PySTEPS-BE ensemble nowcasts for extreme rainfall warnings in Belgium

F. Erdmann[1], L. De Cruz[1,2], M. Reyniers[1], R. Reinoso-Rondinel[3,1], D. R. Poelman[1], M. Van Ginderachter[1]

[1] *Royal Meteorological Institute of Belgium (RMI), Brussels, Belgium*
[2] *Department of Electronics and Informatics (ETRO), Vrije Universiteit Brussel, Brussels, Belgium*
[3] *Civil Engineering, Hydraulics & Geotechnics, KU Leuven, Leuven, Belgium*

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

Statistical extrapolation | Fast! | But no physics involved..

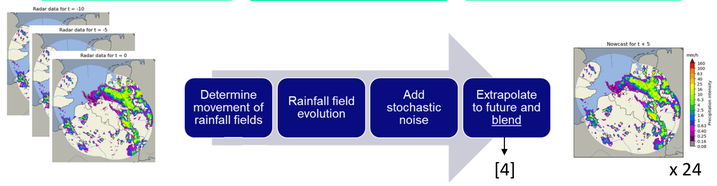

Fig. 1: PySTEPS methodology

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.

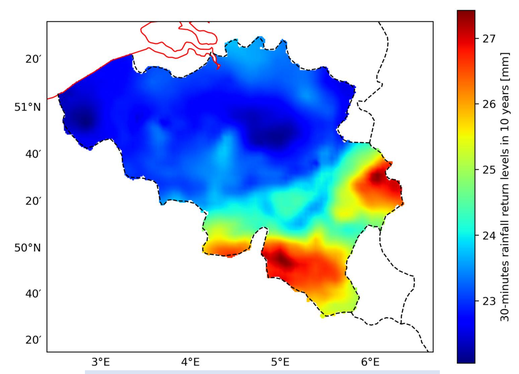

Fig. 2: Return level example

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.

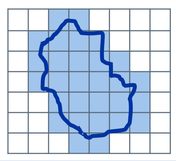

Fig. 3: Minimum overlap method

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.

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

No risk

Return period

Fig. 4: Warning level definitions

5. PyRainWarn output

PyRainWarn = **py**STEPS-based **rain**fall **warn**ings
- Animated map to display the warnings
- Details as a popup window for each municipality
- JSON file to list the municipality warnings
- **Scan me!**

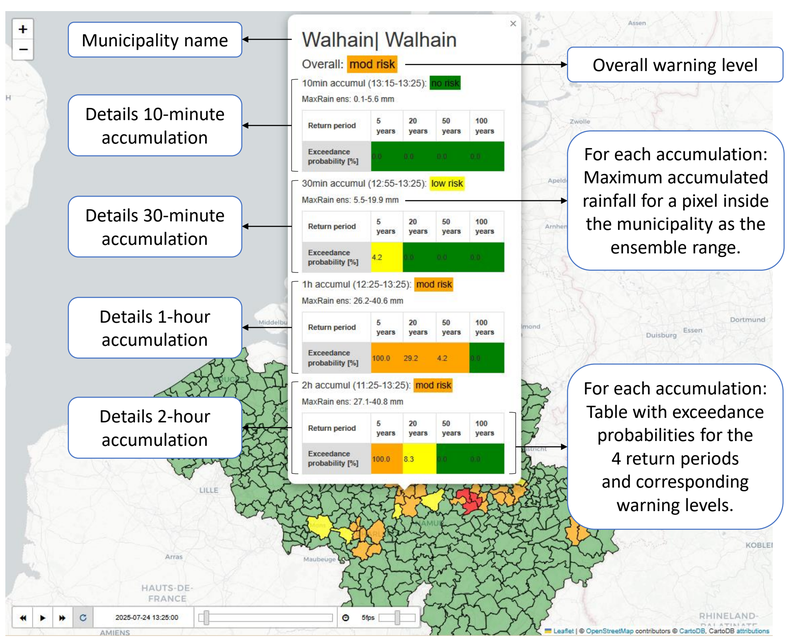

Fig. 5: PyRainWarn map with explanations

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

The project is funded by the Service public de Wallonie (SPW).
We thank all our colleagues who contributed to establishing pySTEPS-BE as the operational ensemble nowcasting system at the RMI and to run pyRainWarn as an operational product in real time.