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Brief communication
"Using the new Philippine radar network to reconstruct the *Habagat of August 2012* monsoon event around Metropolitan Manila"

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Abstract. From 6 to 9 August 2012, intense rainfall hit the northern Philippines, causing massive floods in Metropolitan Manila and nearby regions. Local rain gauges recorded almost 1000 mm within this period. However, the recently installed Philippine network of weather radars suggests that Metropolitan Manila might have escaped a potentially bigger flood just by a whisker, since the centre of mass of accumulated rainfall was located over Manila Bay. A shift of this centre by no more than 20 km could have resulted in a flood disaster far worse than what occurred during Typhoon *Ketsana* in September 2009.

1 Introduction

From 6 to 9 August 2012, a period of intense rainfall hit Luzon, the northern main island of the Philippines. In particular, it affected Metropolitan Manila, a region of about 640 km^2 and home to a population of about 12 million people. The torrential event resulted from a remarkably strong and sustained movement of the southwest monsoon, locally known as *Habagat*. The extraordinary development of the *Habagat* was caused by the cyclonic circulation of Typhoon *Saola* (local name *Gener*) from 1 to 3 August and was further enhanced by Typhoon *Haikui*, both passing north of the Philippines. This mechanism was already discussed by Cayanan et al. (2011). In the following, we will refer to this event as the *Habagat of August 2012*.

The event caused the heaviest damage in Metropolitan Manila since Typhoon *Ketsana* hit the area in September 2009 (Abon et al., 2011). The *Habagat of August 2012* particularly affected the Marikina River basin, the largest river system in Manila. Rain gauges in Metropolitan Manila recorded anywhere from 500 to 1100 mm of rain from 6 to 9 August. A total of 109 people have been confirmed dead. Over four million people were affected by the flood (NDRRMC, 2012).

Despite these numbers and despite the tragic and massive impacts of this flood event, the present study suggests that Metropolitan Manila might have escaped a bigger disaster just by a few kilometres. This analysis was made possible by using the recently established network of Doppler radars of the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) and other meteorological data provided through the country's Project NOAH (Nationwide Operational Assessment of Hazards). The *Habagat of August 2012* was the first major rainfall event after the implementation of this project.

In this paper, we will present a first reconstruction of the rainfall event. It is the very first time such an analysis is shown for the Philippines, and it illustrates the immense potential for flood risk mitigation in the Philippines.

