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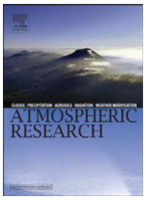

Radar-based hail detection

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ABSTRACT

Damaging hailstorms are rare but are significant meteorological phenomena from the point of view of economic losses in central Europe. Because of the high spatial and temporal variability of hail, the proper detection of hail occurrences is almost impossible using ground station reports alone. An alternate approach uses information from weather radars. Several algorithms that use single-polarisation radar data have been developed for hail detection. In the present study, seven algorithms were tested on well documented recent hail events from Czechia and southwest Germany from 2002 to 2011. The study aimed to find the optimal threshold values for the applications of these techniques over the Czech territory and for evaluating the climatology of hail events. The results showed that the Waldvogel technique and the NEXRAD severe hail algorithm were the most accurate methods for hail detection over the area of interest. A combined criterion was proposed based on a combination of previously tested techniques. The precision of this "combi-criterion" was demonstrated for a severe hail event. The abilities of the tested criteria to provide information about a hail-fall area distribution and hail damage risk over the Czech territory were shown and discussed.

1. Introduction

The occurrence of severe hail in Czechia is rare, but these are significant meteorological phenomena from the point of view of damage to agriculture and property. Hail events are limited in time and space, and the ground observation network can provide only partially complete information about the hail spatial distribution. The difficulty of determining the hail spatial distribution based on ground station data was expressed in the Climate atlas of Czechia (2007), which presented a map of the average annual number of days with hail for the period from 1981 to 2000. In this work we are interested in large hail, which can cause significant damage. The hail dimension implicitly comes out from the data about hail occurrence used in this study.

Experimental or operational hailpad networks in some European countries provide more detailed information about hail on the ground (Manzato, 2012; Berthet et al., 2011; Pocakal, 2011; Sioutas et al., 2009). For example, four hailpad networks operating in the most hail prone regions of France use more than 1000 hailpad stations (Berthet et al., 2011) and the studies of Giaiotti et al. (2001, 2003) demonstrate the potential of ground based networks in the Italian plain of Friuli Venezia Giulia. However, there is currently no hailpad network in Czechia.

To obtain information about the hail risk distribution over the Czech territory, it is useful to use weather radar data, possibly in combination with aerological or satellite data. The radar data provide information with high temporal and spatial resolution. There are two C-band single-polarisation radars that have been operating in Czechia since 2000 (Novak, 2007). Single-polarisation weather radar cannot distinguish among different types of hydrometeors, but some features in the reflectivity data, including high reflectivity occurrences at specific levels, can represent physical processes that are related to hail growth. Several methods for hail detection with single-polarisation weather radar data were developed and tested in different parts of the

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world. Some methods use threshold values for a hail-related quantity, such as reflectivity in low-level CAPPI (Geotis, 1963), vertically integrated liquid water (Amburn and Wolf, 1997) or the height difference between the zero isotherm and the highest level of the 45 dBZ reflectivity (Waldvogel et al., 1979). Other methods transform radar-based quantities into probability values, such as the Hail Detection Algorithm (Witt et al., 1998) and the Probability of Hail (Delobbe and Holleman, 2006). Some hail detection algorithms are based solely on radar measurement data (Geotis, 1963; Amburn and Wolf, 1997). Several algorithms make use of radar measurements together with other meteorological information; for example, aerological data are often used (Waldvogel et al., 1979; Witt et al., 1998). Auer (1994) and Hardaker and Auer (1994) proposed a method that combines radar reflectivity data with infrared cloud-top temperatures from satellite imagery.

Some more recent studies deal with radar-based identification of hail. Lopez and Sanchez (2009) calculated a number of variables derived from radar parameters, classified them by means of logistic regression and linear discriminant analysis, and combined selected variables to develop a new discriminating tool. Both statistical models selected mostly the traditional radar parameters for hail identification such as VIL, maximum reflectivity, height of the maximum reflectivity, maximum reflectivity change rate, storm top, and the tilt of the storm. The variable with the greatest weight in the final function was in both cases VIL. Makitov (2007) dealt with the algorithm for separating hail and rain parts of radar echo, which is needed to improve the accuracy of radar-based estimation of hail kinetic energy. He proposed an algorithm based on the empirical relationship between hail probability and the altitude of the 45 dBZ contour above the level of zero isotherm.

