LATENT DIFFUSION MODELS AND MULTI-CHANNEL DATA INTEGRATION

A new road to high-resolution statistical downscaling

This presentation participates in OSPP

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Outstanding Student & PhD candidate Presentation contest

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OVERVIEW

To understand and mitigate climate change, we require **high-resolution climate projections**, especially when investigating **impacts on a local scale**. This work is focused on developing models for **statistical downscaling** of climate model outputs for **Danish hydrology** by integrating advanced **deep learning** and computer science techniques. We present a **Diffusion Model** [1,2] tailored for generating high-resolution (2.5 km x 2.5 km) climate variables relevant for hydrological models: precipitation, evaporation, and temperature.

Our approach is inspired by advancements made in Computer Vision, specifically in the areas of **latent image generation** and **conditional diffusion models** [3,4]. It further incorporates **multi-channel climate data** and geographical features to improve model accuracy and stability. The model attempts to map between two reanalysis products, **ECMWF Reanalysis v5** (ERA5) [5] and the **DANish atmospheric ReAnalysis** (DANRA) [6], as a proof of concept, and future work will focus on creating a **synchronized training dataset** between DANRA and realisations from the Regional Climate Model ensemble **EURO-CORDEX** [7], to develop a model for actual climate projection downscaling.

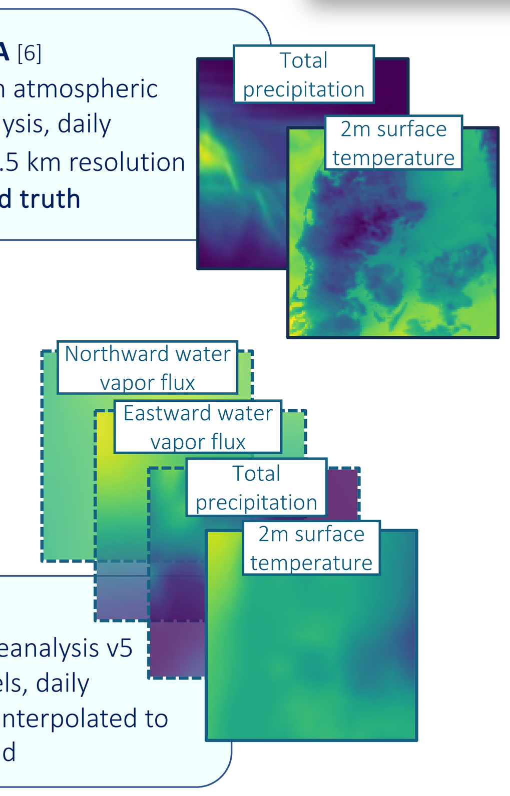
This work is part of a broader effort to **narrow the gap** between **global climate projections** and **local-scale analysis**. It covers the initial phase, where future advancements will focus on integrating this model with **RCM** and possibly **GCM** outputs instead of reanalysis data, to explore ensemble downscaling methods. Our end-goal is to **establish a robust pipeline for translating global climate projections into more actionable local climate statistics**.

WHAT'S NEW?

DATA

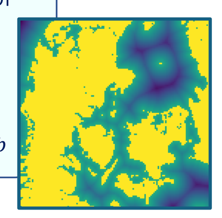
DANRA [6]
DANish atmospheric ReAnalysis, daily
2.5 x 2.5 km resolution
Ground truth

ERA5 [5]
ECMWF Reanalysis v5
Single levels, daily
Bilinearly interpolated to DANRA grid



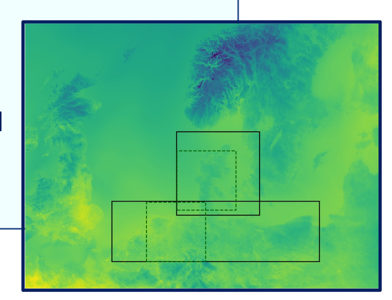
TRAINING

Loss function
- Signed Distance Function for weighted loss
- Hybrid loss [6] to capture multi-modality $L_{hybrud} = L_{simple} + \lambda L_{vlb}$



