ASSESSMENT OF THE HAIL HAZARD IN SOUTHWEST GERMANY

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I. INTRODUCTION

Severe hailstorms pose a significant and increasing threat to modern societies and their assets. In the federal state of Baden-Württemberg in Southwest Germany, nearly 40% of the total damage to buildings (1986-2008) are related to large hail, with a mean annual loss amounting to almost EUR 50 million. For loss prevention and risk management purposes, comprehensive information about the local probability and intensity of severe hail storms is required. This is a difficult task because hail is not captured accurately and uniquely by a single observation system. By combining 3D reflectivity data from a C-band radar with insurance loss data, the constraints inherent in both data sets are assumed to be compensated, enabling high-resolution detection of hail streaks and assessment of the hail hazard (Kunz and Puskeiler, 2009).

II. DATA SETS AND METHODS

Data from the IMK radar located 10 km north of Karlsruhe were used to identify hailstorm tracks and intensities between 1997 and 2007. To consider severe hailstorms only, a lower threshold of 55 dBZ was defined for the maximum radar reflectivity in a vertical column (Hohl et al., 2002). Frequency and intensity of convective cells are determined by applying the tracking algorithm TRACE3D (Handwerker, 2002) to the 3D reflectivity data. The algorithm identifies convective cells by specific radar signatures and follows them in space and time.

To close the gap between radar reflectivity measured at a certain level in the atmosphere and hail occurrence on the ground, insurance loss data (hereinafter: SV data) were additionally used. A building insurance against natural hazards was mandatory in Baden-Württemberg until 1994 and offered exclusively by a monopolist. Hence, the data are characterized by a high areal coverage and consistency. Hailstorm tracks as determined by TRACE3D are merged with SV loss data using a geographical information system (GIS). A total of 65 days with damage-causing hailstorms were considered in the study.

III. RESULTS

A. Hailstorm Tracks

Significant spatial differences in hail climatology can be derived from the track density displayed in Figure 1. Highest density is found over the agglomeration of Stuttgart, whereas the activity is lowest over the two mountain chains of Black Forest and Swabian Jura as well as over the northern parts of the study area. A striking feature is the sharp gradient in track density at the northwestern edge of the Swabian Jura, where most of the cells proceed approximately parallel to the mountain ridge. It is obvious that orography play a decisive role for the spatial distribution of hail occurrence.

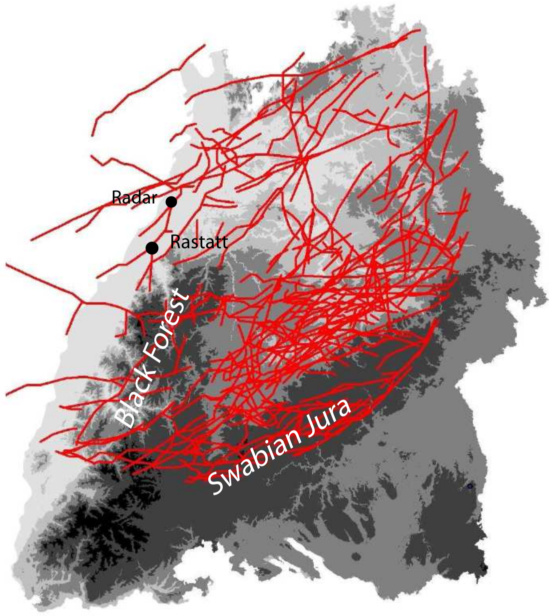

FIG. 1: Tracks of hailstorms ($Z > 55$ dBZ) according to radar data between 1997 and 2007. Only tracks that were related to damage to buildings according to SV data are displayed.

The majority of hailstorms proceeds from southwest to northeast, which corresponds more or less to the mean wind direction in the middle troposphere according to sounding data at the station of Stuttgart. In most cases, the tracks have a length of more than 70 km. Given a mean wind speed of 15.1 ± 6.5 m s^{-1} between 700 and 500 hPa for the days considered, this yields a persistence in excess of 1 or 2.5 hours, respectively. Note that during this time span, the convective cells exhibit a radar reflectivity above 55 dBZ. Assuming additional time scales for development and dissipation in the order of 30 min each, it may be inferred that damage-related hail usually is associated with organized convection like multicells, supercells, or mesoscale convective systems. This finding is supported by the fact that substantial vertical wind shear, a prerequisite for organized convective systems, was present on most of the hail days.

