11th European Conference on Severe Storms
Bucharest, Romania
8 – 12 May 2023
P24: ECSS2023-130

Deutscher Wetterdienst
Wetter und Klima aus einer Hand
DWD

Radar-based Hail Detection and Hail Size Estimation at Deutscher Wetterdienst (DWD)

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Hail is a pronounced natural hazard in Germany. Nevertheless, major hail events are quite rare and there is a lack of information in hail occurrence, size, and its spatiotemporal distribution. Areal information from weather radar networks with a high resolution in space and time might help to overcome this issue. The Deutscher Wetterdienst (DWD) utilizes a C-Band dual-polarimetric weather radar network consisting of 17 radar stations that provide scans of eleven elevation angles every five minutes. DWD's hydrometeor classification algorithm HYMEC (Steinert et al., 2021) is able to detect hail. For the analysis of hail sizes, the Maximum Expected Size of Hail (MESH) and a method based on Vertically Integrated Ice (VII) are used. The results indicate a reasonable agreement of all three approaches with in-situ hail occurrence reports, whereas reliable radar-based hail size estimations are still challenging. Machine Learning methods integrating additional data might offer potential for improvements.

Data

Radar data

- Dual-polarimetric quality-assured radar sweep moments: horizontal reflectivity Z_h, differential reflectivity Z_{DR} and co-polar correlation coefficient ρ_{hv} at azimuthal/range/time resolution of 1°/250 m/5 min
- Grid-based (1 km, 5 min) Vertically Integrated Ice (VII)

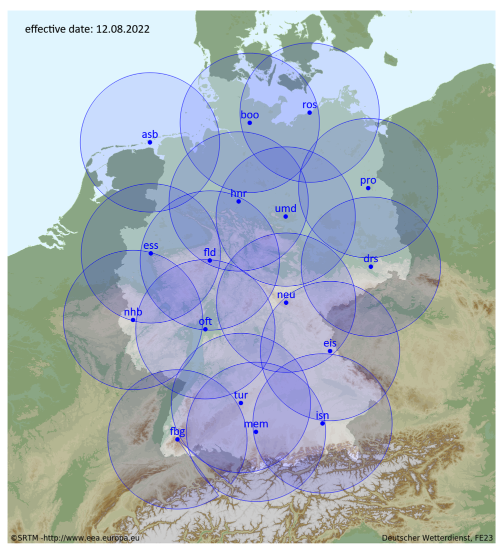


Fig. 1: Operational DWD weather radar network consisting of 17 dual polarization radar system shown with 150 km coverage radius. Geo data: http://www.eea.europa.eu

NWP data

- ICON-D2 data at horizontal grid spacing of 2.2 km and vertical resolution of 65 layers; update: every 3 h
- 3D profiles of temperature (T) every hour
- 2D field of snowline (above MSL) every 15 min

Hail reports

- Automated SYNOP reports of Germany (10 min)
- Manual METAR reports of German airports (30 min)
- Eye-observations from European Severe Weather Database (ESWD)
- User reports from DWD's WarnWetter App (see Poster P28: ECSS2023-54)

Algorithms: HYMEC, MESH & VII-based

Hydrometeor classification (HYMEC)

- Input: Z_h, Z_{DR}, ρ_{hv}, VII, Snowline
- Pre-filtering, Fuzzy-logic algorithm
- Input/output on polar radar grid for terrain-following low-elevation scan
- Merging of all radar stations on 1x1 km regular grid (Fig. 2, right)
- Distinguishes between hail & no hail

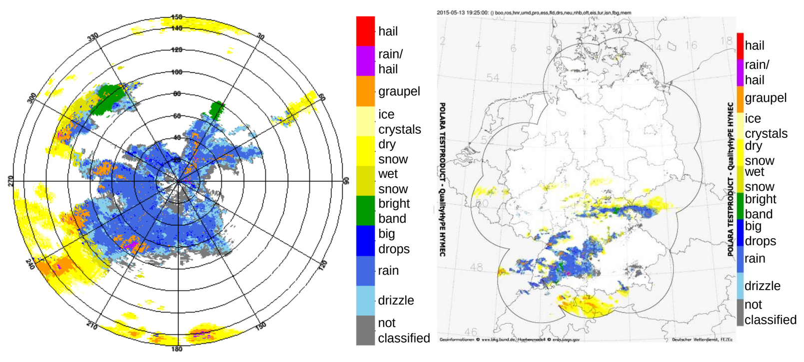


Fig. 2: Exemplary HYMEC output on radar grid (left) & merging of all available radar stations on 1x1 grid (right).