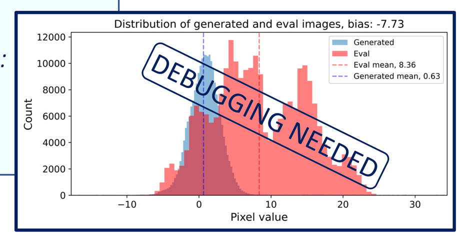
Data split
- *Training*: 9 years (1991-1999)
- *Validation*: 1 year (2000)
- *Test*: 100 randomly selected dates in 2001-2005

Data randomly shifted (geographically) for stability

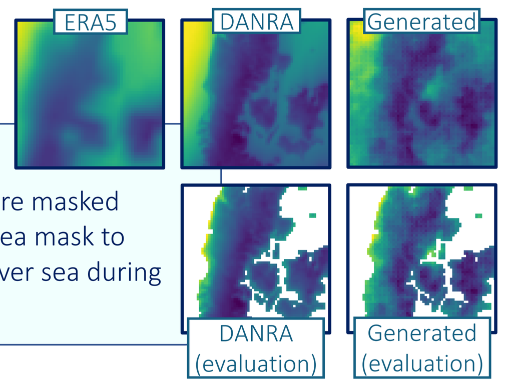


PRELIMINARY RESULTS

Quantitative
Distributions of generated and evaluation images (masked to land only)
Not capturing the mean:
May be an issue with standardization in code.



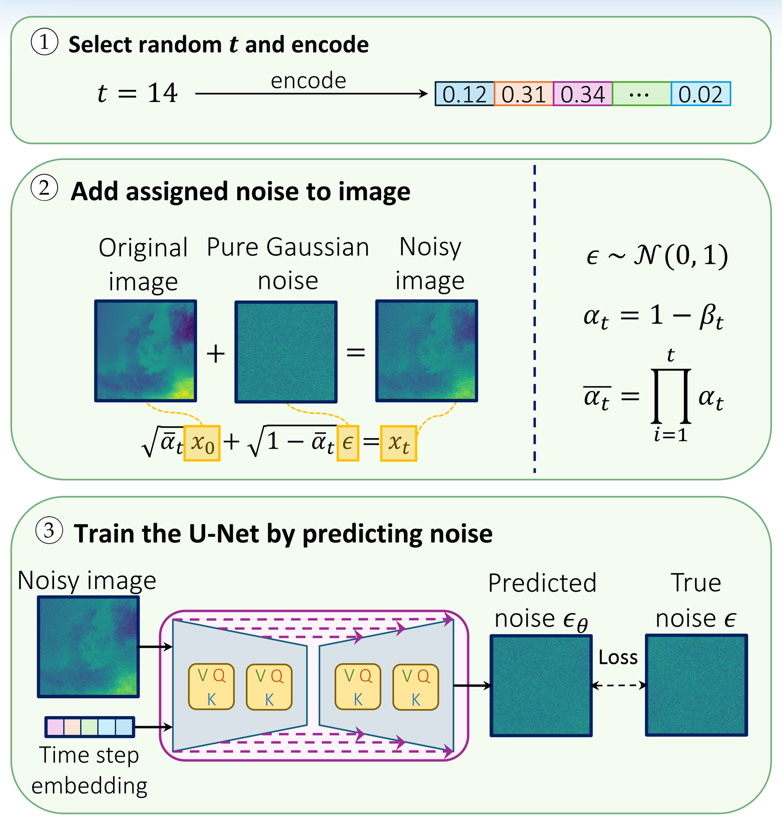
Qualitative
Predictions are masked with a land-sea mask to omit pixels over sea during evaluation.



