Radar-based statistics of point and areal rainfall

Edouard Goudenhoofdt, Laurent Delobbe
Royal Meteorological Institute, Brussels, Belgium, edouard.goudenhoofdt@meteo.be
(Dated: June 5, 2012)

I. INTRODUCTION

Weather radars provide quantitative precipitation estimates (QPE) over large areas at high spatial and temporal resolution. Those estimates are mainly used for precipitation monitoring and its very short term forecasting. However long-term analysis of those radar-based precipitation estimates is currently lacking in Belgium. The complete volume data from two C-band radars are archived at the Royal Meteorological Institute (RMI) since 2003. Therefore a careful processing of the radar data is possible to obtain the best estimation of rainfall rate (e.g. ground echoes removal, application of a vertical profile of reflectivity). In addition, radar-based rainfall depth can be combined with raingauge measurements using the most efficient methods. The resulting long-term precipitation dataset is used to study the characteristics and space-time variability of point and areal rainfall depth. For this purpose, the uncertainty of the precipitation estimates should be taken into account. The results can also be compared with similar studies based on raingauges.

In Europe, the use of radar data for long-term precipitation statistics remains relatively limited. In the Netherlands Overeem et al. (2009) derived a radar-based climatology of rainfall using ten years of 2D hourly radar data corrected by raingauge. Similar results can be found in e.g. Paulat et al. (2008) and Wuest et al. (2010) for Germany and Switzerland respectively.

In this early stage of the study, we will only use a raingauge-corrected PCAPPI. Preliminary statistical results are presented to demonstrate the possible applications. In particular, exceedance probability of averaged precipitation depth will be calculated for several catchments of different size.

II. DATA AND METHODOLOGY

Since 2001, RMI operates a C-Band (5GHz) Doppler radar located in Wideumont (South-East of Belgium). The radar performs a 5-elevation scan (0.3°, 0.9°, 1.8°, 3.3°, 6.0°) every 5 minutes. The volumetric data have a resolution of 1 deg. in azimuth and 250 meter in range (more information can be found in Delobbe and Holleman 2006). Most of the non-meteorological echoes are removed using the Doppler filter. A basic QPE is obtained using a PCAPPI and an interpolation on a 0.6 km Cartesian grid. The volume data are first corrected by a static clutter map. A more advanced algorithm computes a vertical profile of reflectivity to derive an estimation at the ground. The latter algorithm is still unstable and is not used in this study. Both algorithms use the Marshall-Palmer relation $Z = 200R^{0.6}$ to convert the reflectivity Z into rainfall rate R. 2 consecutive radar rainfall rate estimates are used to compute 5-min rainfall depth by linear interpolation. Severals 5-min rainfall amounts are then added to obtain rainfall depth for a given duration. In a final step, radar-based rainfall depths are combined with raingauge measurements.

RMI controls a climatological raingauge network with manual measurement at 8 am Local Time since 1950. Since April 2004, RMI also receives hourly data from a network of automatic (tipping bucket) raingauge owned by a regional hydrological service. Both networks are very dense with an average density of 1 gauge per $100\,km^2$. Since the 60's, RMI also maintains a small network of automatic raingauge at 10-min resolution. A very long dataset starting in 1903 is available for one single raingauge located at the RMI. All raingauge data archived have been quality controlled by several automatic and manual procedures.

The merging methods used in this study is the mean field bias correction. More advanced methods like the external drift kriging will be used in the future. Those methods are applied using 1h rainfall depth from the radar and the dense automatic network. The description and performance of the algorithms for 24h rainfall depth can be found in Goudenhoofdt and Delobbe (2009) with verification against the climatological network.

