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Improving weather radar precipitation estimates by combining two types of radars

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ABSTRACT

This paper presents a demonstration of how Local Area Weather Radar (LAWR) X-band measurements can be combined with meteorological C-band measurements into a single radar product. For this purpose, a blending method has been developed which combines the strengths of the two radar systems. Combining the two radar types achieves a radar product with both long range and high temporal resolution. It is validated that the blended radar product performs better than the individual radars based on ground observations from laser disdrometers. However, the data combination is challenged by lower performance of the LAWR. Although both radars benefit from the data combination, it is also found that advection based temporal interpolation is a more favourable method for increasing the temporal resolution of meteorological C-band measurements.

1. Introduction

Weather radars have some obvious advantages compared to point measurements from rain gauges. The radars cover large areas and measure the temporal and spatial variations of the rainfall. This can only be achieved by rain gauges if a dense network is available, which is seldom the case. Moreover, the radar technology makes it possible to obtain rainfall measurements from areas where it can be difficult to use traditional rain gauges, such as remote rural areas or build-up urban areas. One of the most attractive features of weather radar measurements is that they provide the opportunity to forecast the precipitation in advance. As the radar detects the precipitation before it reaches the area of interest, the motion of the rainfall can be used to predict the path of intense precipitation using advanced nowcast models (Reyniers, 2008).

Despite the advantages of distributed measurements by weather radars, it is widely acknowledged that the property of the radar measurements challenges comparisons with ground observations from other instruments. Instruments such as rain gauges and/or disdrometers are supposed to capture the ‘truth’ of the rainfall event, whereas the weather radar provides a snapshot of the radar reflectivity above the ground. The radar reflectivity measurement represents a volume of the atmosphere defined by the characteristic of the radar. Meaningful comparison of precipitation measurements from different sensors can be a challenge due to the different properties and, thereby, different meanings of the measurements (Michaelides et al., 2009). The rain gauges and disdrometers only observe the temporal variation near the point where they are installed. The weather radar measurements can contain significant bias if e.g. the sampling volume is only partly filled or if the radar reflectivity measurement of the atmosphere does not represent the radar reflectivity at ground level due to vertical variations. Measuring the temporal and spatial variation of precipitation is far from trivial and cannot be obtained by a single instrument, thus combination is often necessary for hydrological applications of the data (e.g. Joss and Lee, 1995; Krajewski and Smith, 2002; Villarini and Krajewski, 2010).

In most hydrological applications, rainfall is the primary driving input. Weather radar measurements are today used in a wide variety of applications e.g. flood risk management, road inundation warning, hydropower production and urban hydrology (Versini, 2012; Cole and Moore, 2009; Terblanche

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et al., 2001; Tapiador et al., 2011; Krajewski and Smith, 2002; Einfalt et al., 2004; Anagnostou et al., 2009, 2010).

The required temporal and spatial resolution for urban hydrology is typically higher than for rural hydrology. The reason is that urban catchments and sewer systems are often fast responding as they are designed to efficiently transport the storm water away from the urban areas (Schilling, 1991; Einfalt et al., 1998). The precise requirement depends on the properties of the specific urban area, regarding size and slope of the catchments and how the urban surfaces are composed with respect to permeability. Berne et al. (2004), Einfalt and Maul-Kötter (2002), and Einfalt et al. (2004) suggest that a spatial resolution of around 1–3 km and a temporal resolution of around 1–5 min are adequate for modelling runoff from urban areas.

Most modern meteorological weather radars fulfil the requirements regarding the spatial resolution. However, the radars are often operated with a low temporal resolution of 5–15 min in order to obtain a full three-dimensional scan volume of the atmosphere. Meteorological weather radars serve multiple meteorological purposes, and the operation is, therefore, not optimised for urban hydrology applications. The LAWR is a small urban weather radar based on marine X-band technology (Jensen and Overgaard, 2002; Rollenbeck and Bendix, 2006; Pedersen et al., 2010). The LAWR is less sophisticated than traditional meteorological weather radars as it is non-polarimetric without Doppler capability. However, because this radar type is dedicated to urban drainage applications, it contains some obvious advantages with regards to urban hydrology. The LAWR system is small, flexible and agile. The radar location is typically carefully planned with the only objective to cover a certain urban area in order to get the best condition for the LAWR measurement. Furthermore, the LAWR system scans with a fixed elevation (0°) of the antenna (Jensen, 2012). Consequently, the LAWR system is not able to produce three-dimensional scans of the atmosphere. Instead, the radar can be operated with a high temporal resolution (down to 1 min).

