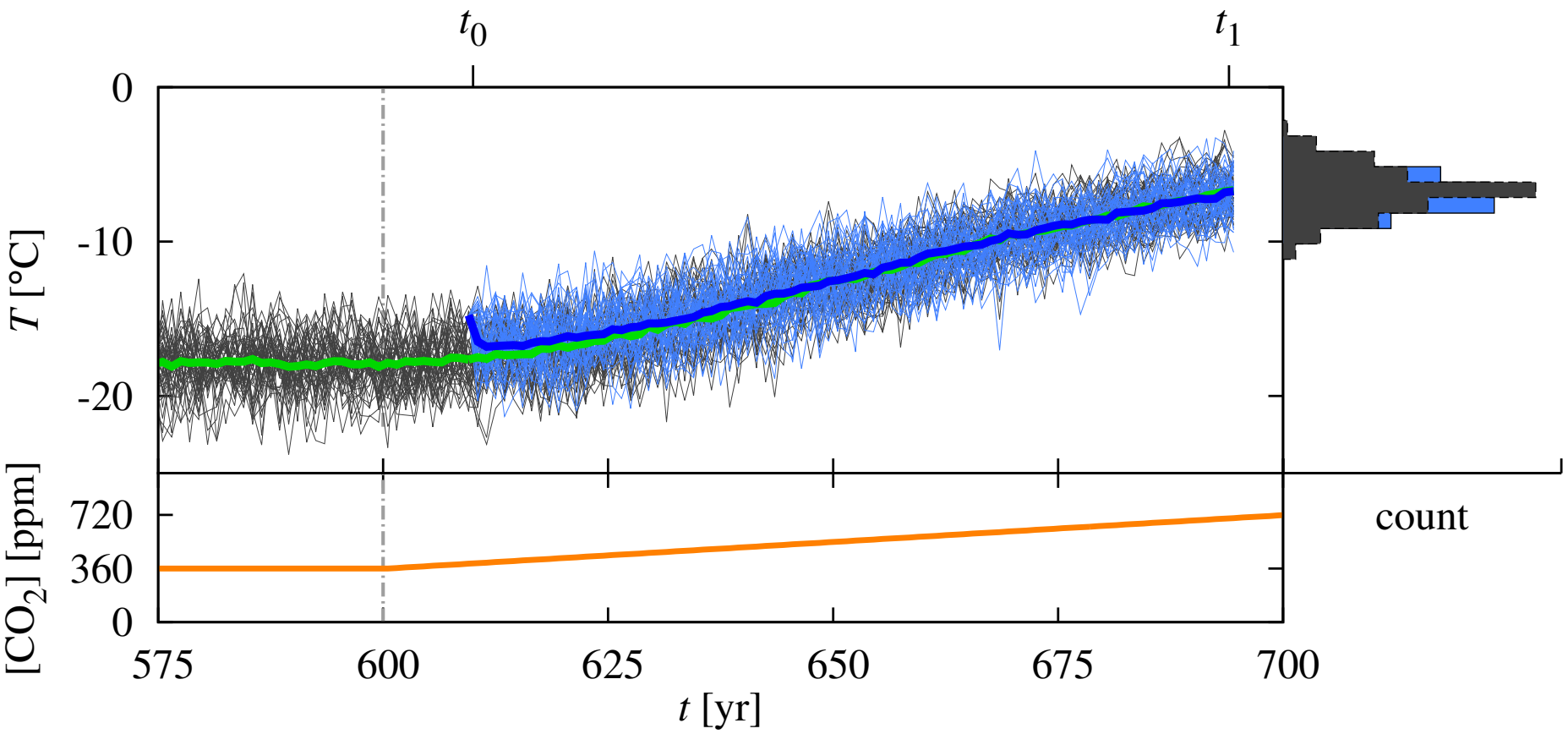
Numerically: do we see the natural probability distribution?

Let us take a reference ensemble (certainly converged)



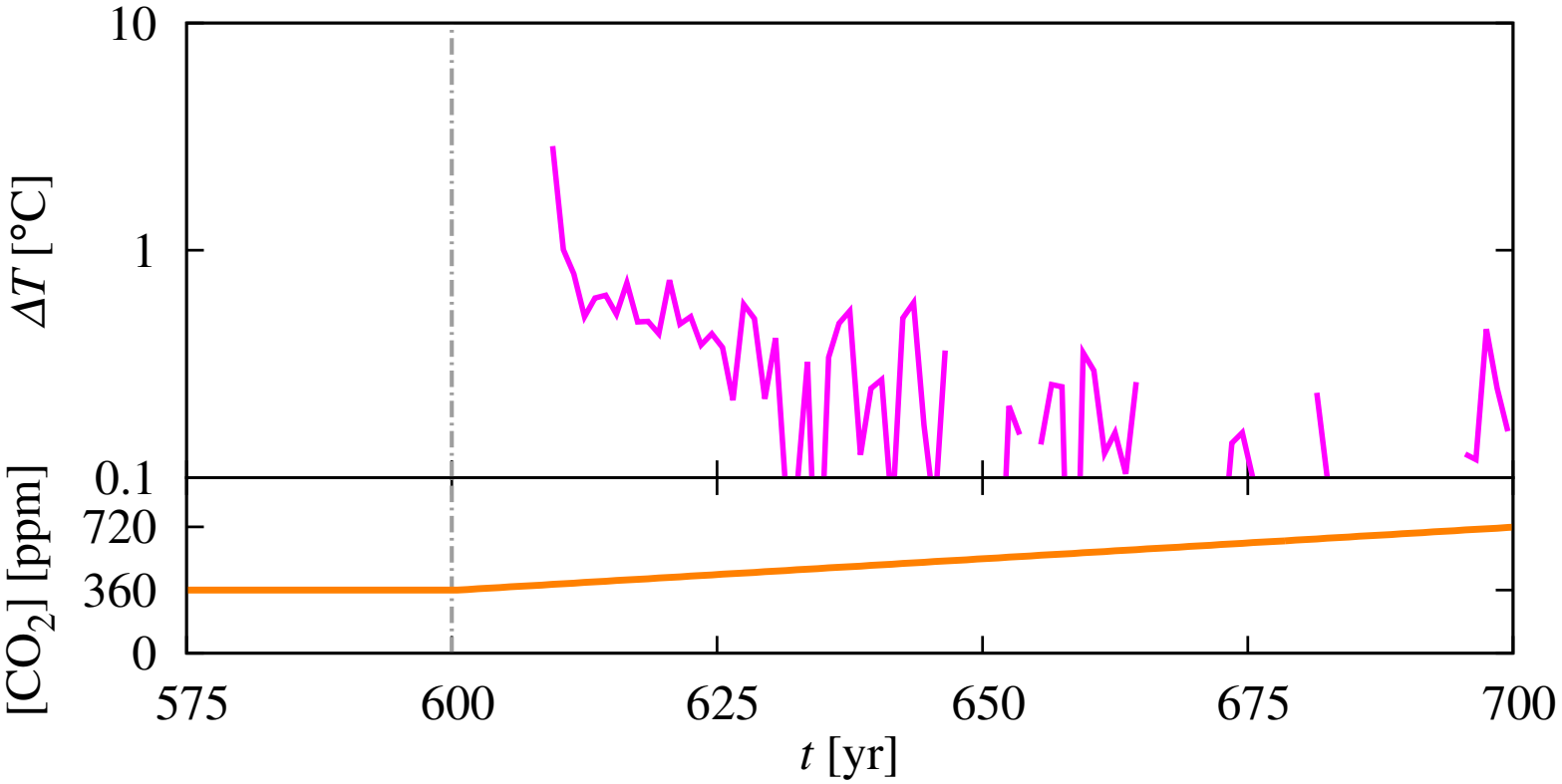
Numerically: do we see the natural probability distribution?

