Microwave communication networks as a sustainable tool of rainfall monitoring for agriculture needs in Africa

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Abstract. Commercial Microwave Links (CMLs), that provide the underlying framework for data transfer between cellular network base stations have been found effective for monitoring rainfall. Wireless infrastructure of this kind is deployed widely by communication providers across Africa and can be used as a complementary monitoring device to the sparse proprietary resources that exist currently, and at minimal cost, or as a substitute tool in the many cases where alternatives do not exist. Here we focus on the potential that lies in this novel approach to acquire valuable information required for agricultural needs over the poverty-stricken countries of Africa.[1]

Keywords: Africa, agriculture, rainfall, microwave links

1. CMLs: a sustainable tool for monitoring rain

Africa's economy is primarily based on agriculture and the continent is rich in natural resources. However, a lack of infrastructure, among other obstacles, does not allow for maximizing the landmass' potential. To date, the ability to acquire extensive and precise Quantitative Precipitation Estimates (QPEs) in Africa has been limited due to technical and practical constraints. State of the art rainfall monitoring tools include, predominantly - rain gauges, radar systems and satellites. Rain gauges, however, provide only local observations which are not representative of the larger space, and further, the deployment of gauges across Africa is extremely low. As a result, the chance that a rainy storm cloud will miss the point rain gauge entirely, in a certain domain, is particularly high. Moreover, even in cases where rain has already been measured by this instrument, the probability that the recorded rainfall intensity represents the entire area is very low. Satellite systems and radars, can provide good spatial coverage, but these systems often suffer from lack of precision in near-ground QPEs (satellites) or clutter effects which limit the measurement (radar, within a certain radius around it). Moreover, because of the high costs, radar systems are not widely deployed in Africa. The optimal way to monitor rain in general and particularly in Africa, should ideally combine the positive elements of each of these instruments, with minimal costs. CMLs that constitute the infrastructure for data transmission in cellular communication networks combine, to a certain extent, the characteristics required: the measurements are taken over large areas (similar to satellites and radars) and from ground level (like rain gauges). Since these systems are already deployed in the field by cellular providers, the costs are minimal. These links operate at frequencies of tens of GHz and are affected by various weather conditions (e.g. David and Gao, 2016). Precipitation, in particular, is the atmospheric parameter that causes the most dominant attenuation of signals in the frequency range in which CMLs operate. As a result, microwave communication systems can be used as wireless sensor networks for monitoring rainfall across Africa. Over the last decade, dozens of works carried out in this field from around the world indicate the ability of CMLs to monitor rain (e.g. Overeem et al., 2013; David et al., 2013; Chwala and Kunstmann, 2019). However, from the wide range of papers in this field, so far only a handful have focused on applying the method in Africa (e.g. Hoedjes et al., 2014; Gosset et al., 2016). Notably, pluvial agriculture is very common on the continent and thus this sustainable approach has great potential to contribute meaningfully to the subject.

2. On added-value for agricultural needs

CMLs were originally designed for communication needs. Naturally, monitoring rainfall using these links is suboptimal and influenced by limitations deriving, for example, from geometric deployment in the field and operating frequencies (that are less than ideal), coarse magnitude resolution of the microwave system, etc. Therefore, the proper approach is to consider the method to be a complementary device to the specialized tools. Nonetheless, in the many cases where there are no dedicated resources, as is common in many developing countries, invaluable information can be derived from this technique. For example, the ability to acquire QPEs

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across an agricultural field using CMLs can help prevention of over irrigation – leading to water savings and more efficient use of fertilizers. On the other hand, an inadequate amount of rainfall at a certain area is also important information since avoiding lack of water is essential to produce healthy crops. As a result of the vast number of CMLs when compared to the low number of sparsely deployed rain gauges, which only exist on some smallholder farms in Africa if at all, the ability to contend with such cases should improve markedly. Further, under some circumstances, the use of CMLs to monitor rainfall can be more effective than proprietary instruments. For example, in mountainous regions, remote sensing systems, such as radars, are limited due to the topographic conditions. A link network deployed in the area, along the various inclines, would acquire QPEs more reliably (e.g. David et al., 2013). Notably, a potential application of CMLs in agriculture is the design of rainfall-based index insurance which has been considered an important risk mitigation tool for local farmers. The major shortcoming of rainfall insurance is the presence of large basis risk – the probability that an index insurance contract will not accurately reflect agricultural losses. A main source of basis risk lies in the differences between local rainfall faced by the insured farmers and the rainfall measured by the weather station or satellite used to calculate the indemnity. CML technology provides a sustainable solution to reduce the basis risks.

3. Method

The following formula describes the relationship between the rainfall induced attenuation, A (dB), and the rainfall intensity R (mm/hr):

$$A=aR^b \text{ (dB/km)}$$

where the parameters a and b are known from the literature and are dependent on the frequency/polarization of the signals, and on the rain drop size distribution. Given the received signal level measurements taken by each CML, A can be assessed and accordingly the rain intensity - R along the propagation path of the CML. Wet antenna attenuation correction should also be applied. For further technical details and measurment uncertainty sources see, e.g., Overeem et al. (2013); David et al. (2013).

4. Results

Figure 1 demonstrates the spatial advantage of CMLs to detect rain over an agricultural area as compared to the point rain gauge method. The observations shown were taken by three 15 GHz links (3.7 and 4.6 km long) and three rain gauges during a precipitation event that took place on 10 May 2013 over a tea farm near the city of Kericho in Kenya. Of the number of CMLs and gauges deployed across the test site, we focused on those situated closest to each other (where, two links are located along the same line of sight (CML2, CML3) and the third is roughly parallel to them (CML1). The rain gauges are installed directly under their propagation paths or up to a few dozen meters from them). While a convincing correlation between the gauges and the CMLs is observed (R=0.64–0.82), one can note that, the third rain gauge (RG3) missed a complete rain episode between 17:45 to 18:15 (marked by the arrow in Fig. 1) due to the spatially unrepresentative nature of measurement acquired by this tool. A difference between the rain intensities taken by the CMLs which represent averages over a few kilometers compared to the point rain gauge is also discernible.

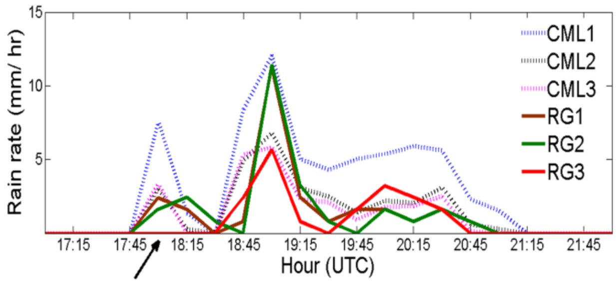

Figure 1. CML vs. rain gauge measurements.

5. Summary

Different technical and environmental factors may lead to the disparities observed between the CML and rain gauge measurements, including spatial variability of rain across space, the different manner through which the observations are taken - point measurement vs an average over several kilometers, etc. (e.g. Overeem et al., 2013; Chwala and Kunstmann, 2019). However, due to the widespread deployment of CMLs across the terrain, these newly available 'sensors' can provide a good response which, at times, even outpaces that of conventional instruments sparsely deployed in the field in Africa. The proposed approach has great potential for hydrometeorological applications, including warning against flash floods, short-term forecasting of hazardous storms, and more. In particular, its contribution to the agricultural sector, which constitutes a major source of income for many poor farmers in Africa, may be invaluable.

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