Spatial variability and trends of hailstorm frequency and the relation to atmospheric characteristics

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overview

Severe hailstorms during the summer months carry a high risk for buildings, vehicles, and crops. In the federal state of Baden-Württemberg (see Fig. 1), almost a quarter of the total damage on residential buildings is related to large hail, yielding a mean annual loss of around 27 Mio €. Comprehensive information about the local probability of hail and possible trends related to global warming are essential for loss prevention and risk management purposes.

In the last three decades, hail days and total hail damage have increased significantly together with changes in atmospheric stability. Several convective indices that depend upon surface temperature and moisture reveal a positive trend regarding both annual extreme values and the number of days above/below specific thresholds. By combining radar reflectivity data with loss data from a building insurance company, tracks of the most severe hailstorms between 1997 and 2007 were identified. The results show a high spatial variability of the probability and intensity of hail that can be related to orographic features.

data sets and methods

Due to their small horizontal extent, hailstorms are not captured accurately and consistently by one single observation system. Therefore, data sets from different observation networks are used and combined to supplement this study.

Convective Indices (CI)
- Soundings at Stuttgart (Fig. 1)
- 1974-2003, 12:00 UTC; April-Sept
- Convective indices with highest skill for thunderstorms prediction
- Trends of percentiles and days over/below thresholds (thres1: small hail; thres2: large hail)

Radar data (RA)
- 3D radar reflectivity from C-band radar at IMK/FZK (Fig. 1)
- 1997-2007, 10 min time steps
- Cell tracks by TRACE3D for cells R > 55 dBZ (Handwerker, 2002)
- Identification of severe hail tracks by combination with loss data (SV)

Insurance data (SV)
- Building damage; contracts p.a.
- >80% of all buildings are insured
- 1986-2008, daily
- Corrections: trends, vulnerability

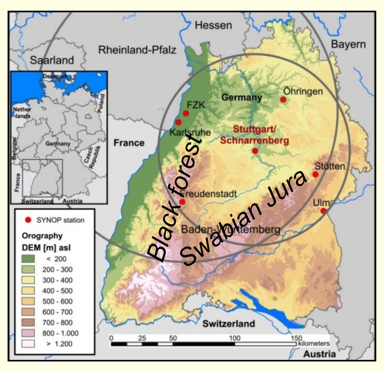

Fig. 1: *Investigation area with radiosonde station (Stuttgart) and radar area (FZK).*

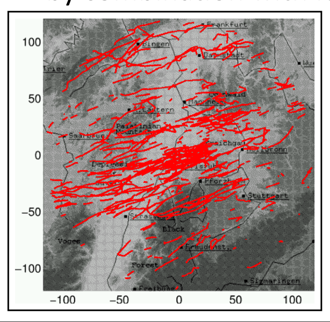

Fig. 2: *tracks of thunderstorms*

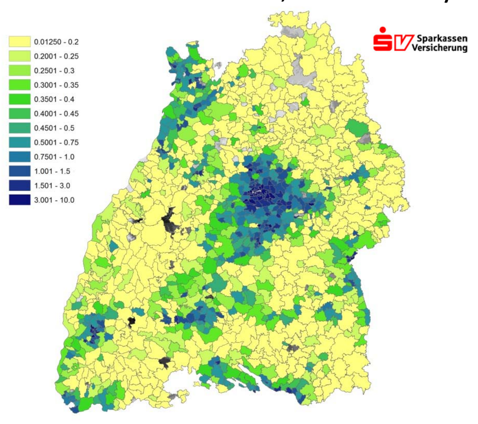

Fig. 3: *Number of hail days per year normalized by the area of the five-digit postal code zones (1997-2008).*

