Ground precipitation types from Belgian C-band radars: Validation of hydrometeor classification

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Motivation

Validate four hydrometeor classification schemes plus their ground transition, and a novel ensemble approach, to identify the most suitable method for operational use with Belgian C-band dual-pol radar data.

Hydrometeor classification schemes (HMCs)

- The Australian Bureau of Meteorology Research Center (***BMRC***) uses 1D-membership functions and a fuzzy logic approach based on [1].
- The 1D fuzzy logic classification method of ***Dolan*** [2] uses parameters of [3] for C-band radars.
- The semi-supervised classification algorithm of ***Besic*** [4] is used with default C-band centroids in this work.
- A 2D membership function approach based on [3], [5] as implemented in the ***wradlib*** Python library [6].

Ground transition + homogenization

The hydrometeor class at radar beam height is transitioned towards the ground using Steinert et al. (2021) [7] with vertical temperature profiles and pressure from RMI's ALARO NWP.

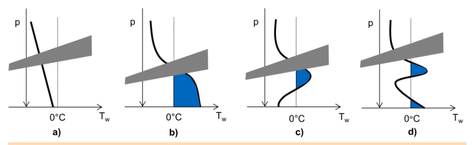

Fig. 1: Temperature vertical profiles (black) and melting area (blue) below the radar beam (gray). Steinert et al., Fig. 6.

All HMCs are simplified to surface precipitation types of (1) Rain/drizzle, (2) Liquid/frozen mix, (3) Snow/aggregates, (4) Small ice/graupel, (5) Hail/melting hail, (6) Undetected, (7) No data.

Ensemble approach: Majority vote

This approach involves the four literature-based HMCs. It is applied directly on the surface precipitation types. The ***majority vote*** is used if any type had a maximum among the four HMCs (3 or 4 count, or a single 2 count). In case of ***four different estimated types***, there is evidence of both liquid and frozen precipitation, and the Liquid/frozen mix type is used. ***2-to-2 tie*** tie-breaking: prioritize hail, then hydrometeor classes over undetected/no data, liquid/frozen mix, and snow over graupel.

Validation

Benchmark: INCA-BE

The INCA-BE deterministic nowcasting system [8] includes an analysis of five precipitation types at the ground, provided on a 1km grid. As current operational system for precipitation type analysis, it was compared to the radar-based methods as a current benchmark.

Ground truth + case selection: HARVEST reports

Weather reports (**HARVEST**) are received from users via the RMI smartphone app. The raw reports are checked for plausibility, clustered in space (1km) and time (5min) to reduce ambiguity, and matched to the 1km grids of dual-pol radar-based precipitation types.

The study is unique in the sheer amount of reports that are included in the statistics. **236 independent cases** contain a total of **8,679 clustered HARVEST reports**. They are used to validate the radar-based types (Fig. 2). A case was defined as a 20-minute period with at least ten HARVEST reports and two different reported precipitation types.

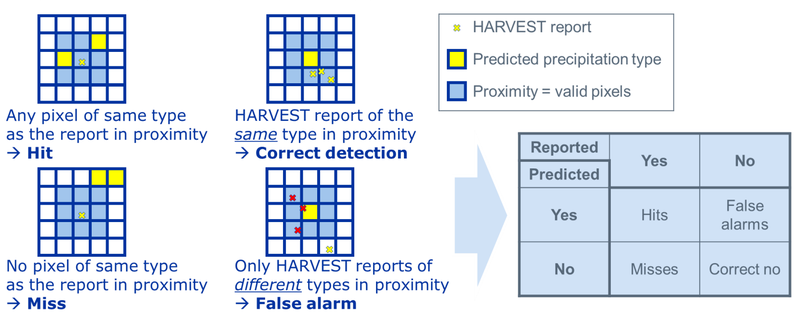

Fig. 2: Matching of HARVEST reports and HMCs pixels for a 3x3 pixel matching proximity leading to the contingency table

Example: Ensemble approach, 10/02/2025 1500UTC

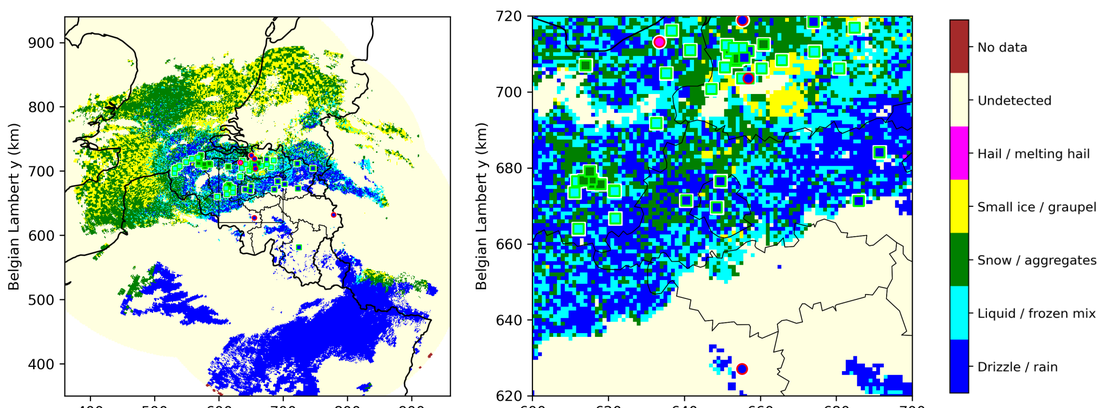

Fig. 3: Winter weather precipitation type case over (a) full domain and (b) zoom showing the ensemble precipitation type (colored grid) and HARVEST reports (colored markers, hits as squares with green edges, misses as circles with red edges).

