Real-time recognition of surface precipitation type (SPT) for high-resolution precipitation data

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SPT (SURFACE PRECIPITATION TYPE) SYSTEM

The SPT (surface precipitation type) system has been developed at Institute of Meteorology and Water Management – National Research Institute (IMGW-PIB) to recognize the precipitation type with very high spatial and temporal resolution (respectively, 1 km and 10 min). The following precipitation types are recognized:

- rain, freezing rain, snow/rain, and snow,
- hail and its probability.

PRECIPITATION TYPE RECOGNITION: RAIN, FREEZING RAIN, SNOW/RAIN, AND SNOW

The algorithm follows the general rule of favourable conditions for different precipitation types (Fig. 1) and employs four parameters defined in Table 1 based on wet-bulb temperature computed from NWP-provided forecasts of temperature, pressure and specific humidity at 50 hybrid levels.

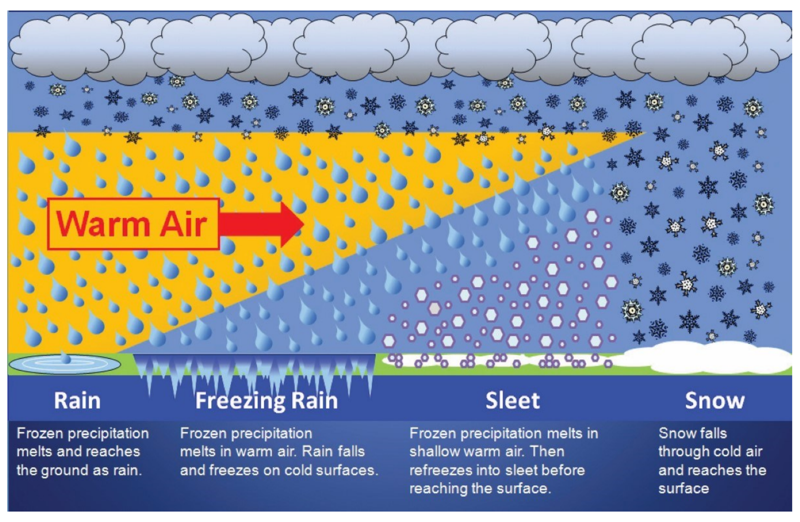

Fig. 1. Precipitation types (source: https://www.weather.gov/bmx/outreach_wwaw2017).

Table 1. Parameters of the algorithm for recognition of rain, snow/rain, freezing rain, and snow.

Parameter	Description	Precipitation type
TWP, $\int(+T_w)$	Integrated positive wet-bulb temperature T_w in the whole atmospheric column	snow freezing rain rain
TWP$_{200}$, $\int(+T_w)_{200}$	Integrated positive wet-bulb temperature T_w in the atmosphere column up to 200 m a.g.l.	snow snow/rain freezing rain rain
TWM$_{200}$, $\int(-T_w)_{200}$	Integrated negative wet-bulb temperature T_w in the atmosphere column up to 200 m a.g.l.	snow snow/rain freezing rain rain
TWM$_{500}$, $\int(-T_w)_{500}$	Integrated negative wet-bulb temperature T_w in the atmosphere column up to 500 m a.g.l.	snow snow/rain freezing rain rain

The four classes of SPT are determined applying fuzzy logic scheme, in which membership functions for particular classes have been empirically optimized (Fig. 2). In the fuzzy logic scheme values of membership functions for all parameters are accumulated for each precipitation class:

$$\mu(class) = \sum_{i=1}^{n_{class}} \mu_i(X_{i,class}) \cdot w_{i,class}$$

Estimated precipitation type results from the class with the biggest summarized value of μ.

