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Comparison and optimization of radar-based hail detection algorithms in Slovenia

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ABSTRACT

Four commonly used radar-based hail detection algorithms are evaluated and optimized in Slovenia. The algorithms are verified against ground observations of hail at manned stations in the period between May and August, from 2002 to 2010. The algorithms are optimized by determining the optimal values of all possible algorithm parameters. A number of different contingency-table-based scores are evaluated with a combination of Critical Success Index and frequency bias proving to be the best choice for optimization. The best performance indexes are given by Waldvogel and the severe hail index, followed by vertically integrated liquid and maximum radar reflectivity. Using the optimal parameter values, a hail frequency climatology map for the whole of Slovenia is produced. The analysis shows that there is a considerable variability of hail occurrence within the Republic of Slovenia. The hail frequency ranges from almost 0 to 1.7 hail days per year with an average value of about 0.7 hail days per year.

1. Introduction

Hail events can cause significant damage to buildings, vehicles, and crops. Hail can occur in most of Europe but occurs more frequently in mountainous regions such as the Alps (Punge et al., 2014), which includes Slovenia. Information about the climatological aspects of hail frequency is important for insurance companies and the wider economy, while near-real-time hail detection can help reduce hail-related damage.

Hail events are usually recorded at manned stations, but the density of the station network is usually too coarse to capture local-scale hail events reliably (Punge and Kunz, 2016), and the hail events are not reported in real time so the information cannot be used for near-real-time hail detection. Another source of hail observation data are the observation networks using hailpads. However, while such networks exist in several regions throughout Europe, including parts of France (western, central southern), northern Italy, eastern Austria, parts of Spain, Greece, and Croatia (Dessens, 1998; Svabik, 1989; Giaiotti et al., 2003; Počakal et al., 2009; Berthet et al., 2011; Punge and Kunz, 2016), there are none available in Slovenia. Hail-related data can potentially also be obtained from private companies or government agencies that deal with hail-related damage reports and insurance claims. However, such data are not available in Slovenia. A different approach to in situ observations and hail-related damage reports is to use a remote sensing technique to detect hail events. This is usually done by surface-based weather radar or by satellite observation based on cloud top brightness temperatures and the detection of overshooting cloud tops (Punge and Kunz, 2016).

The advantages of radar-based hail detection are the near-continuous coverage of the region covered by the radar, the near-real-time availability of data and good horizontal spatial resolution (at least near the radar station). At the same time radar-based hail detection suffers from some of the same limitations as the traditional rainfall intensity detection along with some additional problems which make the radar detection of hail less reliable (e.g. low vertical resolution of data far away from the radar station, small temporal resolution, assumptions about the dynamics of hail storms).

Nevertheless, in recent years several studies analyzed and tried to optimize radar-based hail detection algorithms for several European countries. For example, Skripniková and Řezáčová (2014) tested seven hail detection algorithms on 25 hail days in 2002–2011 in the Czech Republic and southwest Germany; Holleman et al. (2000) analyzed five different algorithms for severe weather events with hail over Netherlands that occurred during the summer of 1999 while Kunz and Kugel (2014) analyzed five different algorithms for a 15-year period in southwest Germany. Moreover, several radar-based hail climatologies have been made, e.g. Kunz and Puskeiler (2010), Puskeiler et al. (2016), Skripniková and Řezáčová (2014), Kunz and Kugel (2014), and Nisi et al. (2016).

An improvement in radar-based hail detection is also possible by the

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use of polarimetric radar. For example, Besic et al. (2016) showed very promising results with a statistical clustering based approach used with Doppler dual-polarization measurement to discriminate hydrometeor types on the MeteoSwiss radar network. The approach was able to differentiate between a number of liquid and solid hydrometer classes which included hail, melting hail and grauple. In Slovenia, a dual-polarization radar station was installed in 2013, however, the dual-polarization measurement mode is not yet operational. Thus, the only available real-time measurements, as well as the radar archive from 2002 onwards, consist only of data in single-polarization mode.

A proper study of radar-based hail detection algorithms for Slovenia has not yet been made. Nevertheless, some limited studies have been done, which either focused on a smaller part of Slovenia (Klemenčič et al., 2009), did not evaluate the success of the hail detection algorithms (Klemenčič et al., 2012), or analyzed only a few selected severe weather events (Kolarič, 2014). Moreover, none of the previous studies attempted to optimize the hail detection algorithms and adjust them to the climate specific to Slovenia.

In this study, we evaluate four commonly used radar-based hail detection algorithms in Slovenia. The algorithms are verified against ground observations of hail in the period between May and August from 2002 to 2010. The algorithms are optimized by determining optimal values of algorithm parameters. In the end, using the optimal parameter values, a hail frequency climatology map for the whole of Slovenia is produced.

Section 2 provides the description of the datasets used in the study while Section 3 presents radar-based hail detection algorithms and verification methodology. Section 4 presents the results, which is followed by conclusions and discussion in Section 5.

