Hail hazard in Germany related to atmospheric and orographic characteristics

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overview

In several Central European regions such as Southwest Germany, Northern Switzerland, or parts of Austria, most of the damage to buildings are caused by large hail. A current example is the hailstorm on 28 July 2013 south of Stuttgart, which caused damage in the order of 1 bn €.
Due to the local-scale impacts of a few hundred meters to some kilometers only, hail is not captured accurately and uniquely by a single observation system. Therefore, we reproduced tracks of severe hailstorms using a **multicriteria approach** that combines different data sets from radar, lightning detections, and numerical models. This approach allows estimating the number and intensity of hail events with a spatial resolution of 1 × 1 km².
The results show a very **high spatial variability in the occurrence probability of hail** with several hotspots. It is found that in particular flow direction, convective energy (CAPE), and orographically induced flow modifications are most relevant for the detected spatial variation.

Supercell on 28 July 2013 near Kirchheim / Teck (Image: B. Wolf)

data sets

Radar data

- 2D / 3D radar reflectivity from German Weather Service (DWD) radar-network
- 2005-2011, time steps 5 / 15 min

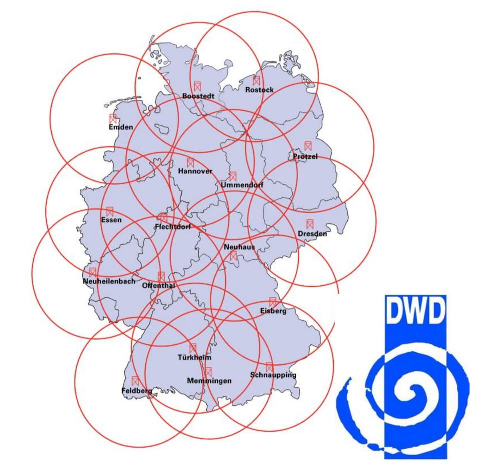


Fig. 1: *DWD radar network*

Model / lightning

- BLIDS – Lightning detection network (Siemens)
- COSMO-DE (0°C level)
- ERA-Interim

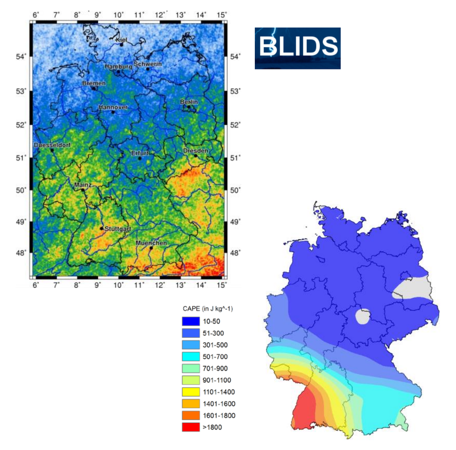


Fig. 2: *Lightning density and CAPE*

Calibration

- Insurance loss data Germany / SW-Germany
- Damage to buildings & crops

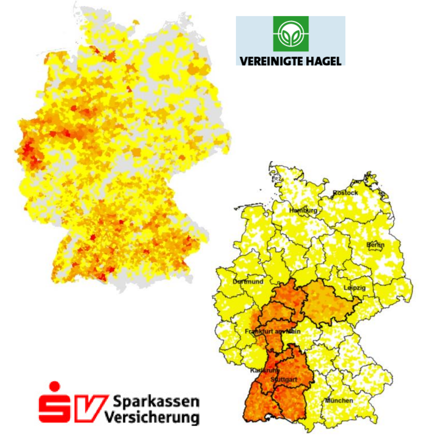


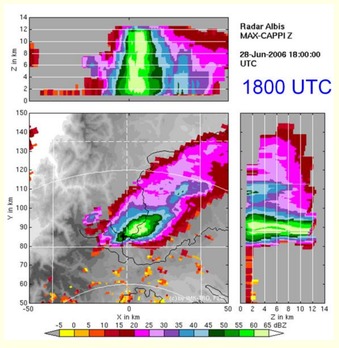
Fig. 3: *Insurance loss data*

methods

hail detection from radar

HC (3D)

Z (2D)



