Development and verification of a real-time stochastic precipitation nowcasting system in Belgium

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Motivation

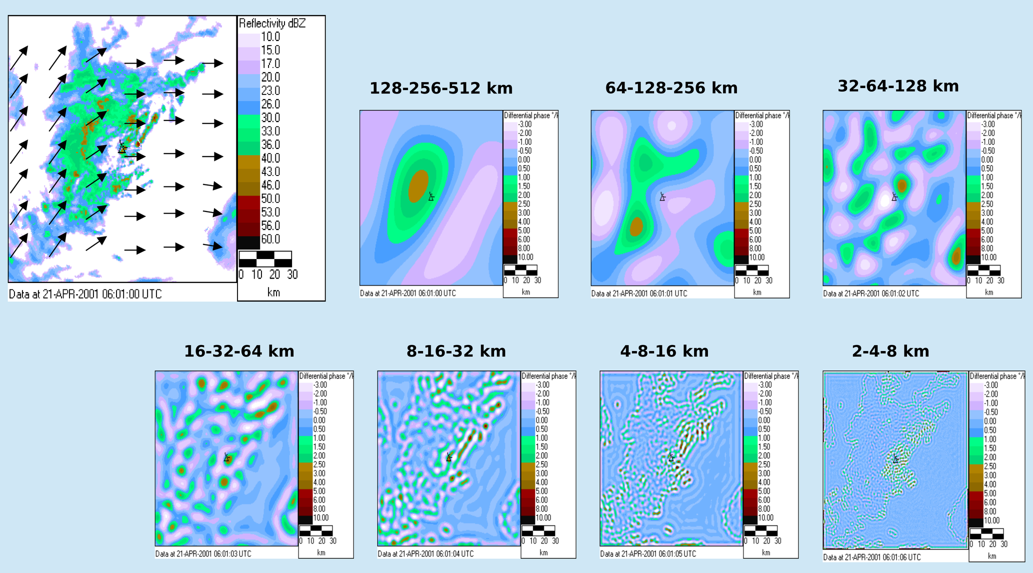
Belgian Science Policy Office SSD project PLURISK: *"Forecasting and management of rainfall induced risks in the urban environment" (2012-2016)*

Current operational nowcasting system at the Royal Meteorological Institute (RMI): INCA-BE (Integrated Nowcasting through Comprehensive Analysis in Belgium) provides deterministic precipitation nowcasts

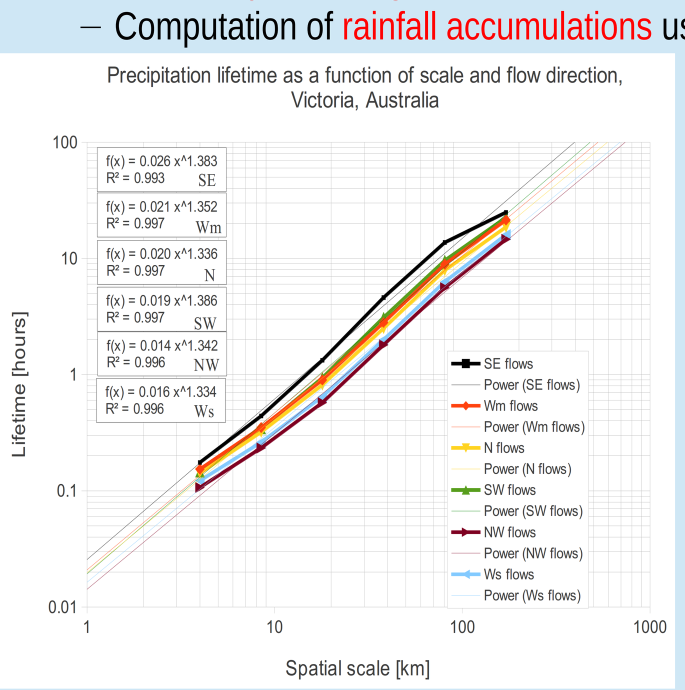
In order to represent the forecast uncertainty the RMI implemented the Short-Term Ensemble Prediction System (Bowler *et al*., 2006; Seed *et al*., 2013) in Belgium STEPS-BE

