An optimized radar-derived cloud ice mass model for nowcasting lightning

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A new radar-derived model is presented that serves to improve and extend the forecast horizon of lightning activity at a desired location. The model relates present-time calculations and short-term automated forecasts (nowcasts) of radar reflectivity vertically integrated over environmental heights where ice formation and charge separation is known to occur to recent lightning observations (flash rate densities) made over the same coverage area.

Radar reflectivity and derived products have previously been shown to provide on the order of 10-20 min of lead time to impending lightning activity based on natural relationships (i.e., without a nowcasting model). For example, lightning activity has been shown to reliably initiate about 10 min after detecting reflectivity values of 40 dBZ corresponding to -10 to -15 degree Celsius environmental heights in successive radar observations. In the method presented, nowcasts of vertically integrated radar reflectivity are dynamically numerically optimized to extend the lead time of nowcasting lightning activity at a specific time and specific location.

The method presented reframes an intractable bulk microphysics problem into a numerical optimization problem that is completely data-driven to improve reliable lead times for nowcasting lightning activity. Previously, a simplified bulk microphysical model with fixed parameters was used to estimate ice mass aloft. The new weather radar-based ice mass estimator uses a novel numerical optimization approach to dynamically update the parameters of this bulk microphysical model to improve lightning nowcasts. The linear model is comprised of gridded integrated reflectivity values, the most recent gridded lightning observations, and coefficients to be determined by the numerical optimization process.

Based on the variable nature of the observations, both matrices in the inversion problem will likely be ill-conditioned. Regularization is thus used to improve the conditioning of the problem enabling an optimized, direct numerical solution of the originally ill-conditioned problem to be found. Thus, the bulk microphysical problem is reframed into one of determining the regularization matrix and the weighting parameter.

Parallel computations are performed over a suitable range of parameters whenever new observations become available and the output of the best performing model is selected for each lead time. In this manner, relatively rapid storm evolution in a convective setting is accounted for by the selection of optimal and less-variable model parameters via real-time verification.

A study was performed to demonstrate the efficacy of the method. The radar data used for this study were collected by the Weather Service Radar-1988 Doppler (WSR-88D) radar located near Fort Worth, Texas, during a severe convective storm event occurring on 03 Apr 2014 from 000335 to 235741 UTC. The data were processed into CAPPI grids with a north-south and east-west grid spacing of 1 km at altitudes from 500 m to 12 km in 500 m increments. Thus, given the approximate temporal resolution of 4.5 min, the radar data consist of 172 data frames at 24 altitudes covering an area of +/-100 km horizontally from the radar site. Vertically integrated reflectivity data were created using the 5 km through the 9.5 km CAPPI
The lightning data used for this study were collected by processing detections of lightning discharges from multiple Vaisala remote lightning sensors part of the National Lightning Detection Network within approximately 1000 km of the KFWS radar. The flash density data were processed to grids with 1-km north-south and east-west spacing at ground level covering an area of +/-100 km from the radar site.

The Dynamic Adaptive Radar Tracking of Storms (DARTS) method was used to generate the radar-based nowcasts. DARTS estimates a distributed motion vector field based on a past history of observations (50 min in this study). This motion vector field is then combined with the most recent observation via a separate bilinear backward mapping advection algorithm to produce the nowcasted data fields.

A new verification method is also described. Previous research used a cell-based approach to lightning nowcasting and verification, where storm cells were first identified and lightning activity was associated with a particular cell. Lead times and lightning locations were not specified in the nowcasts. Since the method presented uses a grid-based approach, nowcasts are associated with a particular grid point (location). The concept of “first flash” is important in many lightning protection applications. In this study, a first-flash is defined to be the presence of lightning observed or forecasted at a grid point where none was observed within a 15-km radius within the past 20 min. Since the concept of first flash is relative to a location, first flashes can be attributed to advection as well as new growth within the storm.

The results show that the optimized radar-derived cloud ice mass model provides better performance in terms of Probability of Detection (POD) after a lead time of about 15 min and False Alarm Ratio (FAR) for all lead times versus the traditional radar-based ice mass model and direct extrapolation of lightning data.

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