Assessment of the hail hazard from a combination of radar and insurance data

Marc Puskeiler and Michael Kunz
Institute for Meteorology and Climate Research (IMK-TRO), Karlsruhe Institute of Technology (KIT), Germany

overview

Over the last decades, loss due to severe hailstorms has been increased significantly in Central Europe. In the state of Baden-Württemberg, for example, most of the damage to buildings is caused by large hailstorms (1986-2008). Examples of severe hailstorms include the local-scale Villingen-Schwenningen hailstorm on 28 June 2006 or the large-scale hail streak on 26 May 2009 with a track length in excess of 600 km. Due to the high damage potential, quantifications of the hail hazard and risk as accurate as possible are essential for the economy, especially for the insurance industry. Within the frame of the project HARIS-CC (Hail Risk and Climate Change) it is aimed at quantifying the hail hazard for Germany in a high spatial resolution.

First results reveal a high spatial variability of the intensity and probability of hail tracks that can be (partly) explained by orographic flow modifications. In the future, a hail loss model will be created to convert measured and modelled intensities (e.g., radar reflectivity or hail kinetic energy) into monetary parameters like mean loss or maximum loss. From that, it is will be possible to quantify the local-scale hail risk for certain return periods.

data sets

Due to their local-scale impacts of a few hundred meters only, hailstorms and their intensities are not captured accurately and uniquely by a single observation system. Therefore, several appropriate meteorological data (radar, lightning, radiosoundings, satellite) complemented by insurance data are used and combined to identify tracks of single hailstorms in the past.

Radar data **(DWD)**

- Radar reflectivity from DWD-Radar-Network
- RX- and PZ- data
- 2004-2010, 5 min time steps
- Resolution :1 km

Fig. 1: *DWD Radar Network*

Insurance data **(VH)**

- Agricultural damage
- Germany
- > 60% of the insured agricultural area
- 2001-2011, daily

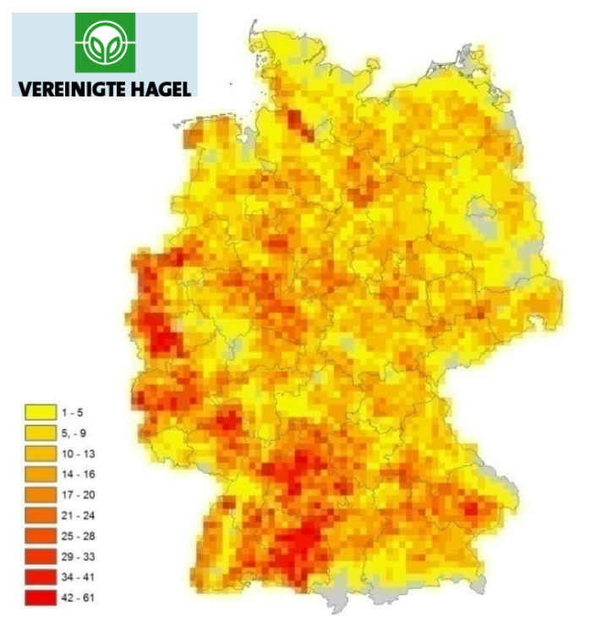

Fig. 2: *Number of hail days (2001-2009).*

Insurance data **(SV)**

- Damage to buildings
- Baden-Württemberg, Hesse and Thuringia
- >80% of all buildings
- 1986-2010, daily
- Corrections: trends