Short-Term Ensemble Prediction System STEPS

1. Estimation of the advection of radar rainfall images using optical flow
2. Decomposition of the rainfall field into a multiplicative cascade using a Fast Fourier Transform to isolate a set of spatial frequencies (see below)



3. Estimation of the rate of evolution of rainfall in moving coordinates due to unpredictable growth and decay processes at each spatial frequency (Lagrangian auto-correlations)
4. Lagrangian extrapolation of the rainfall cascade
5. Stochastic evolution of each cascade level according to its estimated Lagrangian auto-correlation (AR(1) model on spatially correlated noise)
6. Re-composition of the cascade into a rainfall field
   - Probability matching of the forecast field with the last observed field
   - Computation of rainfall accumulations using advection correction



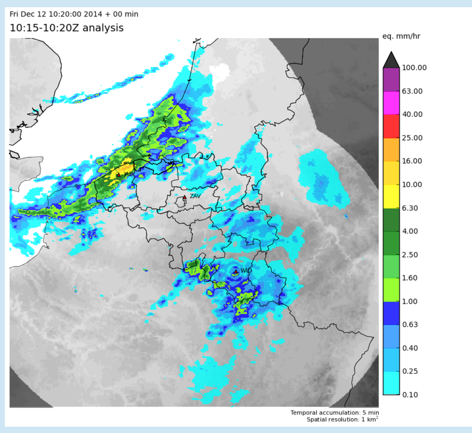
Foresti and Seed (2014)

STEPS reproduces:
- the scale-dependence of the predictability of precipitation (left)
- the spatio-temporal correlations of the forecast errors
- the spatial scaling of the rainfall field

STEPS-BE integrates as input the composite including the C-band radars of Zaventem, Wideumont, Jabbeke and Avesnois