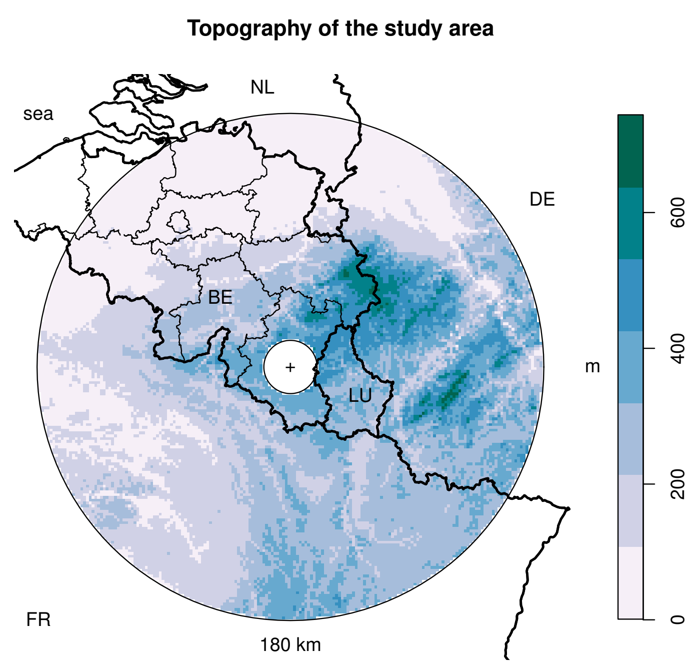

FIG. 1. Topography of the study area

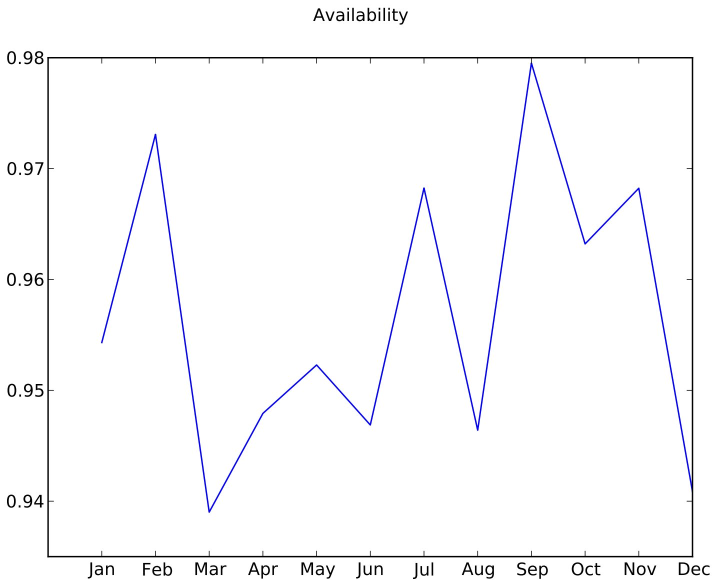

FIG. 2. Availability of corrected radar-based 1h rainfall depth

III. STATISTICAL ANALYSIS

The study area (Fig. 1) is limited to 180 km from the radar to limit the effect of the distance. Figure 2 shows the availability of the 2004-2012 dataset in function of the month. It ranges from 94 % to 98% with a relatively random variability. Therefore the different precipitation types which depends on the season will be captured equally. Due to limitation in computational cost, the preliminary analysis performed here is based on the year 2008 and using a maximum range of 154 km

A first analysis of the dataset showed that it was still contaminated by some permanent ground clutter. Using one year of radar data, pixels which exhibit a probability of non-zero 1h rainfall amount above 25 % are removed from the grid. 2413 pixels have been discarded using this rule. There was also a problem with pixels close to azimuth 0° (North) where the interpolation scheme induces a systematical overestimation.

Weather radars provide an estimation of rainfall amount averaged over a given area. The size of the estimation area increases with the distance due to beam broadening. For the interpolated product, each pixel correspond to an area of $0.36\,km^2$. If we assume that the precipitation statistics are the same for a given region, all the pixels inside this region can be used to compute exceedance probability. Therefore the radar-based rainfall dataset is extended and larger than a typical raingage dataset.

As a first step, the spatial variation of rainfall depth statistics is analyzed. Figure 3 shows the mean 1h rainfall amount including zeros. It highlights some artifacts related to the radar measurements such as (i) peaks of higher values due to remaining permanent clutter (ii) a decrease with range due to attenuation and overshooting, (iii) concentric bands of higher values due to the scanning geometry and the bright band effect and (iv) a straight line toward East due to interference. There are also artifacts related to the interpolation scheme : (i) increasing and decreasing values appear along the range due to weighted contribution of different elevation beam and (ii) rays corresponding to the 360 azimuthal angles. Besides those artifacts, the mean 1h rainfall ranges from 0.08 mm to 0.15 mm which correspond to annual rainfall of 700 mm and 1300 mm respectively. There is a clear influence of the topography. In particular, one notes the higher values North-East of the radar where the Ardennes mountains are located. Regions of lower values are found on the North-West and East of the radar which corresponds to the Meuse and Moselle valleys, respectively. Those results are in good agreement with those obtained from raingauge measurements (not shown).