Let us take a reference ensemble (certainly converged)



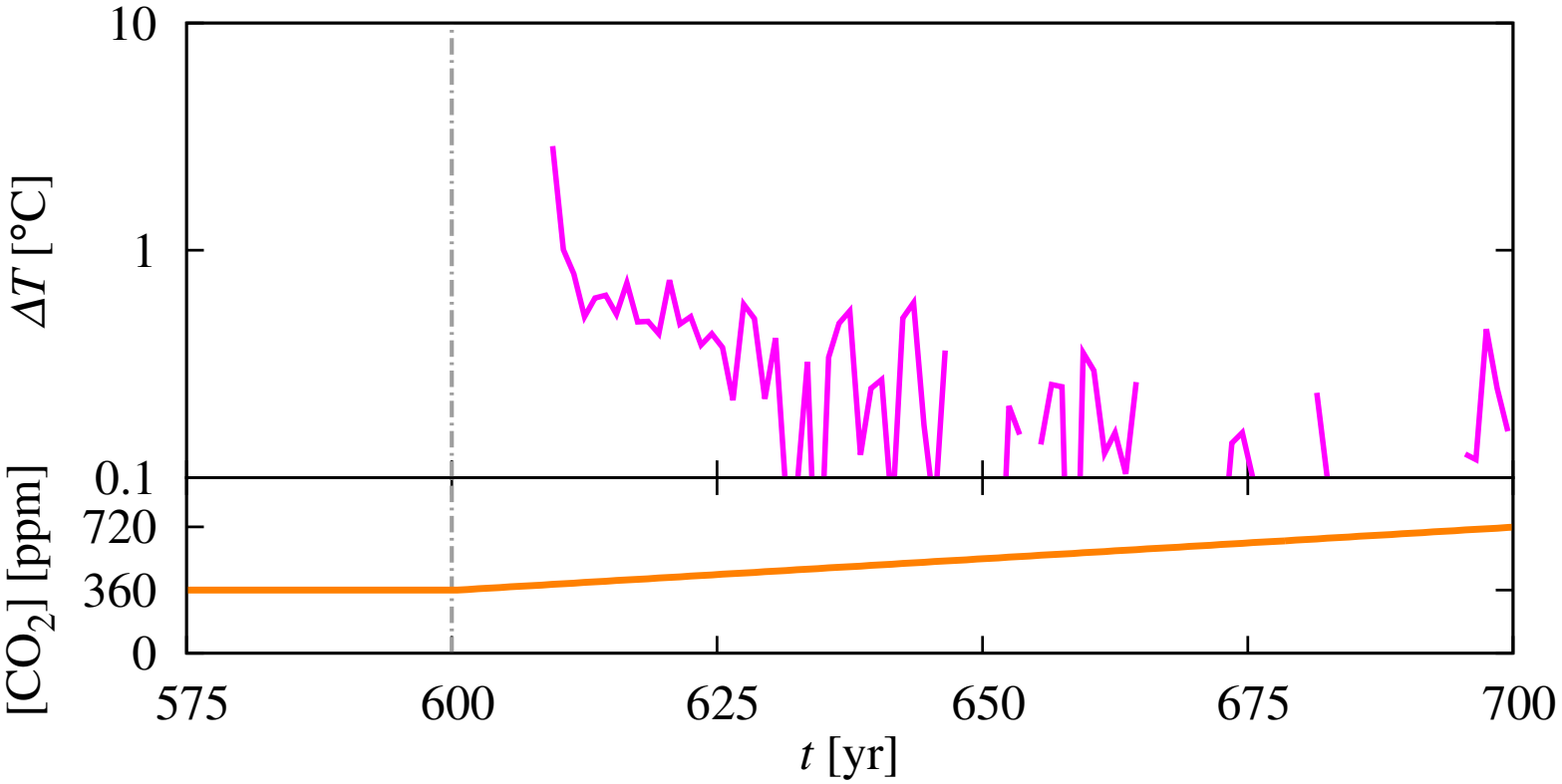
Numerically: do we see the natural probability distribution?

Difference



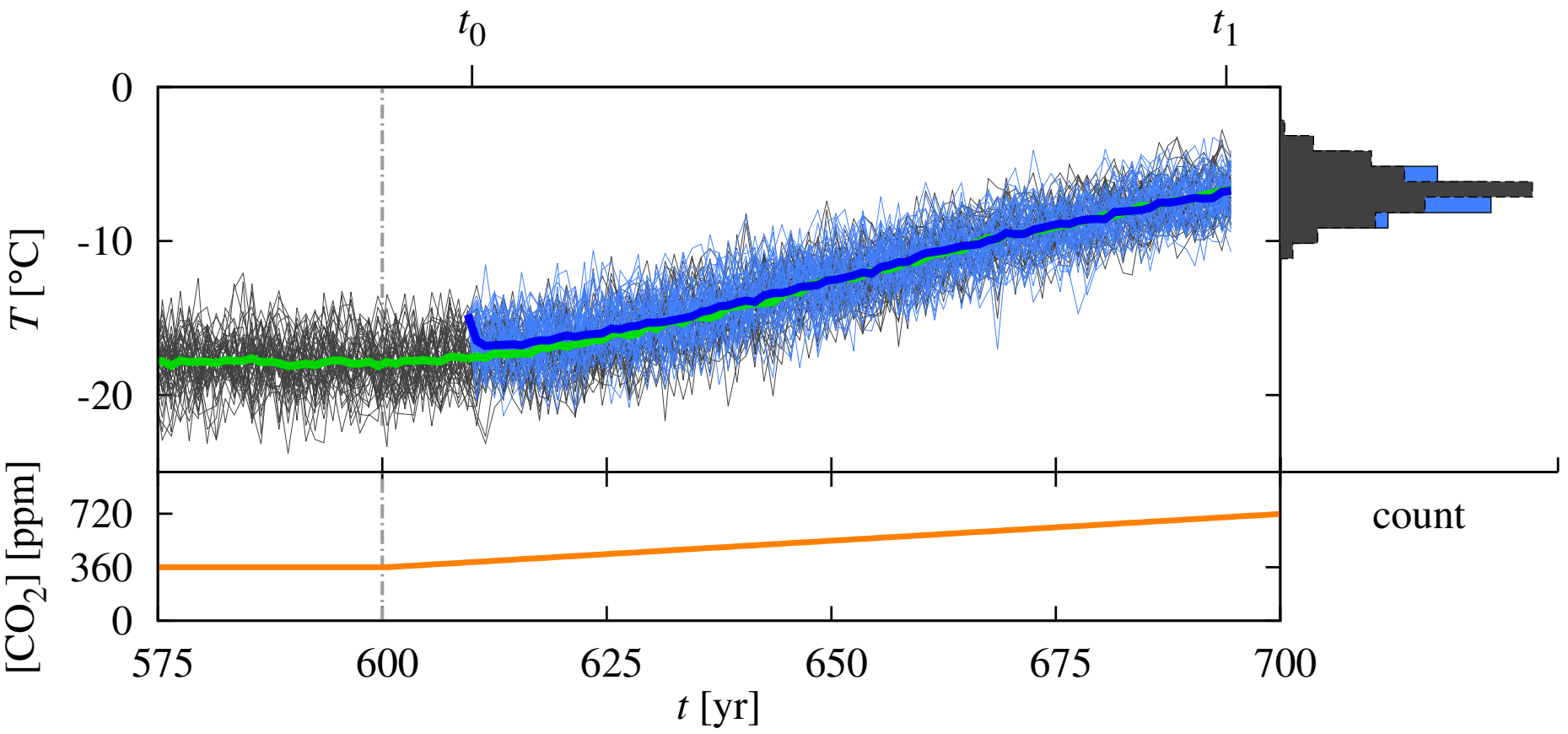
Numerically: do we see the natural probability distribution?