loss data and hail days

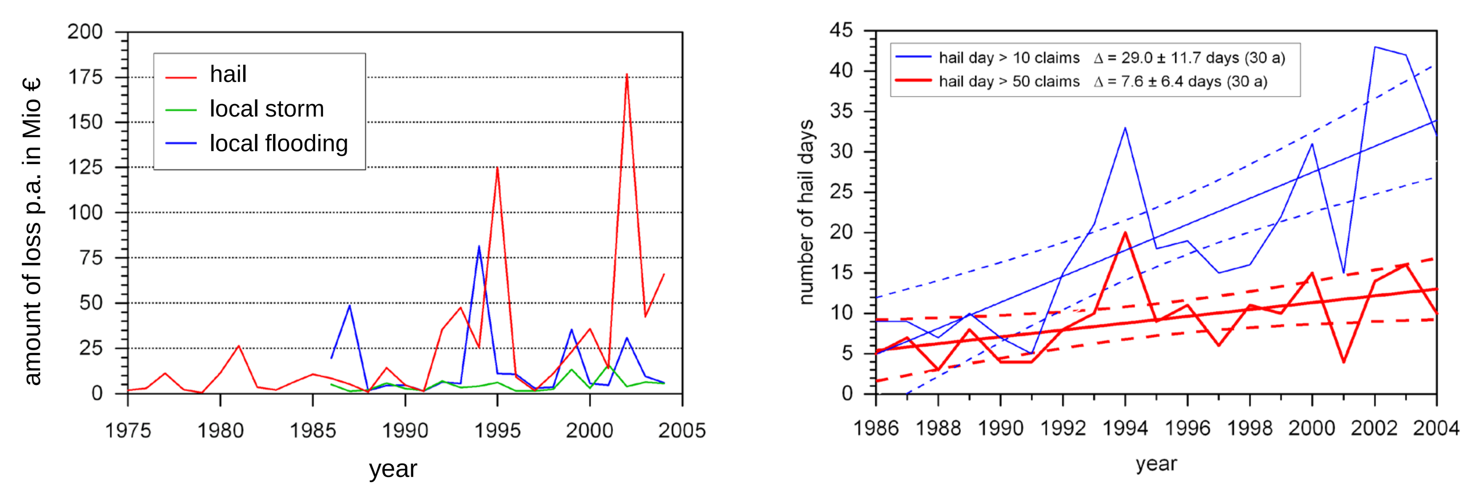

Fig. 4: *Amount of loss per year due to hail damage to buildings (left) and number of hail days per year (b) according to damage reports of the SV building insurance company in Baden-Württemberg. If on a day a threshold of 10 or 50 claims is exceeded, it is defined as a hail day; indicated is the linear trend (referred to as Δ) with 95% confidence intervals (dashed).*

results I: trends of convective indices

$$\mathrm{CAPE} = \int_{NFK}^{EL} R_d (T_p - T_U)\, d\ln p$$

Most of the convective indices that depend upon near-surface temperature and moisture reveal a positive trend regarding the annual extreme values and the number of days above/below specific thresholds (see Fig. 5 and Figs. 6a-b for the convective available potential energy, CAPE). A relationship can be established between these indices and the annual number of hail damage days with correlation coefficients between 0.65 and 0.80.

The trend directions of the indices can be attributed to different temperature and moisture stratification in the various atmospheric layers (see Fig 6c for moisture). The significant positive trends of both surface temperature and water vapour indicates the presence of warmer parcels throughout the whole troposphere during convection.

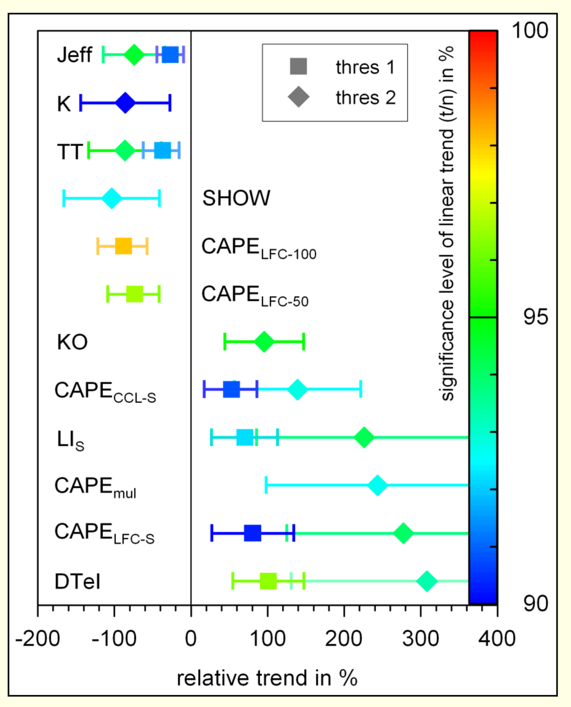

Fig. 5: *Relative linear trends of the number of days per year above / below two different thresholds of the convective indices (1974-2003) with 95% confidence intervals.*