In Denmark, two parallel networks of weather radars exist: a meteorological C-band radar network which covers the whole country and a secondary X-band LAWR network which covers the larger cities in Denmark. The C-band network consists of five C-band Doppler radars whereof two contain dual-polarisation technology (Gill et al., 2006). All the C-band radars are operated and owned by the Danish Meteorological Institute (DMI). In contrast, the LAWR radars are operated and owned by water utility companies, and most of the LAWR radars have no overlapping coverage with each other.

A significant downside of the LAWR system is that the range is limited. Typically, the max range for Quantitative Precipitation Estimates (QPE) is about 15–20 km for this specific type of X-band radar (Pedersen et al., 2010). Although, a range of 15–20 km might be sufficient to cover the urban area of interest, the forecast possibilities will be limited. In order to achieve reasonable forecast lead times based on radar measurements, the radar has to be able to detect the precipitation before it reaches the area of interest. In comparison, the meteorological C-band weather radar has typically a QPE range of 100 to 120 km and a maximum range of 240 km (Thorndahl et al., 2013; Gill et al., 2006).

The choice of radar will result in a trade-off between strengths and weaknesses of the two radar systems. The perfect radar for urban drainage applications is one with long range, high temporal resolution, located close to the urban area of interest and with best possible visibility conditions. Since a trade-off has to be made by using one radar, combining the radar types is an obvious solution. This is the key motivation for this work, and the presented approach combines measurements from the two types of radars in Denmark: LAWR and meteorological C-band measurements.

The concept of combining the LAWR measurements with other radar measurements (with different bandwidths) is novel; however comparison and integration of precipitation measurement from multiple sensors including disdrometers, rain gauges, space borne and ground based radars have been documented by several authors (e.g. Morin and Gabella, 2007; Gabella et al., 2005, 2013; Anagnostou et al., 2010; Joss and Lee, 1995). The closest related research found on the topic is by Pedersen et al. (2008). Here, a small version the LAWR system (4 kW City-LAWR) is compared and assessed against a meteorological S-band radar regarding QPE performance. In the study, the city-LAWR was calibrated on the basis of the S-band radar QPE for a single event for a small area of 2 × 2 km. However, due to lack of sufficient data the study is inconclusive although the few presented results looked promising.

2. Challenges in combining meteorological C-band radar with LAWR

Although the two radar systems use the same fundamental working principle, the systems contain significant differences, which challenge the data fusion process.

Both radars are pulse radars, meaning that the precipitation is estimated based on the backscattered signal of the directional radar pulses transmitted from the radar. However, the radars use different wave lengths. The LAWR radar uses 3.2 cm X-band waves whereas the C-band radar uses 5.4 cm waves. Due to the shorter X-band wavelength, the LAWR system has to correct for atmospheric attenuation in its radar reflectivity measurements (Pedersen et al., 2010). Specifications of the C-band and LAWR radar systems used in this study are listed in Table 1.

The antenna design and the scanning strategy are also different in the radar systems. While the C-band radar operates with a symmetrical narrow beam with a beam width of 1°, the LAWR radar uses an asymmetrical antenna with a wide vertical beam width (±10°) compared to the horizontal width (1°). Whereas, the C-band radar scans the atmosphere in different elevations in order to conduct volume scans of the atmosphere, the LAWR scans in the fixed 0° elevations. The different scanning methods and strategy are illustrated in Fig. 1.

Because of the wide vertical beam used by the LAWR, the radar integrates a large fraction of the atmosphere into its measurements. Approximately half of the beam is aimed towards the ground and so this part of the beam is typically deflected by nearby obstacles or by a clutter fence installed close to the radar (Jensen, 2012). It is this simple scanning strategy that makes measurements of high temporal resolution possible for the LAWR system. The LAWR scans continuously and its measurement is integrated over time. In comparison, the meteorological C-band measurement represents instantaneous measurements every 10 min.

In the traditional use of meteorological weather radars, the CAPPI product (Constant Altitude Plane Position Indicator) is