Precipitation Measurement using High Resolution X-Band Radar

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1 Introduction

X-Band radar is not commonly used for operational precipitation measurements due to its strong attenuation as compared to S-Band or C-Band radar. The huge advantage of X-band though, is the high spatial resolution of the system over distances where attenuation is not yet a huge factor as well as its potential as a ground based validation of space-borne measurements in conjunction with other remote sensing instruments. Also it is fairly cheap compared to other radars. As a result, over the last years this type of radar has received more interest in applications like hydrology and meteorology.

With the upcoming installation of an improved version of the X-band radar SOLIDAR at the Cabauw Experimental Site for Atmospheric Research (CESAR) in the Netherlands, data gathered during earlier testing of the system is being analyzed. During its earlier operation it was located on the roof of the Faculty of Electrical Engineering at Delft University of Technology. In the area covered by the radar 4 rain gauges had been placed for comparison.

For this research a dataset containing 6 years of data gathered in the period from 1991 to 1997 is analyzed for its applicability in hydrology. Two detailed case studies on December 19, 1991 and August 12, 1993 are presented using SOLIDAR and the S-Band radar DARR, and the 4 rain gauges. Having high resolution rainfall maps will have great utility for water boards and hydrological applications.

First the sensitivity of the radar system to attenuation and ground clutter is being investigated. Subsequently, the rainfall measurement capability of the radar at different space-time resolutions relevant for hydrological modeling is investigated. Future work will incorporate the use of DARR as well as the operational C-band weather radar operated by KNMI and rain gauges maintained both by KNMI and water boards. The installation of SOLIDAR at CESAR will offer many new research possibilities for this X-Band system, for example the ground validation of the upcoming GPM (Global Precipitation Mission) at this location.

2 Equipment and dataset

SOLIDAR is an X-Band FM-CW (Frequency Modulated Continuous-Wave) Solid-State Weather Surveillance Radar and was located on the roof of the Faculty of Electrical Engineering of Delft University. The radar operated at an elevation of 1.7º and made a full rotation every 16 seconds (see Table 1 as well as Ligthart and Nieuwkerk, 1990).

DARR (Delft Atmospheric Research Radar) is an S-Band FM-CW radar. This radar was located near SOLIDAR and scans along a fixed line in westerly direction at 266 º and makes a scan full scan every 3.2 seconds. Also see Table 2 (Uijlenhoet et al 1997, Russchenberg et al 1997). Due to the location of DARR next to SOLIDAR a gap in the covered area is located in the southeastern part of X-band radar the map (figure 1).

The four available rain gauges had been installed in a nearly straight line in the same westerly direction as DARR. These had been placed at 5450 m, 7450 m, 7950 m, and 9550 m from the radars. The rain gauges are tipping-bucket gauges with an area of 500 cm^2 and tipping resolution of 0.2 mm.

The main dataset consists of 6 years of SOLIDAR data gathered in the period January 1991 to June 1997. During this period there is not a full coverage as the radar was not always operational. These data offer a huge collection of both clear weather as well as numerous rainfall events for analysis.

Two detailed rainfall events gathered with SOLIDAR are analyzed here in conjunction with the 4 aforementioned raingauges. The first occurred on December 19, 1991, and was a frontal stratiform passage with measured rain intensities of 1 to 10 mm h^{-1} and a total rain amount of 3.8 mm. During the second event on August 12, 1993, the wind was south-westerly and passed over the 4 rain gauges. A peak rain intensity of 20 mm h^{-1} was measured just past 1

PM UTC when a very small but active raincell passed near the gauges. For this second event data from DARR are also available, unlike for the first rainfall event. Due to gaps in the SOLIDAR data the only fairly long continuous data available are from 12 AM to 2:20 PM.

Table 1. Specifications of SOLIDAR

Centre frequency	9.47 GHz
Range resolution	30 m
Antenna revolution time	15.36 s
Elevation	1.7 º
Range Resol. post processing	120 m
Azimuth resol. post processing	1.875 º
Maximum range	15.36 km

Table 2. Specifications of DARR

Centre frequency	3.315 GHz
Temporal resolution	3.2 s
Elevation	4 º
Range resol. post processing	75 m
Antenna beam width	1.9 º
Maximum range	19.2 km

2. Results and discussion

The goal of the research is to demonstrate the benefit of a high resolution radar system like SOLIDAR over small catchments, as it can provide both qualitative and quantitative information of rainfall, which the use of rain gauges only does not offer.

First the fairly high intensity rain cell that passed nearly over the rain gauges on the second rainfall event is discussed here. At 1 PM the cell appeared on the western edge of the map and quickly moved in an easterly direction just south of the furthest rain gauges and passed directly over the nearest gauge to the radar (see Fig. 1 and 2). The rain rate in these figures is estimated from the SOLIDAR reflectivity using the standard Marshall-Palmer Z-R relation. It is interesting to note that while the peak does show up in both the rain gauge and SOLIDAR observations, the peak just past 1 PM is at all locations much higher for the rain gauges than for the radar. In itself this does not have to be too surprising as even at its highest resolution SOLIDAR will always represent an area average while the gauge represents a (near) point measurement. What is striking though is that the peak is not only much higher but also much broader for the gauges as can also be seen in Fig. 2. This results in the sudden strong increase in the cumulative rainfall for the gauge while there is hardly any large increase noticeable for the radar. An answer for this is not obvious, but might be partially explained due to the fact that the radar signal was attenuated. This clearly shows the need for a post-processed rainfall map with accurate correction algorithms.

