Hail frequency in central Europe estimated from 2D/3D radar data and the relation to atmospheric characteristics

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Benke, 2014
Hailstorm Andreas, 28 July 2013

(Kunz et al., 2017)
Severe hailstorms 2013 - Germany

Data:
- 2-4 cm
- 6-7 cm
- > 8 cm

27 July
28 July
6 August

Total loss: 4.2 bn €
Insured loss: 3.3 bn €
only 27+ 28 July: 2.8 bn €

(Swiss Re, 2014)
Questions…

Hail hazard assessment?

Pre-convective conditions?

Frontal vs. non-frontal hail?
Methods: Hail estimation from radar

(1) 2D: Maximum Reflectivity (Mason, 1971)
\[ Z > X \text{ dBZ} \quad X = 55 \text{ dBZ} \]

(2) 3D: Vertical Distance (Waldvogel, 1979)
\[ Y \geq H_{0^\circ C} - H_{45} \text{ dBZ} \]
- Cell tracking & advection & clutter corr.
- Calibration & verification: insurance losses

(Puskeiler et al., 2016)
Radar-based hail *climatologies*

France, Belgium, Lux.  
2D; 2005-2014

Germany  
3D; 2005-2015

Days with hail signals  
(2D/3D radar reflectivity)

(Fluck, 2017; Schmidberger, 2017)
Hail signals vs orography

- Location of hail hotspots: preferably over/downstream of mountains

\[ Fr = \frac{U}{NH} \approx 0.6 \]

(mean of 70 hail events)

(Kunz and Puskeiler, 2010, modified)

(Fluck, 2017)
Hail probability vs orography

- Semi-idealized COSMO-DE simulations (2.8 km)
- Initialization: ambient conditions prior to damaging hailstorms (Fr ~ 0.6)

Flow convergence

\[ \nabla \cdot \vec{v}_H = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = \frac{\partial |\vec{v}|}{\partial s} + \frac{|\vec{v}|}{R_n} \]

Convective available potential energy CAPE

(Köbele, 2014)
Hail signals vs orography

- Elevation vs. number of haildays (normalized)

(Fluck, 2017)
Track characteristics

- Hailstorm tracks vs hail size (diameter from ESWD)?

Mapping hail reports ESWD with radar-detected hailstorm tracks

(Baumstark, 2017)
Pre-convective conditions

Hailstorm tracks vs hail size (diameter from ESWD)?

Mapping hail reports ESWD with radar-detected hailstorm tracks

(Baumstark, 2017)
Pre-convective conditions

- Combination hailstreaks with ESWD data (D_max)
- **Composite of ambient conditions** around hailstreaks centered in the domain

Hail footprints from radar

Mean (percentiles) of all events
Pre-convective conditions

- Mean fields around hailstreaks

Lapse rate (1.5_5.5 km)

0-6 km wind shear

Distance from the center (km)

Distance from the center (km)

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Distance from the center (km)
Pre-convective conditions

- Composite Lapse rate $\text{fct}(L, D)$

Max diameter hailstones (ESWD)

- $< 3$ cm
- 3-4 cm
- $\geq 5$ cm

Track length

- $< 50$ km
- 50-100 km
- $> 100$ km

Hail and pre-convective conditions in Europe

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21 Sept 2017

IMK-TRO, Karlsruhe
Pre-convective conditions

Composite **0-6 km wind shear** $\text{fct}(L, D)$

- **< 3 cm**
  - $9 \text{ m s}^{-1}$

- **3-4 cm**

- **\geq 5 cm**
  - $17.7 \text{ m s}^{-1}$

- **< 50 km**
- **50-100 km**
- **> 100 km**

Max diameter hailstones (ESWD)

- < 3 cm
- 3-4 cm
- \geq 5 cm

Track length

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Pre-convective conditions

- Effect of **temporal/spatial resolution**: ERA_Interim (Δx ~ 80 km, 6 hrs.) vs CoastDatIII (Δx ~ 10 km; 1 hr)

Shear

- ERA
- CoastDat

Lapse rate

- ERA
- CoastDat

- **D<3 cm, L<50 km**
- **D ≥5 cm, L>100 km**
Pre-convective conditions

- Categorical verification:
  Large hail & long track vs. small hail & tracks

Events: $D \geq 4$ cm; $L \geq 100$ km
Non-events: $D < 4$ cm; $L < 75$ km
Ambient conditions: Fronts

- Hailstreaks vs cold fronts?

**Cold fronts** $1^\circ \times 1^\circ$; 6-hourly; 2005-2014

ERA-Interim-Reanalysis (Schemm et al., 2015)

thermal frontal parameter

$$TFP = -\nabla|\nabla \theta_e| \cdot \frac{\nabla \theta_e}{|\nabla \theta_e|}$$

(Baumstark, 2017)
Ambient conditions: Fronts

- Relative probability of frontal hailstreaks

0.5° x 0.5°; ERA-Interim / Radar-based streaks
SHJ 2005-2014

(Baumstark, 2017)
Hailtracks: frontal vs non-frontal

- Track length: $L_{\text{frontal}} - L_{\text{non-frontal}}$ (90% percentiles)

0.5° x 0.5°; ERA-Interim / Radar-based streaks SHJ 2005-2014

(Baumstark, 2017)
Hailtracks: frontal vs non-frontal

Orientation (median)

0.5° x 0.5°; ERA-Interim / Radar-based streaks
SHJ 2005-2014
Backward Trajectories

- ERA-Interim / LAGRANTO (Lagrangian Analysis Tool)
- 182 hail events from ESWD
- Trajectories 120 hrs backwards
- Hail events: ESWD reports

(Busch, 2013)
Backward Trajectories

Ensemble mean: equivalent potential temp. $\theta_e$ and specific humidity $q_v$

- ERA-Interim / LAGRANTO (Lagrangian Analysis Tool)
- 182 hail events from ESWD
- Trajectories 120 hrs backwards
- Hail events: ESWD reports

(Busch, 2013)
Conclusions

- **Hail hazard assessment** from radar is robust and physically plausible

- High spatial variability of **radar-derived hail signals**:
  - large-scale: increase with distance to the sea
  - local-scale: hot spots preferably downstream of the mountains

- **Pre-convective conditions**
  - Lapse rate (maximum SE of event); ~ insensitive to diameter / length
  - 0-6 km wind shear; both diameter and track length decisive
  - Shear already captured by low temporal / spatial resolution

- **Streaks vs Fronts**
  - 15-50% of all streaks are related to a cold front; large spatial differences
  - Frontal streaks exhibit different characteristics: longer, direct. to the west,…