The right image in Fig. 3 shows the maximum value of 1h rainfall amount recorded. A few values above 100 mm are unrealistic precipitation values caused by stationary non-meteorological echoes. The higher precipitation values are produced by stationary severe storms. It can be mostly associated with strong hail which produces a much higher reflectivity than rain. Lines with ripple effect are generated by fast moving intense convective cells. This jumping effect can be corrected by taking into account the advection of precipitation between successive radar images. More generally the rainfall maxima exhibits high variations which are due to the localised nature of extreme convective precipitation. There are no evidence for large scale spatial trends in the maximum 1h rainfall depth.

The probability to exceed 1 mm (Figure 4, left) ranges from 0.02 to 0.04. Beside radar artifacts, the general pattern is relatively similar to the mean which suggests that the occurrence of precipitation is an important factor of the spatial variations. The probability to exceed 5 mm exhibits more variations with maximum probability around 0.005 which corresponds to an averaged return period of 5 days. At first sight, no general trends can be found.

Figure 5 shows exceedance probability of average 1 h rainfall depth for several catchment with increasing size. All catchments are located within 20-80 km range limits of the radar. For example, the probability for the Meuse catchment to exceed an averaged of 2 mm per hour is 0.01 which corresponds to an averaged return period of 4 days. The probability to have an averaged 0.1 mm 1h rainfall depth is slightly higher for larger catchment. On the opposite, the probability for this quantity to exceed 2 mm decrease slightly with the catchment size. The probability to reach higher values (e.g. 5 mm) is significantly higher for smaller catchments. Extreme values close to 10 mm are reached by the smallest catchment (i.e Semois, $80km^2$).