2D-radar data

threshold exceeding of radar reflectivity

$$Z > X\ \text{dBZ}$$

3D-radar data

threshold exceeding of vertical distance Waldvogel, 1978)
→ Hail criterion HC

$$HC = H_{46\,\text{dBZ}} - H_{0^\circ\text{C}}$$

$$HC > X\ \text{km}$$

tracking of hail signals

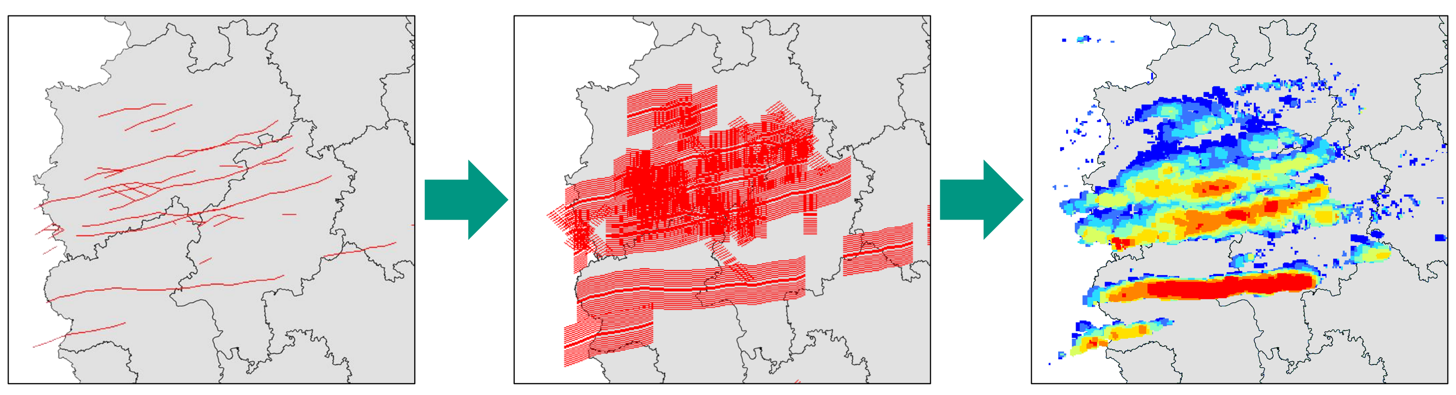


Fig. 4: *Thunderstorm tracks on one day (middle) by TRACE3D (Handwerker, 2002), duplication of shifting vectors (middle) and interpolation of the hail criterion HC parallel to the tracks (right).*

calibration / evaluation

- Determination of optimal thresholds by categorical verification; verification with insurance loss data
- Best results (highest HSS) for HC > 3.5 km based on 3D reflectivity

Table 1: *Contingency table and skill scores used for categorical verification.*

radar criteria	damage YES	damage NO
YES	a	b
NO	c	d

$$FAR = \frac{b}{a+b} \qquad POD = \frac{a}{a+c} \qquad HSS = \frac{2\cdot(a\cdot d - b\cdot c)}{(a+c)\cdot(c+d)+(a+b)\cdot(b+d)}$$