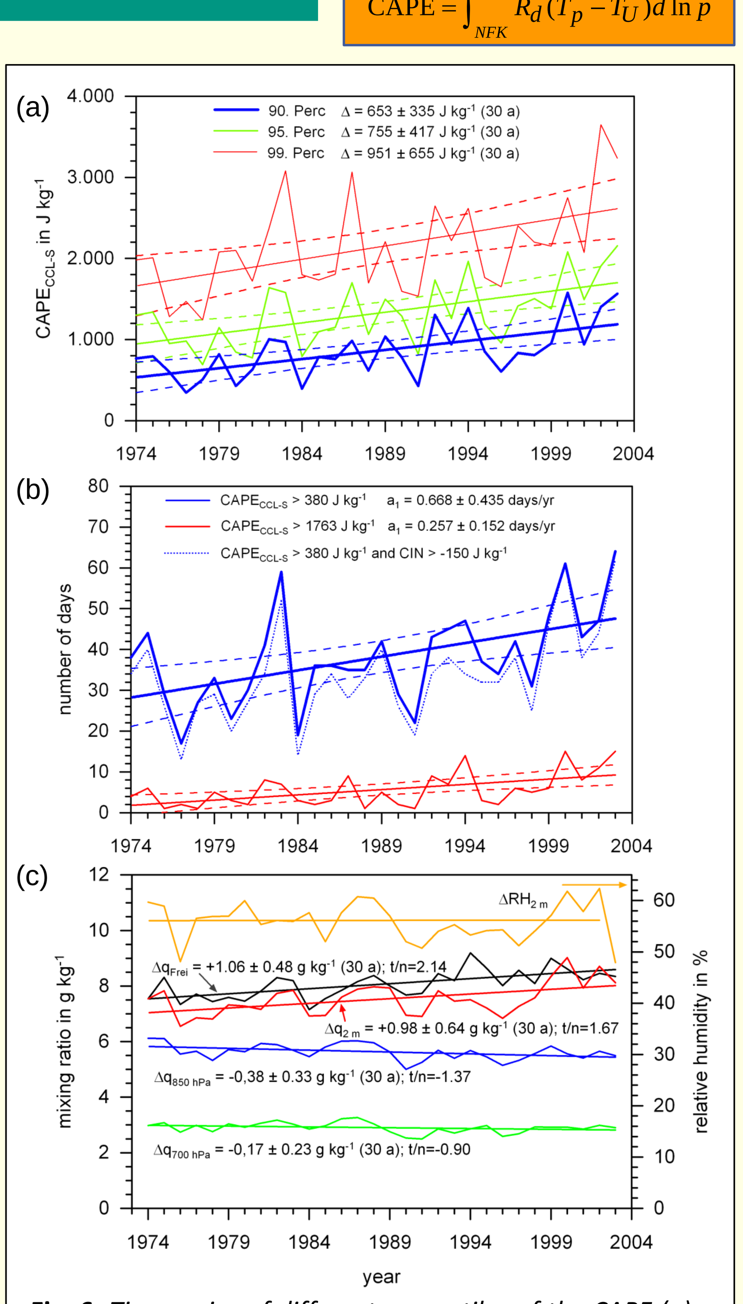

Fig. 6: *Time series of different percentiles of the CAPE (a), number of days per year above two specific thresholds (b), and time series of mixing ratio and relative humidity at the indicated levels (c). t/n is the trend to noise ratio.*

results II: hail storm tracks

Tracks of hailstorms are identified by merging insurance data with radar data applying the tracking algorithm TRACE3D. In most cases, both data show a good agreement (Fig. 7, top). Selected for the subsequent analyses were in total 60 days between 1997 and 2007 with the highest loss and number of claims.

The identified tracks exhibit a significant spatial variability that is supposed to be due to orographic influences (Fig. 7, bottom). Lowest probabilities are found over the rolling terrain in the north as well as over the elevated terrain of Black Forest and Swabian Jura. Between the two mountain ridges, the probability of hail to occur is highest.