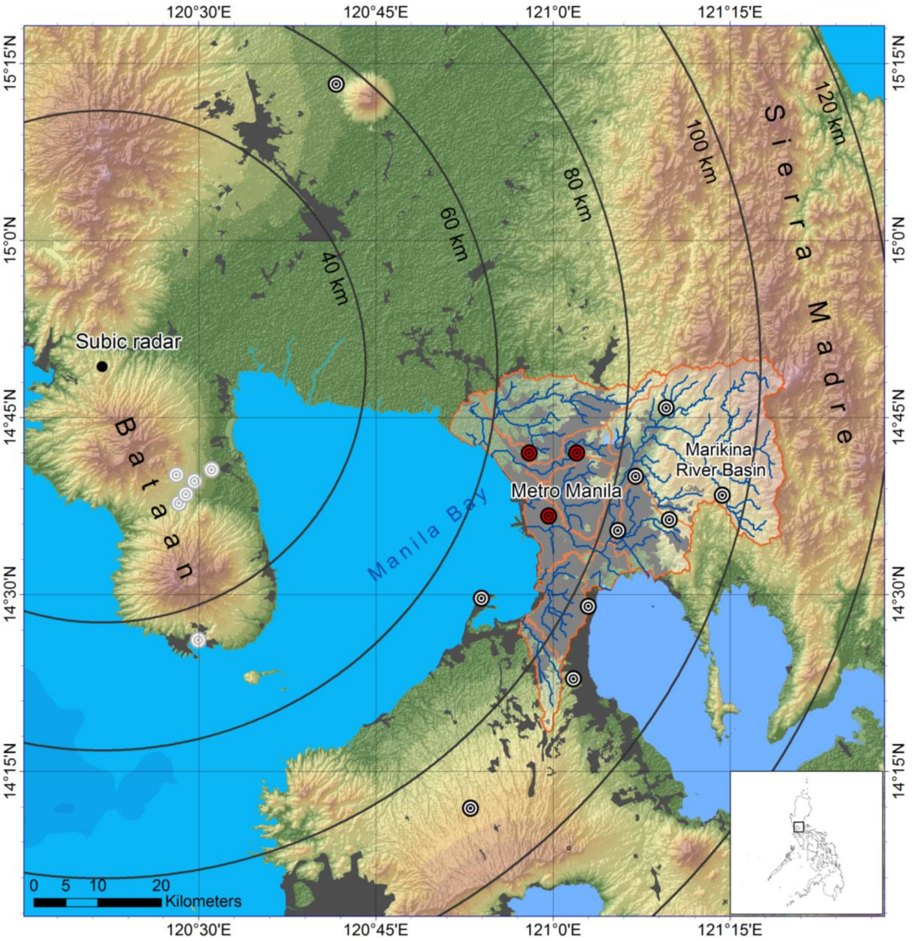

Fig. 1. Geographical overview of the area, including Subic radar, different radar range radii as orientation, and the NOAH rain gauges (small circles). The red circles are the gauges shown in Fig. 2. The gauges with grey circles have been ignored in this study, because the entire Bataan Peninsula is affected by massive beam shielding. Urban areas (including Metropolitan Manila) are shown in grey. Major rivers (blue lines) draining to Metropolitan Manila are shown together with their drainage basins (orange borders).

2 Radar data and data processing

Figure 1 shows a map of the area around Manila Bay. Radar coverage is provided by a Doppler S-band radar based near the city of Subic. The radar device is located at 500 m a.s.l. and has a nominal range of 120 km, a range resolution of 500 m, and an angular resolution of 1°. Radar sweeps are repeated at an interval of 9 min and at 14 elevation angles (0.5°, 1.5°, 2.4°, 3.4°, 4.3°, 5.3°, 6.2°, 7.5°, 8.7°, 10°, 12°, 14°, 16.7°, and 19.5°).

In addition, 25 rain gauges were used as ground reference. The rain gauge recordings were obtained from automatic rain gauges (ARGs) and automatic weather stations (AWSs) under Project NOAH; all instruments have a temporal resolution of 15 min.

For radar data processing, the *wradlib* software (Heistermann et al., 2012) was used. *wradlib* is an open source library for weather radar processing and allows for the most important steps of radar-based quantitative precipitation estimation (QPE). The reconstruction of rainfall depths from 6 to 9 August included all available radar sweep angles and was based on a four-step procedure (see library reference on http://wradlib.bitbucket.org for further details):

1. Clutter detection: clutter is generally referred to as non-meteorological echo, mainly ground echo. Clutter was identified by applying the algorithm of Gabella and Notarpietro (2002) to the rainfall accumulation map. Pixels flagged as clutter were filled by using nearest neighbour interpolation.

2. Conversion from reflectivity (in dBZ) to rainfall rate (in mm h^{-1}): for this purpose, we used the Z-R relation which is applied by the United States national weather service NOAA for tropical cyclones ($Z = 250 \cdot R^{1.2}$). According to Moser et al. (2010), the use of this tropical Z-R relation could be shown to reduce the underestimation of rainfall rates in tropical cyclones as compared to standard Z-R relationships.

3. Gridding: based on the data from all available elevation angles, a constant altitude plan position indicator (Pseudo-CAPPI) was created for an altitude of 2000 m a.s.l. by using three-dimensional inverse distance weighting. The CAPPI approach was used in order to increase the comparability of estimated rainfall at different distances from the radar – an important precondition for the following step of gauge adjustment.

4. Gauge adjustment: the radar-based rainfall estimate accumulated over the entire event was adjusted by rain gauge observations using the simple, but robust mean field bias (MFB) approach (Goudenhoofdt and Delobbe, 2009; Heistermann and Kneis, 2011). A correction factor was computed from the mean ratio between rain gauge observations and the radar observations in the direct vicinity of the gauge locations. Basically, this procedure is equivalent to an ex-post adjustment of the coefficient a in the Z-R relationship.

3 Event reconstruction

Figure 2 shows the rainfall dynamics in the area of Metropolitan Manila over a period of four days, based on rain gauge recordings. The main portion of rainfall accumulated rather continuously between noon of 6 August and the evening of 7 August. However, significant periods of intermittent, but intense rainfall followed until the early morning of 9 August. Keeping in mind that the distance between the gauges is only around 10 km (Fig. 1), and that the accumulation period lasted four days, the differences between the rainfall accumulations are quite remarkable. As will be seen later (in Fig. 4), this heterogeneity is consistent with the distribution of rainfall inferred from the radar.

According to Fig. 3, three marked convective cells poured rain around Manila Bay, the largest of them extending from the centre of Manila Bay eastwards over Metropolitan Manila. Over the entire period of three days, the position of these cells remained quite persistent. This persistence – together with the high average rainfall intensities – explains the extreme local rainfall accumulations. Figure 3 also illustrates the mean vertical structure of rainfall between the evening of August 6 and the early morning of 7 August. The convective structures exhibit a marked decrease in rainfall intensity above an altitude of 5 to 6 km, which is typical for shallow convection. This vertical structure is also representative of the duration of the entire event.

