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Vertical pointing weather radar for built-up urban areas

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ABSTRACT

A cost effective vertical pointing X-band weather radar (VPR) has been tested for measurement of precipitation in urban areas. Stationary tests indicate that the VPR performs well compared to horizontal weather radars, such as the local area weather radars (LAWR). The test illustrated that the VPR could discriminate between precipitation at ground level and reflectivity higher in the atmosphere due to ice and snow. This registered reflectivity did not result in precipitation at ground level. The measurements during mobile test though urban areas seems to underestimated the precipitation compared to the LAWR - properly due to simplifications in the attenuation model. A combination of the two instruments opens up for an improvement of both.

KEYWORDS
Urban Drainage modelling; LAWR; calibration, Weather Radar; precipitation, Vertical Pointing Radar.

INTRODUCTION

Weather radar has a significant potential for improving the function of sewer systems and wastewater treatment plants by supplying distributed precipitation information for whole catchments (Einfalt et al, 2004). Information on both intensity and spatial distribution offers possibility for better real time control of the sewer system and wastewater treatment plant.
Traditionally, research within urban drainage has relied on tipping bucket rain gauges for precipitation data. The clear advantage of rain gauges is the simplicity of the measuring technique. The accuracy of tipping bucket rain gauges are not without problems at especially small time scales (Habib et al., 2001). Also the conversion from point measurement to area measurement presents unique challenges (Ciach and Krajewski, 1999). However, the primary disadvantage is the limited number of rain gauges. Often, there are only a few rain gauges in the catchments and sometimes there are none.

The measurement of precipitation in an urban setting can be challenging. Micro climate conditions caused by the buildings affecting local wind conditions or heat islands in the city can create significant problems in measuring precipitation correctly. Oke (2006) recommends that precipitation measurements are done in open areas, such as parks, playing fields and sports areas.

In the case of Aalborg, the fourth largest city in Denmark, the urbanised area is approximately 72 km^2 around the city centre. As a part of the monitoring program, the municipality has installed 8 automatic rain gauges of the Rimco type is placed around the city and one north of the city. However, as indicated by figure 1, the gauges are all placed at the perimeter of the city core. The LAWR weather radar is placed approximately 10 km from the city centre. The rain gauges are placed based on practical aspects, such as available space, appropriate shelter conditions, data and power access. For these reasons, it has been difficult to locate any rain gauge in the most built-up part of the city.

An alternative to rain gauges is weather radar. The weather radar offers the possibility to measure over a large area with one radar. Pedersen et. al, (2005) illustrated that spatial variation in the precipitation could have significant effects on the subsequent runoff, even for small catchments. For urban drainage application it is important that the radar is able to measure with a high spatial resolution. For traditional meteorological C-band radars, the resolution is often in the 2 x 2 km range. This is considered to be too coarse for hydrological studies in urban areas, because of the complex hydrology of the urban drainage systems. Precipitation within a 100 meter scale can easily end up in different hydrological catchments.