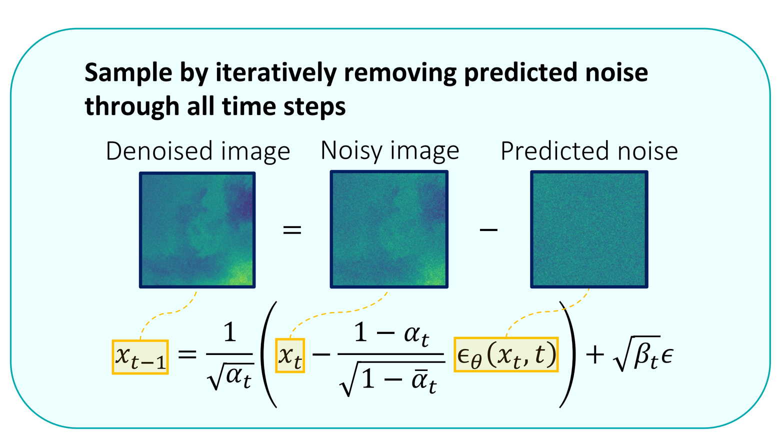
DIFFUSION MODEL

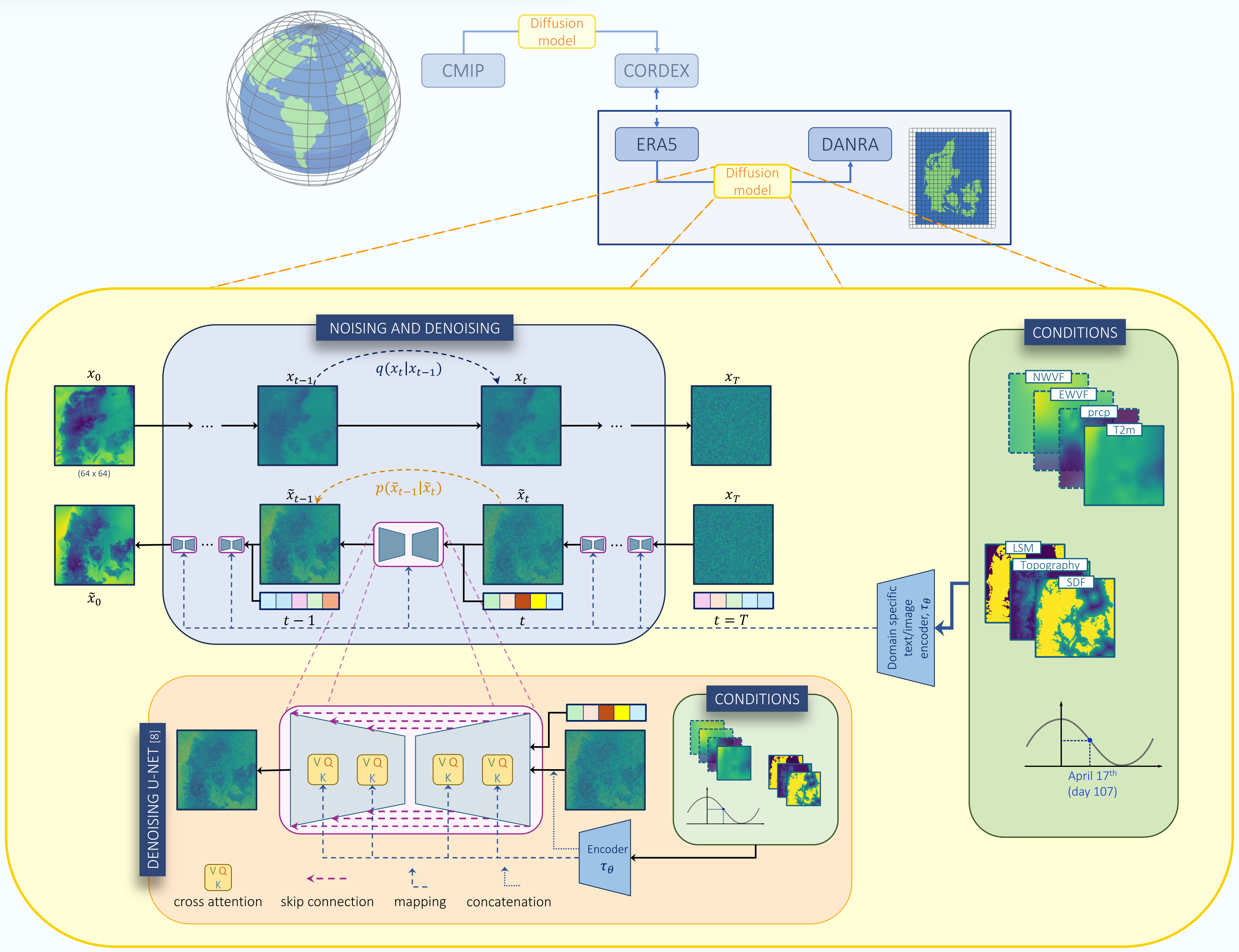
Generative diffusion models [1] [2] work by **computing a forward diffusion** process by iteratively adding gaussian noise with cosine sampling, then **learning the reverse diffusion** process with a U-Net, and finally **sampling through iterative denoising** of random noise.

