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Enhancing quantitative precipitation estimation in the NWP using a deep learning model

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Precise quantification of precipitation is crucial for effective planning and minimizing property damage or loss of human life caused by extreme weather events, especially under the rapidly changing climate. Currently, quantitative precipitation forecasting (QPF) in numerical weather prediction (NWP) models rely heavily on parameterization schemes for microphysics, boundary layers, cumulus, etc., rather than directly solving physical-based governing equation sets to predict fundamental variables such as temperature, wind speed, and humidity. These parameterization schemes introduce significant uncertainties in precipitation forecasting due to the limited knowledge of precipitation processes, which bottlenecks the performance of precipitation forecasting in NWP models.

To overcome this challenge, we propose a deep learning model based on Vision-Transformer that directly ingests fundamental meteorological variables solved by NWP models as predictors and maps them quantitatively to the precipitation map from a satellite-merged precipitation product. In this study, we conducted Weather Research and Forecasting (WRF) model simulations at 27km grid resolution for five years from 2017 to 2021 over China and the southeast region of Asia, and we used simulation results for the wettest season from June to September in 2017-2019 as training data, while validating and testing the model performance on data from 2020 and 2021. The deep learning model aims to circumvent uncertainties in physical parameterization schemes, which are due to the incomplete understanding of physical processes, and directly reproduce the high-resolution satellite rainfall observation product, the Climate Prediction Center morphing method (CMORPH) data.

Our evaluation results on the test dataset show that the deep learning model effectively extracts features from meteorological variables, leading to improved precipitation skill scores of 21.7%, 60.5%, and 45.5% for light rain, moderate rain, and heavy rain, respectively, on an hourly basis. We also evaluate two case studies under different synoptic conditions and show promising results in estimating heavy precipitation during strong convective precipitation events. Overall, the proposed deep learning model can provide vital insights for capturing precipitation-triggering mechanisms and enhancing precipitation forecasting skills. Additionally, we discuss the sensitivities of the

fundamental meteorological variables used in this study, training strategies, and performance limitations.