Preliminary Study on the Feasibility of Performing Quantitative Precipitation Estimation Using X-band Radar

Jordi Figueras i Ventura[1], Remco van de Beek[2], Herman W.J. Russchenberg[1], Remko Uijlenhoet[2]

[1]*IRCTR-TU Delft, P.O. Box 5031, 2600GA Delft, The Netherlands, Hj.figuerasventura@tudelft.nHl*
[2]*Wageningen University, P.O. Box 47, 6700AA Wageningen, The Netherlands, HRemko.uijlenhoet@wur.nl*

ABSTRACT

IRCTR has built an experimental X-band Doppler polarimetric weather radar system aimed at obtaining high temporal and spatial resolution measurements of precipitation, with particular interest in light rain and drizzle. In this paper a first analysis of the feasibility of obtaining accurate quantitative precipitation estimation from the radar data performed using a high density network of rain gauges is presented.

1. INTRODUCTION

IRCTR has built an experimental X-band Doppler-polarimetric weather radar system called IDRA (IRCTR Drizzle Radar) aimed at obtaining high temporal and spatial resolution measurements of precipitation with particular interest in light rain and drizzle. The data set obtained is meant to be used in studies of the dynamics of precipitation and in hydrological studies in general. For an explanation of the motivation of the system as well as its specifications refer to [1].

A recurrent issue in the field of radar hydrology is the feasibility of obtaining accurate quantitative precipitation estimation from radar data. A first analysis of the feasibility of obtaining such measurements using IDRA data, using a high density network of rain gauges operated by the Wageningen University as a reference, is performed following a similar methodology as that in [2].

In section 2 the instrumentation used for both obtaining the precipitation intensity and assessing the weather conditions during the precipitation events is described. Section 3 describes the method used in the preliminary analysis of the data and some of the initial conclusions obtained. In section 4 two precipitation events considered to be representative of cold and warm periods in the Netherlands respectively are analysed in more detail. Conclusions are summarized in section 5.

2. INSTRUMENTATION USED

The IDRA radar has been operating almost continuously from April 2008. It is placed on top of a 213 m tower situated at latitude 21.97N and longitude 4.92E. The most usual configuration during precipitation events is fully polarimetric, transmitting a 20 W signal with a frequency sweep of 5 MHz, which corresponds to a 30 m range resolution. With this configuration the surface covered has approximately 15 km radius. A scan of the total area is completed each minute.

Wageningen University operates a network of 13 tipping bucket rain gauges distributed in the area surrounding the Cabauw tower (See their position in Table I). The rain gauges provide 1 minute-averaged precipitation rates. The bucket capacity is 0.2 mm and has a temporal resolution of 0.5 s.

Table I. *Position of the Wageningen University rain gauges in geographical coordinates using the WGS84 datum and respect to the IDRA radar.The radar is located on top of a 213 m tower at position 51.97N and 4.92E.*

RG	Latitude-longitude [°]	Radar C. [m-Deg]
1	51.97N - 4.99E	4562.8 - 92.4
2 & 3	51.94N - 4.93E	3849.7 - 159.9
4	51.94N - 4.88E	4604.1 - 130.7
5	51.97N - 4.94E	840.9 - 103.2
6	51.97N - 4.93E	285.9 - 132.0
7	51.97N - 4.91E	1122.2 - 71.8
8	51.97N - 4.87E	3817.9 - 96.9
9	51.98N - 4.91E	1840.7 - 37.8
10	51.98N - 4.84E	6091.8 - 79.3
11	52.02N - 4.85E	7489.7 - 47.8
12	52.02N - 4.92E	6010.7 - 19.8
13	52.02N - 4.98E	7208.9 - 38.3

Various other instruments have been used to assess the data quality. KNMI operates a rain gauge placed at the remote sensing site south of the Cabauw tower (close to rain gauge number 6) that provides 10 minute-averaged precipitation rates with an accuracy of 0.2 mm. This rain gauge is part of the national rain gauge network, currently composed of 35 elements, approximately one per 1000 km^2. Wageningen University operates a present weather sensor (PWS) and a 2-D video disdrometer located in the same site.

Aside from the instrumentation measuring the precipitation rate, other devices have been used to assess the meteorological situation. The wind speed and direction and the temperature at various altitudes have been obtained from instrumentation placed on the meteorological tower. Temperature gradients of the lower part of the troposphere have been measured by radiosondes launched from De Bilt, 22 km away from Cabauw. It is assumed that the differences in average air temperature at such close distance are negligible. A 35 GHz cloud radar has provided vertical profiles of reflectivity, mean Doppler velocity and Doppler spectrum width while from a CT75 ceilometer vertical profiles of the backscattering attenuation coefficient have been obtained. Both these instruments are operated by KNMI.