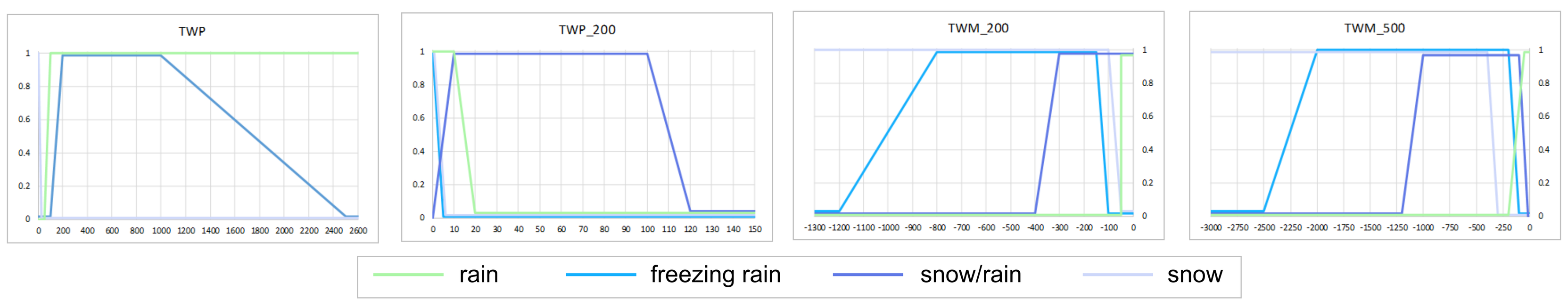

Fig. 2. Membership functions for particular classes of SPT.

DETECTION OF HAIL

The algorithm is based mainly on weather radar data. The following dedicated parameters have been defined:

- ΔH40 – thickness of layer above isotherme of 0ºC where radar reflectivity > 40 dBZ,
- ΔH45 – thickness of layer above isotherme of 0ºC where radar reflectivity > 45 dBZ,
- ΔH50 – thickness of layer above isotherme of 0ºC where radar reflectivity > 50 dBZ.

The isotherme of 0ºC altitude is provided by COSMO 2.8-km NWP model. In order to avoid false alarms for the following parameters the thresholds, below which hail is impossible, have been preset:

- CMAX – maximum radar reflectivity in vertical profile: 35 dBZ,
- CAPPI – radar reflectivity on 4 km a.s.l.: 25 dBZ,
- VIL – vertically integrated liquid water: 1 mm,
- ETOP (4dBZ) – altitude of cloud top with minimum reflectivity of 4 dBZ: 5.5 km a.s.l.

Similarly to rain/snow recognition algorithm, fuzzy logic scheme has been applied to hail detection.

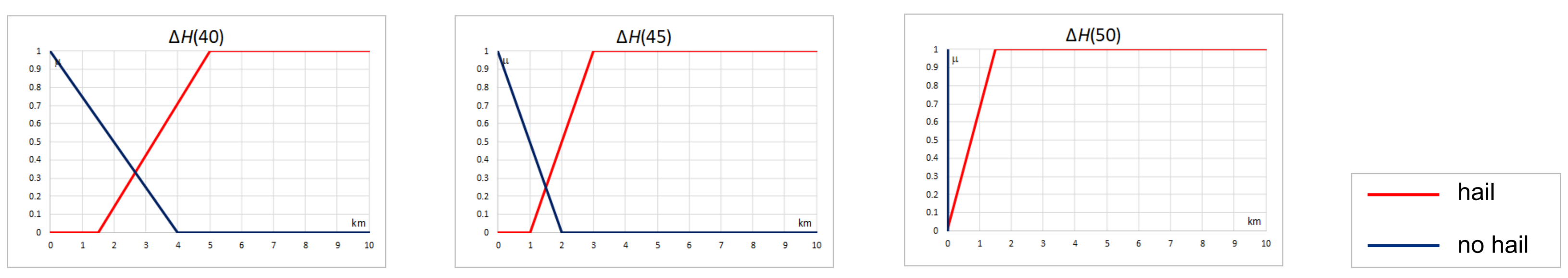

Fig. 3. Membership functions for classes "hail" and "no hail".

An additional parameter employed in the algorithm is Hail Detection Ratio (HDR) based on dual-pol weather radar product ZDR (differential reflectivity):

$$HDR = Z - f(ZDR), \quad where \quad f(ZDR) = \begin{cases} 43.5 & ZDR \le 0 \\ 8.1 \cdot ZDR + 43.5 & 0 < ZDR \le 0.62 \\ 50 & ZDR > 0.62 \end{cases}$$

If HDR > 0 then summarised membership function for "hail" is increased by 0.1.
Probability of hail is calculated from the following formula:

$$P_{hail} = \frac{hail}{hail + no.hail}$$

VALIDATION

Effectiveness of the SPT system has been assessed based on comparison to information from synoptic stations where observations are made every hour. Quantitative metrics of uncertainty are based on contingency table:

Table 2. Contingency table.