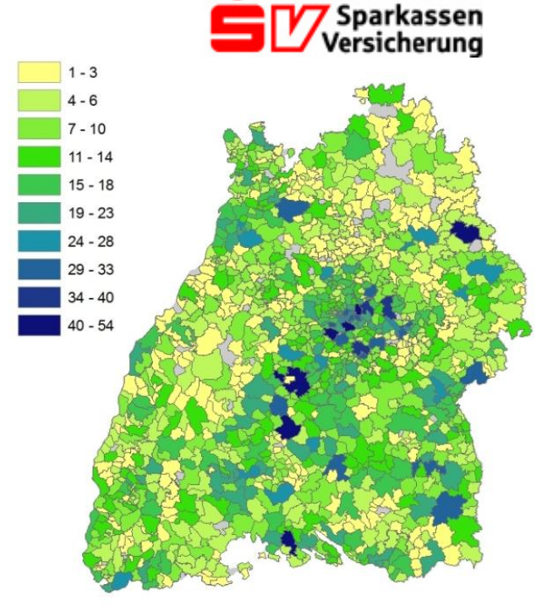

Fig. 3: *Number of hail days (1997-2008).*

Lightning data

- BLIDS – Lightning detection network (Siemens)
- Germany
- 1991-2010

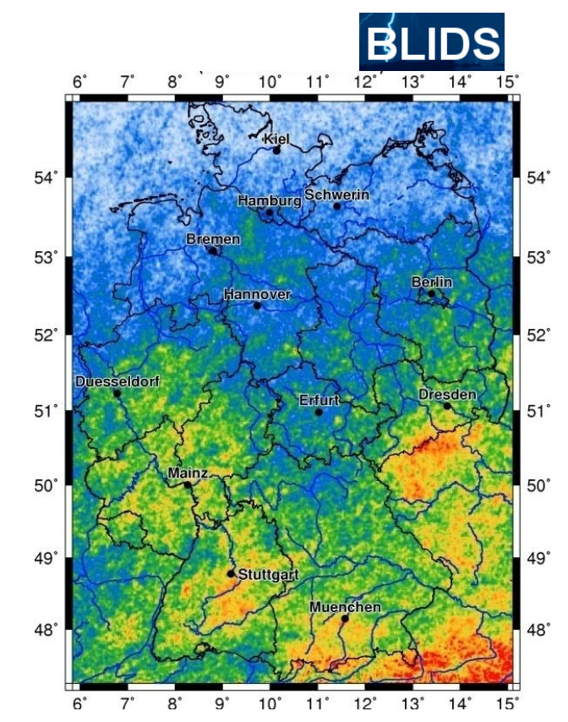

Fig. 4: *Lightning densitiy (2001-2009); Damian (2011)*

methods

- Identification of thunderstorms from radar data using different thresholds for the radar reflectivity in different heights.
- Combination with insurance loss data (Fig. 5) to identify hailstorms with damages on the ground.
- Tracking of the hailstorms (Fig. 6: TRACE-3D, Handwerker, 2002).
- Analysis of the radar reflectivity along the track of the hailstorm.
- Projection of the hailstorms tracks on a equidistant grid (10 x 10 km²).

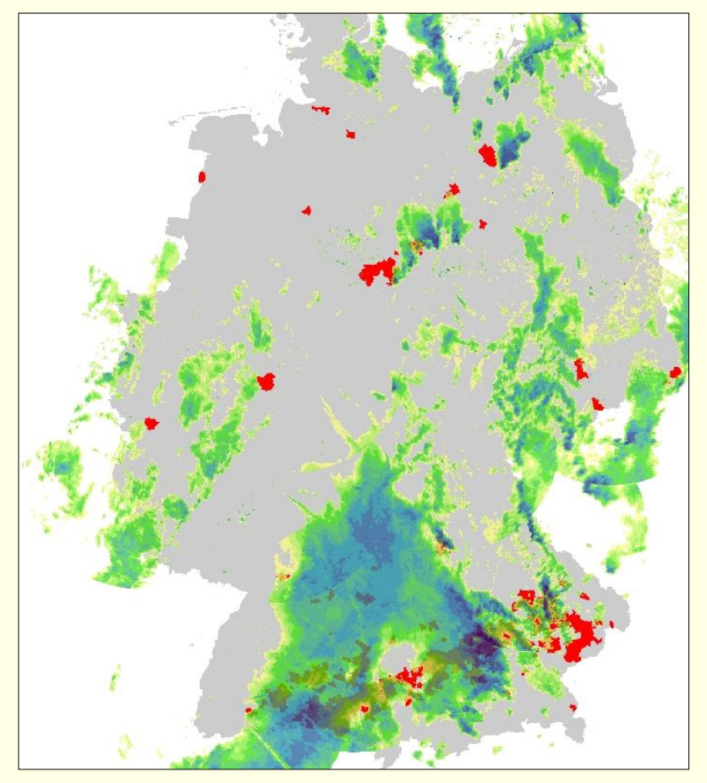

Fig. 5: *Loss data (VH) during the hail event on 26 May 2009 (red areas) combined with maximum radar reflectivity at 7 km (DWD).*

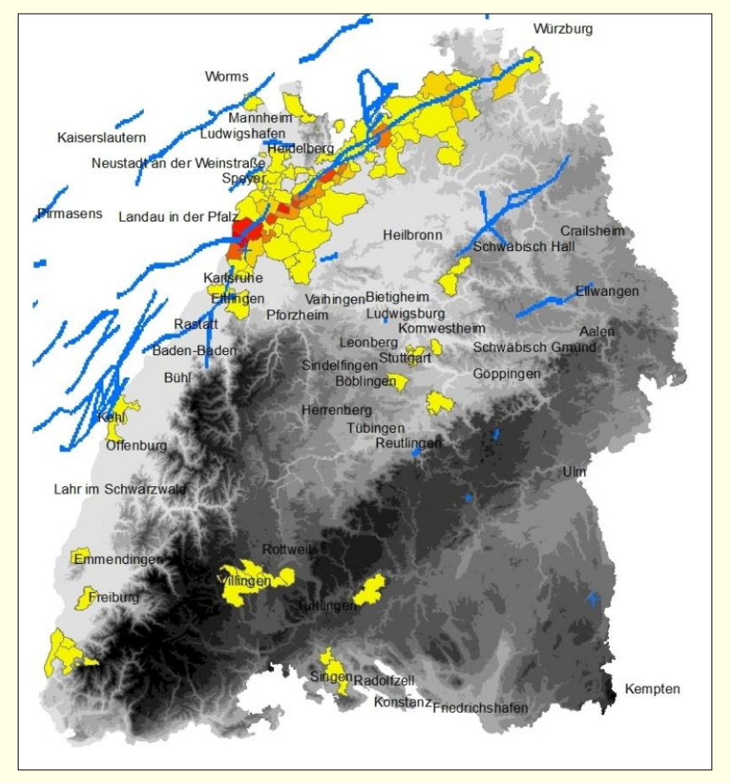

Fig. 6: *Hailstorm track on 20 June 2002 according to radar data (blue) and SV insurance data (loss frequency).*