STEPS-BE example nowcasts

Last radar rainfall observation



Rainfall nowcasts

+5 min | +120 min

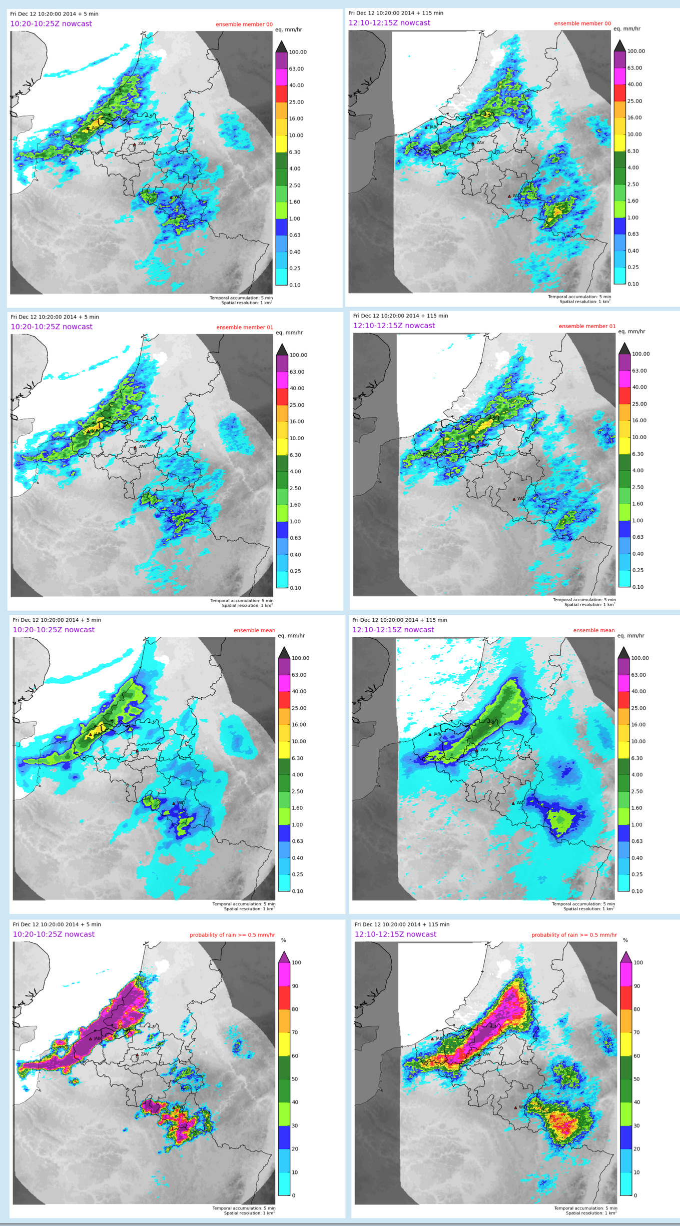
1st stochastic realization

2nd stochastic realization

...

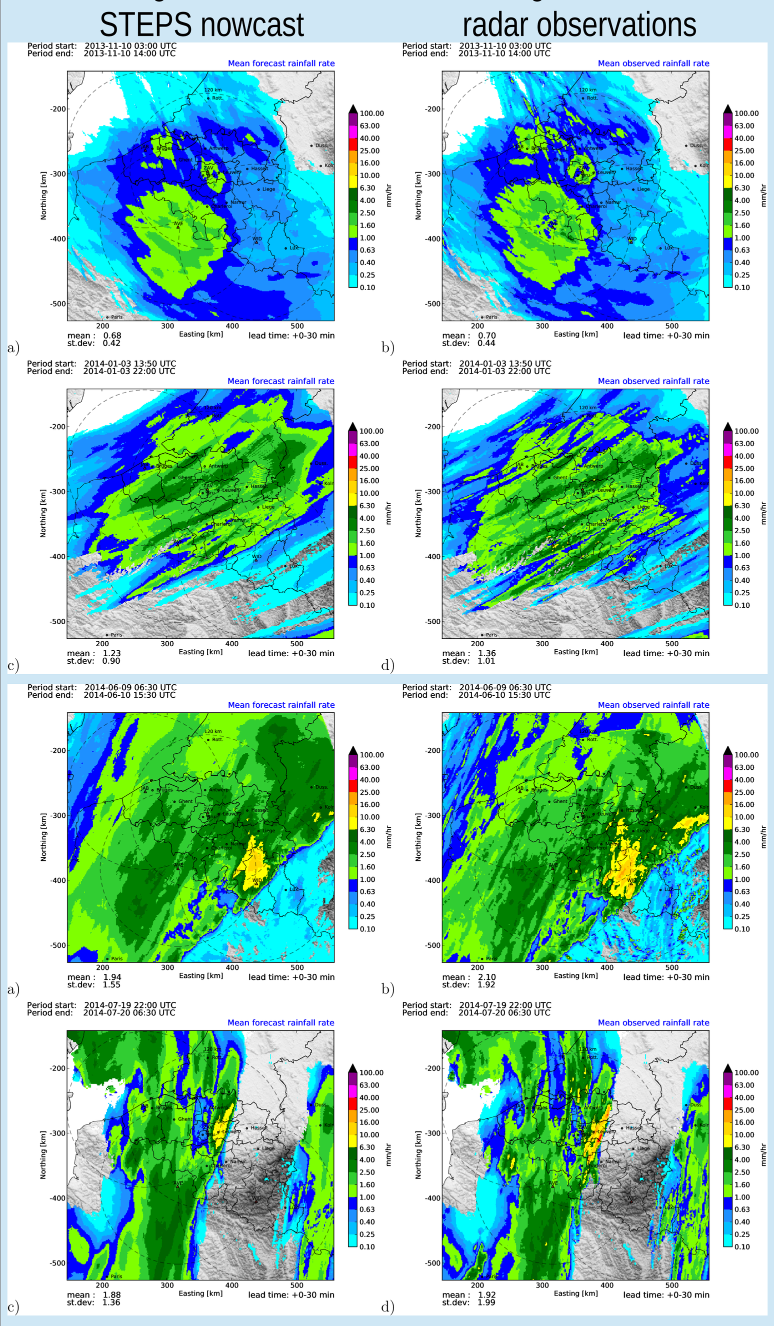
Ensemble mean nowcast

Probabilistic nowcast of rain >= 0.5 mm/hr (0.25 mm / 30min)