Maximum Expected Size of Hail (MESH)

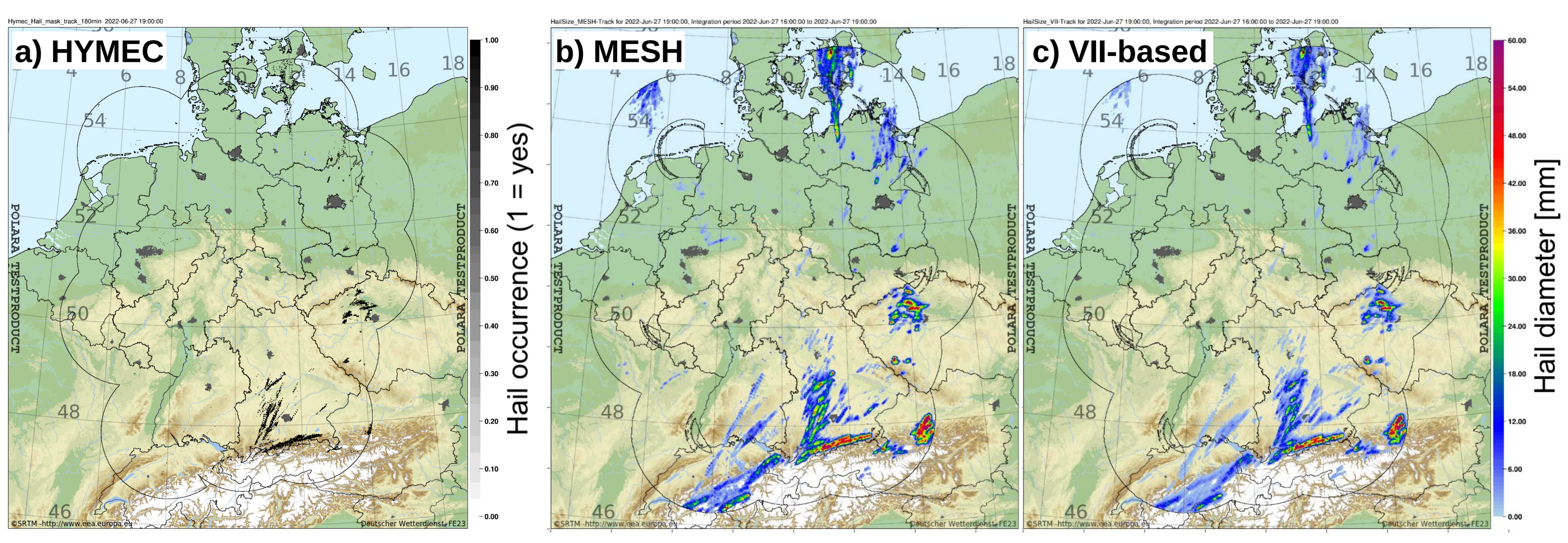
- Based on Severe Hail Index (SHI) $(\mathrm{hailsize(mm)} = 2.54 * \sqrt{SHI})$
- SHI: reflectivity-based height-weighted ($H > H_{0°C}$) vertical integral of hail kinetic energy flux (Z_h> 40 dBZ); Witt et al. (1998)
- Data of Z_h: 3D data cube (1x1 km, 250 m)
- $H_{0°C}$ & $H_{-20°C}$: NWP temperature profile, respective height mapped on 1x1 km grid

VII-based

- Motivated by linear relation between maximum reported hail size and VII proposed by DWD's forecasters (internal evaluation)
- $\mathrm{hailsize(mm)} = 0.75 * \mathrm{VII}$

integrated in C++ Framework POLARA Polarimetric Radar Algorithms

Case Study: June 27, 2022 (16-19 UTC)



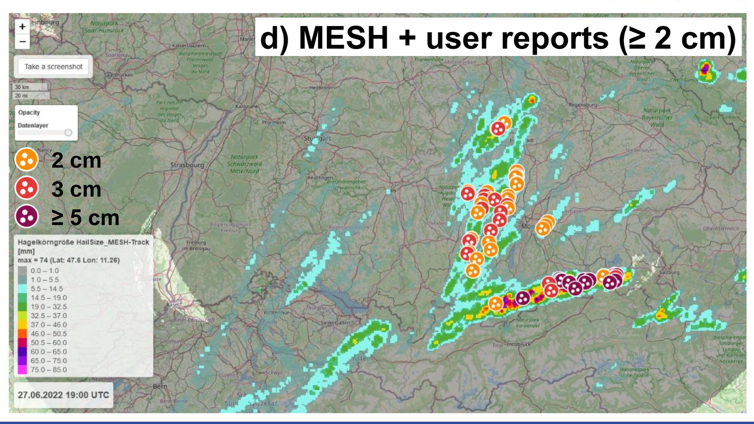


Fig. 3: Case study for June 27, 2022 between 16 and 19 UTC in a "high-shear, high-CAPE" environment (MLCAPE > 1500 J/kg, DLS > 35 kn) over Bavaria. Results for a) hail detection with HYMEC, b) MESH hail size estimation and c) VII-based hail size estimation. For MESH and VII-based a minimum threshold of 5 mm is applied. d) MESH and user reports from DWD's App over Southern Germany. Only hail reports with a diameter of at least 2 cm are presented. Reports by trained storm spotters (not shown here) indicate hail with a diameter of up to 7 cm for the supercell(s) over Southern Bavaria.