GPD $X_T = \zeta + \frac{\alpha}{k}[1-(\lambda T)^{-k}]$

ML $L(\alpha,k) = \prod f(\alpha,k,x_i)$

$$\frac{\partial \log[L(\alpha,k)]}{\partial(\alpha,k)} = 0.$$

X_T: return level for return period T
ζ: threshold (55 dBZ)
α, k: scale and form parameter
λ: exceedance rate
L: likelyhood function

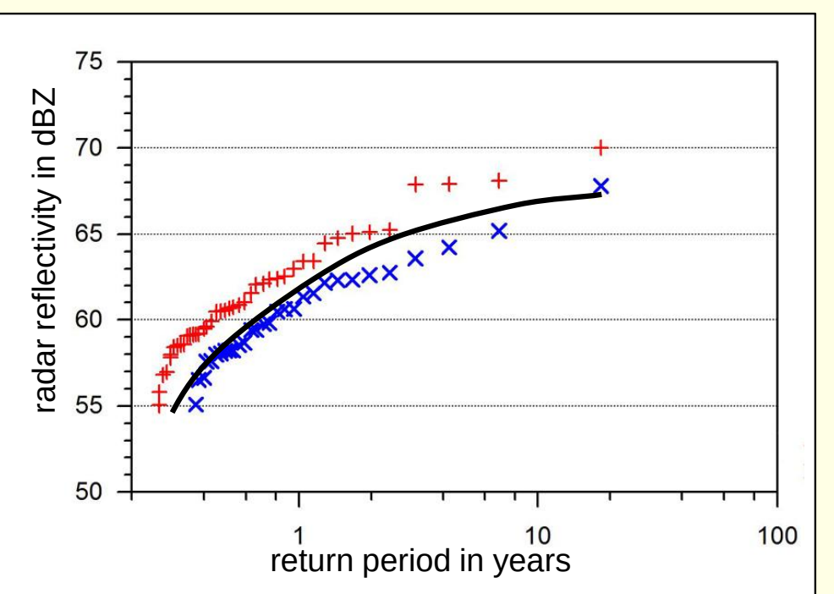

Fig. 7: *Radar reflectivity vs return period*

- Determination of the maximum reflectivity values for each grid box.
- Extreme value statistics: Generalized Pareto Distribution (GPD) with Maximum Likelihood (ML) estimator.
- Estimation of return values or periods of radar reflectivity (intensity of a hailstorm) for each grid box (Fig. 7).

results for test area

In a preliminary study, the conditions in the northwestern part of Baden-Württemberg (test area) were analyzed. For this area, 3D radar data from C-band Radar operated by IMK/ KIT were combined with insurance data of the SV.

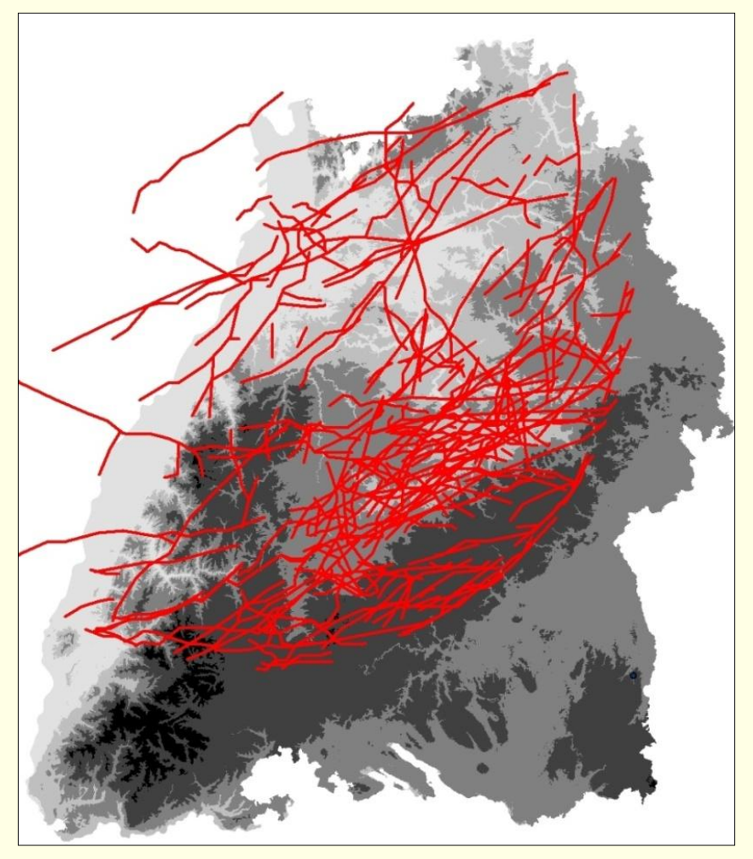

Fig. 8: *Tracks of the 30 most damage-related hailstorms (lines) between 1997 and 2007 from IMK radar data for a reflectivity >55 dBZ.*

