

Stability of the global climate system against strong perturbations

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Abstract

The global climate system is an aggregate of a huge number of interacting components, each having an intrinsic time scale. Such a complex dynamical system demonstrates nontrivial behavior and can exhibit a variety of possible modes of evolution. Gradual change of the parameters of the global climate system can lead to transitions (e.g., the Mid-Pleistocene Transition or to abrupt climate changes) from the observed to a new mode.

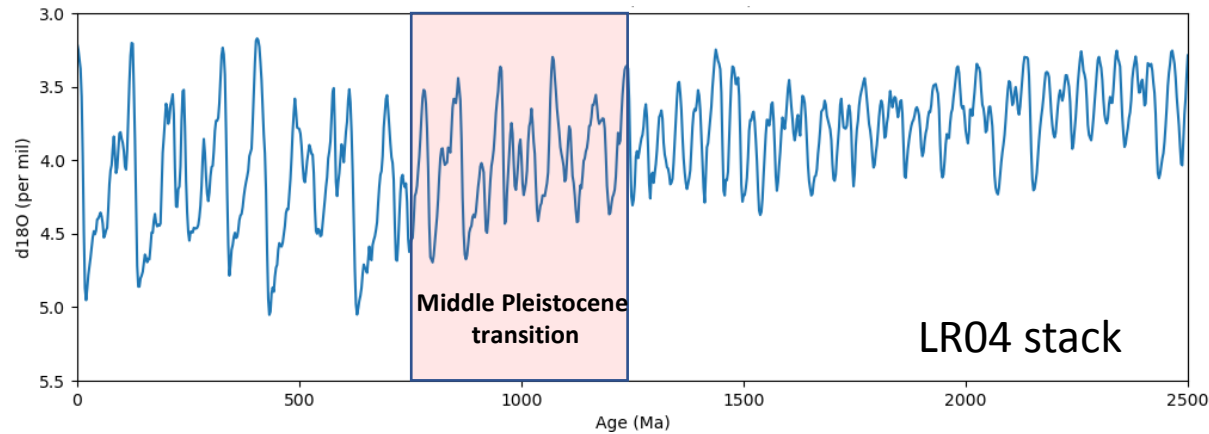
In this work, we investigate the stability of the global climate system against strong sudden perturbations in the last 2.5 million years. This case is fundamentally different from the small perturbations case: in particular, the system response cannot be described by a linearized evolution operator. To estimate the climate system's nonlinear stability during the last 2.5 million years, we use a nonlinear data-driven model of climate dynamics in Pleistocene [1] and basin stability criterion [2]. Our results indicate that the stability of the Pleistocene climate to large perturbations decreases with time: past climates being much more stable compared to the present one.

1. D. Mukhin, A. Gavrilov, E. Loskutov, J. Kurths, A. Feigin. "Bayesian Data Analysis for Revealing Causes of the Middle Pleistocene Transition". *Scientific Reports*, 9 7328 (2019).
2. V. Klinshov, S. Kirillov, J. Kurths, V. Nekorkin. "Interval stability for complex systems". *New Journal of Physics*, v. 20, p. 043040, (2018).

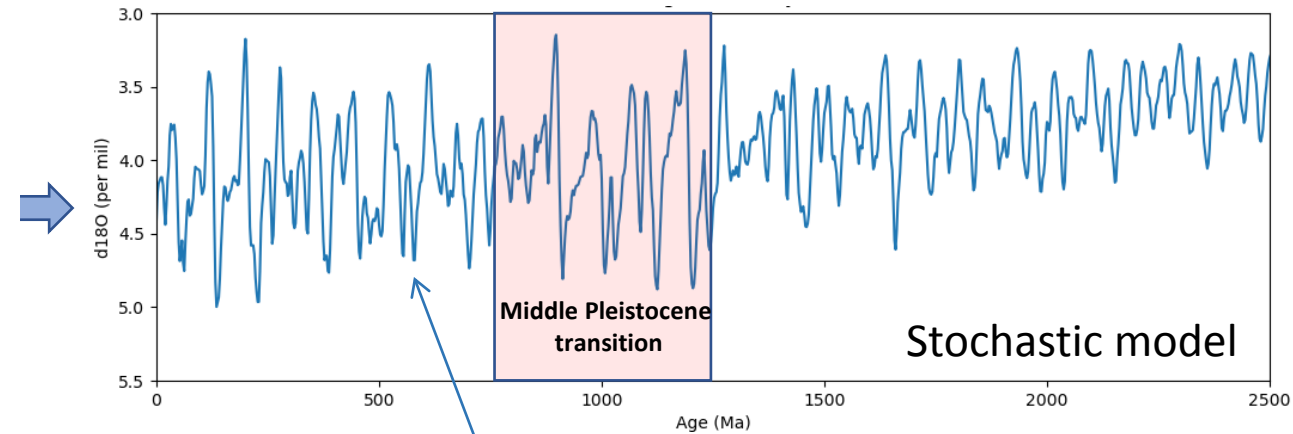
System

We investigate the stability of the **Pleistocene climate** against strong sudden perturbations.