Difference



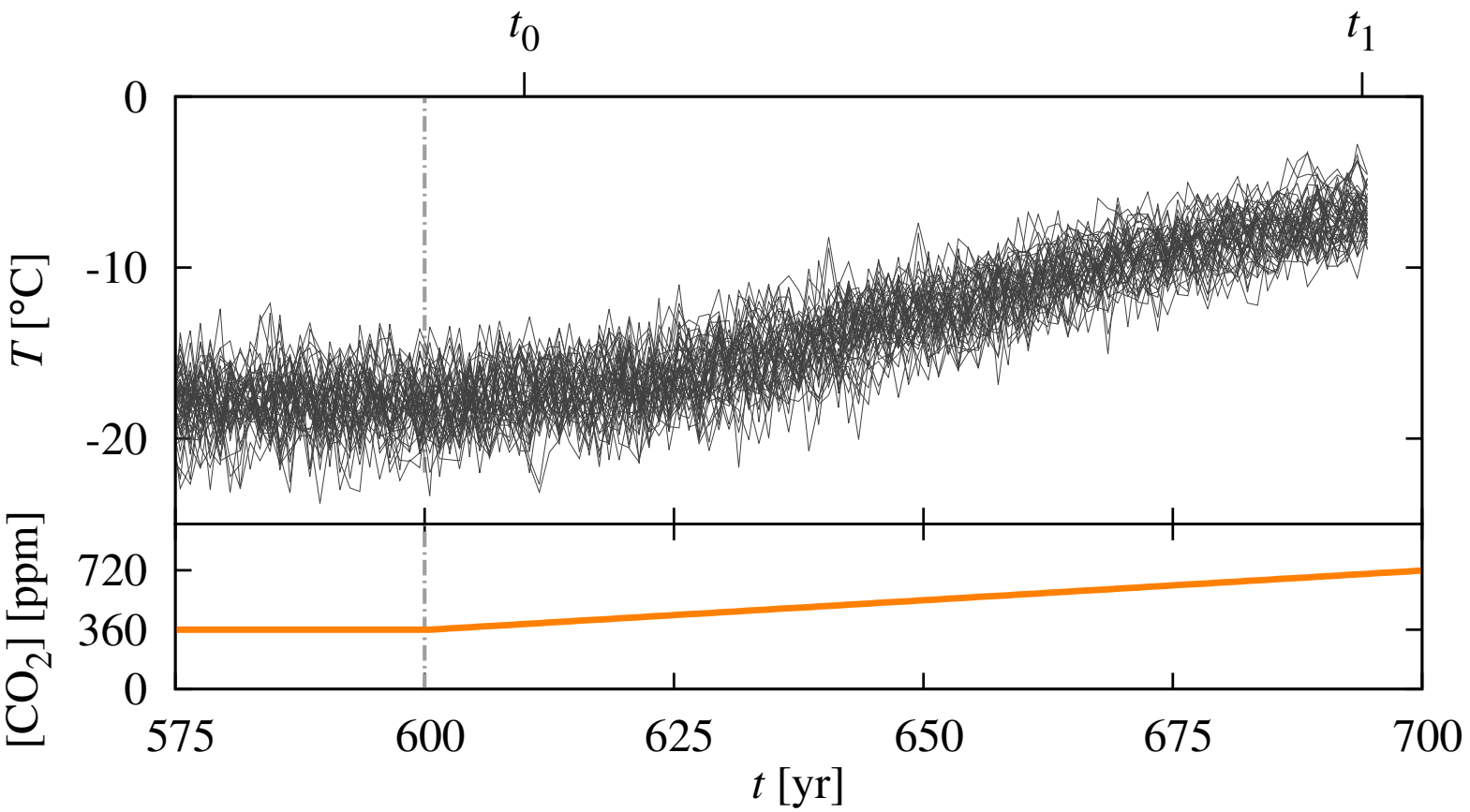
Convergence (unique ensemble spread) in a few decades (exponential-like)

Numerically: do we see the natural probability distribution?

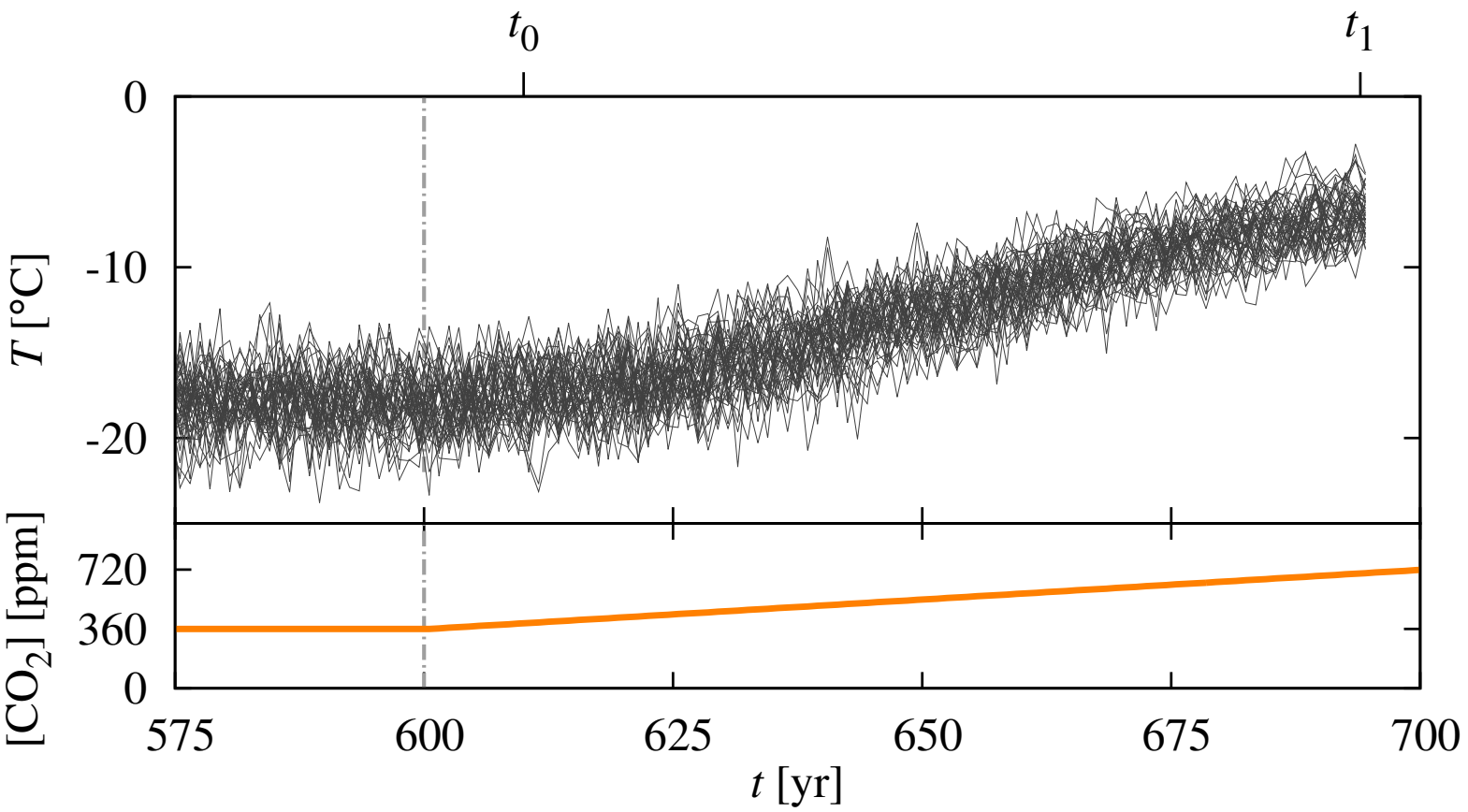


Yes, we do

Numerically: do we see the natural probability distribution?



Numerically: do we see the natural probability distribution?