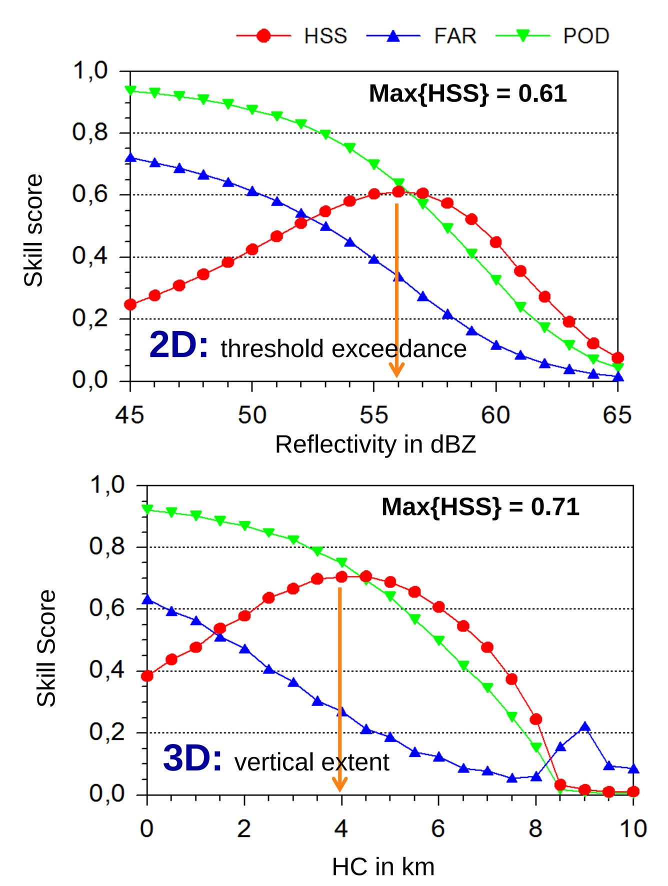
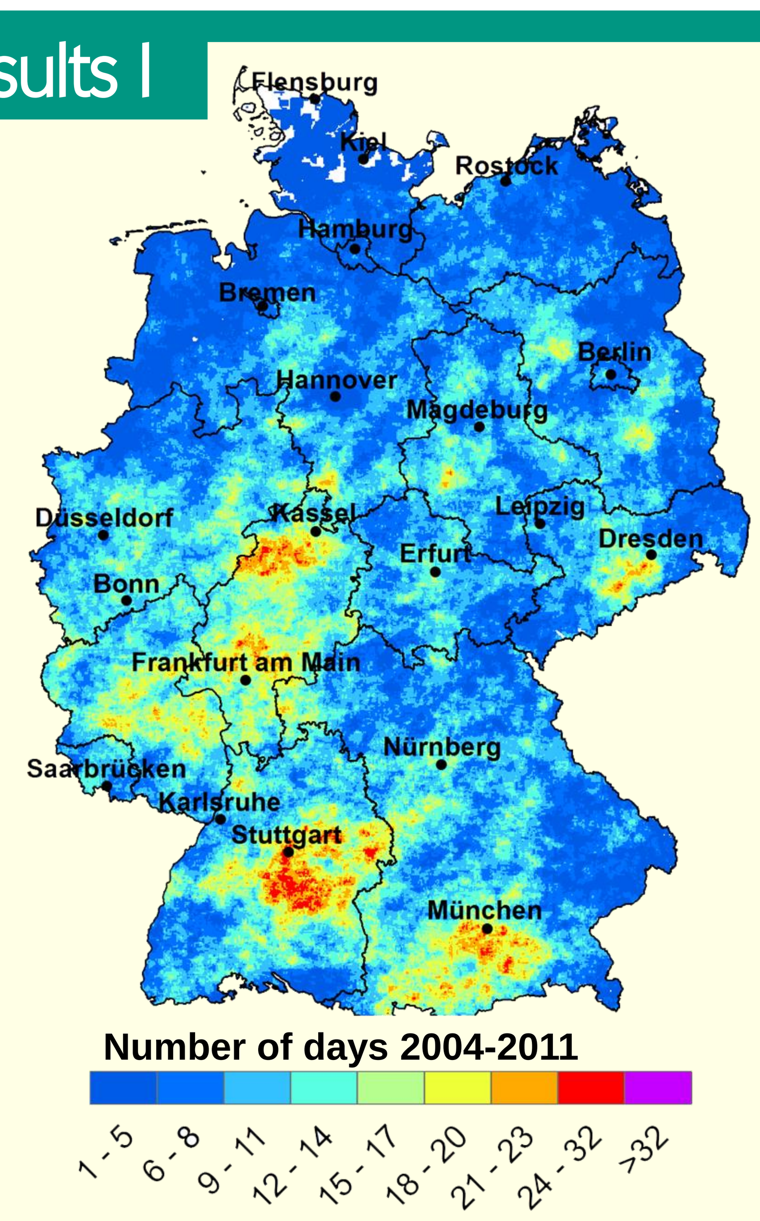