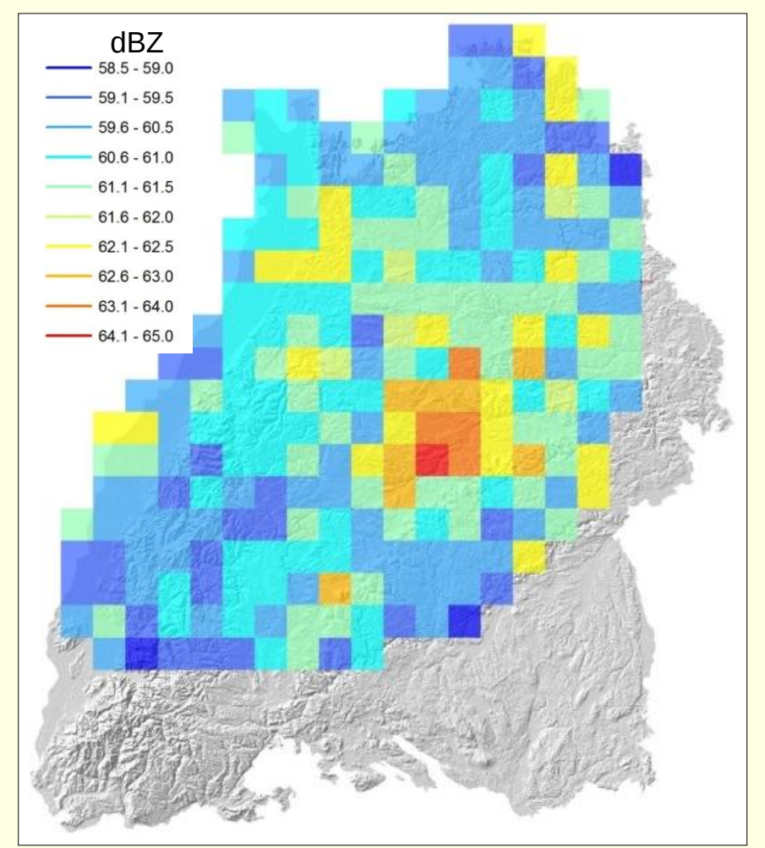

Fig. 9: *Radar reflectivity for a statistical return period of 1 year (p = 1), interpolated from the 10 x 10 km² grid cells.*

- ➡ Good agreement between density and intensity of hailstorms.
- ➡ Significant spatial variability due to orographic influences (Fig. 8).
- ➡ Highest annual reflectivity values between the two mountain ridges of Black Forest and Swabian Jura (Fig. 9).
- ➡ Lowest annual reflectivity values over the north and the elevated terrain in the south-west and south of the test area (Fig. 9).

flow modification by orography

The results for the test area show a high spatial variability of hail events that may be caused by orographic effects. On the selected hail days, the "pre-convective" nondimensional mountain height was $\hat{H}$ = 4.0 ± 1.9 on average (mean ± standard deviation). In that range, the flow from southwest may be partly deflected at the southern Black Forest mountains and to go around them. Downstream, the two branches of the flow will meet again, causing horizontal flow convergence that favors the onset or intensification of deep convection.

- Environmental conditions according to radiosoundings Stuttgart, 1200 UTC
  - U = 4.1 ± 2.0 m s^{-1} (0.5–2 km)
  - N_d = 0.013 ± 0008 s^{-1}

$$\Rightarrow \hat{H} = \frac{N_d H}{U} > 2$$

- ➡ Flow around the southern Black Forest on most of the hail days
- ➡ Development of hailstorms in the convergence area on the leeward side

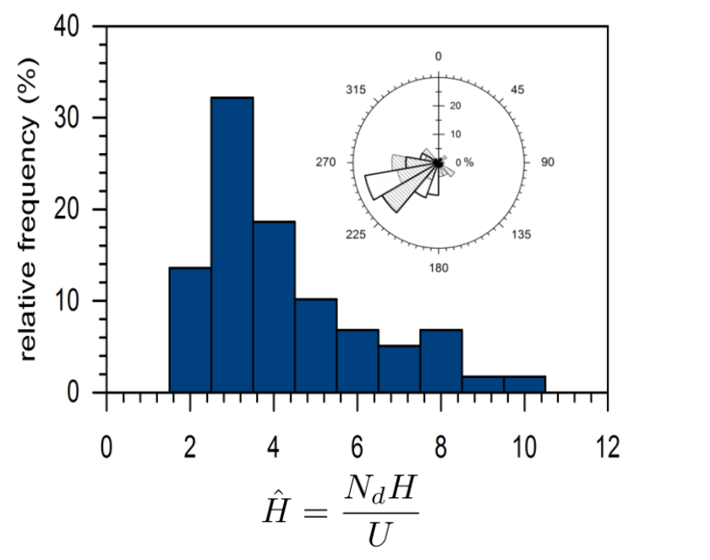

Fig. 10: *Histogram of non-dimensional mountain height H on hail days and wind rose (top).*

