Predicting AMOC collapse probabilities using trajectory-adaptive multilevel sampling (TAMS)

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Abstract & Background

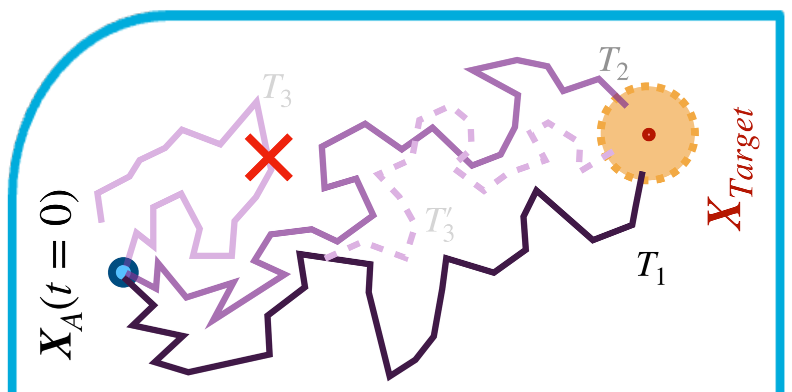
The Atlantic Meridional Overturning Circulation (AMOC) plays a major role in the global and local climates by redistributing heat through the global ocean. Current projections indicating a weakening of the AMOC strength could be sign of a collapse[1]. This work aims at using trajectory-adaptive multilevel splitting (TAMS) in combination with a global ocean model to estimate the probability of an AMOC transition from its current state to a collapsed state by 2100.

[1] van Westen, René M., Michael Kliphuis, and Henk A. Dijkstra. "Physics-based early warning signal shows that AMOC is on tipping course." *Science advances* 10.6 (2024)

Keywords: AMOC, global ocean model, TAMS, high-dimensional stochastic system, high performance computing

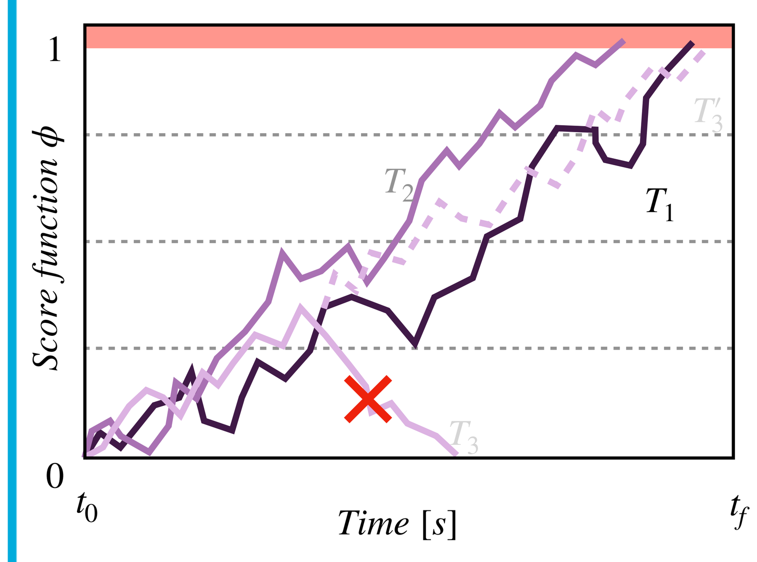
Challenge

- Path sampling into high dimensional systems such as a global ocean model prohibitively expensive with naive Monte-Carlo
- TAMS enables order-of-magnitude reduction of the computational cost by discarding uninteresting paths and branching from promising ones
- TAMS has never been applied to high-fidelity models due to the complex software infrastructure required



Score function: map from high dimensional X into [0,1]

$$\phi(X) \in [0,1]$$



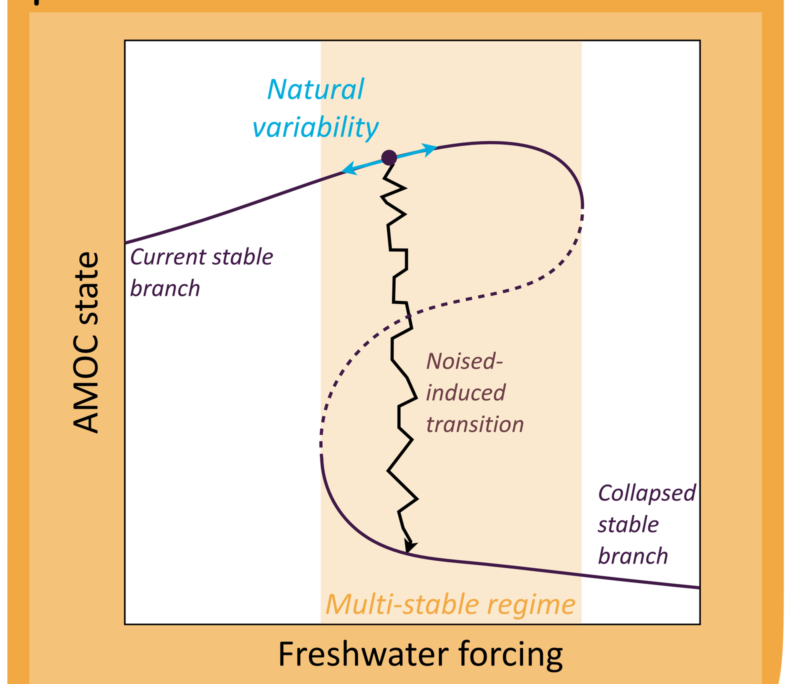
Discarding T_3 and branching T_3' trajectory from T_1