	Observed: yes	Observed: no
Estimated: yes	hits	false alarms
Estimated: no	misses	correct negatives

POD (probability of detection): $POD = \frac{\text{hits}}{\text{hits} + \text{misses}}$

FAR (false alarm ratio): $FAR = \frac{\text{false alarms}}{\text{hits} + \text{false alarms}}$

CSI (critical success index): $CSI = \frac{\text{hits}}{\text{hits} + \text{false alarms} + \text{misses}}$

FBI (frequency bias index): $FBI = \frac{\text{hits} + \text{false alarms}}{\text{hits} + \text{misses}}$

PC (percentage correct): $PC = \frac{\text{hits} + \text{correct negatives}}{\text{number of events}}$

Table 3. Validation of recognition of rain, freezing rain, snow/rain, and snow (on data 2017-2019).

Metric	Rain	Freezing rain	Snow/rain	Snow
Hits	1309	22	101	1524
Misses	233	21	154	115
False alarms	53	51	241	178
Correct negatives	1884	3385	2983	1662
POD	0.849	0.512	0.396	0.930
FAR	0.039	0.699	0.705	0.105
CSI	0.821	0.234	0.204	0.839

Table 4. Validation of detection of hail (on data 2017-2018).

Metrics	Synoptic stations	Synoptic station + ESWD database
Hits	18	173
Misses	17	26
False alarms	1	1
Correct negatives	76	76
POD	0.51	0.87
FAR	0.05	0.01
CSI	0.50	0.87
FBI	0.54	0.87
PC	0.84	0.90

