

Objective: Improve current deterministic nowcast warnings for precipitation by extreme rainfall warnings that include uncertainty information from an ensemble nowcast.

1. PySTEPS-BE ensemble nowcast

Based on STEPS [1, 2], built in the open-source framework pySTEPS [3]

Input:

- Observations: radar rainfall fields, 1km resolution, 5min frequency
- NWP: ALARO+AROME at 1.3km, 5min accumulations

Output:

- 24-member ensemble, every 10 minutes
- Forecast time step of 5min for up to +6 hours lead time

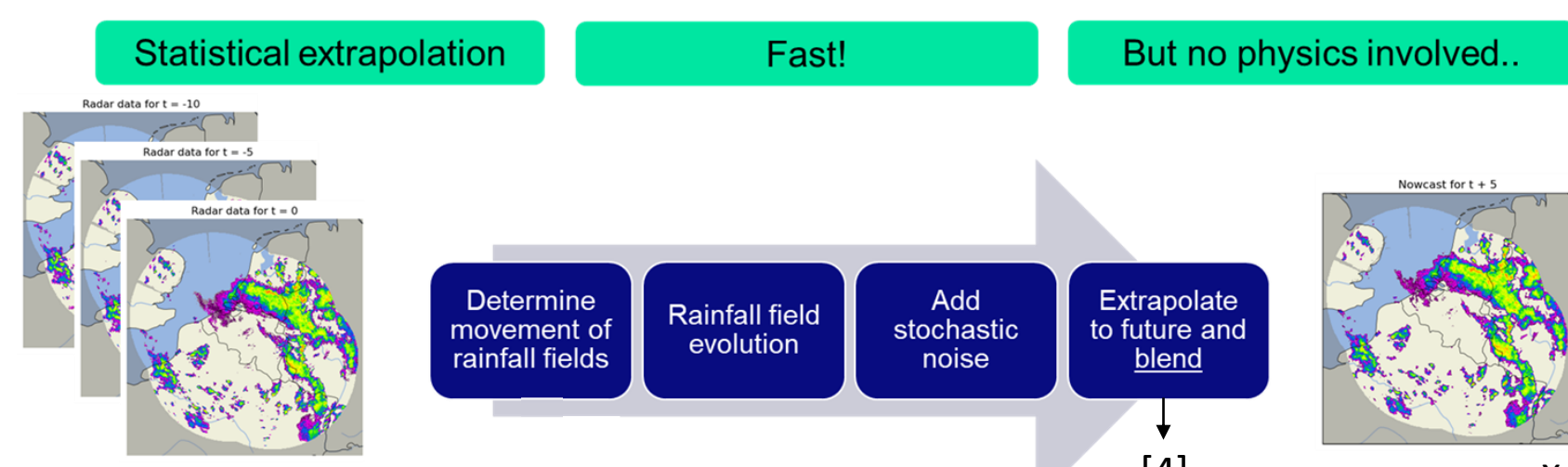


Fig. 1: PySTEPS methodology

2. Extreme rainfall return periods

Extreme rainfall is defined by spatial Generalized Extreme Value (GEV) models based on long-term time series of rain gauge data [5].

- Mean annual rainfall as covariate
- The return level $z(T)$ is defined as the value that is exceeded, on average, once every T years.
- The **return period** (T) is the time interval over which the return level is expected to recur. Longer return periods mean more extreme rainfall.
- Spatial resolution – grid: 1km×1km
- Compare the nowcast of each pySTEPS-BE member to the return levels and identify pixels with exceeded thresholds and the active warning members.

