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Quality control of rain gauge measurements using telecommunication microwave links

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SUMMARY

Accurate rain rate measurements are essential for many hydrological applications. Although rain gauge remains the reference instrument for the measurement of rain rate, the strong spatial and temporal variability of rainfall makes it difficult to spot faulty rain gauges. Due to the poor spatial representativeness of the point rainfall measurements, this is particularly difficult where their density is low. Taking advantage of the high density of telecommunication microwave links in urban areas, a consistency check is proposed to identify faulty rain gauges using nearby microwave links. The methodology is tested on a data set from operational rain gauges and microwave links, in Zürich (Switzerland). The malfunctioning of rain gauges leading to errors in the occurrence of dry/rainy periods are well identified. In addition, the gross errors affecting quantitative rain gauge measurements during rainy periods, such as blocking at a constant value, random noise and systematic bias, can be detected. The proposed approach can be implemented in real time.

1. Introduction

Accurate rainfall measurements are important for hydrological applications, and particularly in an urban context (Schilling, 1991; Berne et al., 2004). Traditionally, rainfall intensity is measured with rain gauges, which require regular maintenance and calibration to provide reliable observations because they are prone to various types of errors (Sevruk, 1999). Sometimes rain gauges are used for the calibration of other instruments, such as weather radars (Collier, 1986), or computer models (Stransky et al., 2007; Fankhauser, 1998) and it is crucial that the information they provide is accurate and does not contain significant biases. These critical biases must be identified and corrected before the observations are integrated with those from other sensors.

When several rain gauges are collocated on nearby, the quality control of their measurements can be done using for instance the double-mass plot (Chang and Lee, 1974). But this procedure is better suited for long periods (several months to years). Upton and Rahimi (2003) proposed a quality control protocol for tipping-bucket rain gauges, with "easily programmable diagnostic checks" to identify errors using the records from multiple rain gauges. They also proposed tests for single rain gauge, but warn at the same time that they were not very successful. This is not surprising because in on-line quality control (e.g., Montgomery, 1996), the use of redundant information, for example from neighboring rain gauges in case of rainfall, is a cornerstone. In the hydrological and aquatic sciences, such redundancy is difficult to achieve and therefore the reliable control of on-line sensors, for example to continuously monitor water quality, is an ongoing field of research (e.g., Thomann et al., 2002). In rainfall monitoring, the strong spatial and temporal variability of rainfall poses additional challenges for the quality control of rain gauges, and especially in urban catchments where dense networks of instruments are needed to capture the relevant dynamics.

The recent growth of mobile telecommunication has lead to the development and expansion of networks of microwave links, mainly used to exchange information between base stations of mobile phone networks. At the frequencies used, the signal from microwave links are attenuated by rainfall, and the path-averaged rain rate can be retrieved from this attenuation (e.g., Messer et al., 2006; Leijnse et al., 2007). The novelty of the present work is to take advantage of this rain retrieval capability and of the dense coverage of telecommunication microwave links in urban areas in order to detect faulty rain gauges. In the following, possible rain gauge errors (Fankhauser, 1998; Sieck et al., 2007) are divided in two main categories: (1) so-called "occurrence errors", which are defined as failures to correctly observe dry and rainy weather conditions and (2) quantitative errors in the measured rain rate. Both

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types of errors are commonly encountered in practice, for example because of clogging of the funnel or a time shift due to malfunctioning of the internal sensor clock for the first type, and because of partial filling of the bucket, shielding or miscalibration for the second type. Therefore the main objective of this study is to develop algorithms based on nearby microwave link measurements to detect errors from each of these two categories in real time.

The paper is organized as follows: the data used in the study are first presented in Section 2, in order to illustrate the underlying concepts; the relationship between the attenuation of a microwave link signal and rainfall is explained in Section 3; the proposed algorithms for data analysis are described in Section 4, the results obtained with these approaches are presented and discussed in Section 5. Finally, the main conclusions are provided in Section 6.

2. Data

Measurements of the received signal level values (RSL, expressed in dBm) of 14 operational microwave links over a period of about one year (from March 2009 to March 2010), in the area of Zürich, Switzerland, have been provided by Orange CH (see Fig. 1). These telecommunication microwave links work at 23, 38 and 58 GHz and have different lengths, polarizations, and power resolutions (see Table 1). RSL values are collected with temporal resolutions from 2 to 5 min. The transmitted power is unknown but constant, therefore the attenuation due to rainfall can be estimated from RSL data. In the same area, data from 13 tipping-bucket and one weighing rain gauges are also available from the local sewer operator ERZ, from MeteoSwiss and from Eawag (Swiss Federal Institute of Aquatic Science and Technology). The different rain gauges collected data over different periods, limiting the availability and overlap with microwave link data.