Acknowledgements
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Results: Statistic and Scores

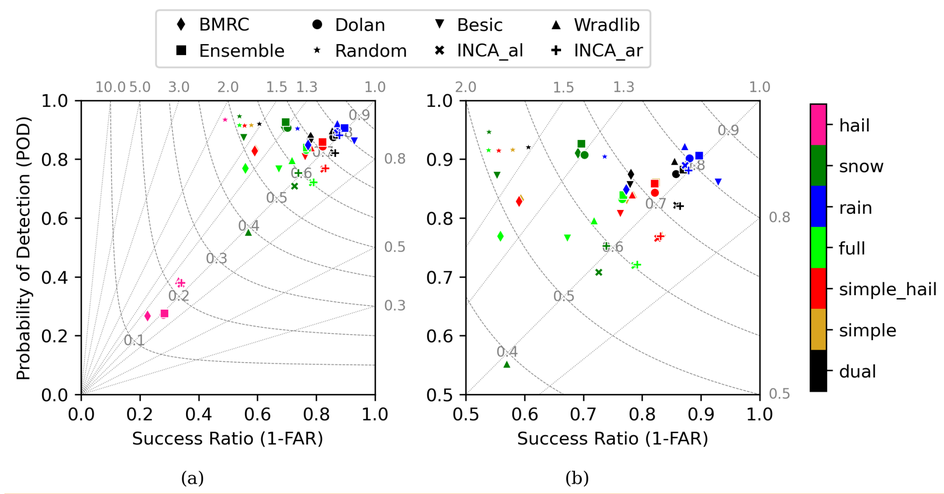

Fig. 4: Roebber performance diagram (a: complete, b: top right corner) to compare all approaches (markers) for different validation strategies (colors, Dual: liquid vs frozen, simple: liquid, mix, frozen, simple_hail: liquid, mix, froze, hail, full: liquid, mix, snow, graupel, hail)

The statistical analysis of all cases reveals the contingency tables to calculate scores Probability of Detection (POD), False Alarm Ratio (FAR), Critical Success Index (CSI), and Frequency Bias Index (FBI). The scores are summarized in the Roebber performance diagram (Fig. 4) and Tab. 1.

A class-by-class comparison (Fig. 5) shows which HARVEST types were reported for the analyzed types of the Ensemble approach.

Tab. 1: Validation scores for Method to validate ground-truth HARVEST precipitation types. Validation strategy: simple_hail.

Method	*POD*	*FAR*	*CSI*	*FBI*
BMRC	0.83	0.41	0.53	1.40
Dolan	0.84	0.18	0.71	1.03
Besic	0.81	0.24	0.65	1.06
Wradlib	0.84	0.18	0.68	1.07
Ensemble	0.86	0.18	0.72	1.04
Random	0.91*	0.44	0.53	1.67
INCA-BE_al	0.77	0.17	0.66	0.93
INCA-BE_ar	0.77	0.17	0.67	0.92

* High random POD due to 9-fold sampling (9 pixels) from 5 precipitation types, where the probability of getting it right once is high. However, the FAR is also very high.

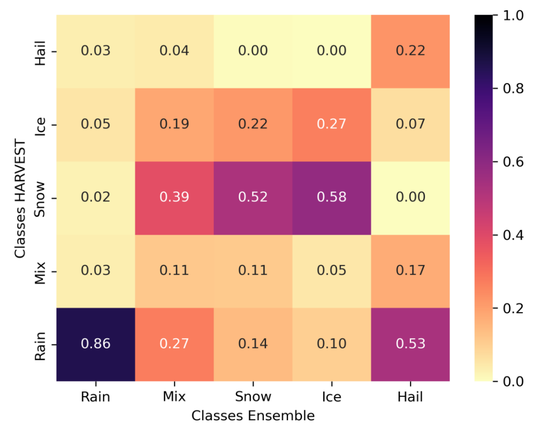

Fig. 5: Confusion matrix HARVEST reports vs. Ensemble approach – Normalized per column. Colors show relative frequency per column.

Conclusion

Results demonstrate the potential of C-band dual-pol radar data for improving precipitation-type analysis over Belgium.

- **Dolan** and **Ensemble** outperform the INCA-BE benchmark in CSI.
- **Ensemble** achieves the **best overall performance** among the tested HMC approaches.
- The Ensemble approach combines the strengths of the four HMCs and provides a promising candidate for **operational precipitation-type analysis**.

References
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