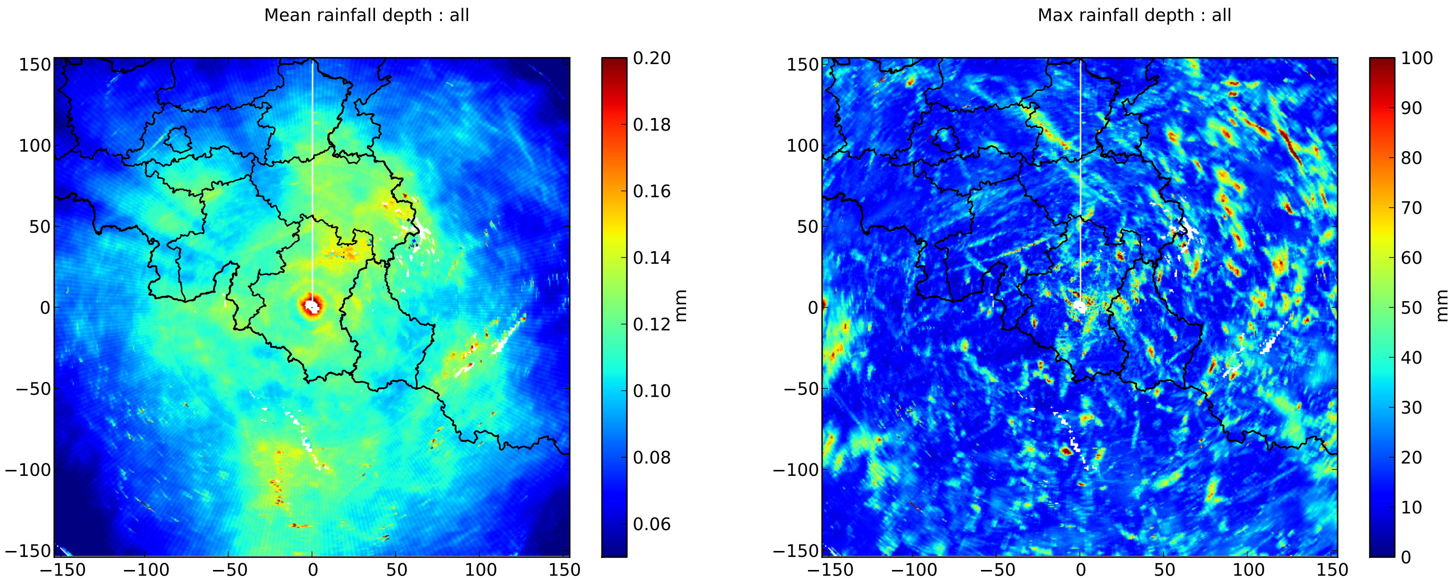

FIG. 3. Mean (left) and maximum (right) 1h rainfall depth

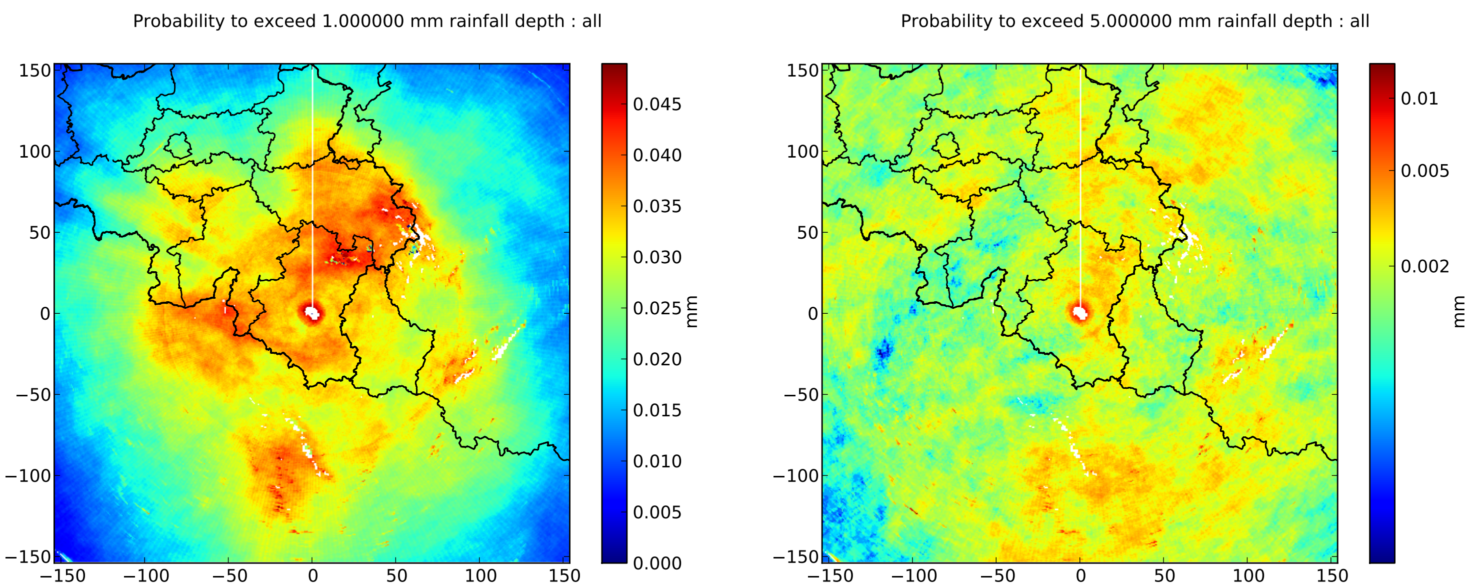

FIG. 4. Probability of 1h rainfall depth to exceed 1 mm(left) and 5 mm(right)

Figure 6 shows precipitation amount exceedance probability for increasing accumulation periods. The accumulations are computed for each hourly timestep but only for March and maximum 77 km range due to computational costs. As expected, the probability to exceed a given amount increases for increasing period duration. The tail of the distributions are perturbed by higher non-meteorological values.

IV. CONCLUSIONS

Preliminary results of gridded precipitation statistics are presented using one year of radar-based 1h rainfall depths. The rainfall depths are corrected by raingauge measurements using a mean field bias. There are some variations in the mean 1h rainfall depth with a significant effect of topography. The maximum reflectivity exhibit big variations with no large-scale trends. The probability to exceed 1 mm is correlated with the mean rainfall amount. The probability to exceed