TRAINING



SAMPLING

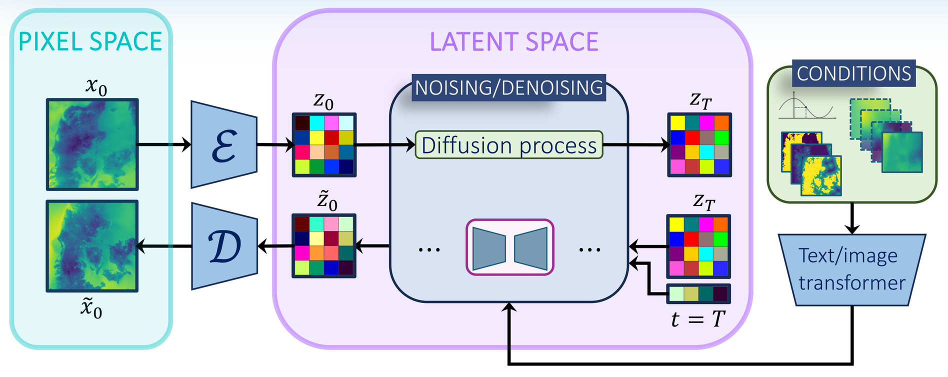




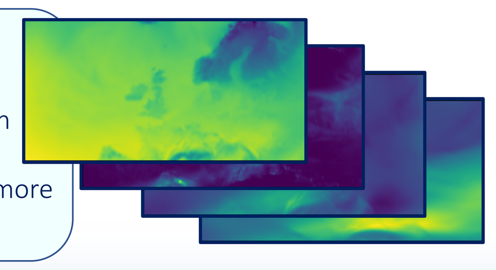
WHAT'S NEXT?

ON THIS MODEL

An ongoing effort is currently underway to speed up the training process through the implementation of a **Latent Diffusion Model** [4]. Alongside this, the conditioning will be modified to incorporate a **larger geographical and temporal domain** for capturing **large-scale atmospheric dynamics**.



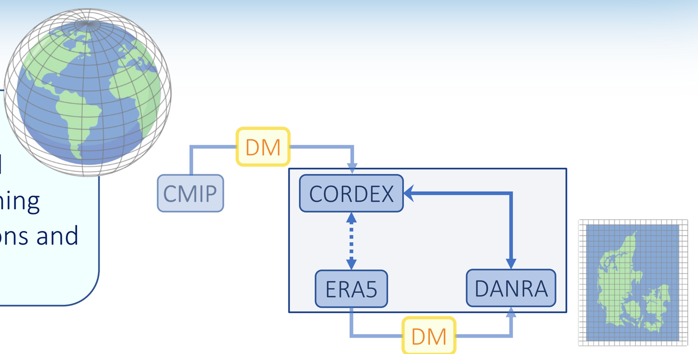
Extended domains
To capture larger atmospheric dynamics, especially in the North Atlantic. Adding a temporal component (synoptic scale) for more accurate projections



ON NEXT STEPS

The immediate next work will focus on generating a synthetic synchronised dataset between select EURO-CORDEX realisations and DANRA, to create a training dataset useful for making climate projection downscaling – for single models and full ensembles.

Next in the pipeline
Creating synchronised and futurized datasets for training model to climate projections and not just reanalysis data.



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