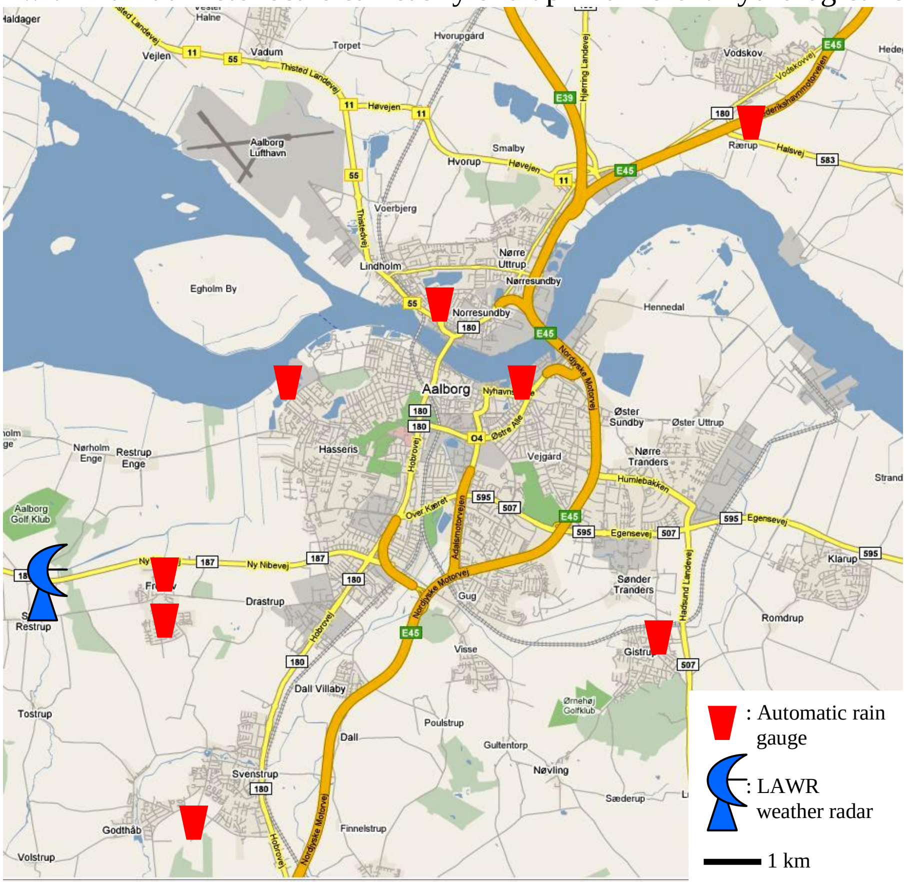

Figure 1. Placement of the 8 automatic rain gauges around the city of Aalborg.
Map source: Google Maps ©

Development of high resolution X-band radars (Jensen and Overgaard, 2002) opens the possibility to measure with a 100 x 100 meter resolution over urban areas. The Local Area Weather Radar (LAWR) is designed on basis of marine ship radar. The antenna design of the radar integrates the reflectivity from -10 to 10 degrees vertically. The advantage is a higher signal to noise ratio and the disadvantage is a significant amount of ground clutter (Rollenbeck and Bendix, 2006). Especially in cities and built-up urban areas, the ground clutter and beam blockage can be significant. This can reduce the signal quality from these areas. One way to compensate for this is to measure the precipitation with rain gauges and calibrate the radar locally. In this way, weak signals from these areas can be amplified to match ground observations. However, traditional tipping bucket rain gauges can be more unreliable in built-up urban areas due to the shadowing effect of high buildings and trees.

A method often used in relation to LAWR is to accumulate measurements over a longer period (i.e. months) and assume the precipitation is evenly distributed. This approach assumes linearity in the blockages effects and the different meteorological characteristics of the precipitation, which is not yet well understood.

This study proposes to use a mobile vertical pointing X-band radar (VPR) to measure the local precipitation. By mounting the radar on a vehicle, measurements can be made in many places during the same storm event, thus improving the calibration. Also, the radar can be transported to areas where it actually rains and not depend on chance, whether the thunderstorm moves above a fixed rain gauge. This is only done in measuring campaigns where clutter and beam blockage needs to be established. In between measuring campaigns, the radar is adjusted with more traditional rain gauges. Figure 2 illustrates the prototype installation of the VPR.

METHODS

The system combines marine radar, GPS, 3G high speed Internet and a data acquisition system to measure the microwave reflectivity vertical above the car. The measuring point is located 500 m. above surface level and thereby eliminates local effects of buildings. The VPR is based on the very affordable Furuno 1715 marine X-band radar. The radar uses a microstrip patched array antenna, with a horizontal beam width of 5.2^{o} and a vertical beam height of 25^{o}.

