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Extreme Precipitation Nowcasting using Deep Generative Models

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Abstract—**Extreme precipitation usually leads to substantial impacts. Floods in the Netherlands, Belgium and Germany in the summer of 2021 have caused loss of lives, destruction of infrastructures, and long-term effect on economics. To avoid such disasters, it is important to develop a reliable and accurate method to predict heavy rain.**

Nowcasting is an observation-based method, which uses observations of the current state of the atmosphere to forecast future weather conditions, with statistical and optical-flow techniques, up to several hours in the future. Currently, there are two main pathways in nowcasting. The first are the conventional nowcasting methods, consisting of field-based methods, object-oriented methods and analogue-based methods. A number of these methods are included in PySTEPS, an open-source framework considered the state of the art in nowcasting [1]. Second, deep-learning models play a key role in the nowcasting field due to their strong regression ability. Various approaches to do nowcasting with Recurrent Neural Network (RNN) and Generative Adversarial Network (GAN) variants also lead to skilful predictions. Among them, DeepMind introduced a GANs network with two discriminators and convolution GRU as a generator [2]. This model can extract both spatial and temporal features and outperforms PySTEPS in overall performance. Nowcasting results from deep-learning models and PySTEPS show that deep-learning nowcasting methods lead to a lower bias and shorter processing time than PySTEPS. However, current nowcasting models are only sufficient for modelling normal weather conditions, but they are not suitable for extreme weather conditions due to the imbalance in the dataset. The imbalance originates from the skewed distribution of rainfall, which predominantly has zero rainfall and only few high-intensity amounts.

The focus of the study is on developing a deep generative model for nowcasting and incorporating extreme event-related conditions and constraints for better extreme rainfall forecasting. The proposed model was inspired by previous research in visual synthesis [3]. The model (shown in Figure 1) makes use of a two-stage structure: the first stage is a Vector Quantization Variational Autoencoder (VQ-VAE) which compresses the original input into a low-dimensional latent space. The second stage is an autoregressive transformer which predicts the future weather map's latent space. For better modelling of extreme events, Extreme Value Loss (EVL) proposed in [4] is incorporated with the proposed model. In addition, a memory module is introduced for the transformer in the second stage to memorize historical extreme events that happened in particular catchments.

The model was tested and validated on the KNMI radar dataset from 2008 to 2021, which includes 5-min precipitation accumulations over the Netherlands with a 1-km spatial resolution. The emphasis of the study is on 3-hour rainy events, and the extreme events are defined based on the precipitation intensity of 12 catchment areas across the Netherlands. Specifically, an event is labelled extreme if one of the catchments has a 3-hour precipitation amount that is among the top 1% of this catchment's historical 3-hour precipitation sums. The model receives precipitation maps 30 minutes before the event as input to predict the precipitation maps for the following 3 hours, with a time interval of 30 minutes. The results are compared with PySTEPS, GAN and RNN models from the literature based on the Critical Success Index (CSI), Pearson Correlation Factor (PCF) and Fractions Skill Score (FSS). In addition, to identify whether extreme events are detected, the average precipitation of particular catchments is compared.

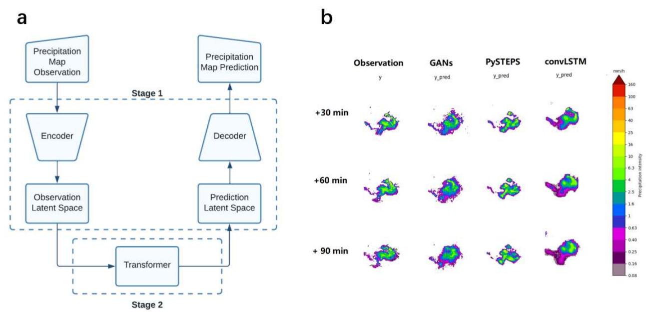

Fig. 1. (a) Proposed model structure. (b) Example prediction of precipitation intensity for 30, 60 and 90 min using nowcasting methods GAN, PySTEPS and convLSTM [1], [5], [6].

§Equal contribution

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