High-resolution climate simulations using generative diffusion models

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October 25, 2024

1 Background

Extreme weather events, such as heat waves and cloudbursts are projected to become more frequent in many regions of the world due to climate change. Climate models are essential tools for understanding extreme weather events, however, most global and regional climate models (GCMs/RCMs) simulations remain at relatively coarse resolutions (e.g., 10-100 km). The new generation of climate models, that are, the convection-permitting regional climate models (CPRCM), run at km-scale spatial resolution and provide a step improvement in reproducing extreme weather events. However, performing high resolution climate simulations requires extensive computational resources. This limitation hinders the practical application of km-scale climate data to different sectors of society.

Recently, generative diffusion models have emerged as a successful method in statistical machine learning for a number of applications, such as image generation and Bayesian inference. At the heart, a generative diffusion model consists in a diffusion process that bridges between a target and a reference, so that simulating the target can simplify to simulating the reference and the bridge. One key advantage of generative diffusions is that they scale better for high-dimensional inference problems, making them suitable for tasks that require precise generation or prediction. Moreover, diffusion models immediately provide uncertainty quantification in their predictions, which is important when modelling weather and climate systems. Recent research have demonstrated the capability of these models to simulate fluid dynamics and weather patterns, therefore, they have great potentials for inference with high-resolution climate data.

In this project, we will apply generative diffusion models to simulate high resolution climate data. This will allow for a robust statistical assessment of future changes in extreme events, providing more precise information for climate change adaptation. In this project we will closely collaborate with Swedish Meteorological and Hydrological Institute (SMHI) at Norrköping who will provide the data and problem formulation.

2 Learning outcomes

You will substantially learn new knowledge in statistical machine learning as well as applications in numerical weather/climate prediction. These include, for instance:

- Generative diffusion models, a trending research topic in machine learning.
- Data-driven approaches for regional climate and weather modelling, in close collaborations with researchers at SMHI.
- JAX, a Python library for high-performance and differentiable computation (optional).

3 References

The following papers are closely related to this project.

- Zheng Zhao, Ziwei Luo, Jens Sjölund, and Thomas B. Schön. Conditional sampling within generative diffusion models. *arxiv:2409.09650*, 2024.
- Gefan Yang and Stefan Sommer. A denoising diffusion model for synthetic fluid field prediction. In *NeurIPS 2023 Workshop on Diffusion Models*, 2023.
- Morteza Mardani, Noah Brenowitz, Yair Cohen, Jaideep Pathak, Chieh-Yu Chen, Cheng-Chin Liu, Arash Vahdat, Mohammad Amin Nabian, Tao Ge, Akshay Subramaniam, Karthik Kashinath, Jan Kautz, and Mike Pritchard. Residual corrective diffusion modeling for Km-scale atmospheric sownscaling. *arxiv:2309.15214*, 2023.
- Ling, Fenghua and Lu, Zeyu and Luo, Jing-Jia and Bai, Lei and Behera, Swadhin K and Jin, Dachao and Pan, Baoxiang and Jiang, Huidong and Yamagata, Toshio. Diffusion model-based probabilistic downscaling for 180-year East Asian climate reconstruction. *npj Climate and Atmospheric Science*, 7(1), 131, 2024.

4 Eligibility requirements

- Strong background in probability and statistical machine learning is required. Preferably the candidate also has a good hands-on skill of training neural networks.
- Strong motivation for applying the developed method for climate models.

5 Contact

To apply, please send your CV and transcript to Zheng Zhao (zheng.zhao@liu.se, see also the website https://zz.zabemon.com), assistant professor at STIMA, IDA, LiU. Our partners at SMHI are Fuxing Wang (fuxing.wang@smhi.se), Yi-Chi Wang (yi-chi.wang@smhi.se), and Tomas Landelius (tomas.landelius@smhi.se). When apply, please also have them cc'd.