Fig. 5: *Skill scores as a function of reflectivity (2D data; top) and Hail criterion HC (3D data; bottom) evaluated with insurance loss data (building damage using SV loss data) for all grid points between 2005 and 2011.*

results I

hail probability



***HC* ≥ 3.5 km**

Fig. 6: *Number of hail days on a 1 × 1 km² grid for a hail criterion HC of ≥ 3.5 km (left) and ≥ 6 km. Whereas the former criteria is most appropriate for hail damage to buildings, the latter capture only very severe hail events. Note the increasing number of hail days from north-to-south and the several hot spots including large spatial gradients.*

hail vs. ambient conditions

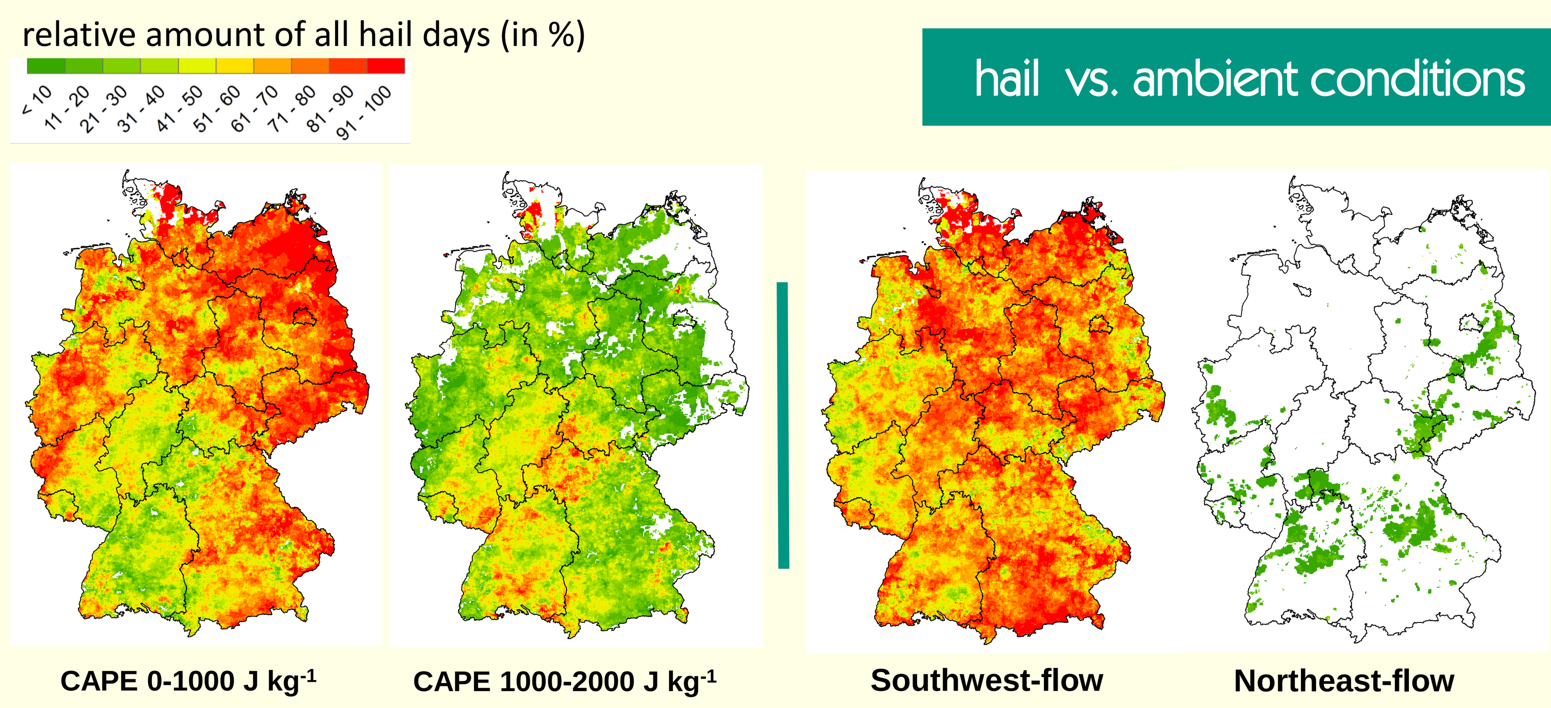
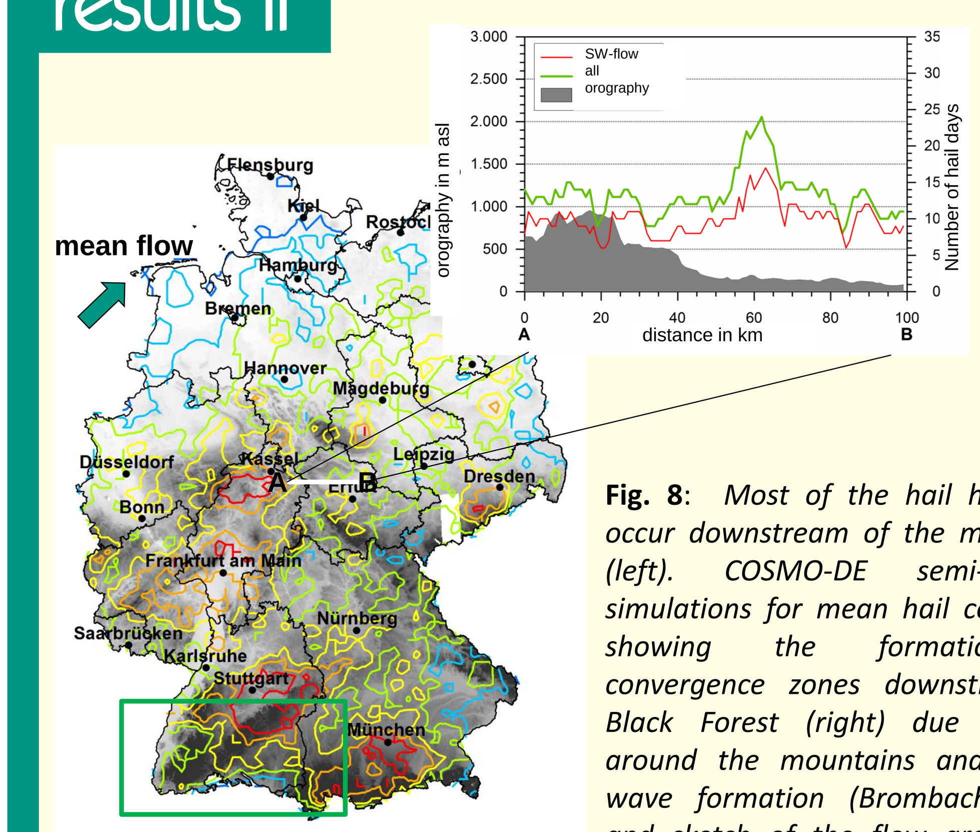