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3. PRELIMINARY DATA ANALYSIS

The data analysis was focused on a period between April and November 2008 for which data from the radar system was almost continuously available. However, an inspection of the rain gauge data revealed serious malfunctions of the tipping bucket of most of the rain gauges during extended periods of time. The rain gauges were prone to suffer from cloaking by leaves, seeds or mud. Moreover, some of the ones situated in farmland were even attacked by domestic animals. To guaranty a high quality data during the whole period an almost daily maintenance of each rain gauge in the network should have been performed and that, unfortunately, was not possible due to the lack of manpower.

For this reason only data from rain gauges 1, 3, 4, 5, 6, 9, 10 and 12 were considered appropriate for the study and the period were both significant data from the rain gauges and the radar was available was reduced to a short period in May and in November. Nevertheless a total of 15 rainy days were encountered in the analysed period and from those 4 days contained significant precipitation events, i.e. more than 1 mm/h precipitation rate in a 10 minute-averaged measurement.

In a first approximation to the comparison of the radar data with the rain gauge data, the reflectivity factor values of rainy days from the radar range gate overlapping each rain gauge was converted to rainfall intensity using the typical Marshall-Palmer Z-R relation and plotted as a function of time together with the rain rate obtained by the corresponding rain gauge. Figure 1 shows an example of such measurement.

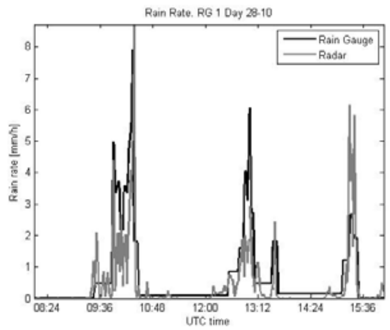


Figure 1. Example of rain gauge 1-radar data comparison graph for a series of precipitation events occurred the 28th of October 2008. 3 precipitation events can be observed. In the 1st one, lasting from 9:30 to 10:30 UTC, there is a good agreement between both datasets; in the 2nd one, from 12:30 to 13:30 UTC, the radar underestimates the precipitation, while in the 3rd the precipitation is overestimated.

A good agreement of the precipitation pattern was observed between both datasets. However the actual precipitation intensity value was differing significantly. In most of the cases an underestimation of the precipitation rate retrieved from the radar data respect to the rain gauge data was encountered but in some cases there was a reasonably good agreement and, in other cases, an overestimation was noticed.

This initial analysis also revealed a very interesting feature. The radar retrieved data was able to determine the precipitation pattern of very light rain (below 0.2 mm/h) that was not correctly measured by the rain gauge due to the lack of resolution of the bucket Therefore, radar data constitutes a very useful tool when studying the dynamics of drizzle and light rain.

The origin of the lack of agreement between the precipitation intensity values measured by rain gauges and those retrieved from radar data is too complex to be determined with certainty. One possible cause has to do with the nature of each measurement. Radar provides quasi-instantaneous measurements over a relatively large volume whereas rain gauges provide time-averaged measurements over a point in space. Moreover, measurements of the radar take place well above the ground while rain gauges measure rainfall at the surface. Secondly, the relation between radar reflectivity and rainfall rate is not a direct one. It is based on the drop size distribution and this varies from rain event to rain event and even within rain events. The Marshall-Palmer Z-R relation was obtained for precipitation in North America and may not be the most convenient for the Netherlands. Finally, errors in the estimation of the radar calibration constant should not be discarded.

4. CASE STUDY PRECIPITATION EVENTS

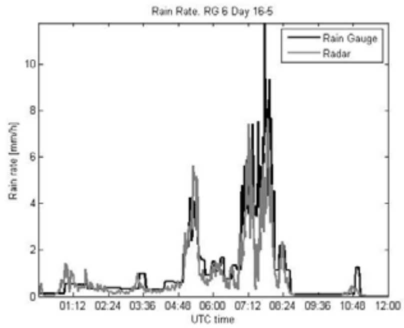
A complete study of the weather conditions of two relevant precipitation events was performed to shed-some light on the differences between the radar and gauge measurements. The first one occurred the 16th of May 2008 and may be considered characteristic of precipitation events during the warm period in The Netherlands (see Figure 2a)). The second one occurred the 11th of November and can be considered an example of cold period precipitation (see Figure 2b)).

Due to the presence of other instruments that can be used as an indicator of the data quality, rain gauge number 6 have been used for the comparison. Furthermore, since it is placed relatively close to the radar, the radar data over rain gauge 6 is less prone to suffer from phenomena like attenuation or misalignment and therefore differences between the actual values can be attributed mainly to the weather conditions or the nature of precipitation..