Data: LR04 benthic stack (Lisiecki and Raymo (2005), A Pliocene-Pleistocene stack of 57 globally distributed benthic $d^{18}O$ records, *Paleoceanography*, 20, PA1003).



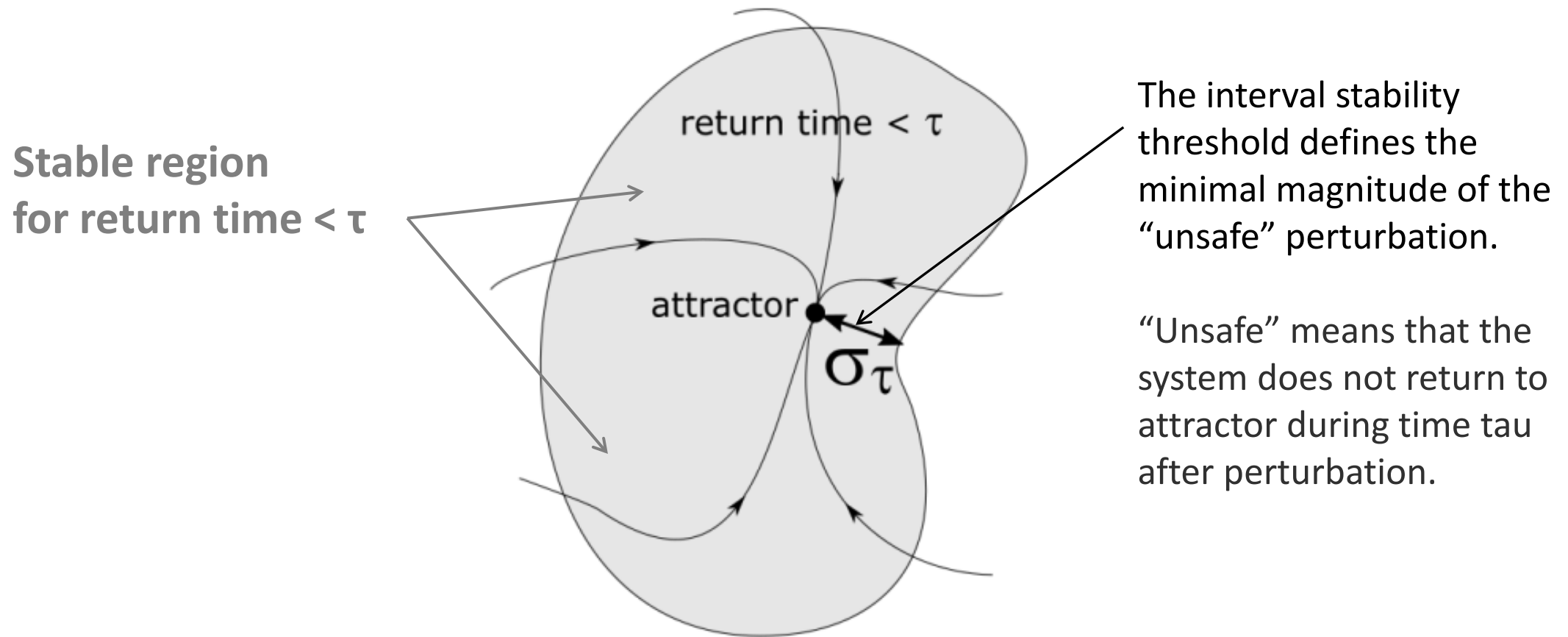
Model: data-driven stochastic model (Mukhin, Gavrilov, Loskutov, Kurths, Feigin, Bayesian Data Analysis for Revealing Causes of the Middle Pleistocene Transition, *ScientificReports*, 9, 7328)



