Precipitation nowcasting using spatiotemporal models and volumetric radar data

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Nowcasts (short-range forecasts) of rainfall can be used for providing early warning of flash floods. Thus, they are of high societal importance especially in densely populated urban areas. Weather radars are ideally suited for this purpose due to their good spatial coverage and high spatial and temporal resolution (e.g. 1 km and 5 minutes).

A novel approach to radar-based rainfall nowcasting is proposed. The forecast model consists of two components: horizontal advection and temporal evolution of rainfall intensities. The advection velocities are estimated from radar-measured rain rate fields using a pattern matching method. A smooth advection field is obtained by interpolating the motion to areas with no precipitation. The extrapolation is done using a semi-Lagrangian scheme.

The temporal evolution of rainfall intensities is described in Lagrangian coordinates by using a spatiotemporal process model. Such models are ubiquitous in environmental and physical sciences. This study presents the first attempt to apply such a model to three-dimensional rainfall measurements to capture the vertical structure of rainfall processes. This is done by using a linear integro-differential equation with the Markovian assumption (i.e. the next time step depends conditionally on the previous one). Spatial dependencies are modeled via a convolution kernel. To reduce the dimensionality of the parameter estimation, the kernel is parametrized by a trivariate Gaussian function, and the model is formulated and implemented in the Fourier domain. Finally, the parameter estimation is done in the Bayesian framework by applying a Markov Chain Monte Carlo (MCMC) method with Gibbs sampling.

The operational feasibility of the proposed model is evaluated by using data from the NEXRAD WSR-88D radar deployed in Fort Worth, Texas. Measurements from 14 elevation angles are used by restricting the analyses to liquid precipitation below the melting layer. The data processing chain consists of 1) temporal interpolation within radar volumes, 2) clutter filtering, 3) attenuation correction, 4) melting layer detection, 5) polarimetric rain rate estimation based on reflectivity, specific differential phase and differential reflectivity and 6) interpolation to a three-dimensional grid.

The focus of the validation is on higher rain rates (> 5 mm/h) using 10 events during 2018-2019
with mixed convective and stratiform rainfall. Predicted rain rates from the nowcasting model are compared to observations from low-angle radar scans. Using standard verification scores (e.g., equitable threat score and mean absolute error), it is shown that for rainfall rates between 5-25 mm/h, the proposed method can yield up to 30% improvement compared to state of the art extrapolation nowcasting methods. This is attributed to using the spatiotemporal model and vertical profile information obtained from three-dimensional input data.