Physically-Informed Video Inpainting: A Deep Learning Approach for Weather Reconstruction

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In the scope of this master thesis, we set out to investigate the potential of artificial intelligence for weather reconstruction. As a result, we propose a tailor-made network architecture, called WeRec3D, which has been optimized by innovative extensions of the training process to the extrapolation of daily pressure and temperature fields.

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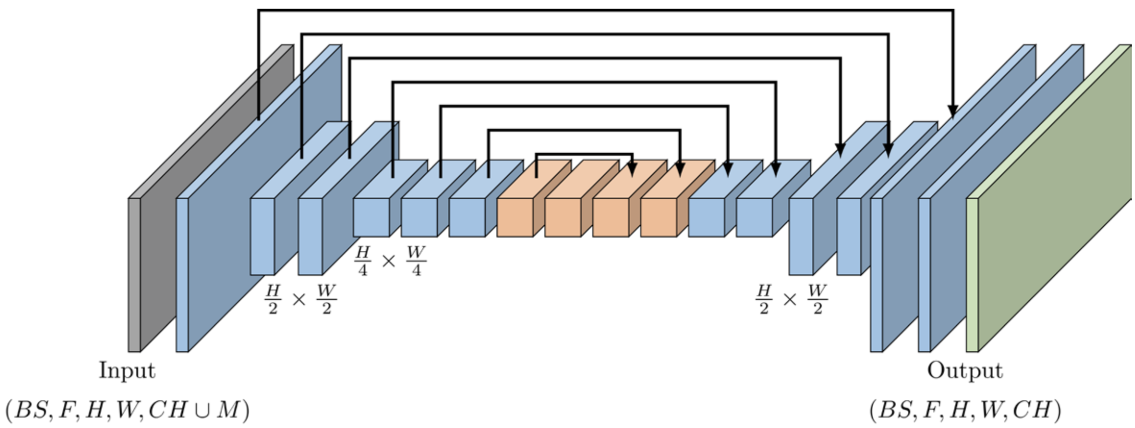
Historical weather observations are a fundamental part of improving our understanding of today's climate. However, the archival records are incomplete in both space and time. They only provide local descriptions of the weather confined to the stations immediate environment. In turn, this is insufficient to gain a comprehensive understanding of climate dynamics, including extreme weather events linked to them. Consequently, climate researchers use weather reconstruction methods to obtain a thorough picture of past conditions. Until now, mainly traditional statistical methods have been used to complete past weather patterns.

In this thesis, we investigate the potential of modern deep learning techniques for weather reconstruction applied to the heatwave of 1807. Inspired by video inpainting, we show that artificial intelligence can accurately fill historical observation gaps. This is demonstrated using meteorological temperature and pressure data. We first utilize the weather reanalysis ERA5 to train our network in a self-supervised manner and initially validate it on daily fields over Europe. In the course of this, we evaluate extensions to the training process and input to improve the reconstruction capability. As a result, an incremental pre-training, a spatially moving window, a physical soft constraint and elevation data as a further predictor revealed a positive influence. This modeling basis is then expanded again, resulting in two methods. On the one hand, an adjustment is made to the static observation locations of the target year. On the other hand, we use random cells from an analogue resampling method (ARM) to artificially increase the proportion of observed measurements. These two modeling variants are then used in parallel for the concrete weather reconstruction of the heatwave in 1807.

The inferences for the historic year show high correlation and low RMSE values in a leave-one-out procedure of the stations in space. This applies both to the model that was trained with statically missing data and to the model that was extended with ARM samples. The latter variant has an average RMSE of 1.16°C for temperature and 179Pa for pressure across all omitted stations. The normalized anomalies show a correlation of at least 0.84 and a maximum RMSE and standard deviation delta of 0.54 and 0.27 respectively.
To the best of our knowledge, this is the first study to investigate weather reconstruction using deep learning algorithms. We propose video inpainting as a new approach to reconstruct missing weather information.



Network architecture of our Three-Dimensional Weather Reconstruction Model (WeRec3D)