deterministic evolution operator

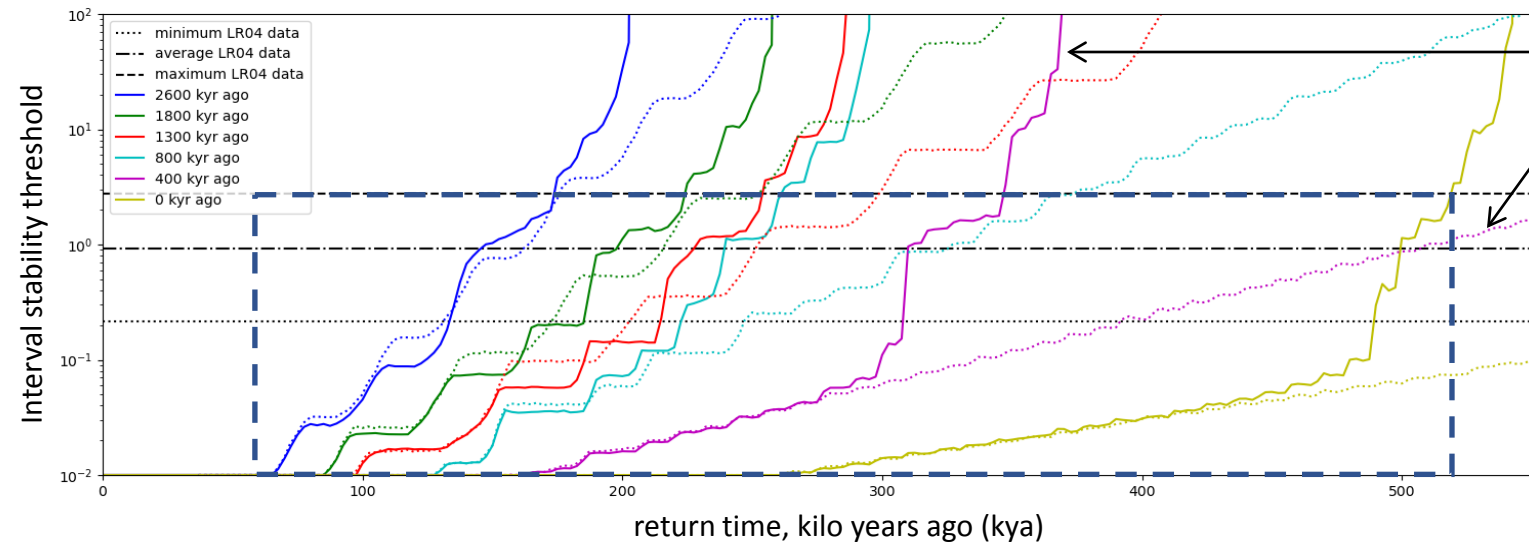
$$X_n = f(X_{n-1}, \dots, X_{n-L}, t_n, \mathbf{q}_n) + g(X_{n-1}, \dots, X_{n-L})\zeta_n.$$

Interval stability threshold (IST)



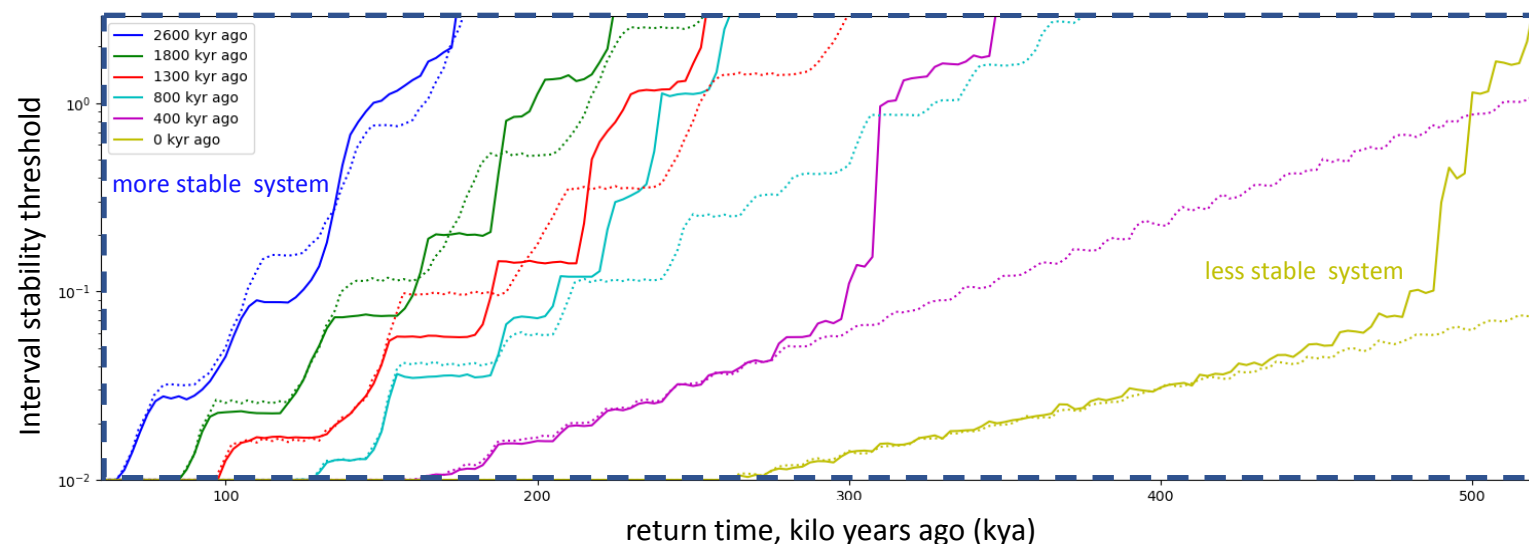
Stability of the Pleistocene climate

Dependencies of **IST** on return time at different time moments:
 $t=2.6$, $t=1.8$, $t=1.3$, $t=0.8$, $t=0.4$, $t=0$ million years ago (mya).