Verification (April 1, 2021 – September 30, 2021)

Hail occurrence

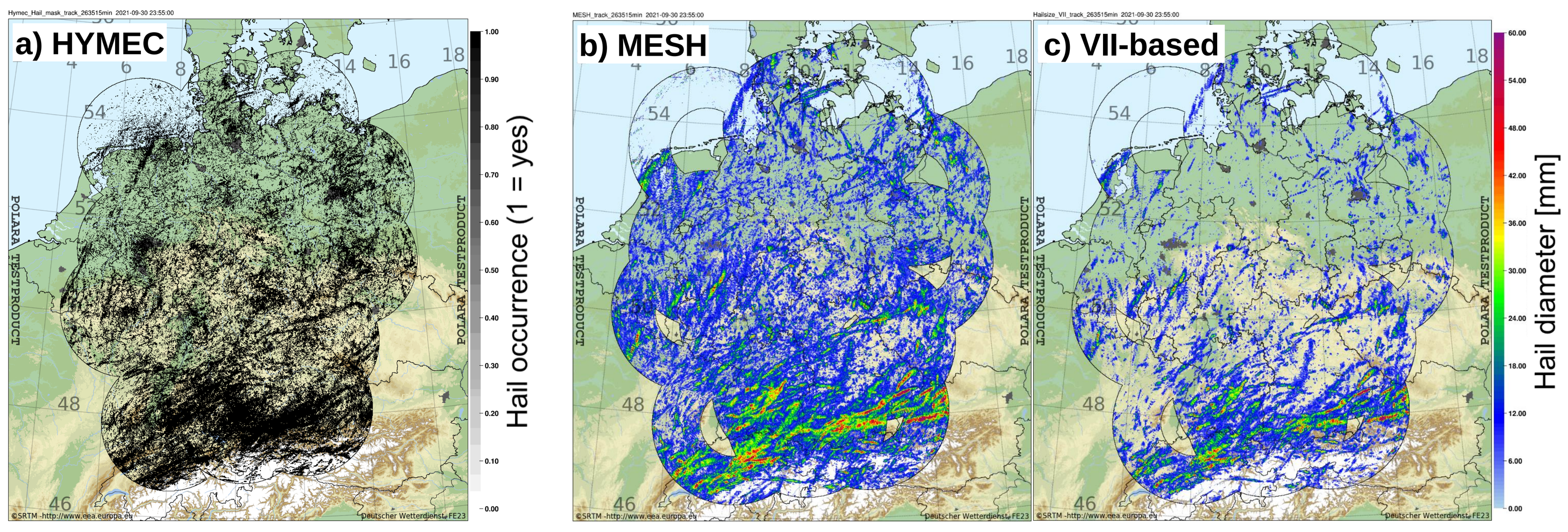


Fig. 4: Results for a) hail detection with HYMEC, b) MESH hail size estimation and c) VII-based hail size estimation. For MESH and VII-based a minimum threshold of 5 mm is applied.

- Objective: Detect the observed hail events with an accuracy of ±5 km/±5 min.

Reference	Algorithm	Total Events	Hits	Misses	Total Detected	POD
ESWD	HYMEC	454	448	6	801k	**99 %**
ESWD	MESH	454	444	10	1161k	**98 %**
ESWD	VII-based	454	439	15	535k	**97 %**
DWD's App Reports	HYMEC	2110	1707	403	3205k	**81 %**
DWD's App Reports	MESH	1770	1442	328	4077k	**81 %**
DWD's App Reports	VII-based	1770	1259	511	1838k	**71 %**
METAR	HYMEC	37	23	14	35k	**62 %**
METAR	MESH	37	21	16	39k	**57 %**
METAR	VII-based	37	16	21	15k	**43 %**
SYNOP	HYMEC	82	43	39	59k	**52 %**
SYNOP	MESH	82	21	61	49k	**26 %**
SYNOP	VII-based	82	8	74	15k	**10 %**