It exists at any time

Defining climate

Natural probability distribution of the attractor: at any time:

- the *a priori* statistical/probabilistic description: independent of the initial condition $\rightarrow$
- characterizes (all possibilites permitted by) the system, not a particular state (the "weather")
- jointly in all variables ("structural information")

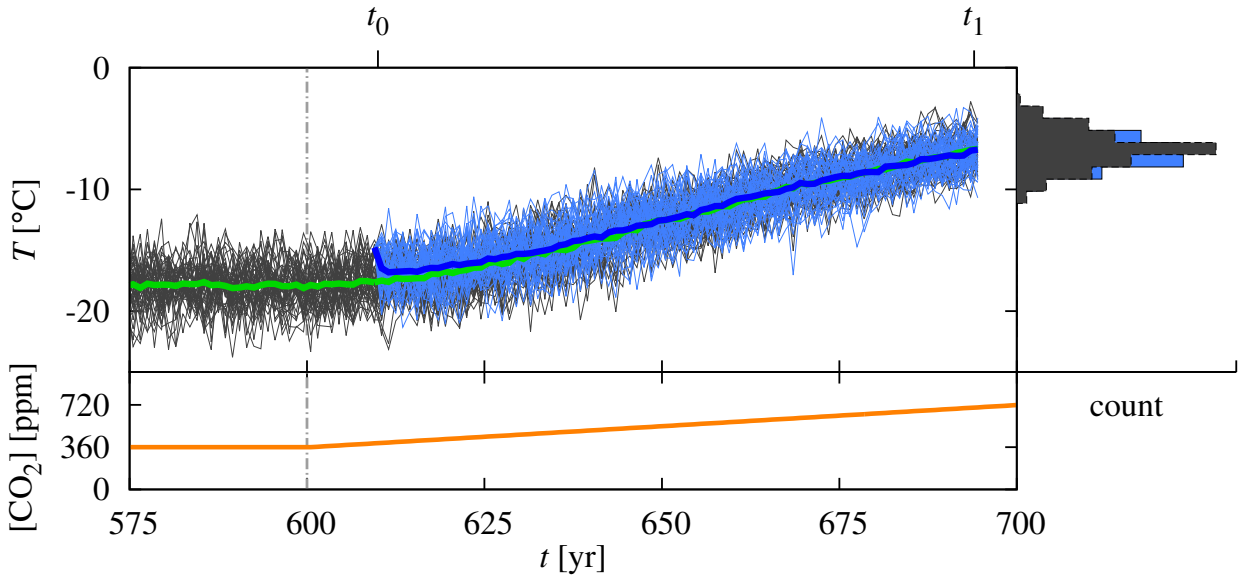
What else could be the climate?

- Climatic mean: ensemble average
- Internal variability: higher-order moments, multivariate quantifiers
- Everything responds to forcing

Numerically: caution

- Finite ensemble size

- Climate is not represented before convergence
  (a theoretical problem in real/realistic systems)

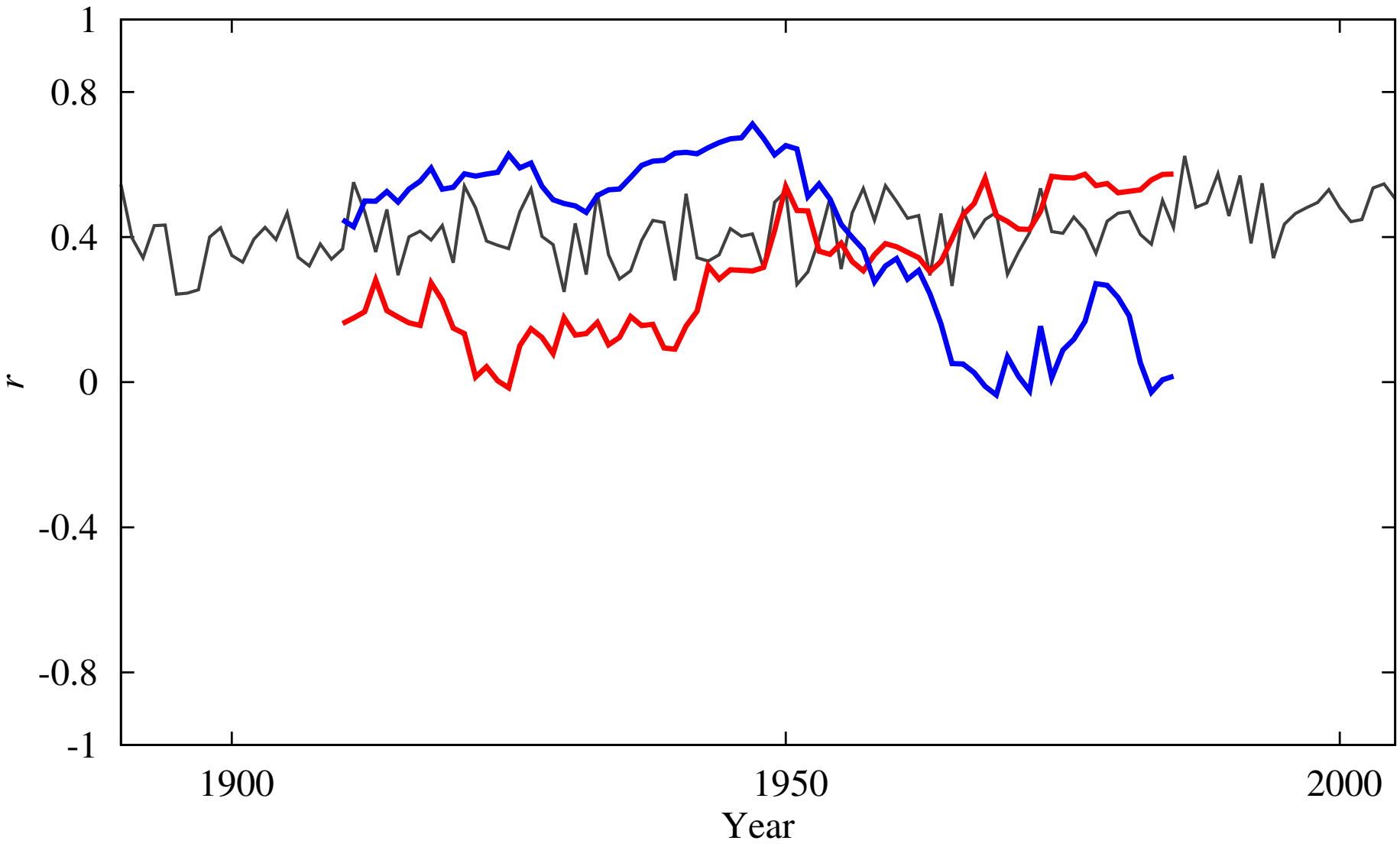


Statistics taken over time

- Temporal average of ensemble statistics: smoothing
  $\rightarrow$ May be justifiable

- Temporal statistics along single realizations
  $\rightarrow$ May be interesting on their own,
  but may approximate poorly the corresponding ensemble statistics

Example: ENSO-IM correlation coefficient in MPI-GE



Conclusions

Climate: "statistics of weather":
natural probability distribution of the attractor, depends on time

- Climatic mean: ensemble average
- Internal variability: higher-order moments, multivariate quantifiers
- Everything responds to forcing

Numerically accessible, but waiting until convergence is important

Most relevant open question: long time scales (deep ocean)

Bódai and Tél, Chaos **22**, 023110 (2012)
Drótos, Bódai and Tél, J. Climate **28**, 3275 (2015)
Herein, Márfy, Drótos and Tél, J. Climate **29**, 259 (2016)
Drótos, Bódai and Tél, Eur. Phys. J. Special Topics **226**, 2031 (2017)
Herein, Drótos, Haszpra, Márfy and Tél, Sci. Rep. **7**, 44529 (2017)
Herein, Drótos, Bódai, Lunkeit and Lucarini, https://arxiv.org/abs/1803.08909
http://theorphys.elte.hu/~drotos/Poster_Climate_ensembles.pdf