Mallafre et al. (2009) considered hail identification techniques for Ebro valley region in Spain. They did not found a significant difference between the various methods, however kinetic energy flux was recognised to be the best parameter for distinguishing between hail and no-hail precipitation in the studied area. The most recent studies use data from dual-polarisation radars, which become widely used (e.g. Chandrasekar et al., 2013; Kaltenboeck and Ryzhkov, 2013).

In the present study, seven hail detection methods were selected according to their data availability and after considering their simplicity of operational use. The selected methods were converted into hail criteria using appropriate threshold values, and those methods with the best capabilities in the studied areas were used to estimate a hail risk distribution over the Czech territory.

The present study addresses the capabilities of selected hail detection methods in southwest Germany and Czechia. In both areas, data from C-band Doppler radars were used. In Czechia, two radars, which are operated by the Czech Hydro-Meteorological Institute (CHMI), cover the territory with measurements, and a merged product of radar reflectivity is provided to users (Novak, 2007). In Germany, radar data from the Institute for Meteorology and Climate Research (IMK) of the Karlsruhe Institute of Technology were used (Kunz and Puskeiler, 2010).

The study has the following sections. In the second section, the selected hail detection algorithms and input data are described. The third section addresses the sensitivity tests of the hail detection criteria and presents the test results; this section includes the application of criteria to several hail events in Germany (Section 3.1) and Czechia (Section 3.2). In the fourth section a new combi-criterion is defined which combines the information of several basic criteria. The capabilities of these criteria are demonstrated through the analysis of a severe hail event in 2010 (Section 4.1), and the hail risk over the Czech territory is considered in Section 4.2. The summary of results and outlook for future work are included in Section 5.

2. Hail detection algorithms and input data

Seven methods that use radar data for hail detection were tested. Data availability was considered when choosing the methods and adjusting the algorithms. CAPPI data from single-polarisation C-band radars were available for the days with several established hail events, and sounding data from Prague and Stuttgart were also accessible. The tested hail detection techniques can be described as follows.

CAPPI method: a simple method that aims to distinguish hail from rain and is based on a plan-position indicator of the radar reflectivity at a constant altitude (CAPPI). Holleman et al. (2000) tested this method and used a CAPPI of 0.8 km. To distinguish rain from hail, Schuster et al. (2006) applied the CAPPI reflectivity at an altitude of 1.5 km with a threshold reflectivity value of 55 dBZ. The same threshold was proposed by Geotis (1963). Mason (1971) reported that if the 55 dBZ value represented rain, then it would imply improbably high rainfall rate values. In this study, we applied CAPPI values of 2 km. This level was selected to be high enough to consider a typical range of the altitudes of Czechia and the altitudes of the radar sites. For instance, the mean height of the zero isotherm in summer months 2007–2011 as detected by the sounding station Prague-Libus is 3100 m a.s.l.

ZMAX method: this method is an extension of the CAPPI method. The ZMAX method uses the maximum radar reflectivity in a vertical column (Z_{max}) instead of the reflectivity at a fixed altitude. The ZMAX method as a hail warning product is present in the Rainbow processing software of Gematronic radars (Holleman, 2001). A threshold value of 55 dBZ is used (Kunz and Puskeiler, 2010).

VIL method: the vertically integrated liquid water content (VIL) is the basis of this method. Greene and Clark (1972) introduced VIL, which converts three-dimensional radar data to a two-dimensional display via the conversion of radar reflectivity to the liquid-water content and subsequent vertical integration. The VIL can be determined by the following equation (Amburn and Wolf, 1997):

$$\mathrm{VIL} = \sum 3.44 \times 10^{-6} \left[\left(\mathrm{Z_i} + \mathrm{Z_{i+1}} \right) / 2 \right]^{4/7} \Delta h, \tag{1}$$

where Z_i and Z_{i+1} are radar reflectivity values at the lower and upper portions of the sampled layer, respectively, and Δh is the vertical thickness of the layer in metres. Although VIL was designed to show the rainfall potential, high values of VIL correlate well with the occurrence of hail. There are no obvious VIL values to use as threshold values for hail detection. Amburn