Figure 2. Left: The modified Furono 1715 Microstrip Antenna mounted on top of a car. Right: data acquisition, communication and positioning system

The antenna is rotated so it is always pointing vertical above the vehicle. This is achieved by disengaging the rotational step motor and fixing the antenna with springs. The antenna is mounted on top of the car with fixed mountings, figure 2.

The signal is acquired after the IF amplifier in the antenna as a raw video signal before any processing has taken place in the display unit. The video signal is measured with a 200 MHz Pc-oscilloscope (Picoscope 3206, Pico technology) and transferred directly to a laptop for final processing and presentation. The Picoscope is controlled by in-house developed software for optimal acquisition rate and data quality. Pulse width and PRF are controlled from the display unit. For all the experiments, the pulse width is set to 0.8 μs and the PRR to 600 HZ. The maximum detection range is set to 10,000 meters.

The position and orientation of the car is measured with an ordinary USB GPS, connected to the laptop. The data are encoded, so that position and signal can always be compared. The GPS data are transferred to Google Map and compared to satellite maps for quality control and verification of blocking objects (bridges, tunnels, overhanging signs and lighting).
Traditionally, radar signals expressed as dBZ is preferred in the literature in order to compare results across direct radar platforms. Unfortunately, the drawback of using marine X-band radar as a platform for the VPR is that not all hardware specifications are disclosed by the manufacturer. A direct conversion from voltage of the video signal to dBZ is therefore not possible.

A simple exponential attenuation model is used for adjusting for attenuation through rain. Time series of the video are extracted in a temporal position equal to 500 m above ground level. The samples are acquired with an interval of 5 seconds. Each sample is an average of 500 individual pulse measurements. The precipitation is for simplicity assumed to be constant in the first 500 meter above ground level. This is used to compensate for attenuation. The marine antenna would under normal conditions yield the radar unpractical for vertical profiling of the atmosphere due to the large asymmetrical main lope. However, as the measurements are taken in a fixed altitude of only 500 meter, the sampling volume is sufficiently small. Also, due to the principle of measuring in the same distance from the radar, all radar constants and volume corrections can be assumed to be constant.

Previous investigations (Rasmussen, et al., 2008) have demonstrated that the VPR performs well compared to traditional C-band weather radar.

RESULTS AND DISCUSSION

The VPR is first tested in a stationary mode, where the vehicle is standing still in one position during a rain event. This is compared to the stationary horizontal weather radar (LAWR), figure 3, with a spatial resolution of 500 x 500 meter. The measurements are calibrated against a rain gauge. However, only rain depth was recorded during the experiment due to a software error.

The VPR is able to measure with a 5 second resolution, while the LAWR presently is set up to measure with a 5 minute resolution. In order to compare the two results directly, the VPR data are also calculated as a 5 minute average so that the two measurements can be compared directly, figure 2. The VPR is due to the high temporal resolution able to capture more of the variation. However, comparing the VPR and LAWR illustrates that there is a fair agreement between the two measurements and that it is feasible to develop the VPR further as a calibration instrument for the LAWR.