Postdoctoral Fellow Position

The forced response of the ENSO-Indian monsoon teleconnection

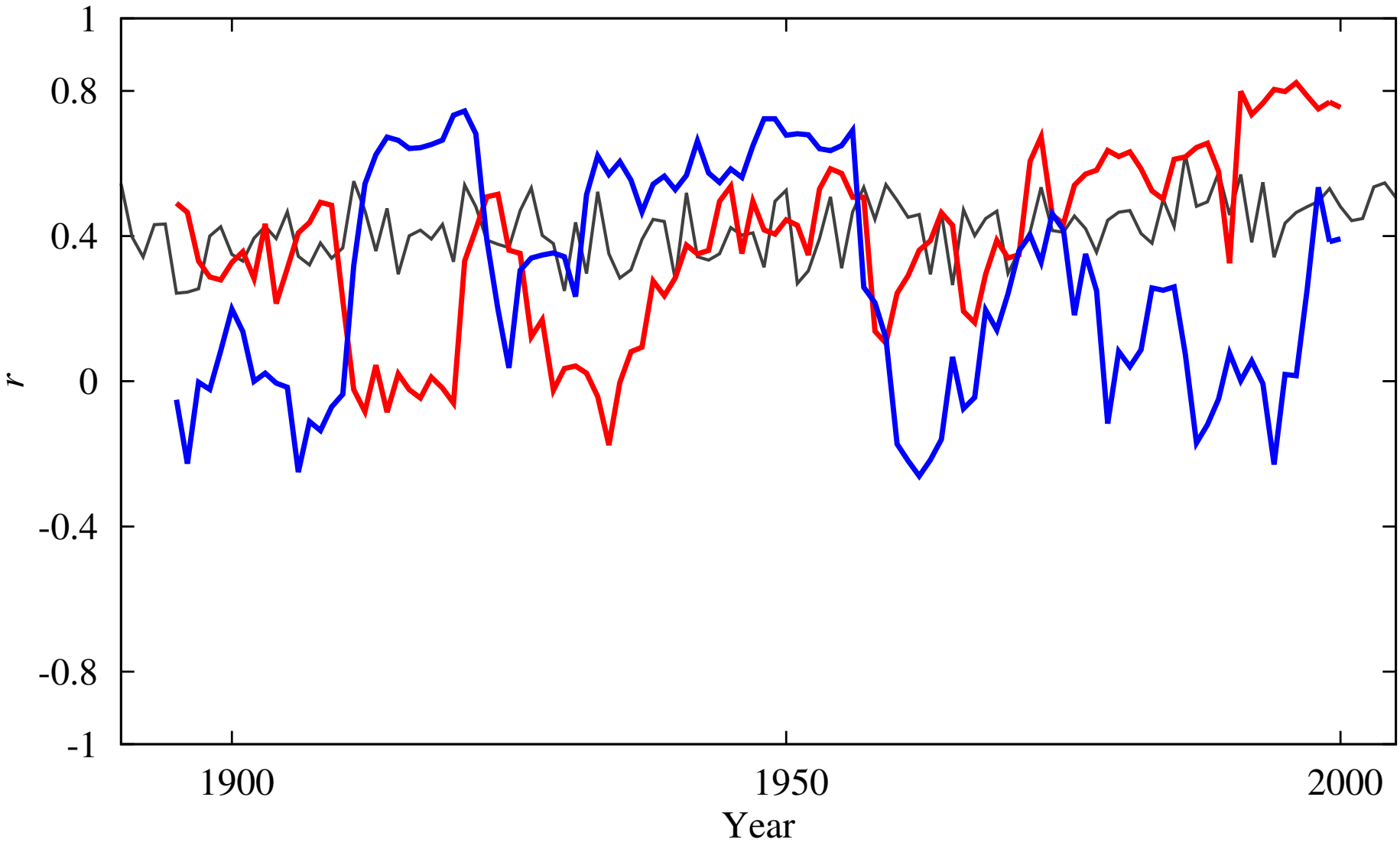
IBS Center for Climate Physics,
Pusan National University (PNU), Busan, South Korea

Full Time, 1 years with possibility for renewal

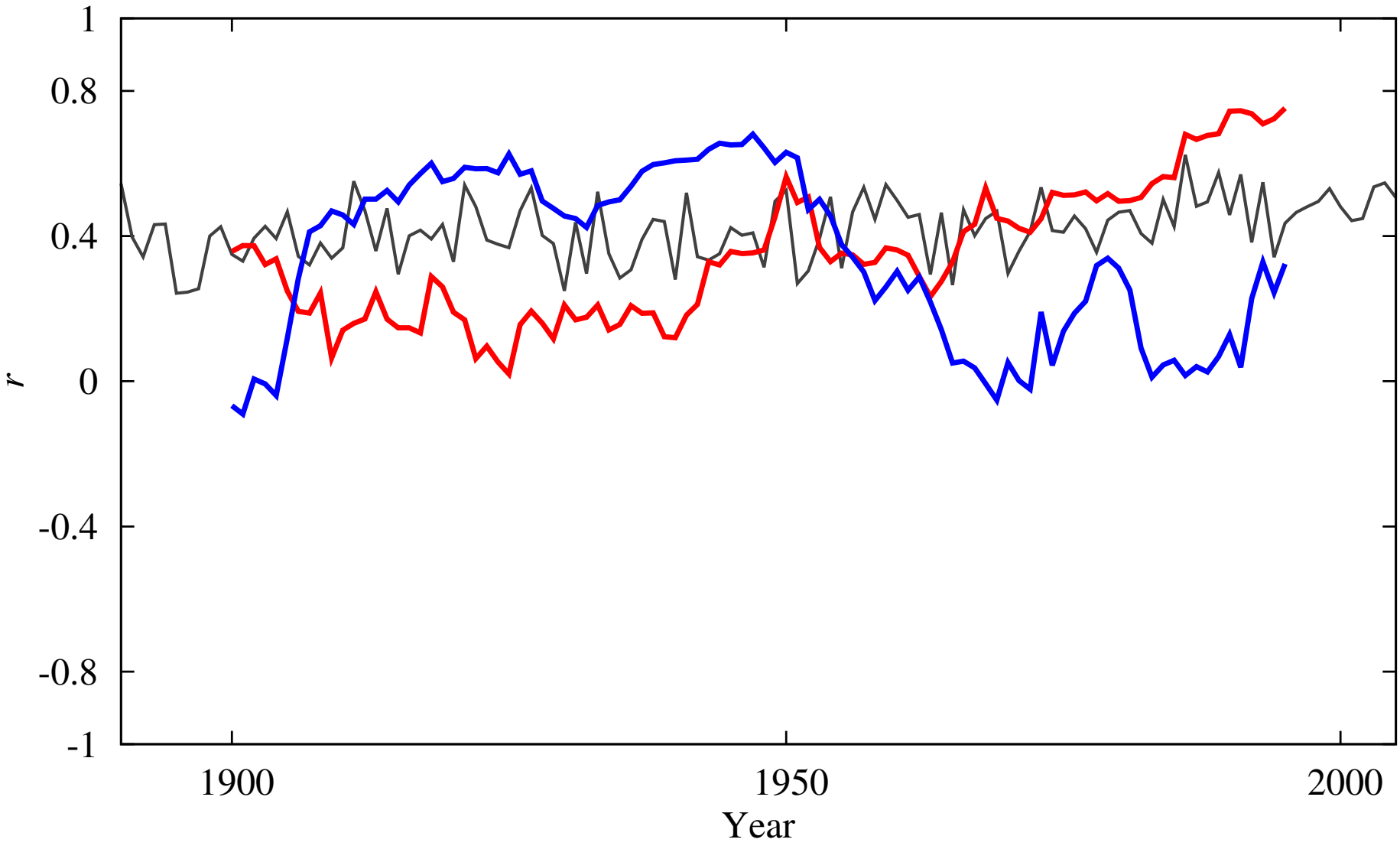
Closing Date: 12 May 2019, Korea Standard Time