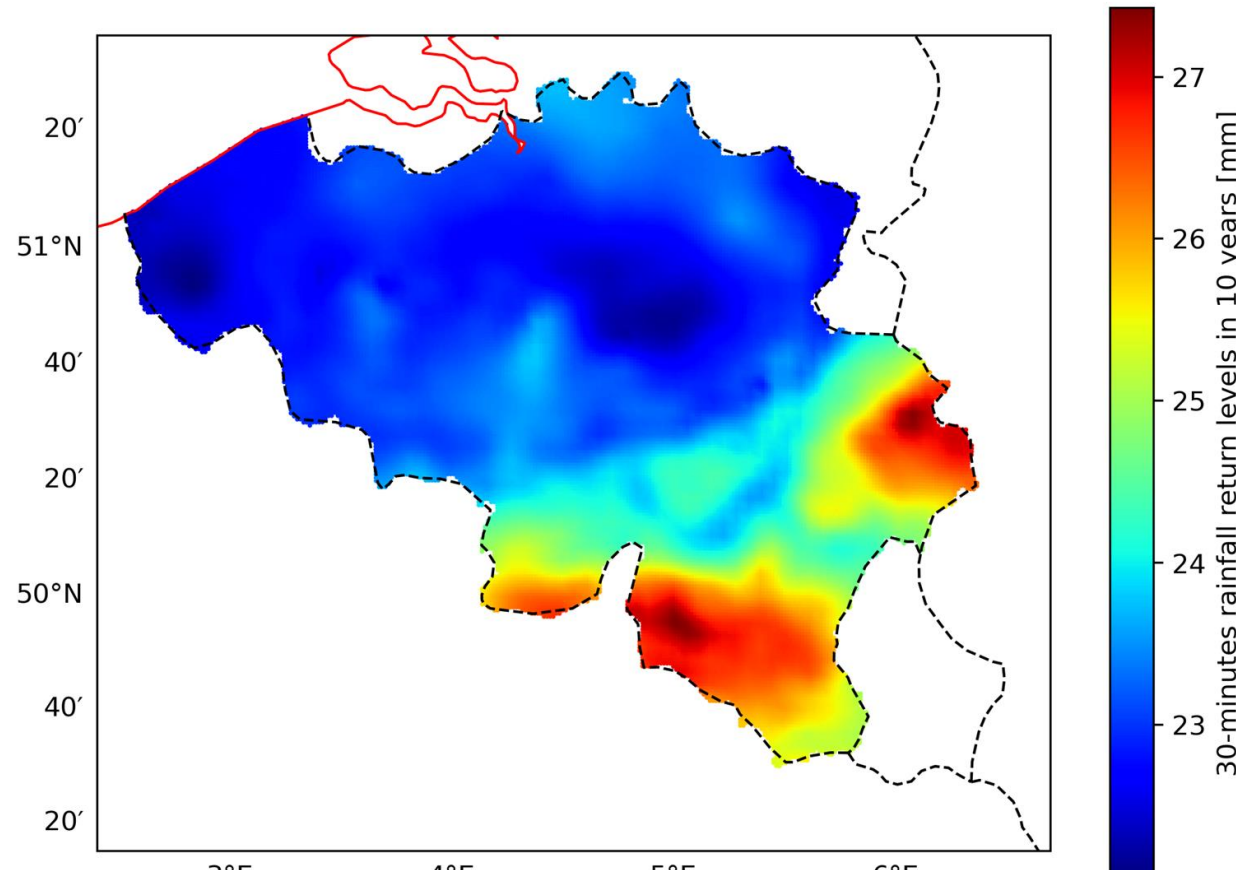


Fig. 2: Return level example

3. Pixels to municipalities

The administrative scales for warnings are the municipalities.

- Match the pixels of the regular grid to the shape of the municipality (minimum overlap method, Fig. 3).
- If any matched pixel exceeds the local threshold, the evaluated pySTEPS-BE member contributes as active warning and the exceedance count of the municipality is increased by 1. The exceedance count is always smaller or equal to the ensemble size.
- The ensemble-based probability can then be calculated as **exceedance probability** = exceedance count / ensemble size.