STEPS-BE case studies

Average +0-30 min STEPS nowcast | Average +0-30 min radar observations



Stratiform case 10 Nov 2013, 13:50 - 22:00

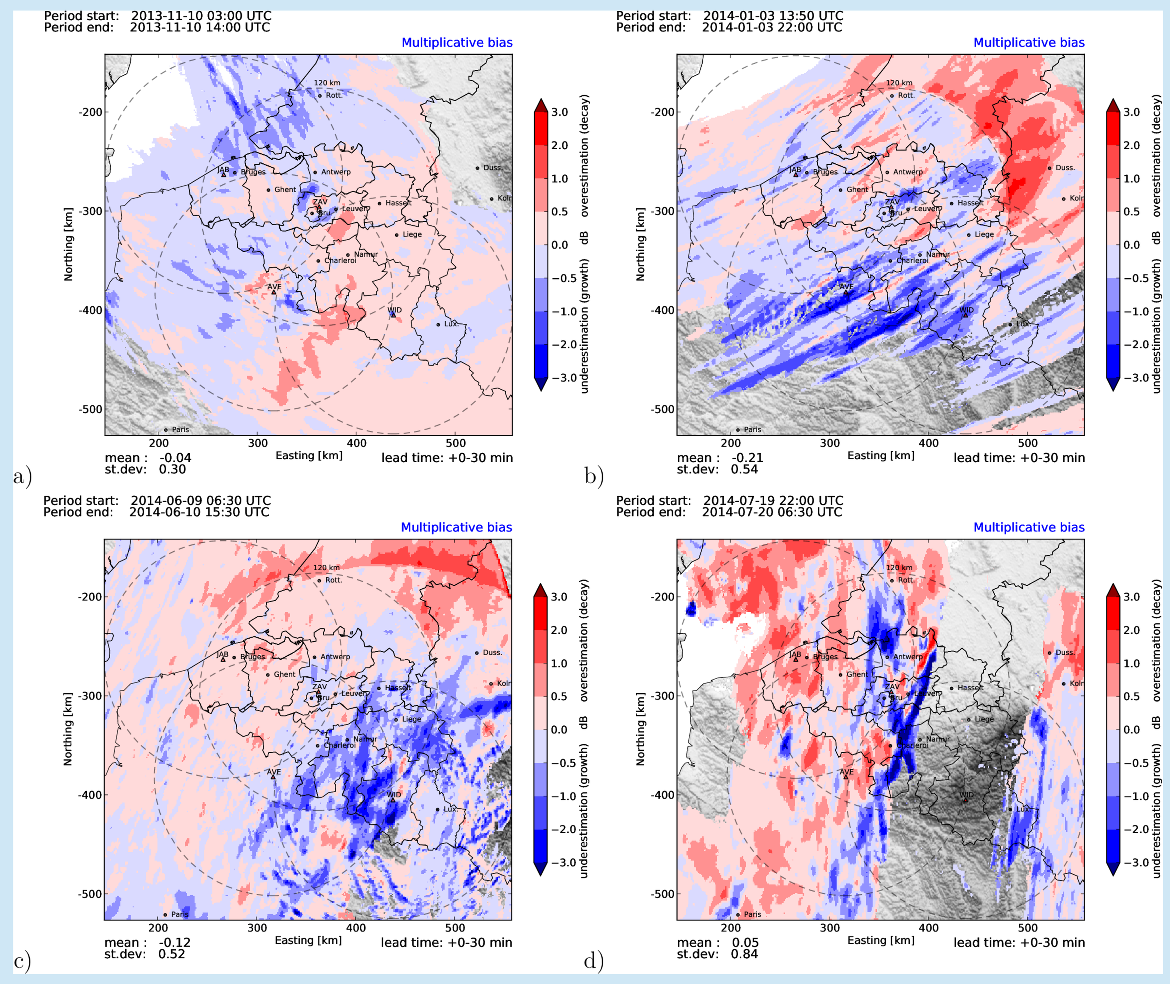
Stratiform case 03 Jan 2014, 03:00 - 14:00