Contact: Tamas Bodai, bodait@yahoo.com

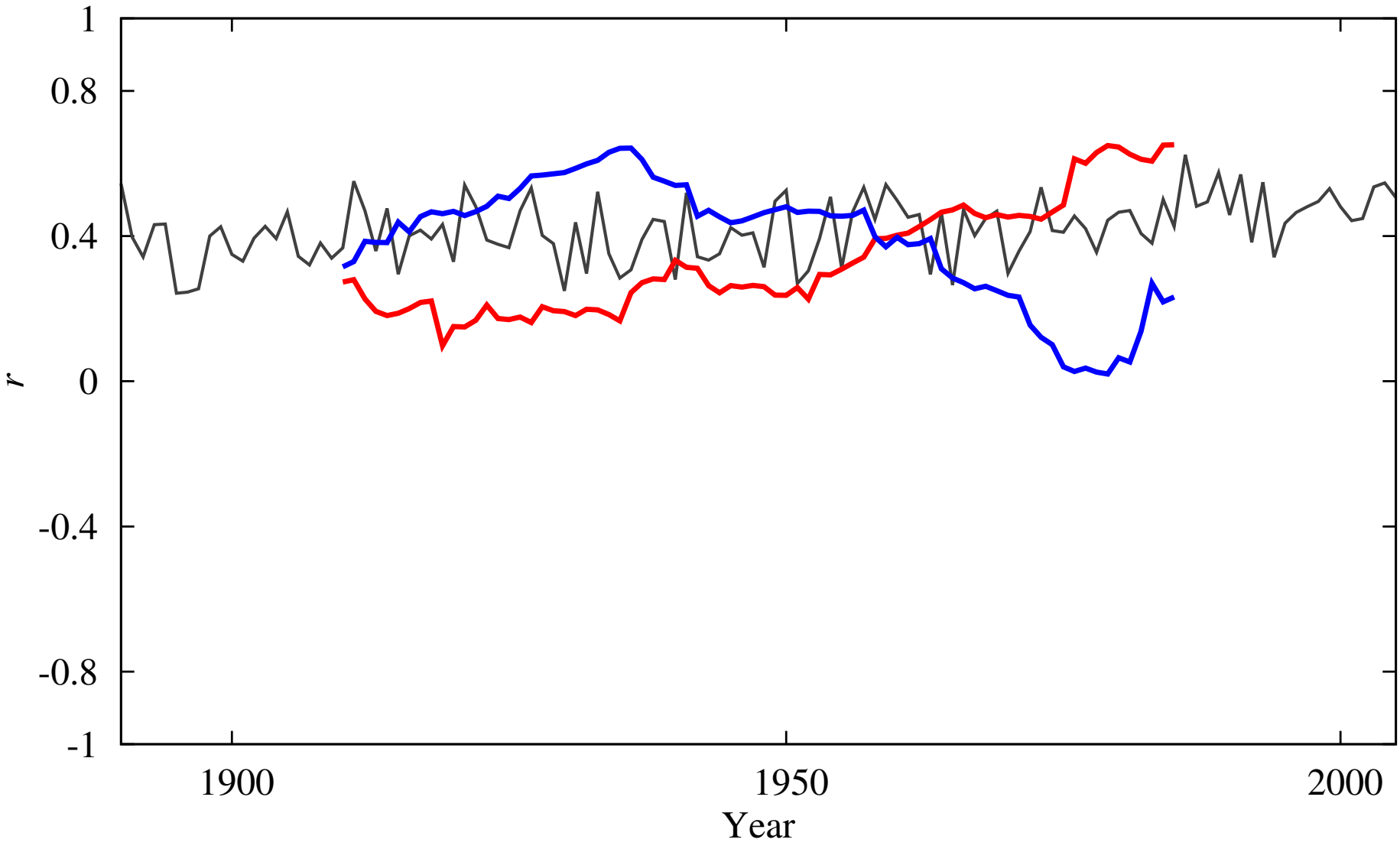
Example: ENSO-IM correlation coefficient in MPI-GE



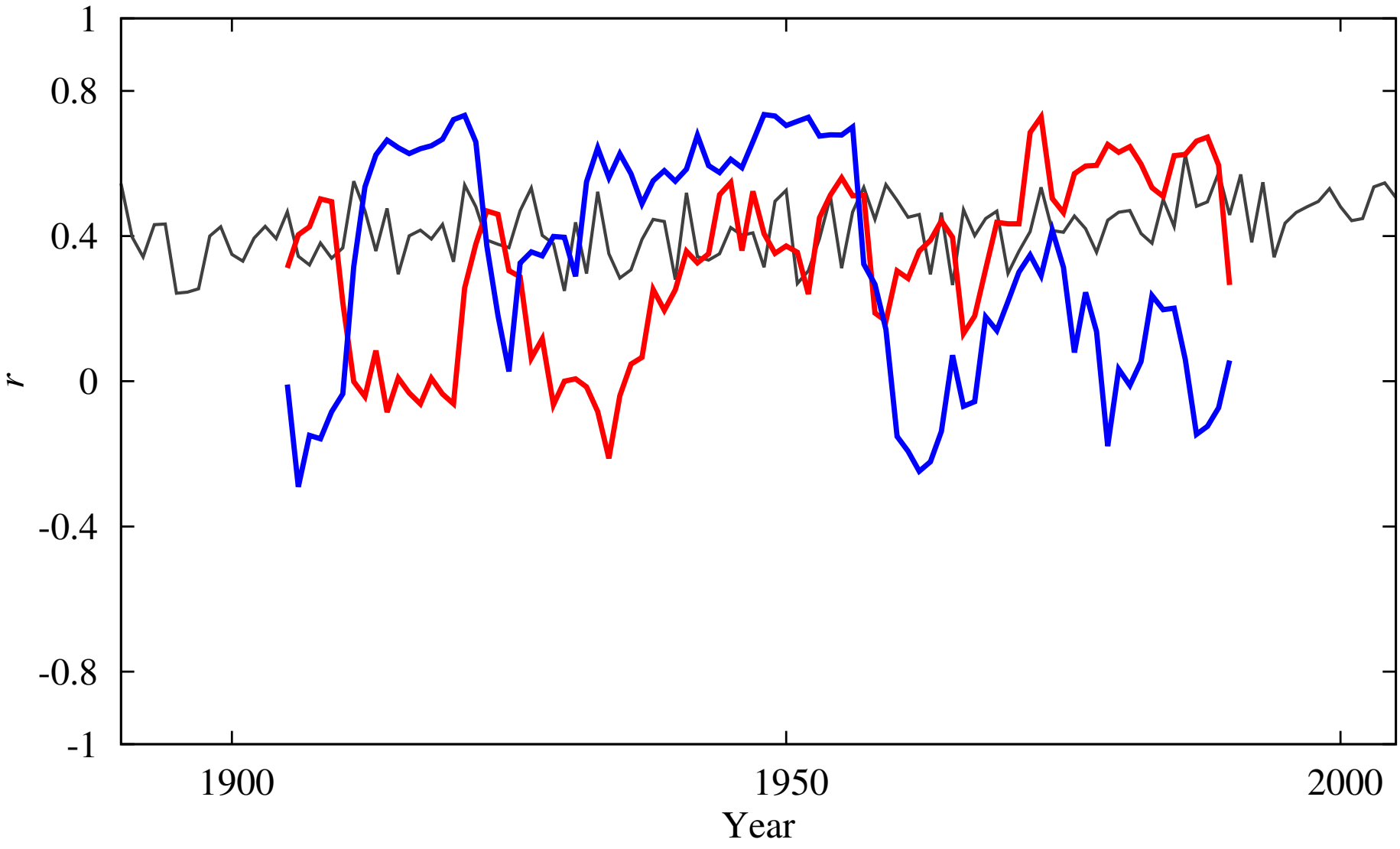
Example: ENSO-IM correlation coefficient in MPI-GE