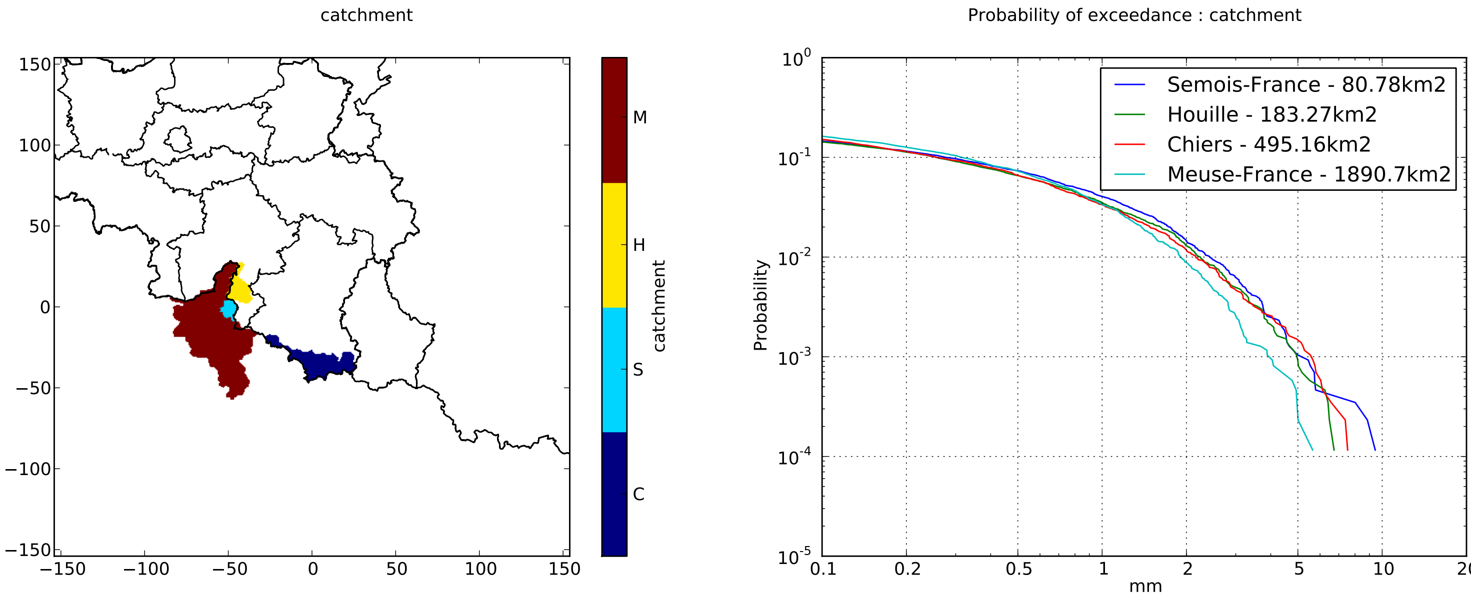

FIG. 5. Map of the catchments and exceedance probability of averaged 1 h rainfall depth.

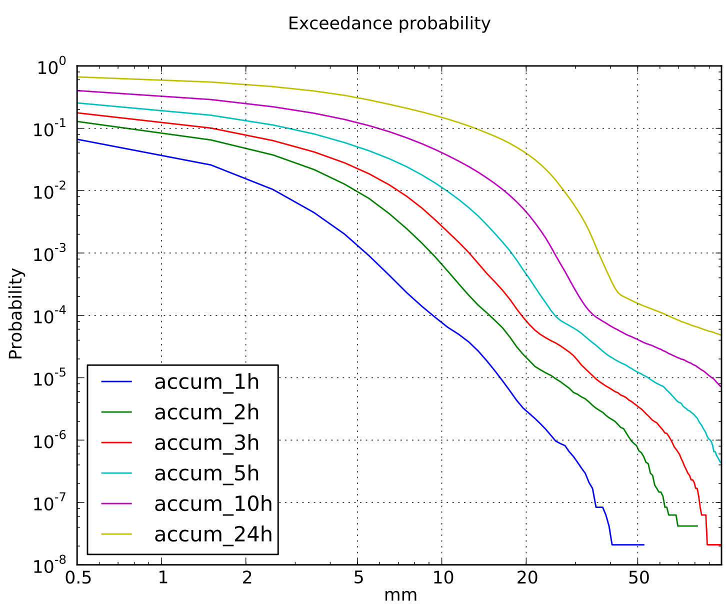

FIG. 6. Empirical exceedance probability of 1, 2, 3, 5, 10 and 24 h rainfall depths.

5 mm is close to 0.002 with no spatial trends The probability of averaged 1h rainfall depth exceedance decreases more quickly when catchment size increases.

While those results are still limited, there are many possibilities for improvements and further investigations. The radar-based QPE will be improved by different algorithms. The uncertainty associated with the estimation will be quantified. The results will be compared with those obtained using raingauge only. In a latter step, radar data will be used to study the small scale spatio-temporal variability of precipitation.

V. ACKNOWLEDGMENTS

This research is supported by the Belgian Federal Science Policy (Research project ACTION 1 MO/34/022).

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