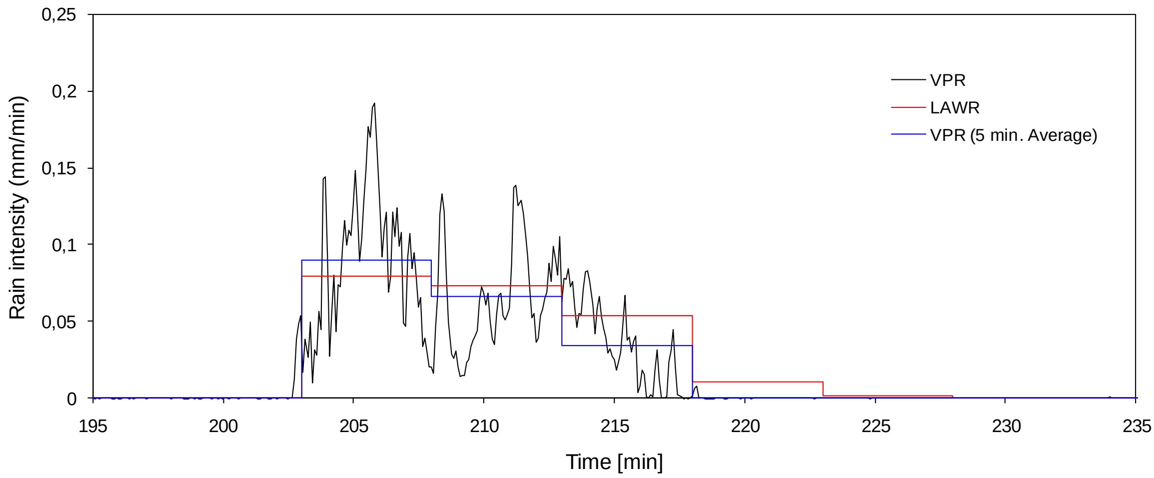

Figure 3. Comparison between vertical and horizontal rain measurement (22/2 2008).

There are however slight differences between the two systems. In the start of the event the LAWR indicates lower precipitation rates than the VPR. At the end of the event, the LAWR indicates higher precipitations rates. This indicates that the simple attenuation model used is not refined enough. The attenuation model is only based on the reflectivity at 500 m and not on the integrated reflectivity from 0 to 500 m. Another reason for difference between the two results can be found in different integration volumes of the antenna. The LAWR has a vertical opening angle of +/- 10^{o}.The distance between the VPR and the LAWR is approximately 11 km. At this distance, the LAWR vertical beam height will be 2000 m. Comparing the raw data in a Height-Time-Intensity (HTI) plot, figure 4 with figure 3 illustrates that the LAWR measures a higher precipitation rate at the end of the event, than the VPR. However, the VPR measurements also reveal that the reason for this difference is that the LAWR integrates over an area of reflectivity, which does not reach the ground. This could be melting ice crystals or snow.

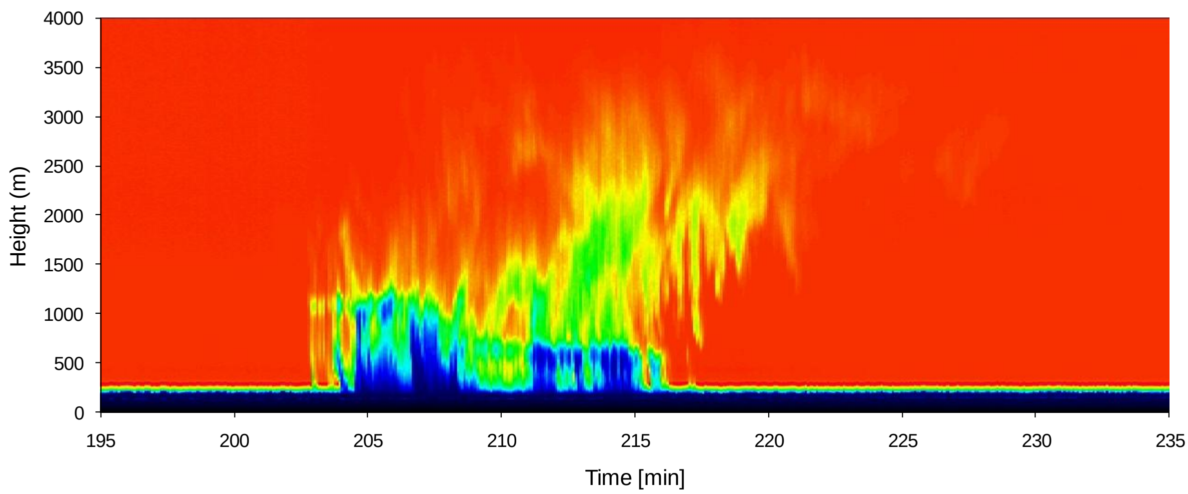

Figure 4. Raw data from the VPR of the vertical distribution of reflectivity during the rain event (22/2 2008). Blue is high intensities, red are low.

