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Downscaling precipitation simulations from Earth system models with generative deep learning

Philipp Hess[1,2], Maximilian Gelbrecht[1,2], Michael Aich[1], Baoxiang Pan[3], Sebastian Bathiany[1,2], and Niklas Boers[1,2,4]
[1]Technical University of Munich, School of Engineering & Design, Earth system modelling, Germany
[2]Potsdam Institute for Climate Impact Research, Potsdam, Germany
[3]Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China
[4]Global Systems Institute and Department of Mathematics, University of Exeter, Exeter, UK

Accurately assessing precipitation impacts due to anthropogenic global warming relies on numerical Earth system model (ESM) simulations. However, the discretized formulation of ESMs, where unresolved small-scale processes are included as semi-empirical parameterizations, can introduce systematic errors in the simulations. These can, for example, lead to an underestimation of spatial intermittency and extreme events.
Generative deep learning has recently been shown to skillfully bias-correct and downscale precipitation fields from numerical simulations [1,2]. Using spatial context, these methods can jointly correct spatial patterns and summary statistics, outperforming established statistical approaches.
However, these approaches require separate training for each Earth system model individually, making corrections of large ESM ensembles computationally costly. Moreover, they only allow for limited control over the spatial scale at which biases are corrected and may suffer from training instabilities.
Here, we follow a novel diffusion-based generative approach [3, 4] by training an unconditional foundation model on the high-resolution target ERA5 dataset only. Using fully coupled ESM simulations of precipitation, we investigate the controllability of the generative process during inference to preserve spatial patterns of a given ESM field on different spatial scales.

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