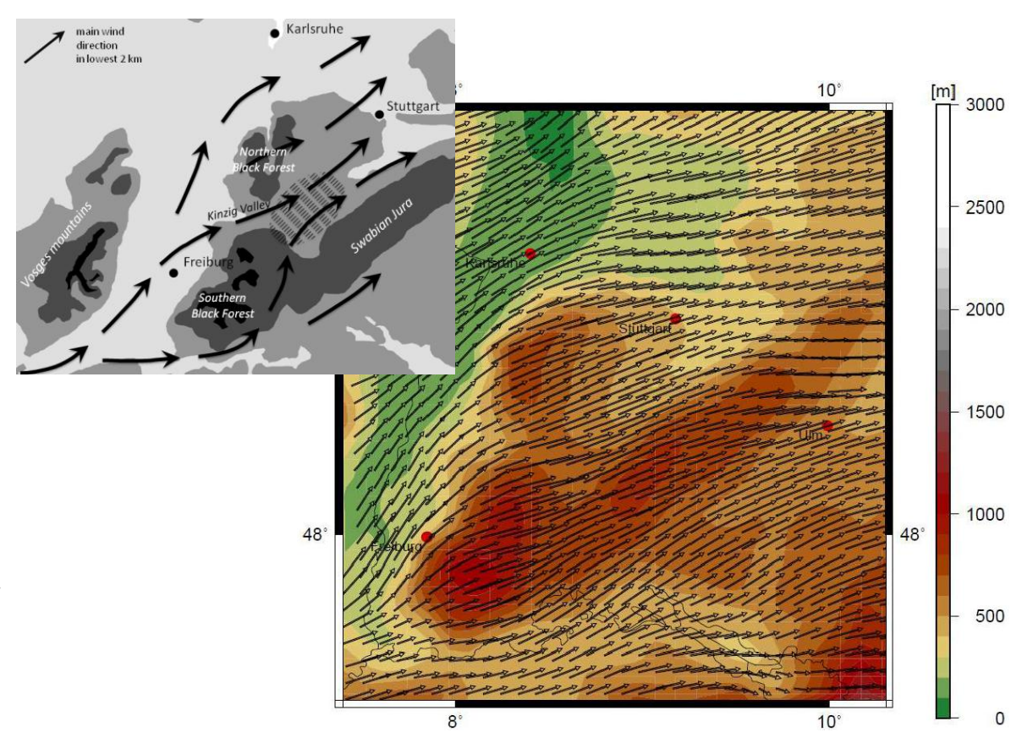

Fig. 11: *Mean wind field on hail days from COSMO-CLM simulations and sketch of flow around the southern Black Forest creating a convergence zone on the leeward side.*

references

Damian, T., 2011: Blitzdichte in Zusammenhang mit Hagelereignissen in Deutschland und Baden-Württemberg. *Seminar thesis*, Institute for Meteorology and Climate Research, Karlsruhe Institute of Technology, 64 pp.

Handwerker, J., 2002: Cell tracking with TRACE3D, a new algorithm. *Atmos. Res.*, **61**, 15-34.

Kunz, M., J. Sander and Ch. Kottmeier, 2009: Recent trends of thunderstorm and hailstorm frequency and their relation to atmospheric characteristics in southwest Germany. *Int. J. Climatol.*, **29**, 2283-2297.

Kunz, M. and M. Puskeiler, 2010: High-resolution assessment of the hail hazard over complex terrain from radar and insurance data. *Meteorol. Z.*, **19**, 427-439.

Puskeiler, M., 2009: Analyse der Hagelgefährdung durch Kombination von Radardaten und Schadendaten für Südwestdeutschland. *Diploma thesis,* Institute for Meteorology and Climate Research (IMK), Karlsruhe Institute of Technology (KIT), 107 pp.

hazard assessment for Germany I: case study

On 26.05.2009, a Mesoscale Convective System (MCS) with a track length > 600 km caused significant damage over Switzerland, Germany and Czech Republic. Both the track of the MCS and the damage patterns are reproduced well byradar data at different levels and overshooting top signals.

