Improved nowcasting of convective rainfall using vertically integrated liquid

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The term nowcast refers to a short-range weather forecast (i.e. the next few hours). Nowcasts of severe rainfall are of high societal importance, as they can be used for providing early warning of rainfall-related hazards. Weather radars are ideally suited for this purpose due to their good spatial coverage and high spatiotemporal resolution (e.g. 1 km^2 and 5 minutes).

Radar-based precipitation nowcasts are traditionally obtained by estimating the advection field from consecutive radar images and extrapolating the radar echoes. Typically this is done by using measurements interpolated to a constant altitude level (CAPPI). The limitation of this approach is the lack of model for the vertical evolution of precipitation. This is particularly the case during convective events, where the time horizon of usable forecast skill can be limited to less than 30 minutes. To address this shortcoming, Boudevillain et al. (2006) proposed the RadVil model based on a mass balance equation of vertically integrated liquid (VIL). The VIL is derived from liquid water content (LWC) based on radar reflectivity measurements (Z). The predicted VIL is then converted to ground level rain rate using a linear relationship. Several improvements to the original method are proposed.

The key idea is to adapt the methodology developed in Pulkkinen et al. (2019) for implementing the forecast model (horizontal advection and VIL equations) exclusively in the spectral domain for computational efficiency. Instead of a constant advection field used in RadVil, the proposed method uses the Dynamic and Adaptive Radar Tracking of Storms (DARTS) method (Ruzanski et al. 2011) for the advection field estimation. The method, that was originally implemented for the CASA nowcasting system, uses the discrete Fourier transform to solve the advection equation in the spectral domain. This formulation of the advection equation is also used for the extrapolation (Pulkkinen et al. 2019). In addition, the potential benefit of using separate advection fields for different altitude levels is shown.

The nowcasting model accounts for scale-dependence of predictability by adaptively filtering the forecast fields based on the autocorrelation function of each scale. The scale decomposition is done using the discrete Fourier transform. A shortcoming of the original RadVil model is the assumption that the source term governing the temporal evolution of the VIL remains constant during the forecast period. In the proposed approach, we thus apply a set of autoregressive integrated moving average (ARIMA) models to the source term to predict its temporal evolution in different scales. Finally, a post-processing scheme is employed to ensure that the forecast rain rate fields have the same statistical properties with the observed ones.

The predictability of different components of the VIL nowcasting model is analyzed in the Lagrangian coordinate system. A power-law relationship between spatial scale and lifetime based on the autocorrelation function is established. It is shown that the lifetime of VIL is up to two times longer than the lifetime of surface rain rate field, while the source term has lifetime up to five times shorter than the VIL field. Nevertheless, usable predictions of the source term can be obtained up to 30 minutes in the 10 km scale, which is enough to obtain a significant improvement compared to a static VIL nowcasting model that does not incorporate the temporal evolution of the source term.

The nowcasting model is tested and validated by using data from the radar network operated by the Finnish Meteorological Institute (FMI). The network consists of 10 C-band Doppler radars covering the whole Finland. The VIL is computed by using six elevation angles from each radar. In this study, we assume that the precipitation is in liquid form in the vertical columns. Identification of the precipitation phase and using different Z-LWC conversions for different phases (e.g. by using polarimetric techniques) are left as a topic of future research.

The verification is done by using 10 convective rainfall events during 2017-2019. Using standard verification scores such as the equitable threat score, mean absolute error and fractions skill score, it is shown that the nowcasts have up to 40% improved skill compared to conventional extrapolation nowcasting techniques and up to 20% improvement compared to the RadVil model. The largest improvements can be seen during convective events with rainfall intensities exceeding 10 mm/h, where significant amount of vertical evolution is present. It is shown that using 1 km^2 spatial resolution and a threshold of 1 mm/h, reliable nowcasts of instantaneous rain rates can be obtained up to 45 minutes, whereas the simple extrapolation-based method is limited to 30 minutes. Reducing the grid resolution to 5 km and using 15 min temporal aggregation period, the time horizon can be extended to two hours.

Keywords: rainfall, convective, nowcasting, vertically integrated liquid, scale decomposition, autoregressive model