Convective case 09 Jun 2014, 06:30 - 10 Jun 2014, 15:30

Convective case 19 Jul 2014, 22:00 - 20 Jul 2014, 06:30

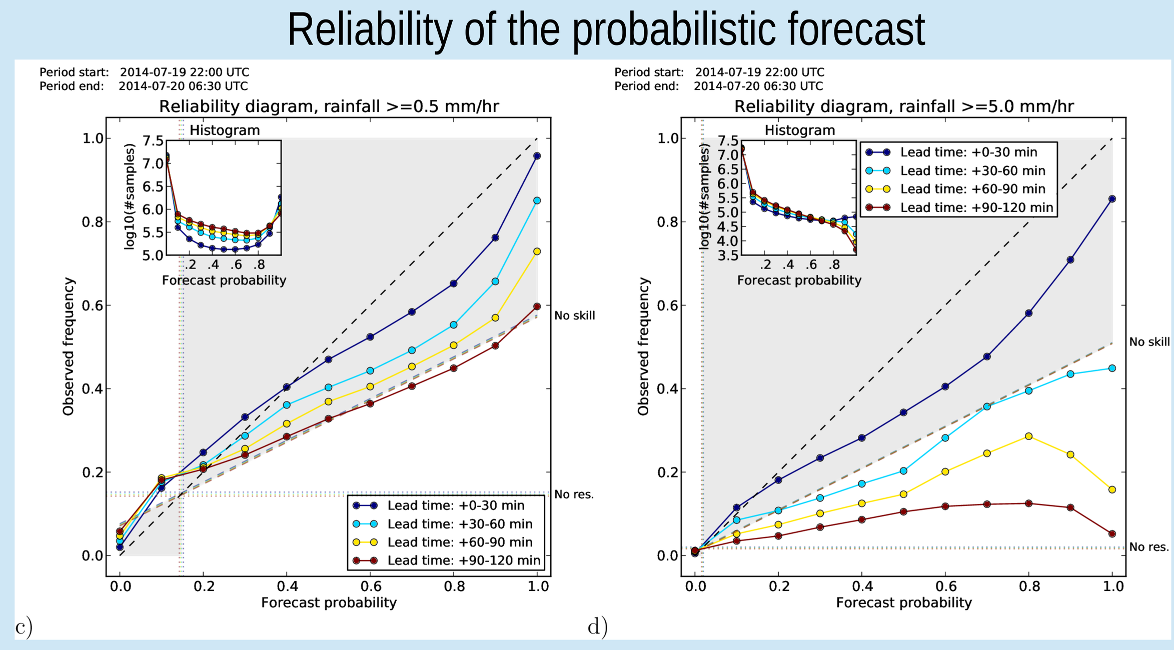
STEPS-BE forecast verification

$$\text{Multiplicative bias} = 10 log_{10}\left(\frac{Forecast + 2\ mm\ hr^{-1}}{Radar + 2\ mm\ hr^{-1}}\right)$$