Fig. 7: *Most hail events occur for CAPE values below 1000 J kg^{-1}, except for a larger region in the south and middle of Germany (left); most of the events occur on days with flow directions from the southwest (right).*

results II

hail vs. orography



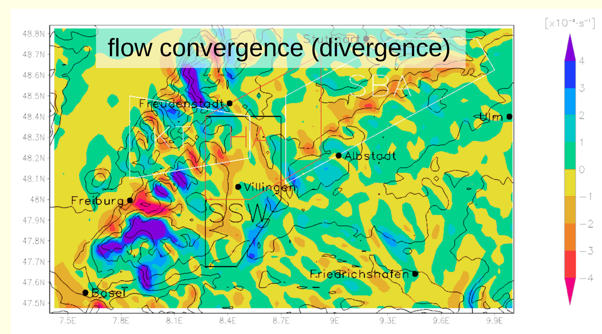
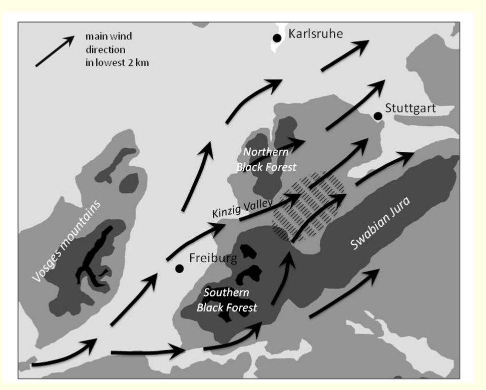


Fig. 8: *Most of the hail hot spots occur downstream of the mountains (left). COSMO-DE semi-idealizes simulations for mean flow conditions (right) showing the formation of convergence zones downstream of Black Forest (right) due to flow around the mountains and gravity wave formation (Brombach, 2012) and sketch of the flow around the mountains.*



conclusions

- Hail hazard assessment using 3D radar data in combination with other data sets is robust and physically plausible; the results show a good connection to hail damage (buildings, crops).
- Large-scale variability (increase in hail days from north-to-south) is due to climate conditions.
- Local-scale variability is caused by flow modifications due to orographic influences; most of the hot spots are found downstream of the mountains.
- Results are further used as input of a hail damage model.

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

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