However, the unadjusted radar-based rainfall accumulation from 6 August (08:00 UTC) to 9 August (20:00 UTC) exhibits a significant underestimation if compared to the rain gauge recordings. While the radar estimates between 300 and 400 mm around Quezon City, rain gauges recorded up to 1000 mm. At the moment, the reasons for this level of underestimation remain unclear. Hardware calibration issues might as well play a role as effects of the vertical profile of reflectivity, which were not yet analysed in the course of this analysis. Beyond this general underestimation, the Subic radar shows massive beam shielding in the southern sectors, which is caused by Mount Natib, a volcano and caldera complex located in the province of Bataan. Other sectors of the Subic radar are affected by partial beam shielding due to a set of mountain peaks in the northern vicinity of the radar.

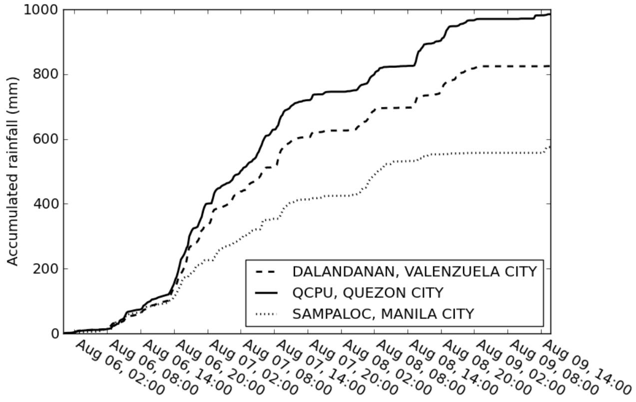

Fig. 2. Cumulative rainfall from 6 to 9 August for three rain gauges in Metropolitan Manila. Refer to Fig. 1 for the position of the rain gauges. The distances between the three gauges are about 10 km.

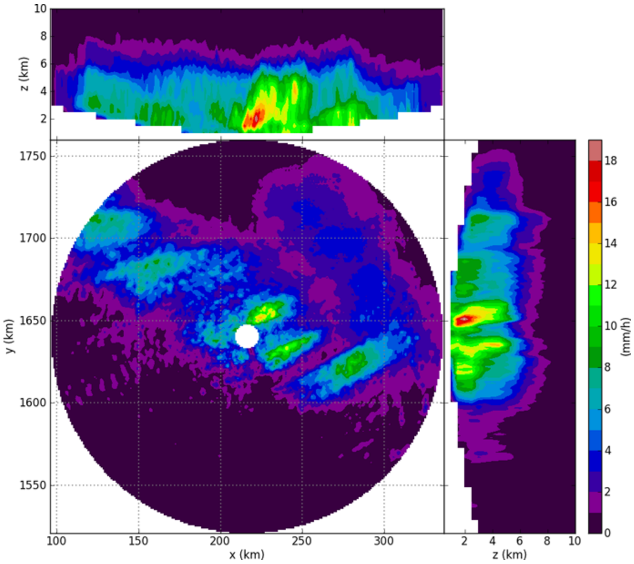

Fig. 3. Mean rainfall intensity in the night from 6 August (20:00 UTC) until 7 August (08:00 UTC) as seen by the Subic S-band radar. The central figure shows a CAPPI at 3000 m altitude (for the rainfall estimation, we used the Pseudo-CAPPI at 2000 m; see Sect. 2). The marginal plots show the vertical distribution of intensity maxima along the x- and y-axis, respectively. In the area around Manila Bay, three marked cells appear. For these cells, the rainfall intensity exhibits a marked decrease above an altitude of 5 to 6 km, indicating rather shallow convection.