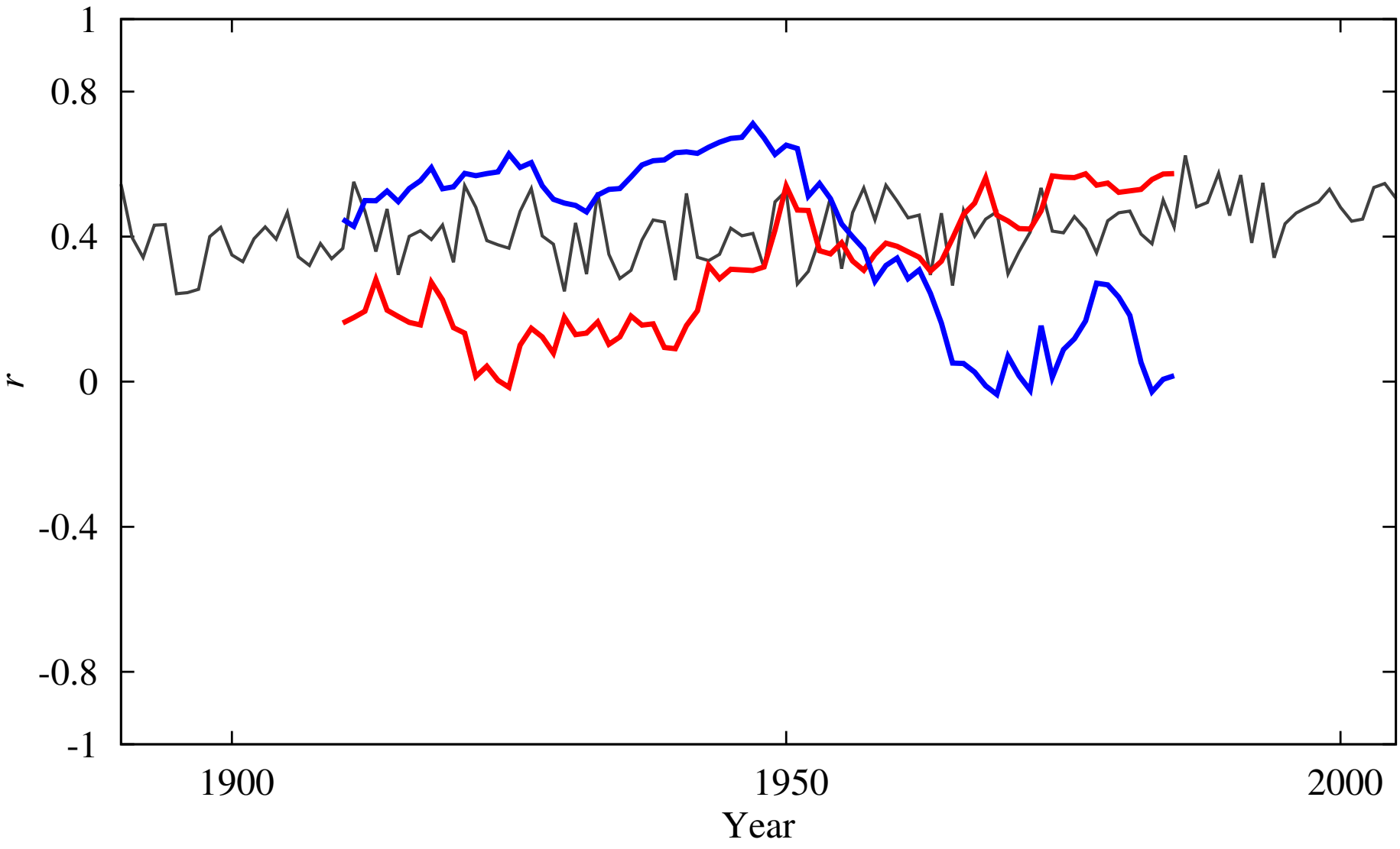
Example: ENSO-IM correlation coefficient in MPI-GE



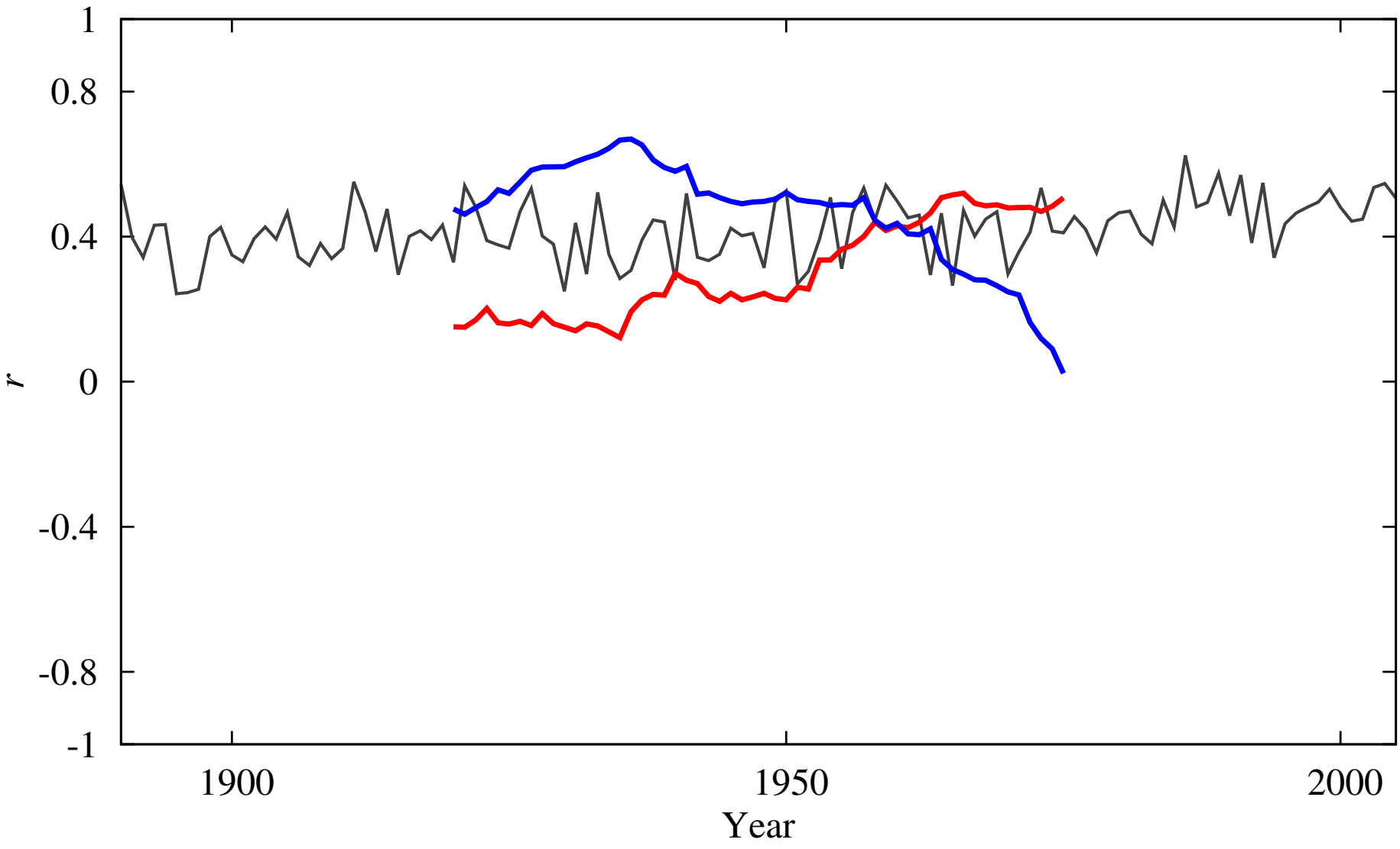
Example: ENSO-IM correlation coefficient in MPI-GE