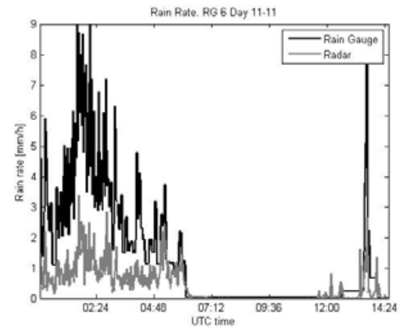
As it is shown in Table II, the total precipitation over the 24 h period retrieved by the radar is in very good agreement with that measured by the rain gauges during the 16th of May. On the contrary, the precipitation is greatly underestimated during the 11th of November.

Table II. *Total rainfall over the 24h period in mm for each case study measured by different sensors.*

	Total Rainfall over 24 h [mm]	
	16-5-2008	**11-11-2008**
Radar over RG 6	12.2	6.9
RG 6	12.5	20.1
KNMI gauge	11.0	18.8
PWS	5.3	N.A.



a) 16th of May



b) 11th of November

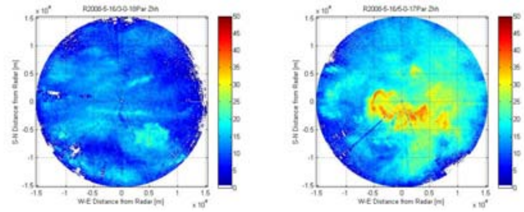
Figure 2. Rain gauge 6-radar data comparison graph for the two case study precipitation events

4.1 Case study 1: 16th of May 2008

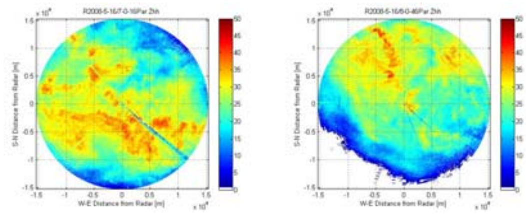
Plan Position Indicator (PPI) graphs of reflectivity obtained by the IDRA radar show a quite uniform precipitation pattern with relatively low precipitation over the whole area covered by the radar until 4:00 UTC, when a squall line appears in the image. The squall line moves from south to north in approximately 2 hours. This relatively low velocity is in correspondence with a situation of calm atmosphere. This squall line is what causes the first peak in the precipitation pattern exhibit by rain gauge 6. From 6:00 UTC to 8:30 UTC strong precipitation is present all over the area measured by the system, which causes the second peak in the precipitation pattern. After 8:30 UTC only scattered low intensity rain is observed. A selection of some relevant PPIs is presented in Figure 3. The complete data sets are available on demand.

During the 16th of May the temperature was mild, with little variation during the whole day. During the rain event the temperature measured on top of the Cabauw tower (200 m) oscillated from a maximum of 14°C to a minimum of 10°C. The temperature measured at the surface was just one degree higher. Radiosonde measurements in De Bilt show that the 0°C altitude was above 2500 m and few temperature variations were observed from midnight to midday The wind velocity measured both on top of the tower and at the surface is low and there is little variation between the two, suggesting a quite stable atmosphere.

The analysis of the 35 GHz KNMI cloud radar data for the period when it was precipitating shows a very distinguishable melting layer situated around 2500 m in accordance to the radiosonde data. Also the two periods of stronger precipitation as shown from IDRA and rain gauge measurements between 5:00 and 6:00 UTC and from 7:00 to 8:30 UTC are clearly observable in the measurements.



a) *3:00 UTC* b) *5:00 UTC*

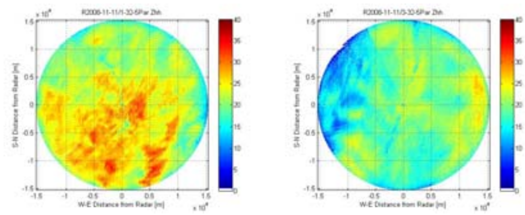


c) *7:00 UTC* d) *8:00 UTC*

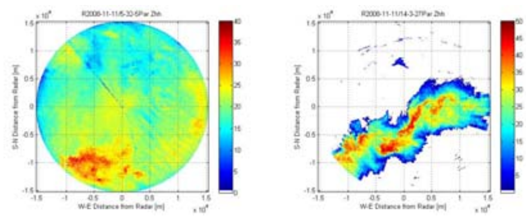
Figure 3. *PPIs of reflectivity obtained during the precipitation event on May 16th.*

4.2 Case study 2: 11th of November 2008

The analysis of the reflectivity PPIs obtained during the 11th of November shows a much more dynamic situation than that in the 16th of May, with little correlation between one image and the next. Overall though, it follows the trend measured by rain gauge number 6 with intensive precipitation from midnight until 6:00 UTC and a squall line crossing the image around midday. A selection of the PPIs can be seen in Figure 4.