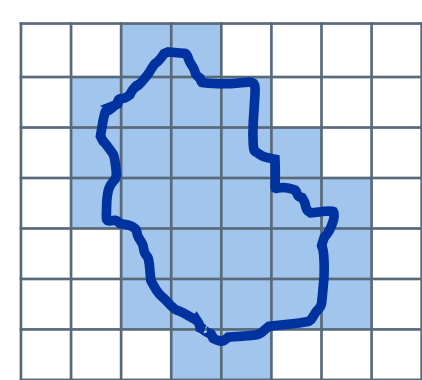
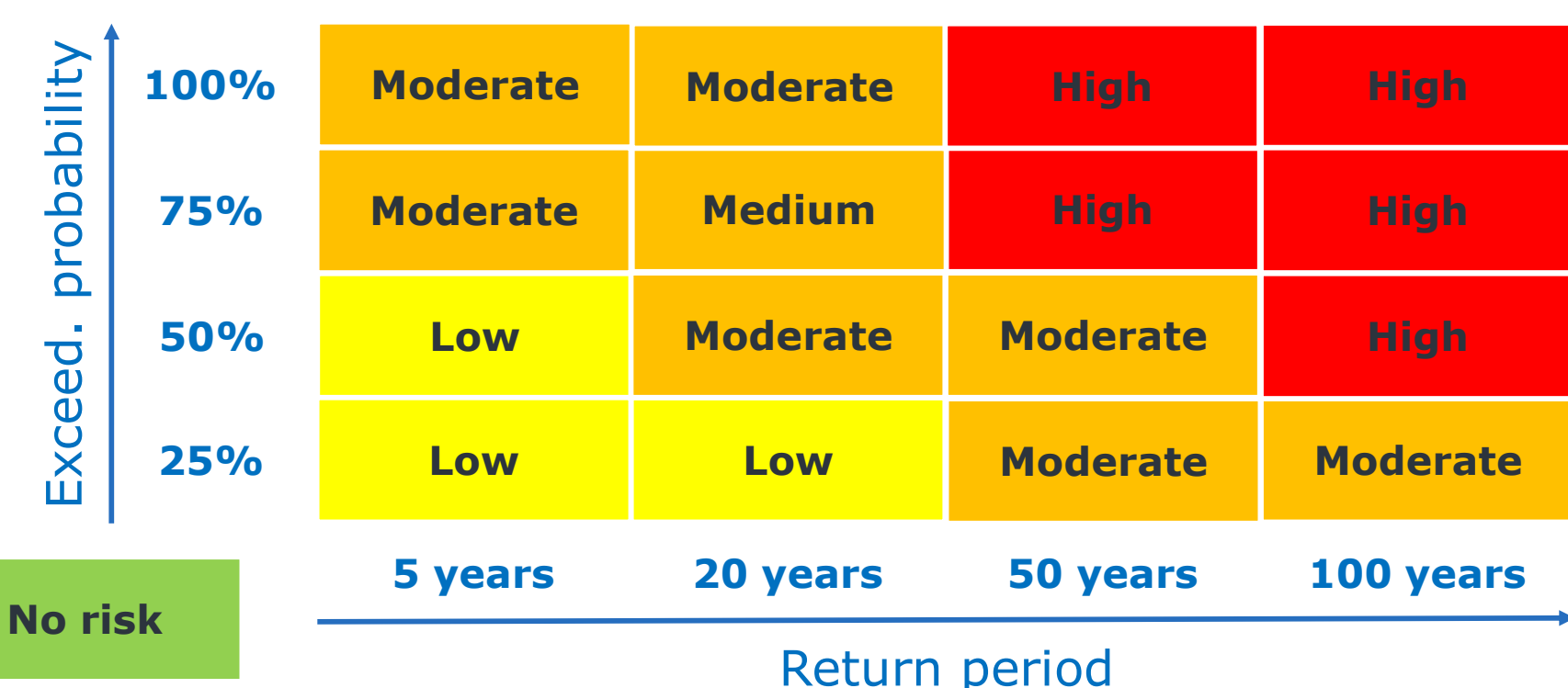


Fig. 3: Minimum overlap method

4. Warning levels

The exceedance probability and the return periods are used to define the warning level.

- 4 levels: green (no risk), yellow (low risk), orange (moderate risk), and red (high risk)
- 4 return periods
- 4 probability thresholds
- These calculations are repeated for the accumulation times of 10min, 30min, 1h, and 2h.
- If the accumulation time is longer than the forecast time step, observations are included.
- The most severe warning level is displayed for each municipality.



A table defining warning levels based on exceedance probability and return period. The table has 4 rows for exceedance probability (100%, 75%, 50%, 25%) and 4 columns for return period (5 years, 20 years, 50 years, 100 years). The warning levels are color-coded: green for 'No risk', yellow for 'Low', orange for 'Moderate', and red for 'High'.

Exceed. probability	5 years	20 years	50 years	100 years
100%	Moderate	Moderate	High	High
75%	Moderate	Medium	High	High
50%	Low	Moderate	Moderate	High
25%	Low	Low	Moderate	Moderate

Fig. 4: Warning level definitions

5. PyRainWarn output

PyRainWarn = pySTEPS-based rainfall warnings

- Animated map to display the warnings
- Details as a popup window for each municipality
- JSON file to list the municipality warnings
- **Scan me!**