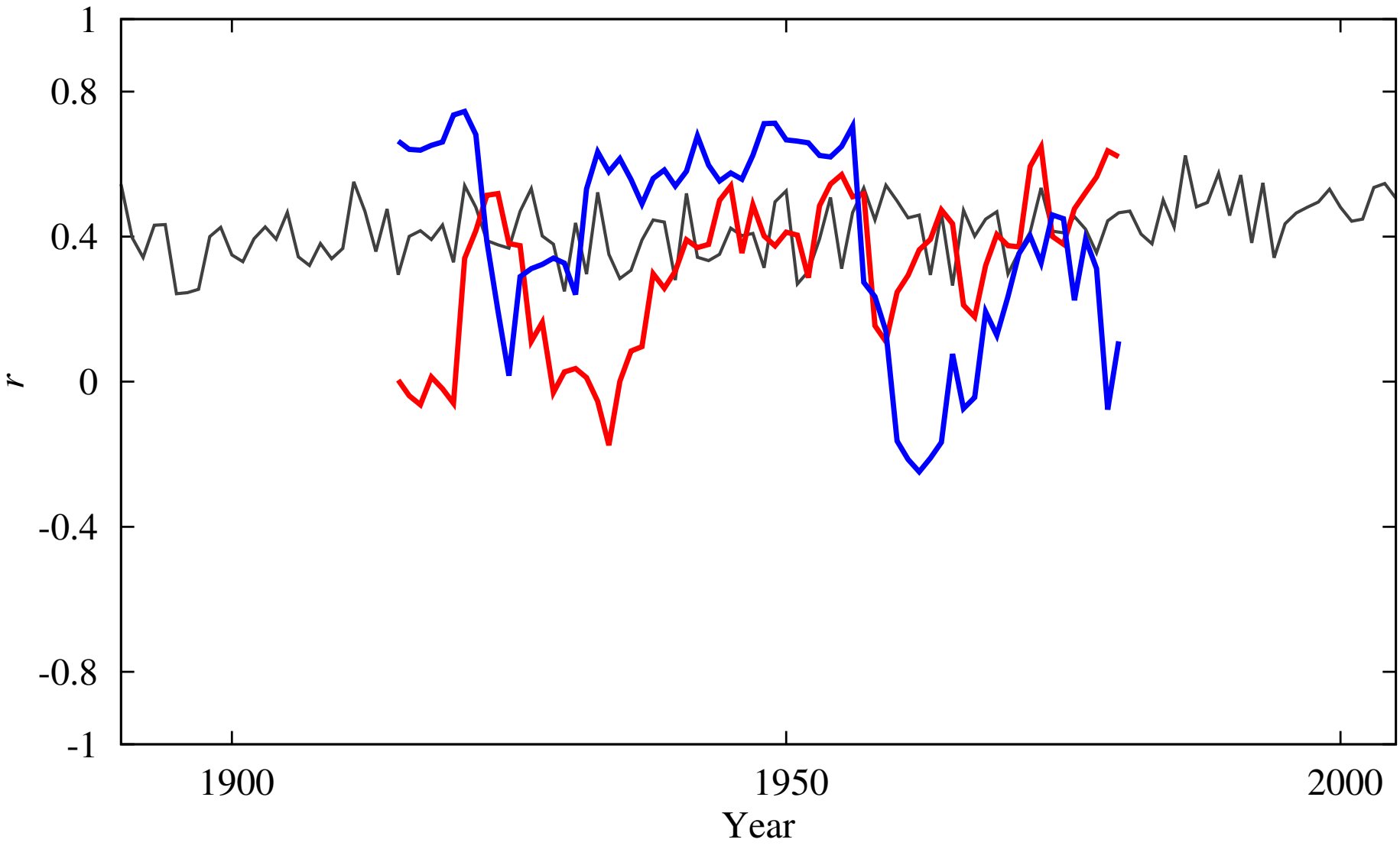
Example: ENSO-IM correlation coefficient in MPI-GE



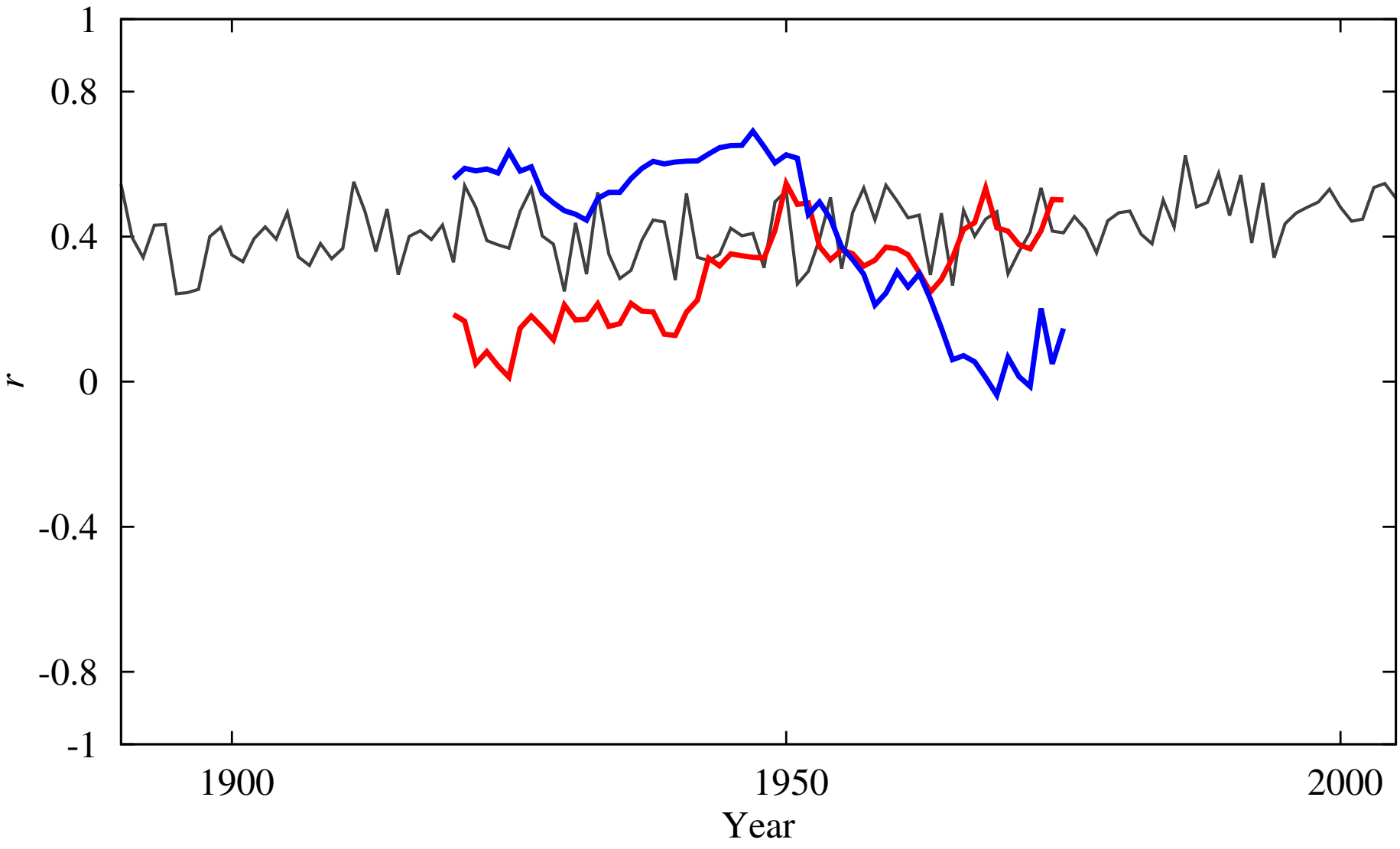
Example: ENSO-IM correlation coefficient in MPI-GE



Example: ENSO-IM correlation coefficient in MPI-GE



Example: ENSO-IM correlation coefficient in MPI-GE



Example: ENSO-IM correlation coefficient in MPI-GE