2. Datasets

2.1. Radar data

The data from the weather radar station at the Lisca mountain is used for the study. It is located at the very top of the mountain which lies in the eastern part of Slovenia at approximately 950 m a.s.l. (Fig. 1a). It is operated by the Slovenian Environment Agency (SEA), which provided all the data for this study. The radar station was produced by Vaisala and is a single-polarization Doppler C-band radar which uses a 5 cm wavelength. Its parabolic antenna (diameter 4 m) rotates at 3 RPM, and scans are performed at twelve elevation angles ranging from 0.4° to 28.3° (see Fig. 1b). A new radar scan is performed every 10 min. The horizontal spatial resolution of the radar data is 1 km. The precision of radar measurements is 0.5 dBZ. The radar station has good coverage of the eastern and central parts of Slovenia, while in the west the coverage is limited due to the large distance from the radar (up to nearly 150 km) or the presence of high mountains (up to 2864 m a.s.l. in the Julian Alps). The radar calibration is performed regularly on a yearly basis thus ensuring a stable estimate of radar reflectivity.

The first weather radar station at Lisca was installed in 1984 but the archiving of full three-dimensional volumetric radar reflectivity fields only started in 2002. Since most radar-based hail detection algorithms require volumetric data as input, we are limited to the period of 2002 onwards for the analysis. Moreover, the radar uses the Vaisala IRIS propriety software. The software archives the volumetric data in a propriety file format, which makes it difficult to convert the data to a more user-friendly format, which can be used as input for our analysis. The conversion can be done using the IRIS software, but it has to be done manually and separately for each hail event. This results in a large amount of manual work that has to be done by the radar operator. This forced us to limit the analysis period to the summer months of 2002–2010. The analyzed months are May–August, which include the majority (81%) of observed hail events (Table 1 shows the number of observed hail events by month). However, even when limited to this

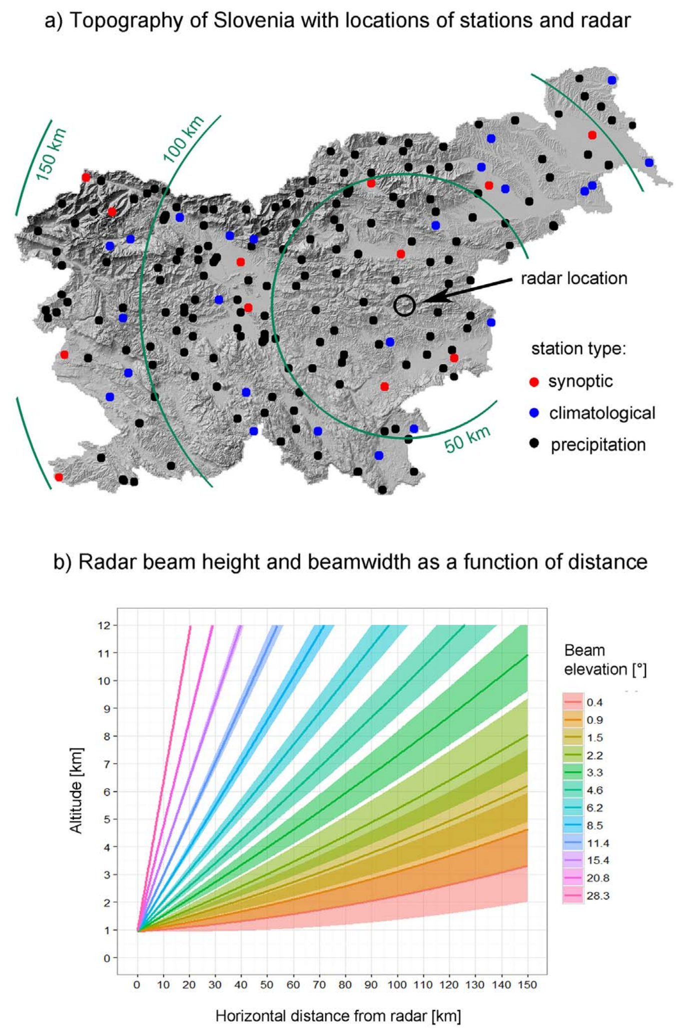

Fig. 1. a) The topography of Slovenia with locations of radar and stations according to station type. b) The radar beam height and beam width as a function of distance from the radar according to Eq. 1.

Table 1
Number of hail observations on manned stations by month in the 2002–2010 period.

Month	Number of hail observations	Percentage
January	6	0%
February	6	0%
March	78	3%
April	218	7%
May	570	19%
June	622	21%
July	660	22%
August	558	19%
September	100	3%
October	154	5%
November	12	0%
December	18	1%

period too much manual work is required to convert all the 10-min measurements, and an additional compromise must be made: to convert and analyze only the cases where the maximum reflectivity (anywhere in the radar domain) is at least 45 dBZ. The analysis in the later sections shows that the probability of hail below 45 dBZ is low since the optimal reflectivity threshold values tend to be higher than 45 dBZ; nevertheless, this criterion adds some uncertainty to the analysis. In total, there are about 35,000 ten-minute cases, spread over 790 days in the nine-year period, that are analyzed. The frequency of missing radar