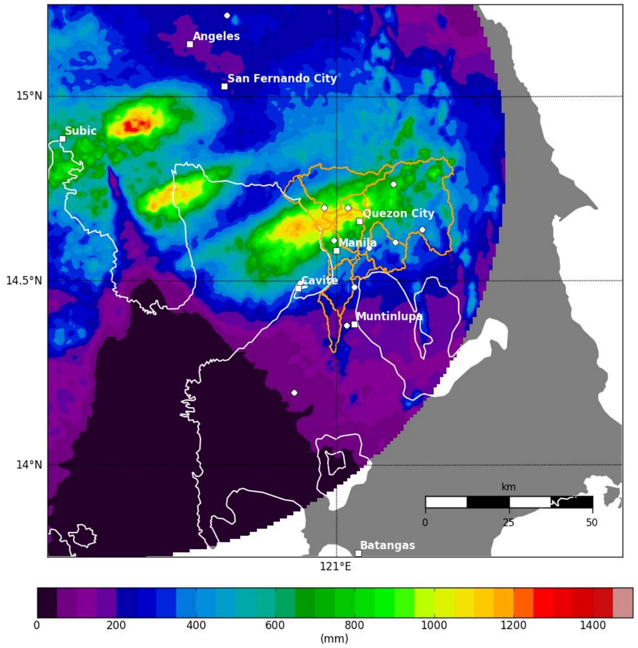

Fig. 4. Gauge-adjusted radar-based rainfall estimation; accumulation period from 6 August (00:80 UTC) to 9 August (20:00 UTC). Basins draining to Metropolitan Manila are shown in orange, coastlines in white. Major cities are shown as white squares, while rain gages are represented as white circles. Note that the corresponding rainfall field obtained from the interpolation of rain gauge observations is available as Supplement.

In order to correct for the substantial underestimation, rain gauge recordings were used to adjust the rainfall estimated by the radar at an altitude of 2000 m (using the mean field bias adjustment approach). This procedure reduced the cross-validation RMSE of the event-scale rainfall accumulation by more than half. The resulting rainfall distribution is shown in Fig. 4. This figure gives an impressive view on the amount of rain that actually came down around Metropolitan Manila. Obviously, the actual "epicentre" of the event was situated rather over the Manila Bay than over Metropolitan Manila itself.

Due to its size and shape, the Marikina River basin (see Fig. 1) – as it did in September 2009 – most strongly contributed to the flooding of Metropolitan Manila during the *Habagat of August 2012*. According to the gauge-adjusted radar rainfall estimates, the areal mean rainfall depth for the Marikina River basin amounted to 570 mm. In contrast, the areal rainfall average would add up to 440 mm (more than 20 % less) if we only interpolated the rain gauge observations (by inverse distance weighting).

If we now assumed a scenario in which the rainfall field had been shifted eastward by no more than 20 km, the areal rainfall average in the Marikina River basin would have increased by almost 30 %. Since the catchment had already been saturated before the onset of the main event, almost all of the additional rain would have been directly transformed to runoff. A very rough, but illustrative calculation demonstrates the potential implications: according to the extreme value statistic for the Marikina River, a 500 $m^3 s^{-1}$ increase in peak discharge at stream flow gauge Sto. Niño approximately corresponds to a 2.5-fold increase in the return period (DPWH-JICA, 2003). For the *Habagat of August 2012* event, the peak discharge at gauge Sto. Niño was estimated to be around 3000 $m^3 s^{-1}$, corresponding to a return period of about 50 yr. Assuming that every additional raindrop had been effective rainfall and assuming linear runoff concentration, the "20 km-shift" scenario would have resulted in a peak discharge of about 3900 $m^3 s^{-1}$ – or a return period of more than 200 yr. The return period of the flood event related to Typhoon *Ketsana* in September 2009 was estimated to be 150 yr (Tabios III, 2009).

4 Conclusions

The local rain gauge recordings in Quezon City already indicate the magnitude of the *Habagat of August 2012* event. However, the rain gauge data alone could not provide a complete picture of what happened around Metropolitan Manila from 6 to 9 August.

Only the combination of the Subic S-band radar and the dense rain gauge network around Metropolitan Manila reveals that a significant portion of the heavy rainfall was dropped right over the shorelines of Manila Bay. Assuming a scenario in which the rainfall field was shifted eastwards by no more than 20 km, the peak discharge of the Marikina River would have increased by almost 30 %, potentially resulting into a return period well beyond the 150 yr of Typhoon *Ketsana* in September 2009. It appears that – despite the terrible harm and damage that was caused by this flood event – the *Habagat of August 2012* was no more than a glimpse of the disaster that Metropolitan Manila missed by no more than 20 km.

Nonetheless, a lot of open questions remain to be answered, particularly concerning the underestimation of rainfall by the radar, the potential effects of inhomogeneous vertical reflectivity profiles, the potential role of wind drift (from Manila Bay to Metropolitan Manila), and also the hydrological processes which resulted from the rainfall event. Beyond, additional data for the region are available from a C-band weather radar located near Tagaytay City. However, these data were not considered in this study since the role of attenuation induced by heavy rainfall has yet to be determined.

All these questions need to be addressed as soon as possible so that the equipment installed can allow for the most accurate analysis of extreme rain events that certainly will occur in the future. However, even with the current level of data processing, the recently installed Philippine radar network demonstrates a huge potential for high-resolution rainfall monitoring as well as for risk mitigation and management in the Philippines.

Supplementary material related to this article is available online at: http://www.nat-hazards-earth-syst-sci.net/13/653/2013/nhess-13-653-2013-supplement.pdf.

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