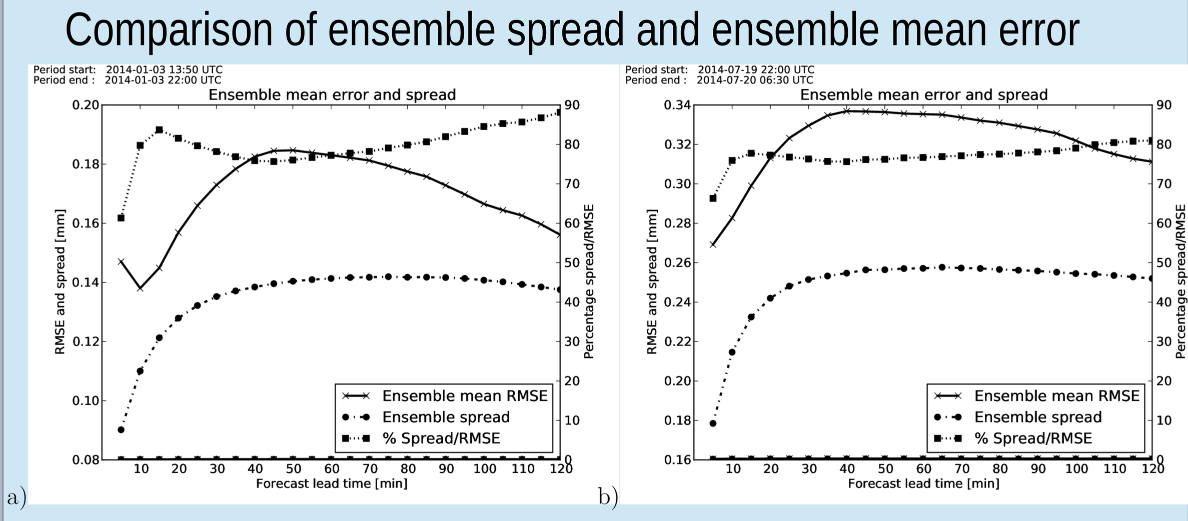
Spatial distribution of the multiplicative forecast bias for the 4 rainfall events considered. Red regions denote an overestimation of rain by STEPS while blue regions an underestimation. Since the radar observations are used as reference for the verification, a certain fraction of the forecast biases are simply due to the radar measurement biases (e.g. range dependence of the rain rates, bright band effect, radar calibration biases) and not systematic rainfall growth and decay processes

Reliability of the probabilistic forecast



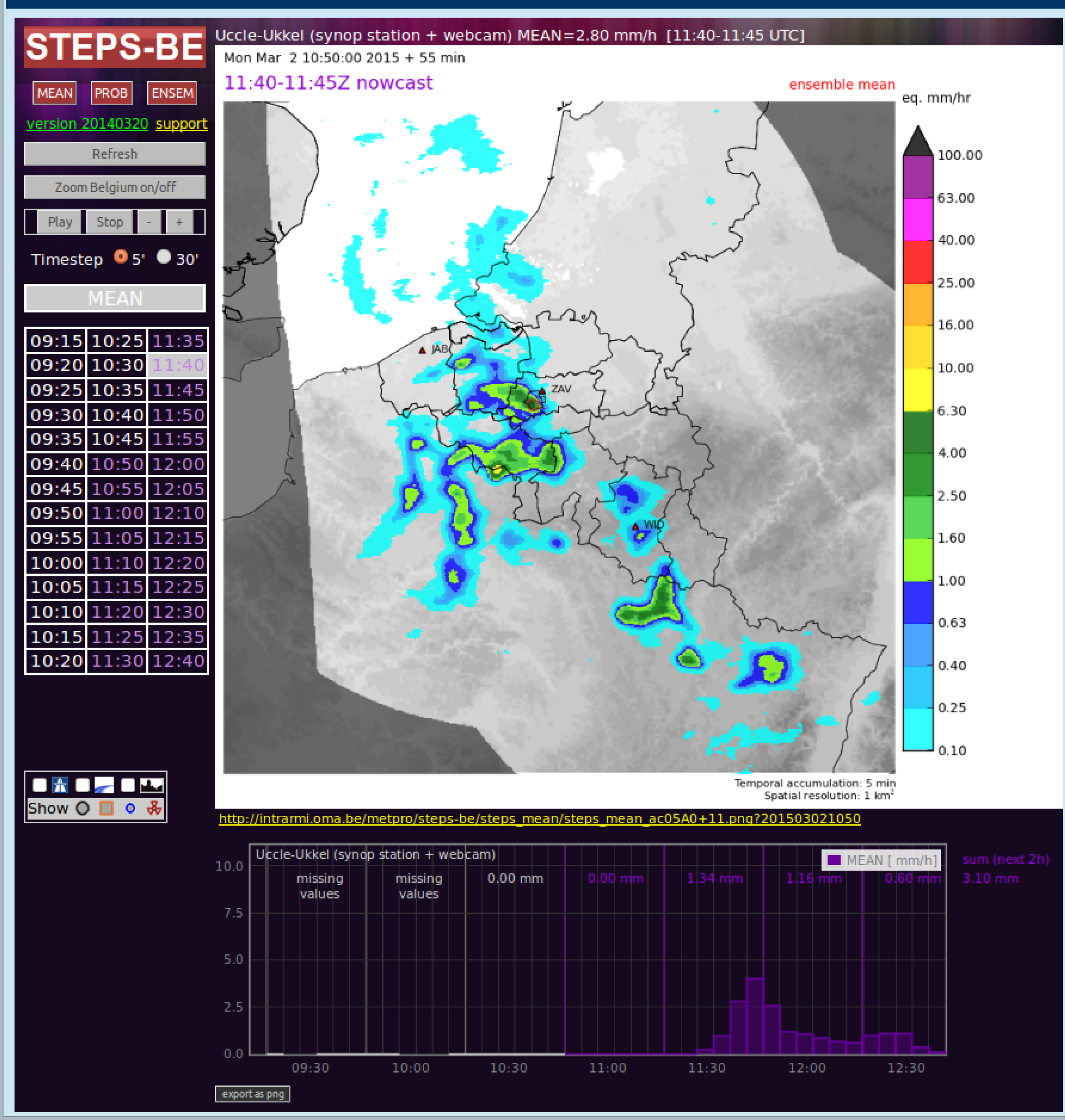
Reliability diagram for the probabilistic forecast of exceeding 0.5 mm/hr (left) and 5.0 mm/hr (right) as a function of lead time