a) *1:30 UTC* b) *3:30 UTC*



c) *5:30 UTC* d) *14:00 UTC*

Figure 4. *PPIs of reflectivity obtained during the precipitation event on November 11th.*

The situation the 11th of November 2008 is very different from that of the 16th of May. The temperature measured on the tower is much lower than that of the 16th of May, oscillating between 10.5°C and 7°C. Also the radiosonde temperature shows a dramatic decrease of the 0°C altitude from midnight to midday that day, going from close to 2500 m to 1500 m. The radiosonde measurements suggest a situation of turbulent atmosphere which is confirmed by the measurements of wind velocity and direction on the tower. This measurements show a much windier day than the 16th of May. Also, the differences between the measured velocities on top and on the bottom of the tower are much wider. The wind speed increases constantly from midnight until noon and then remains approximately the same for the rest of the day.

The data from the 35 GHz cloud radar and the ceilometer show two very distinguishable precipitation periods, one from midnight until 6:00 UTC and another between 12:00 and 14:00 UTC. It is noticeable that during the first precipitation period the melting layer altitude decreases steadily from 2.2 km to 1.2 km. This is in accordance to the measurements from the radiosonde. Also, the melting layer is not as well defined as during the 16th of May. In fact there seems to be a gradual transition of reflectivity until 1 km altitude.

In conclusion, the two case studies are representative of two different precipitation regimes. In the first case there is a stable atmospheric situation which leads to little variations in drop size distribution during the event and a good correlation between the situation at 200 m (the measuring altitude of the radar) and that on the ground. Consequently the precipitation intensity retrieved from radar data is in good agreement with that obtained from rain gauge measurements. In the second case the atmosphere is very turbulent and this leads to significant variations in the drop size distribution in a very short period of time. Disdrometer data from that period, shown in Figure 5, corroborates this hypothesis.

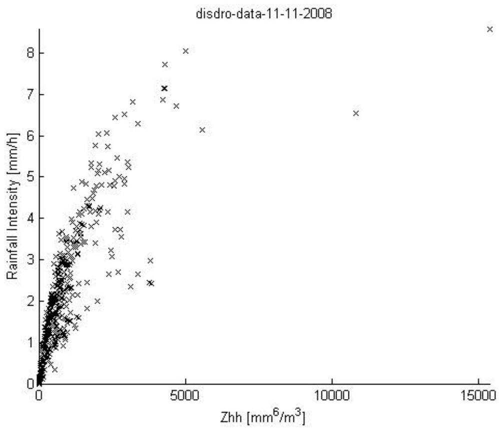


Figure 5. *Rainfall rate as a function of reflectivity obtained from disdrometer data from the 11th of November. The large variance of the measurements shows that the drop size distribution was varying in time.*

5. CONCLUSION

A preliminary study of the feasibility of obtaining accurate quantitative precipitation estimation from IDRA data has been performed, leading to encouraging results.

The analysis shows a good agreement between the precipitation pattern retrieved from radar data and that obtained from rain gauge measurements. Of particular interest is the fact that radar can provide the precipitation pattern of light rain and drizzle, which cannot be measured properly by tipping bucket rain gauges due to the lack of resolution of the bucket. This shows the great potential of this kind of radars in the study of such phenomena.

From an operational perspective it is also relevant to notice that another advantage that radar data offers respect to high density rain gauge networks is the large area covered and the simplicity in the maintenance and the easiness with which malfunctions of the system are detected. In the long term, this can reduce greatly the cost of such measurements. In this study this has proved not to be a minor issue.

However, it has also been shown the great variability of correlation of the absolute value of precipitation obtained from radar data respect to rain gauge data. It is speculated that such variability is caused mainly due to rapid changes in the drop size distribution of precipitation occurring mostly during periods of instability of the atmosphere and, to a lesser extend, by differences in the composition of the precipitation measured at 200 m altitude by the radar system and that on the ground.

Issues like propagation attenuation, which at such high frequencies can already be relevant at moderate precipitation intensities, have not been addressed by this study and they may improve such correlation, particularly for areas at the furthest range of the radar.

The reduced number of precipitation events where both rain gauge and radar data were available has prevented a more thorough statistical study of precipitation. Such study is required in order to obtain Z-R relations adapted to the general characteristics of the precipitation in the area and its seasonal variations.

Having assessed the need for intensive maintenance of the high density rain gauges, a thorough check was performed and a maintenance schedule was established. Therefore it is expected that a similar analysis based on data from 2009 will lead to more accurate relations between radar data and actual precipitation intensity.

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