EXAMPLES

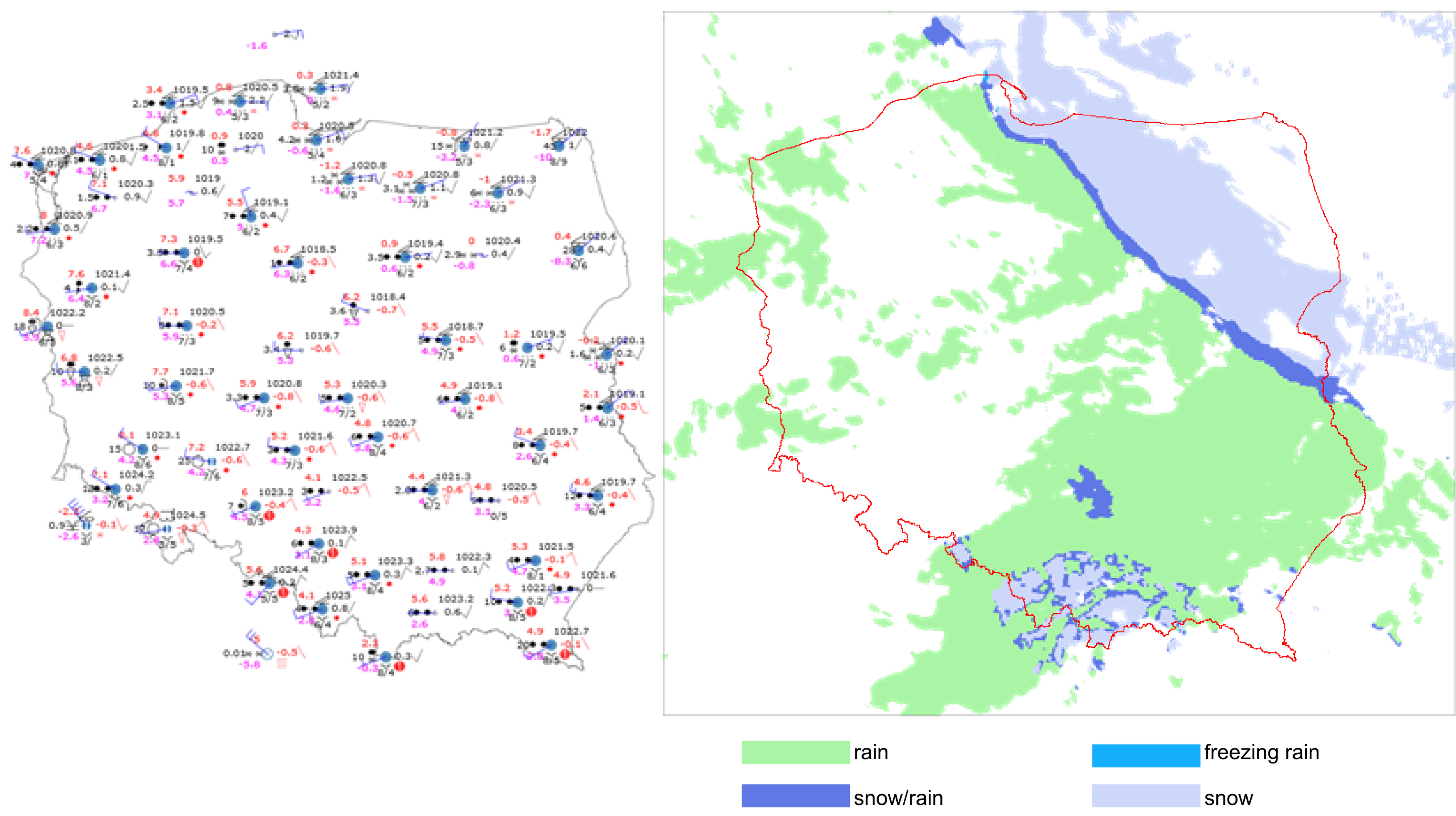

Fig. 4. Recognition of rain, freezing rain, snow/rain, and snow for Poland domain, 21 February 2019, 18:00 UTC.

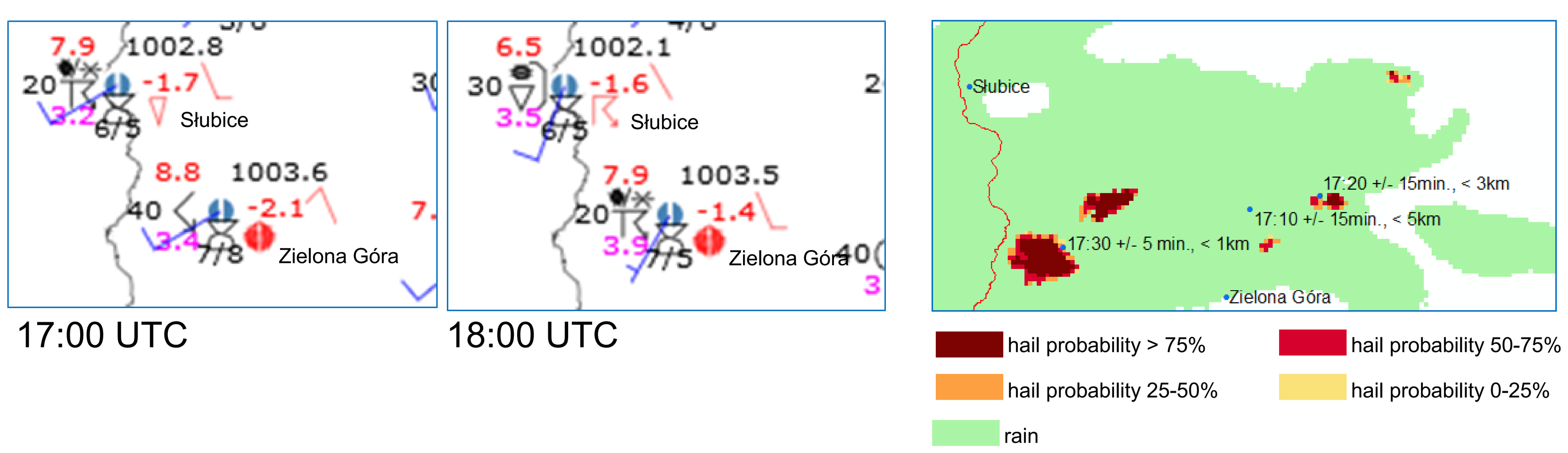

Fig. 5. Detection of hail, 9 March 2019, 17:20 UTC. On the left: excerpts from synoptic stations maps for Poland, on the right: excerpt from SPT field with hail probability and reports from ESWD database.

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