Convolutional Conditional Neural Processes for sub-kilometer wind gust prediction

Efficient modelling of sub-kilometer surface wind

Graduate

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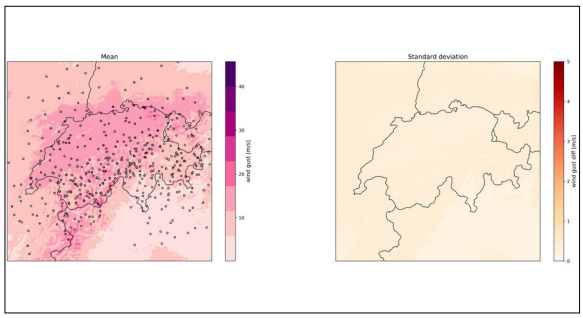
Introduction: MeteoSwiss, Switzerland's Federal Office of Meteorology and Climatology, aims to produce wind climate analyses. The results of such an analysis are often presented as a 2D gridded map of Switzerland, with colours indicating the wind speed value at each grid cell. Given Switzerland's complex topography, the spatial variation in wind speeds is high, and using only the wind gust surface observations at the measurement stations is insufficient to produce a wind map. MeteoSwiss is experimenting with additional data sources to create wind maps, such as Numerical Weather Prediction (NWP) model data. The Consortium for Small-scale Modeling (COSMO-1E) is a NWP model operated by MeteoSwiss, for which historical data are available.

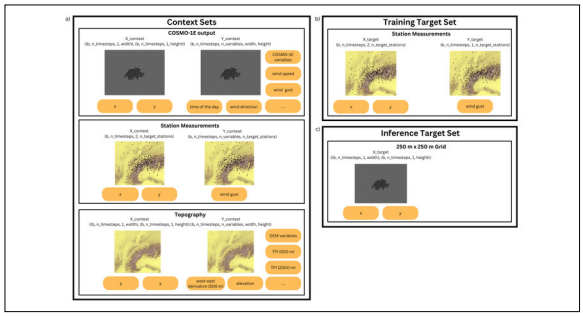
Approach: In this work, we develop a Convolutional Conditional Neural Processe (ConvCNP) model to produce a wind gust prediction at a spatial resolution of 250 m x 250 m. The model is trained and evaluated on two years of COSMO-1E data, surface observations from over 600 stations, and topographic features at a resolution of 250 m x 250 m. Its performance is evaluated against a Gaussian Process baseline.

Result: The results show that the ConvCNP is capable of producing accurate mean predictions, particularly in low wind gust regimes. However, the evaluation revealed that it performs worse than the baseline in estimating predictive uncertainty and in forecasting high wind gusts. To improve the model's performance, one important factor to consider is the dataset, which includes only a small number of high wind gust samples. Stratified batching and stratified loss functions may offer a potential solution. Also given the recent advances in Variational autoencoders and Neural Processes, we expect that incorporating a working latent path will improve the model, particularly in estimating predictive uncertainties more reliably. Given the significant advantage in inference time, it is worthwhile to further investigate neural networks—particularly Neural Processes—to support the generation of higher-resolution wind gust maps in a shorter time.

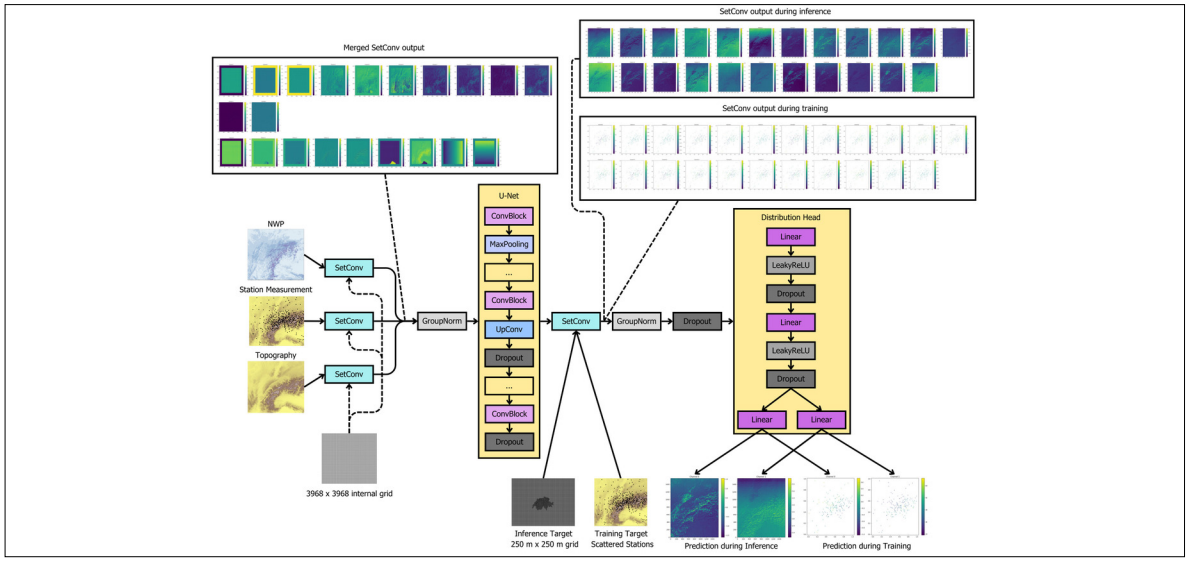
Predicted mean (left) and standard deviation (right) during Storm Frederico at 00:00 on 17 November 2023.
Own presentment



The context sets and target sets used as model inputs.
Own presentment



ConvCNP with input and output, internal structures (dashed arrows), and intermediate representations (dashed lines).
Own presentment



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