The second step therefore is to correct the original SOLIDAR data for ground clutter and attenuation (Holleman 2005; Delrieu et al. 1997; Berne and Uijlenhoet, 2006). A groundclutter map is created using autocorrelation for each pixel. Subsequently available radar images are used to track direction and speed of the rain at each separate pixel. These movement vectors are averaged over small areas to minimize local errors in the tracking algorithm. The pixels where clutter is identified using the cluttermap are corrected using dBZ values from previous radar maps according to the movement of the rainfall field. If the previous map also points to a place where clutter was identified another step back in time is taken until a pixel is found that is not present on the cluttermap. This can go back to a maximum of 10 maps or about 150 seconds. In the unlikely event no pixel to replace the old one is found, a simple nearest neighbour interpolation technique is used. This is also done for the outer edges of the radar where data is at or near the maximum range of detection and is less reliable.

Finally, using the cleaned reflectivity maps, new rainfall maps will created at different spatial and temporal resolutions. For this purpose spatial resolutions of 120 m, 600 m and 1200 m will be taken. Temporal resolutions of 16 seconds 1 minute, 2 minutes and 5 minutes have been selected. The loss in information will clearly be seen when comparing to rain gauges, which also stresses the difficulty of actually comparing point measurements by rain gauges with instantaneous measurements with the radar over small areas.

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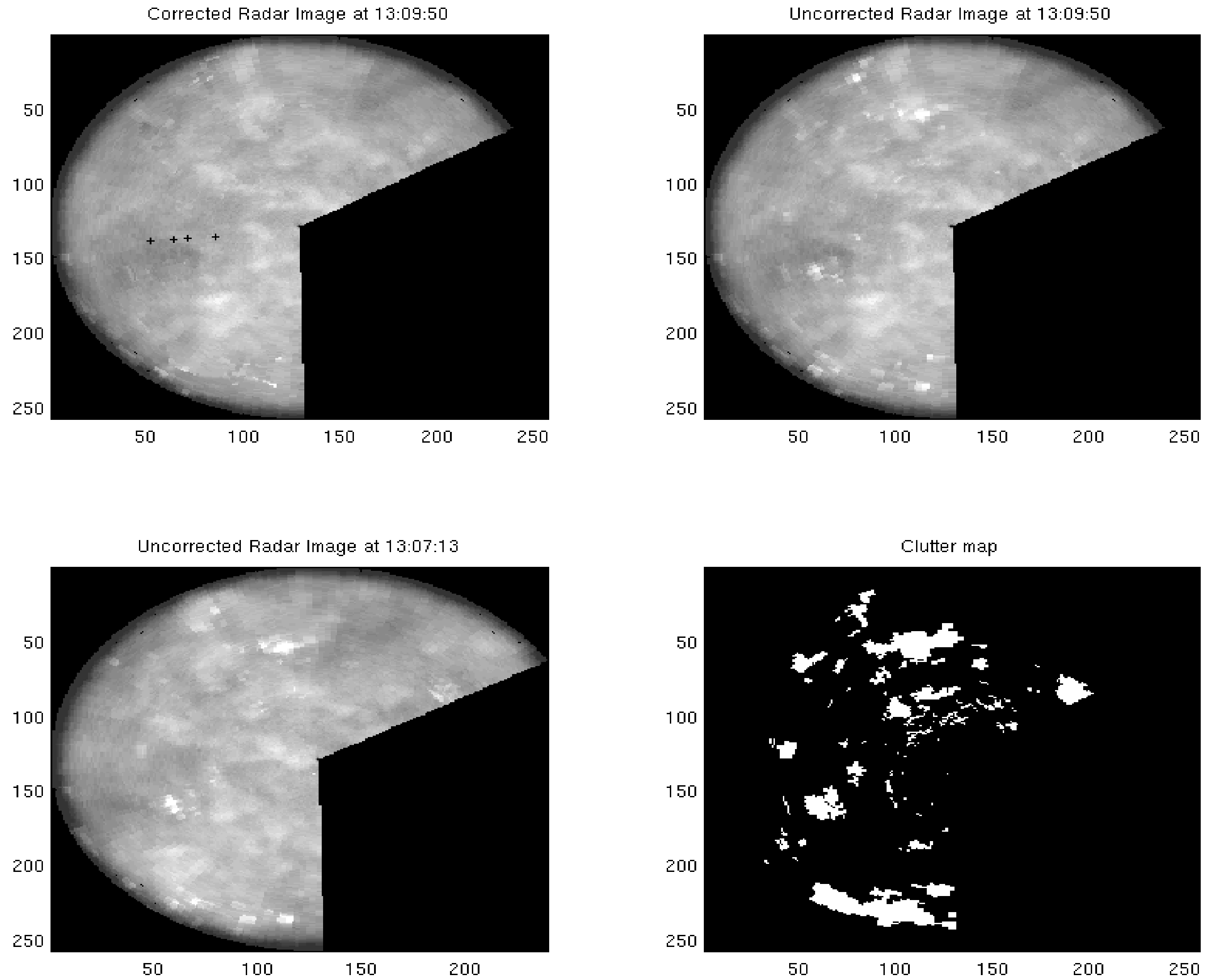