Because the considered rain gauges and microwave links have different initial temporal resolutions and measurement principles, data from both instruments have to be synchronized and resampled at a common temporal resolution. The comparison between the rain gauge and microwave link data is made with a time step of 20 min as a compromise between keeping a high temporal resolution and minimizing the possible discrepancies between rain gauge and microwave link measurements due to the spatial variability of the rain cells and to the different sampling volumes of each type of sensors.

In the following, the proposed approach will be illustrated by controlling the quality of Rain Gauges 5 and 8 using all the available links. Rain Gauges 5 and 8 are appropriate because they have the longest available records (overlapping with link data) and are reasonably close to most of the links. The proposed method has nevertheless been applied to all 14 rain gauges and the performance is similar, influenced by the distance to the links though. To check the capability to detect sensor failure, artificial failure scenarios are created which allow us to test the performance of our algorithms. Interestingly, from visual inspection and field calibration tests, we suspected that Rain Gauge 5, which is a weighing rain gauge (model Pluvio from OTT), had some problems starting in September 2009. Indeed, further examination proved that its pressure sensor started malfunctioning and needed to be replaced. This is a nice real case to test the proposed approach (see Fig. 1).

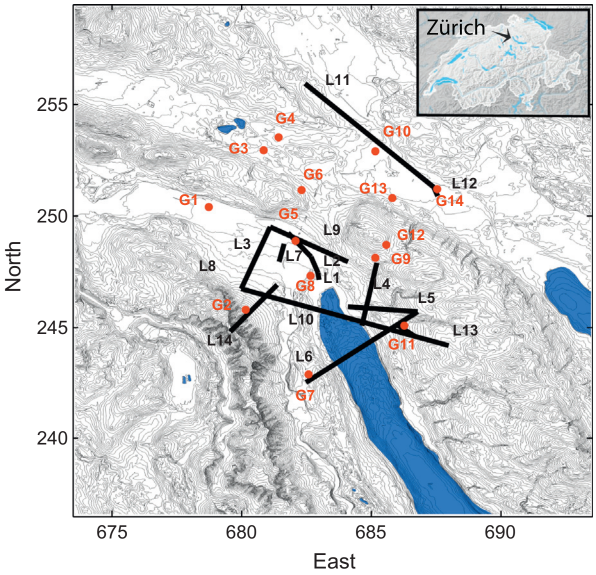

Fig. 1. Locations of the microwave links and rain gauges (Swiss grid in km) in the area of Zürich, Switzerland.

3. Rain rate estimation using microwave links

3.1. From attenuation to rain rate

Microwave links form the backhaul part (i.e., with a high transmission capacity) of modern telecommunication networks, where copper or glass fiber cable infrastructure is too expensive or complicated to build. These radio antennas send and receive information through microwave signals, roughly between 6 and 60 GHz. At such frequencies, the wavelength is comparable to the drop sizes and the received signal power therefore is attenuated due to the scattering and absorption by the raindrops.

Telecommunication engineers have known these adverse effects for decades (e.g., Atlas and Ulbrich, 1977; Olsen et al., 1978). In earlier works, microwave links have been specifically designed and built to monitor rainfall (e.g., Ruf et al., 1996; Rahimi et al., 2003), but these instruments were mainly prototypes. Only the recent development of mobile telecommunication made possible the deployment of networks of operational microwave links over extended areas and the (near) real-time access to fully exploit these signals. Messer et al. (2006) and Leijnse et al. (2007) have demonstrated the possibility to use measurements of the attenuation from operational telecommunication microwave links to monitor rainfall.

The specific attenuation k (expressed in dB km^{-1}) due to rain affecting a microwave link signal can be related to the rain rate R (mm h^{-1}) by a power law (e.g., Olsen et al., 1978):

$$k = \alpha R^{\beta}, \tag{1}$$

where α and β are two coefficients which depend on the frequency, polarization, raindrop size distribution (DSD) and temperature. The exponent β is close to 1 around 35 GHz (Atlas and Ulbrich, 1977)

Table 1
Length (km), frequency (GHz), polarization (H or V) and power resolution (dB) of the 14 microwave links.

Link	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Freq.	58	38	38	38	38	23	38	23	23	23	23	58	38	38
Pol.	V	H	H	V	H	H	H	H	V	V	H	V	H	H
Length	0.3	0.8	0.8	2.9	2.7	5.4	1.4	3.0	3.4	8.4	6.8	0.5	2.8	0.8
P. res.	0.1	1	0.1	0.1	0.1	0.1	0.1	1	1	0.1	0.1	0.1	0.1	1