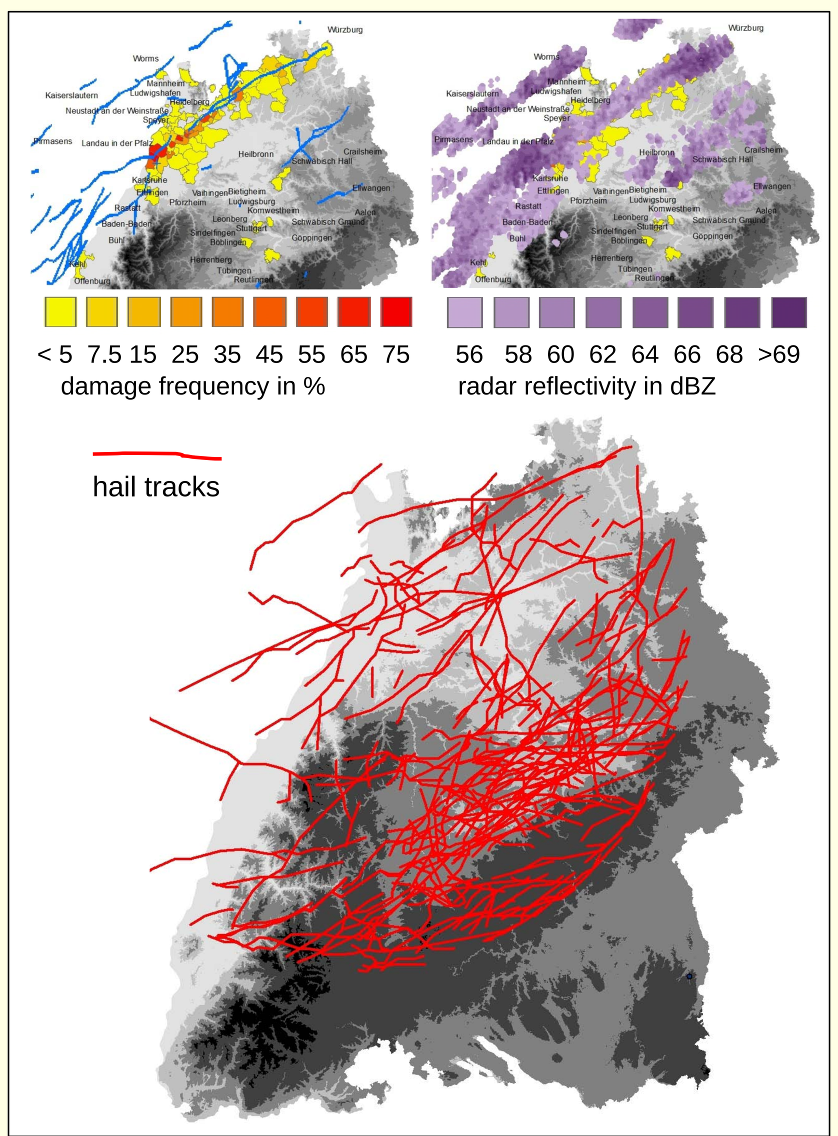

Fig. 7: *Tracks of hailstorms with radar reflectivity and damage frequency on 20 June 2002 (top). Note that the maximum frequency is approx. 80%, i.e. 4 out of 5 insured buildings were damaged. Tracks of damage-related hailstorms between 1997 and 2007 from IMK-radar data for a radar reflectivity >55 dBZ (bottom).*

results III: hazard assessment

For the hazard assessment, all identified hailstorm tracks are projected on a 10 x 10 km² grid and described by extreme value statistics. Highest reflectivities on the hail days between 1997 and 2007 are determined separately for each grid box (see Fig. 8a for two locations). Afterwards, a Generalized Pareto Distribution (GPD) is fitted to the data using a Maximum Likelihood method to estimate the free parameters of the GPD.

The results in terms of radar reflectivity for specific return periods show that the highest track densities are well correlated with the highest intensities (Fig. 8b). The radar reflectivity for a one-year return period exhibits a very high spatial variability with highest values south of Stuttgart and lowest over the mountains.