Hail size

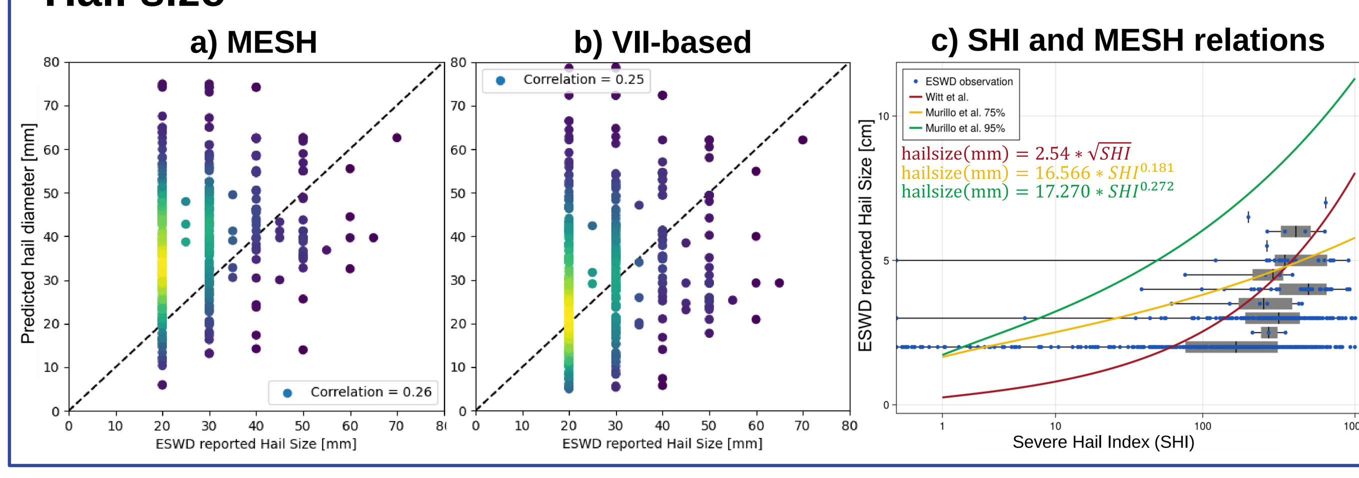


Fig. 5: Hail size with a) MESH & b) VII-based vs. ESWD reports. c) Performance of alternative formulas to calculate MESH from SHI proposed by Murillo et al. (2019).

Outlook

ZDR-columns

- MESH and VII-based methods can hardly distinguish between cells with large hail and cells with masses of small hail (Fig. 6)
- Height ZDR-column correlated with updraft strength: a good hail size indicator?
- First experimental setup with ZDR ≥ 2 dB

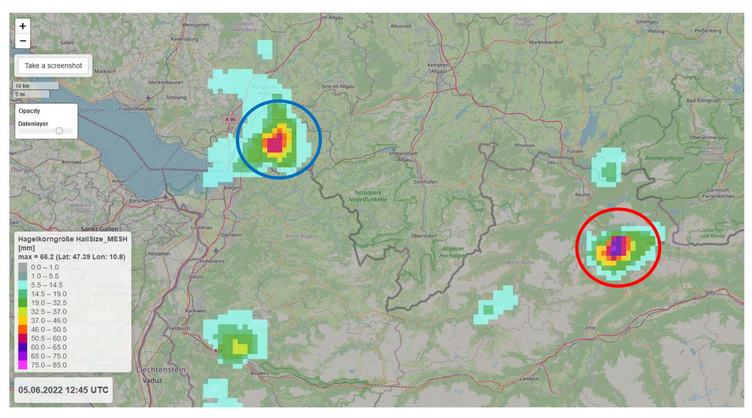


Fig. 6: Case study (June 5, 2022 12:45 UTC) of MESH for two cells over Southern Germany. Both cells show MESH values > 5 cm, a rotating updraft & maximum reflectivity of ~ 65 dBZ (both not shown). According to reports, the western cell (blue circle) produced accumulation of small hail, whereas the eastern cell (red circle) later on generated hail up to a diameter of 7 cm.

Miscellaneous

- Enhanced systematic verification of hail occurrence and hail size using Crowd-Data from DWD's WarnWetter-App & additional quality control
- Ongoing tuning of fuzzy logic parameters in HYMEC and MESH parameters
- Explore options to use machine learning techniques in a multi-data approach (dual-pol radar sweeps, lightning data, environmental conditions from NWP, …)
- Multi-year recalculations & comparison with insurance data

References:

(1) Steinert, J., Tracksdorf, P., & Heizenreder, D. (2021). Hymec: Surface Precipitation Type Estimation at the German Weather Service, Weather and Forecasting, 36(5), 1611-1627.
(2) Murillo, Elisa M., and Cameron R. Homeyer. "Severe hail fall and hailstorm detection using remote sensing observations." Journal of Applied Meteorology and Climatology 58.5 (2019): 947-970.
(3) Witt, Arthur, et al. "An enhanced hail detection algorithm for the WSR-88D." Weather and Forecasting 13.2 (1998): 286-303.

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