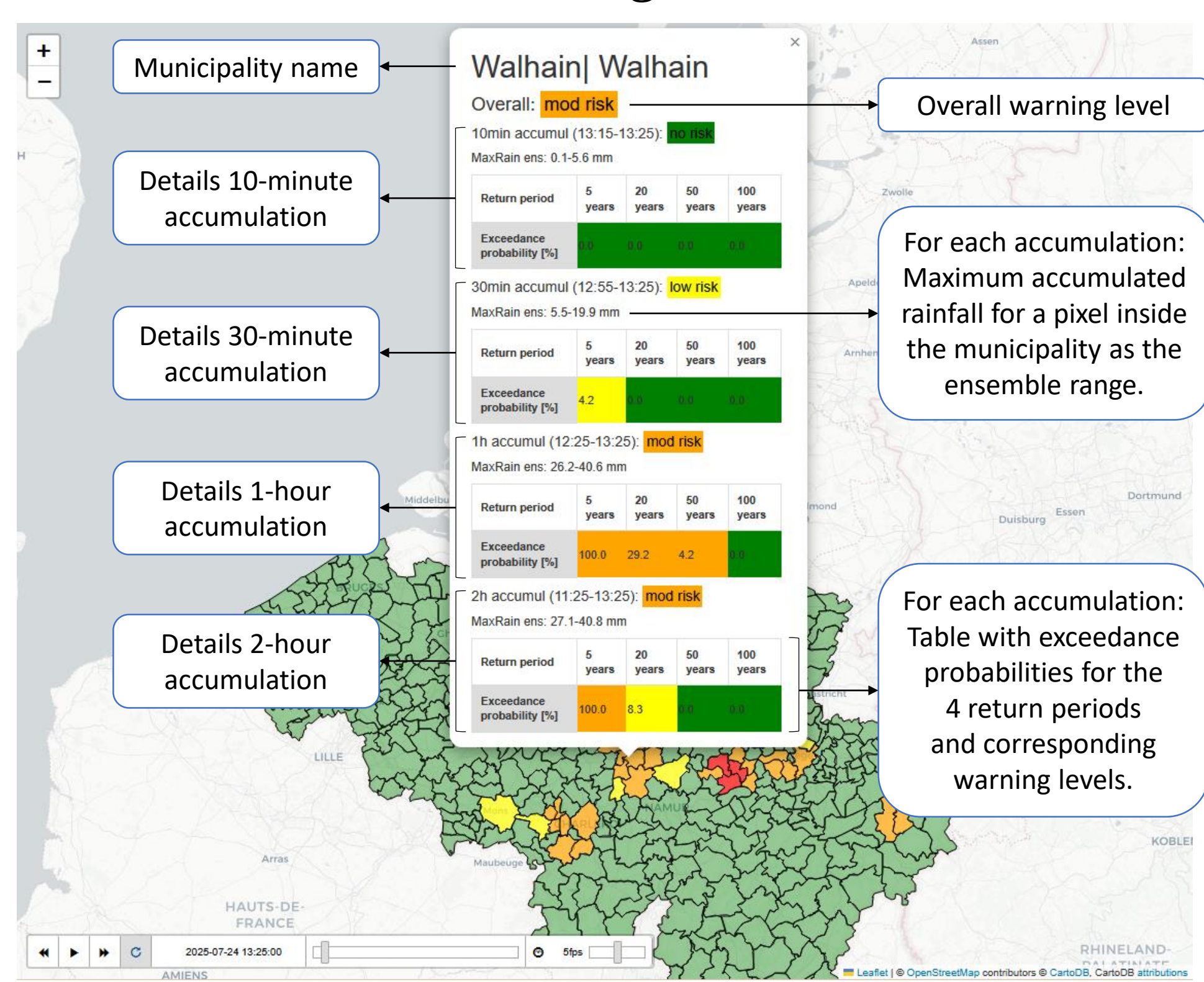


Fig. 5: PyRainWarn map with explanations

Outlook

- Operational at the RMI since October 2025
- Validation and tuning of the warning levels if needed
- User feedback and adaption to their needs
- PyRainWarn extreme rainfall warnings in the RMI mobile app

References

- [1] Bowler, N.E., Pierce, C.E. and Seed, A.W. (2006): <https://doi.org/10.1256/qj.04.100>
- [2] Seed, A.W., Pierce, C.E., and Norman, K. (2013): <https://doi.org/10.1002/wrcr.20536>
- [3] Pulkkinen, S. et al. (2019): <https://doi.org/10.5194/gmd-12-4185-2019>
- [4] Imhoff, R.O. et al. (2023): <https://doi.org/10.1002/qj.4461>
- [5] Van de Vyver, H. (2012): <https://doi.org/10.1029/2011wr011707>

Acknowledgements

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