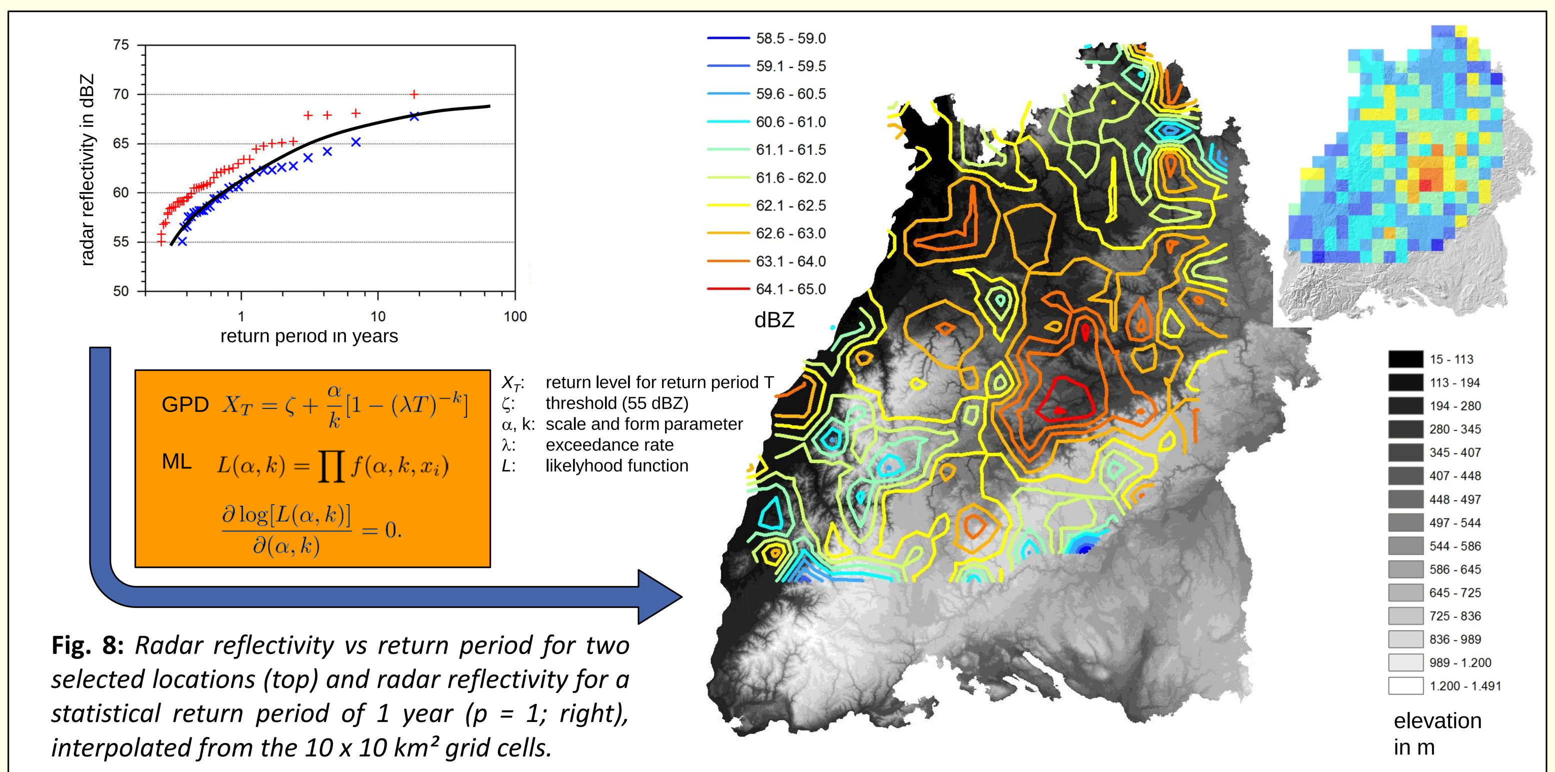

Fig. 8: *Radar reflectivity vs return period for two selected locations (top) and radar reflectivity for a statistical return period of 1 year (p = 1; right), interpolated from the 10 x 10 km² grid cells.*

conclusions

- Both the amount of loss due to hail damage to buildings and the number of hail days significantly increased in the past 20 years in the investigation area.
- Convective indices determined from temperature and moisture of the lowest atmospheric layers show an increase in extreme values and the number of days above/below certain thresholds.
- The different trend directions of the convective indices may be attributed to a strong increase of temperature and moisture in the lowest layers and only marginal or even reverse trends aloft.
- The hail hazard is a local parameter. Hot spots are identified in a region south of Stuttgart, whereas the lowest hazard is given for the mountains of Black Forest and Swabian Jura.
- Orographic effects like flow channelling or local wind systems are decisive for the spatial variability of the hail streaks. Further investigations, e.g. by model studies, are necessary.

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