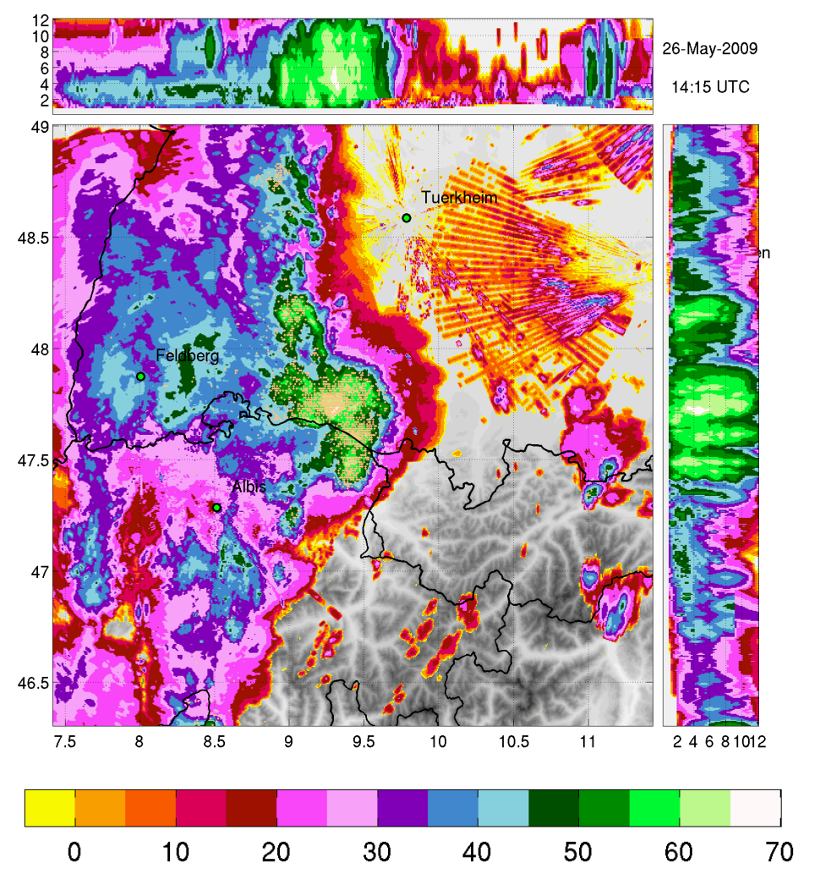

Fig. 12: *Radar reflectivity (dBZ) and lightning data on 26.05.2009, 14:15 UTC*

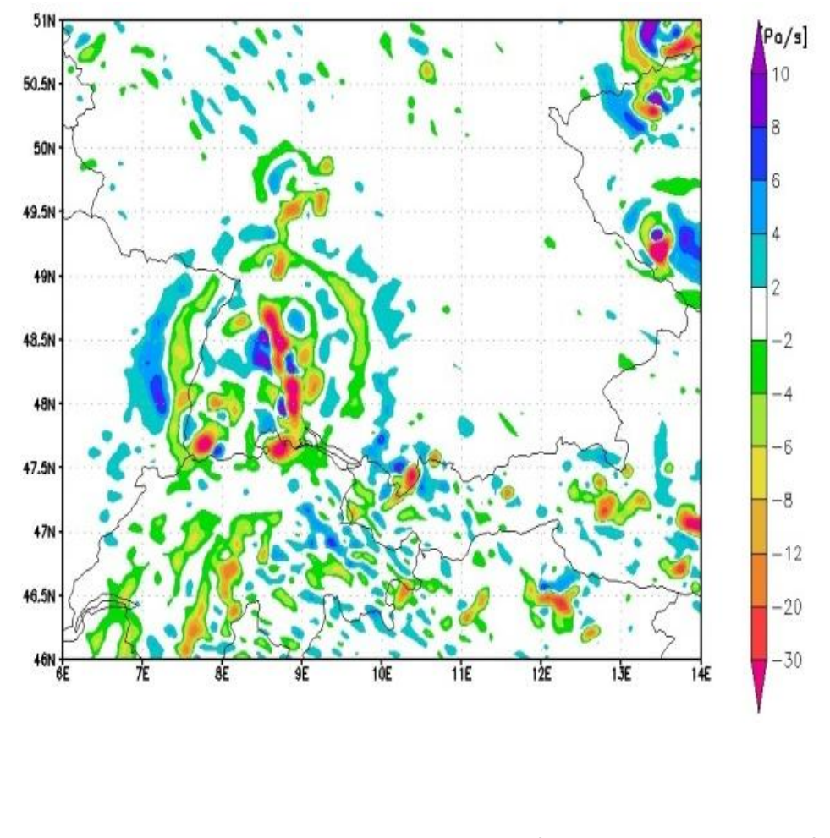

Fig. 13: *COSMO-Reanalysis: Vertical motion (red: lifting; blue: descent) in 500 hPa, 26.05.2009, 15:00 UTC*