This illustrates, that in certain situations, the precipitation measurement with short range LAWR can be complicated to interpret without a vertical profile of the atmosphere. This is not a problem only related to LAWR's with a large vertical beam height. This is also a problem for larger meteorological C-band radars. Although, these types of radars typically have a beam width and height of 1^o, they also operate at larger distances than the LAWR. An operating distance of 100 km. and a vertical beam height of 2000 meter are not unusual. These results indicate that a combination of strategically placed VPR's and a LAWR in combination could improve results from both.

After a stationary test, the vehicle was driven around a section of Aalborg city, with typical 4-5 level apartment buildings, figure 5. The path is logged by GPS.

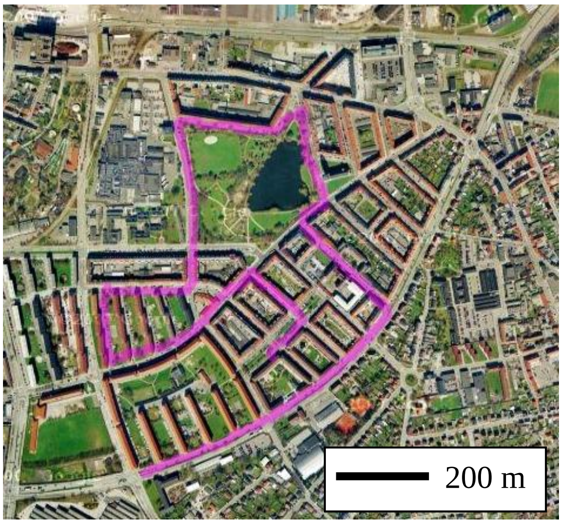

Figure 5. Left: Path followed on the 22/2 2008, Right: Typical view along street.

The time series recorded by the VPR is illustrated in figure 6.

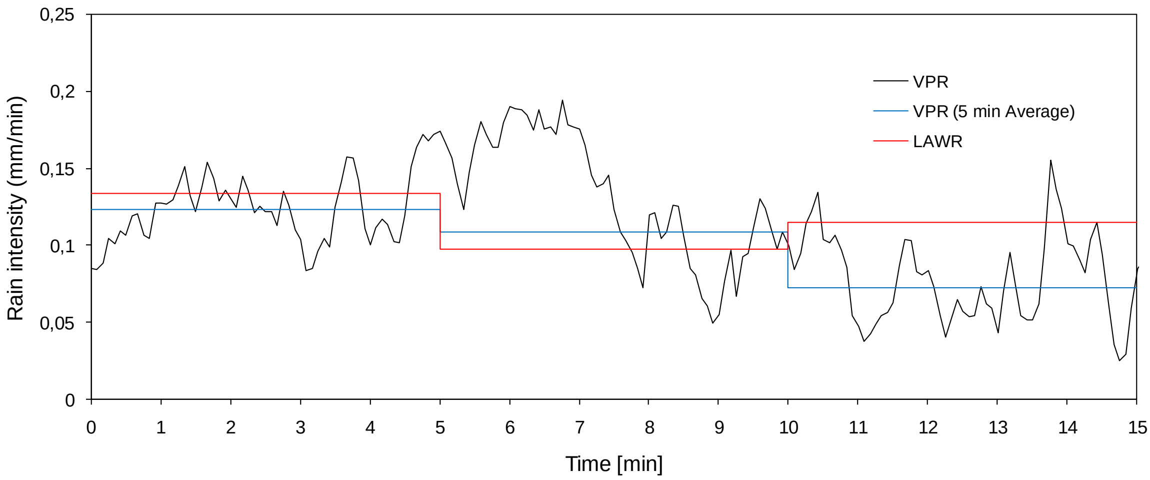

Figure 6. Measured rain intensity during mobile experiment (22/2 2008).

As can be seen in figure 6, the VPR tends to overestimate the precipitation rate at higher reflectivity levels. This indicates, as described before, that the attenuation model is too simple.