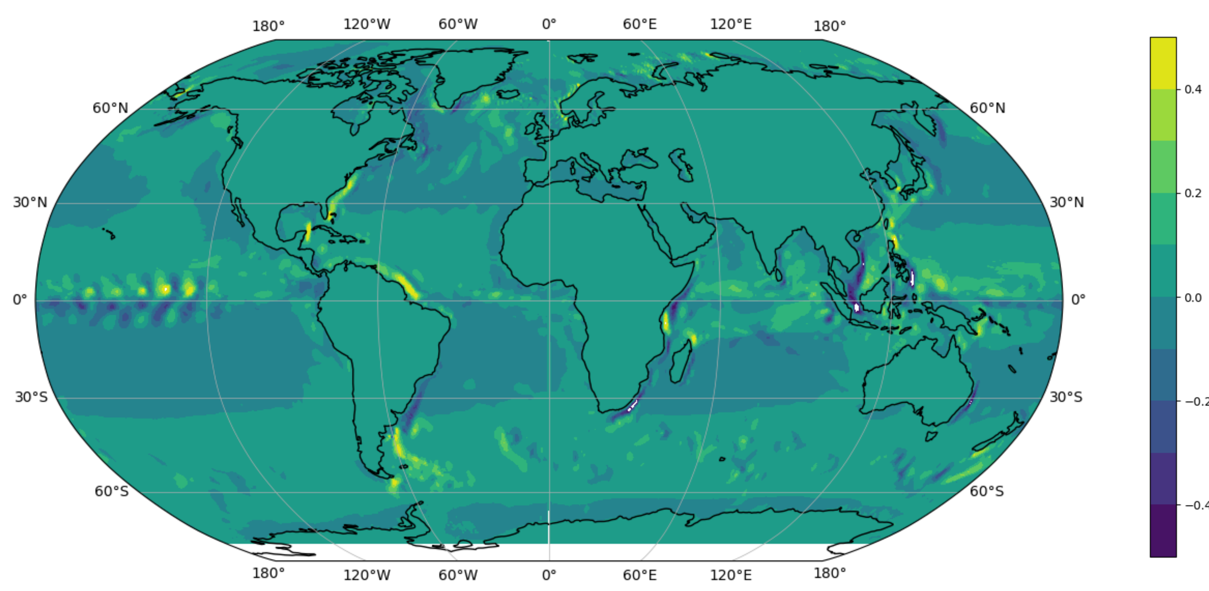
Background

Consider an SDE of the form:

$$\mathcal{M}\, d\boldsymbol{X}(t) = f(\boldsymbol{X}(t), t)dt + g(\boldsymbol{X}(t), t)d\boldsymbol{W}(t)$$

- $\boldsymbol{X}(t)$: state (velocity, temperature, …)
- $f(\boldsymbol{X}(t), t)$: oceanic flow PDE
- $d\boldsymbol{W}(t)$: Weiner random process for freshwater noise





Methods

- **Software:**
  - Use a 1°-resolution POP[2] simulation to represent the global ocean circulation
  - Rely on the OMUSE[3] framework to drive the POP simulation from a Python implementation of the TAMS algorithm
  - Use Dask[4] to distribute individual POP simulations on Snellius
- **Physics:**
  - Initial AMOC state obtained from an hysteresis numerical experiment conducted at UU
  - TAMS score function based on the AMOC strength at 26° North
  - Stochastic freshwater forcing noise obtained from analysis of the CMIP data

PyTAMS: an open-source Python implementation of TAMS for high fidelity models

https://github.com/nlesc-eTAOC/pyTAMS

POP2-CESM

[2] Smith, R., et al. "The parallel ocean program (POP) reference manual ocean component of the community climate system model (CCSM) and community earth system model (CESM)." *LAUR-01853* 141 (2010): 1-140.

[3] Pelupessy, Inti, et al. "The oceanographic multipurpose software environment (OMUSE v1. 0)." *Geoscientific Model Development* 10.8 (2017): 3167-3187.

[4] Rocklin, Matthew. "Dask: Parallel computation with blocked algorithms and task scheduling." *Proceedings of the 14th python in science conference*. Vol. 130. Austin, TX: SciPy, 2015.

Aknowledgments: This work was supported by the Netherlands eScience Center under grant number NLESC.OEC.2022.003.