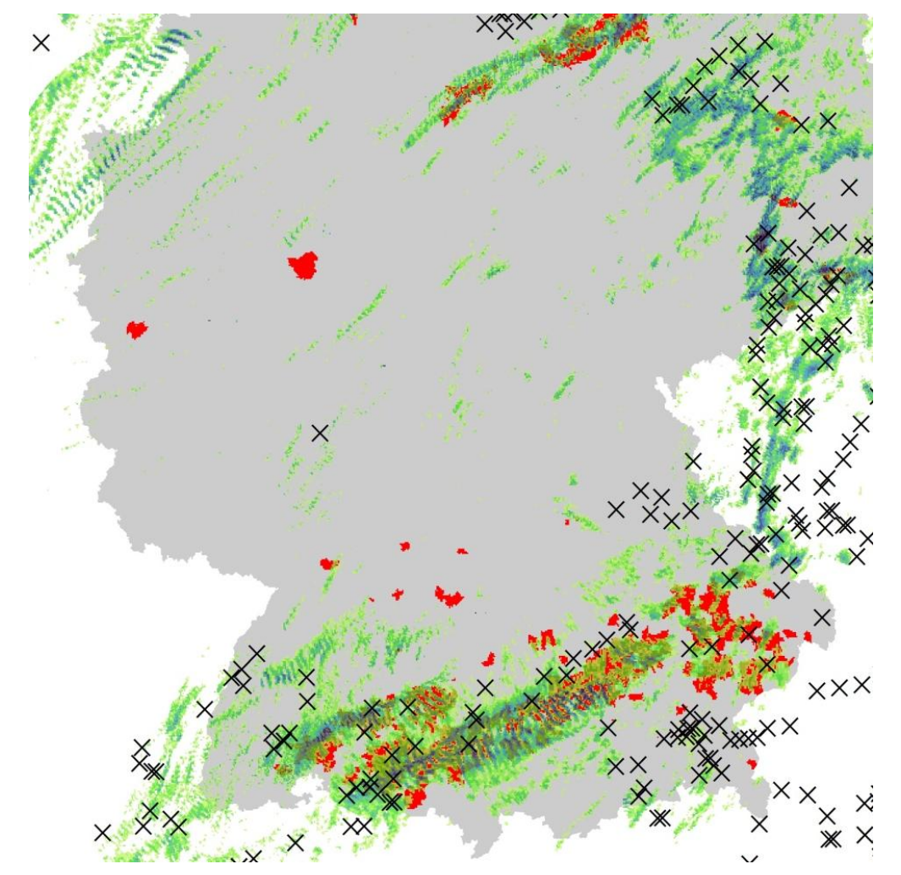

Fig. 14: *Loss data (VH; red), maximum radar reflectivity (DWD) and overshooting tops.*

hazard assessment for Germany II: first results

Over Germany, the number of days above a radar reflectivity of 55 dBZ ("hail signal") show a high spatial variability (Fig. 15). In general, this reflectivity show a good agreement to the VH hail damage data as confirmed by high values of the Heidke Skill Score (HSS; Fig. 16).

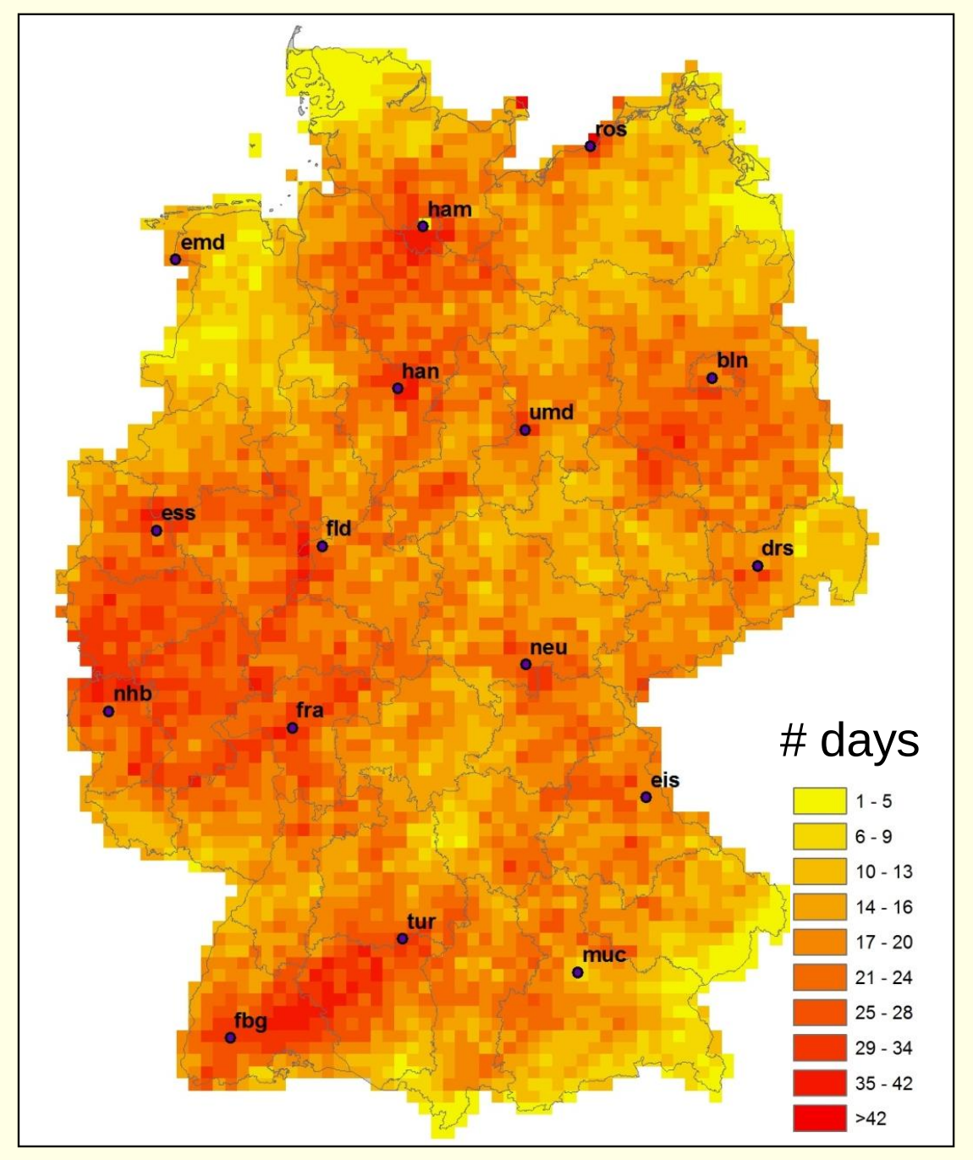

Fig. 15: *Number of days with a radar reflectivity > 55 dBZ between 2004 and 2009 ; derived from DWD RX composite (2 km); indicated are the different radars.*