Comparison of ensemble spread and ensemble mean error



Ensemble mean error (RMSE), ensemble spread and fraction of ensemble spread w.r.t. ensemble mean error as a function of lead time for one stratiform (left) and one convective case (right)

STEPS-BE real-time visualization system



- 20 member ensemble computed in parallel
- Nowcasting rainfall accumulations at 1 km and 5 min resolutions up to 2 hours lead time
- Forecast products:
  - *Ensemble mean*
  - *Probability to exceed rainfall thresholds*
  - *Full 20 member ensemble*
- Time series of rainfall accumulation and probability at the location of major cities and outdoor activities/events
- Computes ensemble forecasts and generates more than 500 figures with python matplotlib library in less than 5 minutes
- Extensive documentation and case studies for users and weather forecasters

Conclusions

- The estimation of the forecast uncertainty is as important as the forecast itself
- STEPS accounts for the temporal variability of the predictability of precipitation
- STEPS biases depend strongly on radar observation biases
- Probabilistic nowcasts are reliable up to 2 hours lead time for rain exceeding 0.5 mm/hr, but only up to half an hour for rain exceeding 5 mm/hr (convective rain)
- The forecast uncertainty is slightly underestimated and represents only 80% of the forecast error

References
- Bowler NE, Pierce CE, Seed AW (2006). A probabilistic precipitation forecasting scheme which merges an extrapolation nowcast with downscaled NWP. *Quarterly Journal of the Royal Meteorological Society* **32(620)**:2127-2155.
- Seed AW, CE Pierce, Norman K (2014). Formulation and evaluation of a scale decomposition-based stochastic precipitation nowcast scheme. *Water Resources Research* **49(10)**:6624-6641.
- Foresti L, Seed AW (2015). On the spatial distribution of rainfall nowcasting errors due to orographic forcing. *Meteorological Applications*, **22(1)**:60-74.
- Foresti L, Seed AW (2014). The effect of flow and orography on the spatial distribution of the very short-term predictability of rainfall from composite radar images. *Hydrology and Earth System Sciences*, **18**:4671-4686.
- Foresti L, Reyniers M, Seed AW, and Delobbe L (2015). Development and verification of a stochastic precipitation nowcasting system for urban hydrology in Belgium. *Hydrology and Earth System Sciences Discussions*, **12**:6831-6879.

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