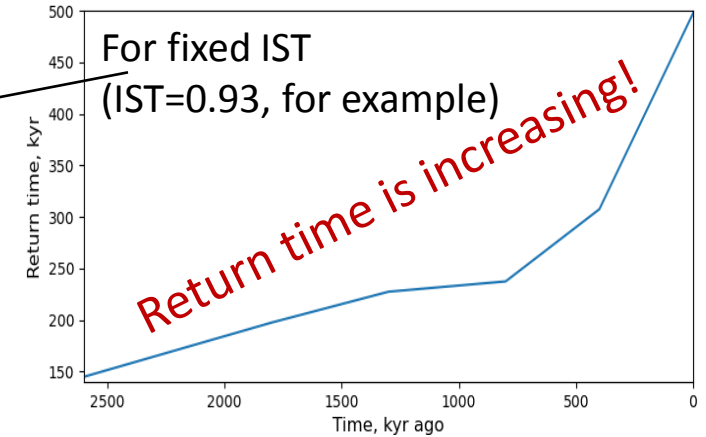
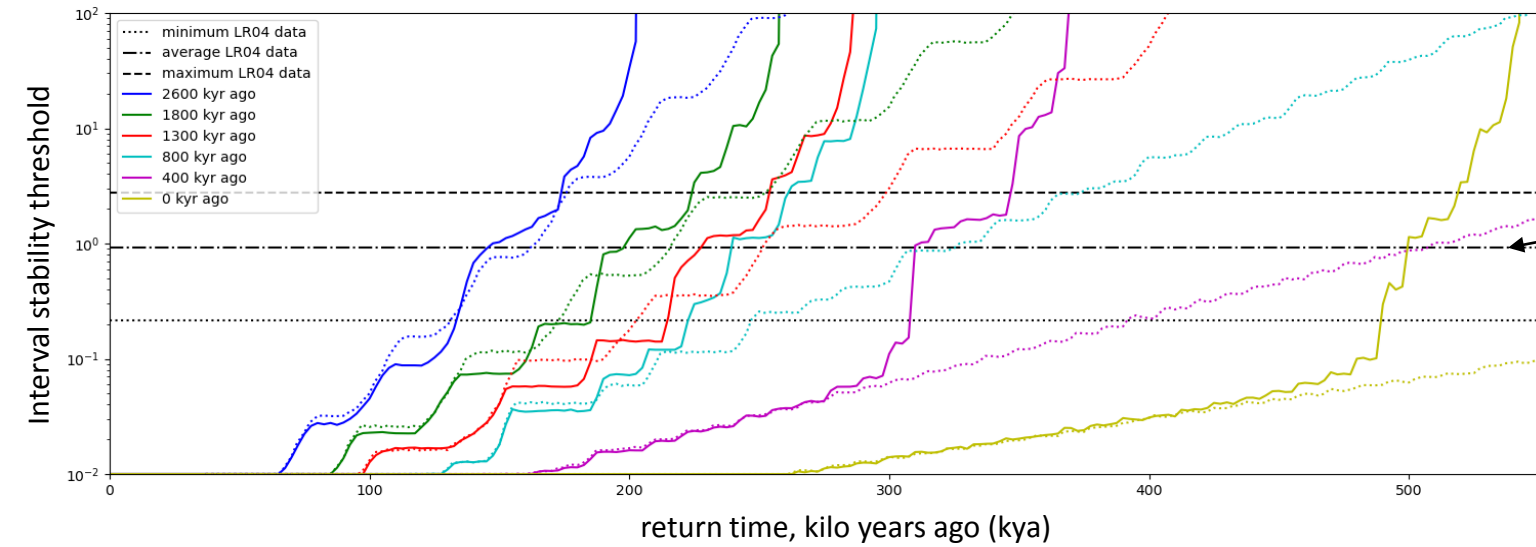
Solid lines: nonlinear model

Dashed lines: linearized model



The range of possible return times for **blue** line is minimal.

The range of possible return times for **yellow** line is maximal.



1. Stability of climate system decreases with time (from past to our days)!
2. Linearized model less stable than nonlinear model.

Main points

- Stability of the Pleistocene climate decreases with time: past climates being much more stable compared to the present one. It can be the reason of MPT.
- Traditional Lyapunov stability analysis underestimates stability of the Pleistocene climate.