Fig. 1. *Illustation of clutterremoval. a) is the cleaned map, b) the map before processing and c) is the unprocessed map 10 timesteps earlier. Finally d) is the cluttermap created for this event. The four '+' indicate where the raingauges were located.*

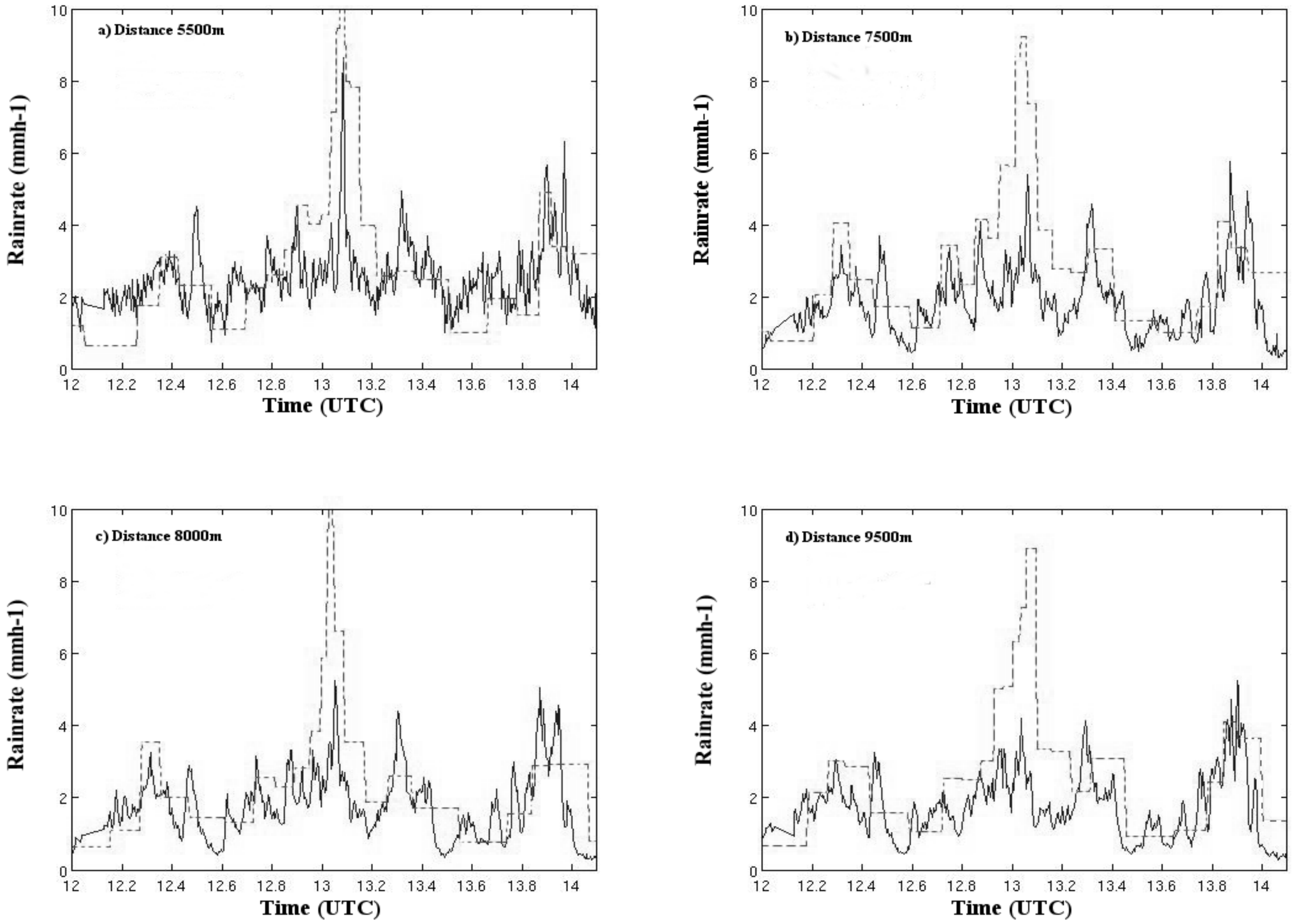

Fig. 2. *Rainrate (mm h-1) per tipping interval for raingauges (dashed) and instantaneous rainrate for SOLIDAR (solid) on August 12, 1993.*

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