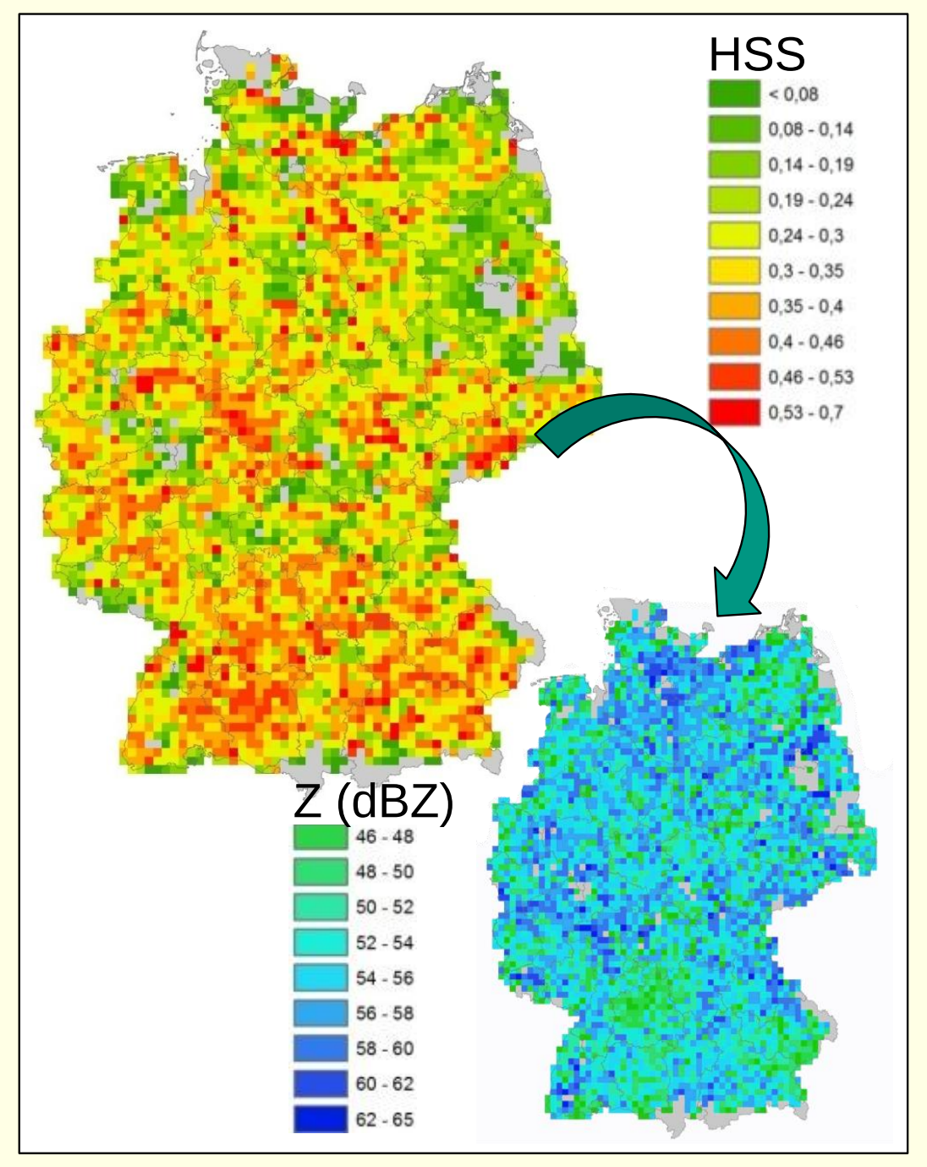

Fig. 16: *Maximum HSS for the relation between VH and radar reflectivity data for different thresholds (2004-2009; top) and most appropriate thresholds (bottom).*

- ➡ Partly high HSS, especially in areas with high density of hailstorms.
- ➡ Low HSS in areas with no insurance data (e.g. mountain areas).
- ➡ Appropriate threshold for hail identification by radar is 55.6 dBZ, average HSS is 0.29.
- ➡ Several errors and inaccuracies in radar data that have to be corrected.

conclusions

- It is possible to identify hailstorm tracks and intensity from a combination of different meteorological data (e.g., radar reflectivity at different altitudes) that are related to hail damage.
- Hail probability shows a high spatial variability. In the test region, a hail hot spot is the region south of Stuttgart, whereas the lowest hazard is given for the mountains of Black Forest and Swabian Jura.
- Orographic effects on the flow such as channelling or local wind systems are decisive for the spatial variability of the hail streaks. Further investigations, e.g. by model studies, are necessary to quantify this effect.
- Further investigations and combination with other meteorological parameters (lightning density, overshooting top analysis, convective parameters…) are necessariy to classify the hail risk with high spatial resolution.

KIT – University of the State of Baden-Wuerttemberg and
National Research Center of the Helmholtz Association

www.cedim.de

**PROJECT HARIS-SV „HAil RISk
SparkassenVersicherung AG"**