



Augmentation of X-Band Radar Precipitation Estimates with Micro Rain Radar Observations using Machine Learning

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Precise rainfall estimation is highly essential for investigating water availability, evaluating weather hazards, and understanding rapid climate variations in urban ecosystems. Accurate runoff response is crucial for land use planning, which requires high spatiotemporal precipitation observations, particularly in urban hydrology for groundwater management and the design of efficient drainage systems. Although a rain gauge provides accurate rainfall measurements at a particular location on the surface, it often lacks the spatial extent of rainfall distribution, depending on the gauge network and the complexity of the terrain. Moreover, the rain gauge accumulates the rainwater and records an observation until the minimum threshold of 0.2 mm for rainfall detection is reached, which might miss the precise starting time of the rain event.

The Weather radar provides a higher spatiotemporal resolution compared to rain gauge monitoring, which tracks precipitation over a larger region at regular spatial and temporal intervals, with an estimate of instantaneous rainfall intensity. X-band weather radar satisfies the need for higher spatiotemporal observation with more accurate rainfall estimates for precise runoff modelling in comparison to S and C-band radars, but at the cost of greater signal attenuation due to its larger operating frequency. X-band radar suffers from the limitation of overshooting for low-lying clouds relative to its sampling volume, which worsens with the increasing range in proportion to the radar elevation angle. X-band radars are also prone to errors resulting from non-meteorological echoes, reflections from ground clutter, and the cone of silence above the maximum elevation angle that causes the rain cells looming above the radar antenna in the zenith direction to remain undetected by the weather radar. Micro rain radar (MRR) is a vertically pointed, specialised, low-cost radar that can continuously measure the drop size distribution and, hence, rainfall rates at different vertical ranges with high resolution. MRR provides fine-scale vertical rainfall characteristics, which can effectively adjust the X-band radar estimates for vertical layers at various elevation angles.

In this research, we have developed a model to perform the bias correction in the rainfall rates of X-band weather radars using the MRR rainfall observation as ground truth. A feed-forward neural network is implemented to improve precipitation estimates from X-band weather radars, utilising

rainfall rate, horizontal reflectivity, and specific differential phase as input features. The MRR observations from multiple range gates are averaged over the vertical extent of the X-band radar beam in order to align with the mean rainfall rates from X-band weather radar. The MRR rainfall estimate is pre-processed to mitigate bias by removing outliers caused by evaporation/wind effects, melting particles, or non-meteorological objects, and further verified against collocated rain gauge observations to identify days with actual rainfall events. Thereafter, the rainfall rates at different altitudes from the X-band weather radar nearest to the MRR location are fed to the neural network model as inputs, while the averaged MRR observations from the corresponding range gates are used as the ground truth for training the model. This approach enables bias correction and improves precipitation estimates, particularly across vertical atmospheric layers.