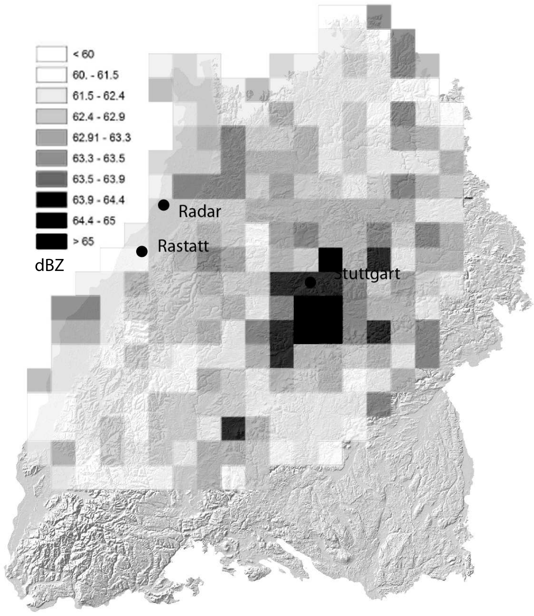

FIG. 2: Radar reflectivity in dBZ for a 1-year statistical return period projected on a 10×10 km^2 grid.

B. Hail Hazard Assessment

In order to consider not only the number of hailstorms, but also the intensity related to probability, extreme value statistics was applied to the radar data. To ensure a sufficient number of events for the samples, the analyses were performed on a 10×10 km^2 grid. For each grid cell, maximum radar reflectivity was determined on each of the selected 65 hail days. If a grid cell was hit more than once by hail on the same day, the highest radar reflectivity only was selected for the sample to ensure statistical independence of the events. The samples in the different grid cells comprise between 10 and 50 events.

As shown in Figure 2, the radar reflectivity for a one-year return period varies between approximately 60 and 65 dBZ within the study area. For the interpretation of the results, it should be borne in mind that radar reflectivity in dB is a logarithmic unit. The results closely resembles the density of hail tracks. This applies to the spatial variability of hail activity as well as to the location of the minima and maxima. Accordingly, in regions, where hailstorms are rare events, like the Rhine valley of Black Forest and Swabian Jura, storm intensity is also low on average. Conversely, over regions, where hailstorms occur frequently like the region south of Stuttgart, they are also more intense.

From various studies it is well-known that the orographic structures of the Black Forest favor the development of deep convection. After triggering, convective cells are advected approximately with the mean wind, while they are intensified further. This advection hypothesis may partly explain the high density of thunderstorms downstream of the mountains of the Black Forest, i.e. the region around Stuttgart, but not their high intensity.

Analyses of radiosounding data on the selected hail days revealed a low Froude number, which is defined as $Fr = U/(NH)$, where U is the wind speed perpendicular to the mountains, N is the static stability, and H is the characteristic mountain height (approx. 1.000 m). It is assumed that in the low Froude number flow ($\bar{Fr} = 0.32 \pm 0.15$ in the mean), the air from southwesterly directions tends to go around the southern Black Forest mountains, causing a convergence zone south of Stuttgart that favors the onset or further intensification of deep convection.

IV. CONCLUSIONS

The estimation of hail occurrence and hail hazard at high spatial resolution is a new and innovative task and can be applied for several purposes. The information can be used to identify regions, where prevention and mitigation measures are most effective. Considering the increasing damage by hail due to both, a higher number of intense hailstorms and the increasing vulnerability of buildings and assets, mitigation of damage will become more and more important. As regards to operational weather forecasting, the warnings can be adapted to the present hail hazard. Regions can be identified, where issuing of early warnings is of paramount importance.

The work presented is a first step in assessing the hail hazard at a high spatial resolution. Within the project HARIS-CC (Hail Risk in a Changing Climate) we intend to expand the investigations to a wider area by using radar composites and highly resolved reanalysis data and to analyze trends in hail climatology (see Kunz and Mohr in this abstract band).

V. ACKNOWLEDGMENTS

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