As can be seen in figure 6, the HTI plot is similar to the stationary measurement, figure 4 so far that the precipitation appears to be below 1000 m. It can observed, that the signal is reduced after 8 minutes for approximately 10 seconds. This corresponds to a passage of an overhanging tree along the small lake, figure 5. Further studies are needed in order to evaluate whether this simple VPR can be used on a routinely basis.

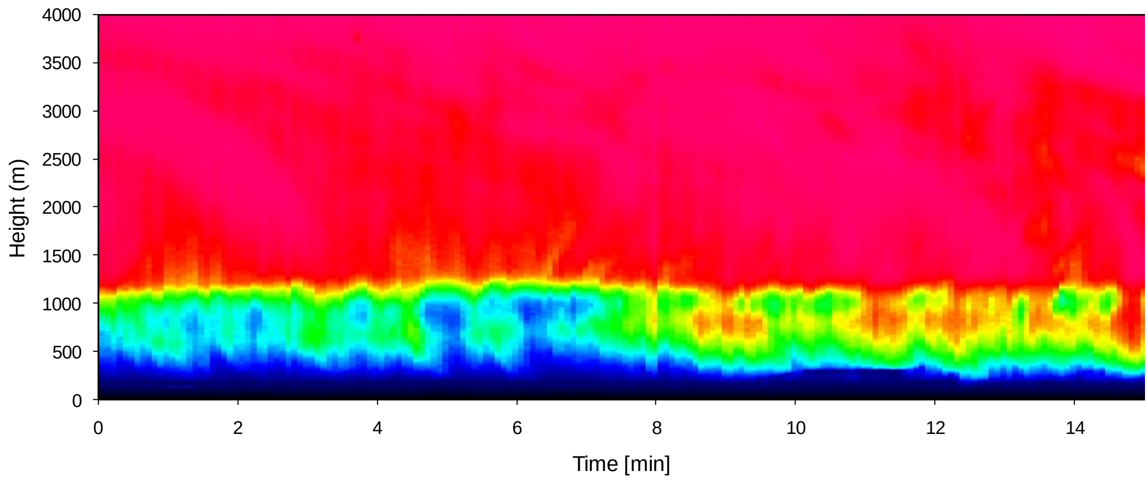

Figure 6. Raw data from the VPR of the vertical distribution of reflectivity during the mobile experiment (22/2 2008). Blue is high intensities, red are low.

The large beam width of 25^{o} could be considered as a huge handicap. However, an opposite argument could be formulated: The larger sampling volume is in the same geographic scale as the resolution as the horizontal radar. Therefore it is potential possible to avoid some of the problems related to point – area comparisons, which plague weather radar measurements.

A significant advantage of the present VPR is that it uses the same measuring principle and hardware as the LAWR. They both use an identical X-band setup, so that measurements in principle can be compared directly. Errors due to variations in the rain drop size distribution will also be reduced, because the two radars measure the same effects. The primary reason for choosing 500 m as a measuring point is that the first 300 meter is blocked because the pulse is not completed, when the microphone opens. This overshadows any measurements from the lowest 500 m. In future studies, a short pulse experiment will be conducted in order to examine if the measuring point can be lowered from 500 m to 50 m. This reduces the need for attenuation correction significantly, but will also result in a significantly shorter range of the radar.

CONCLUSION

The vertical pointing weather radar seems to have some merits towards measuring precipitation in built-up urban areas. The ability to measure precipitation above structures opens the possibility to avoid local wind and shadow effects form structures. The results also indicate that the attenuation model used should be improved. The VPR used in this study is based on a very affordable marine radar. Although tuning is needed, it seems plausible that the platform can be developed further for more accurate profiling of the lower atmosphere. The results clearly illustrated, that the VPR could detect reflectivity patterns, which were wrongfully interpreted by the LAWR as precipitation. It seems likely that a combination of LAWR and VPR could improve both.

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