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Atmospheric Measurement Techniques Discussions

Interactive comment on "Commercial Microwave Links as a tool for operational rainfall monitoring in Northern Italy" *by* Giacomo Roversi et al.

Giacomo Roversi et al.

federico.porcu@unibo.it

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The manuscript aims to evaluate the potential of rainfall retrieval from CML network at regional scale in northern Italy to create rainfall maps for operational purposes. The paper describes the unique data set from the region of interest. It should be noted here that the collection of CML data set in large telecommunication network is still a challenge. However, from global perspective other studies already described similar experiments with identical (or wider) scales employing CML data using more advanced methods.

We thank the reviewer for the comments and for the indications to improve our work. We'll modify the manuscript as outlined below, replying point by point in italic.

Main weakness of the manuscript is therefore related to CML data processing and data analysis which is based on open-source package RAINLINK applied on CML data in northern Italy. I am missing the definition and answering the important research questions which can provide new insights in CML rainfall retrieval. The overall scientific significance of the manuscript is fair. Therefore, the manuscript needs major revisions. I see several aspects that can be studied using such data set. The quality of CML product is questionable and it show systematic underestimation. Then one way could be to test/develop other processing methods of CML data to reduce this bias and improve the quality of the product. Other interesting point could be an orographic aspect which is mentioned in the manuscript, but not studied in detail.

We agree with the reviewer that in this paper we do not address basic research questions, such as to set-up advanced algorithms or tackle challenging issues, but we think that one important task in the research activity is to communicate to potential users possible applications of the research itself.

Moreover, in our opinion, the data available to us was simply not accurate and complete enough to develop and test new algorithms or to analyse the impact of orography or other known critical aspects of the rain retrieval from CMLs. Longer data time series over wider regions and a more reliable and representative reference dataset is needed to do such studies, which was not accessible to us at the time. However, we believe that this work demonstrates a good potential of the technology even at its most basic implementation, and gives valuable hints for future regional improvements.

The objective of our study, indeed, was to test the possible role of CML retrievals in an operational environment without any previous study on the characteristics of the available CMLs. We performed an "out of the box" approach as we aimed to test the performances obtainable without specific calibration (whose related effort could be not sustainable in many places). We assessed that a robust and freely available algorithm (such as RAINLINK) provides a product with spatial and temporal characteristics *comparable to products routinely available to the operators in our region. Moreover, we highlighted how the performances of RAINLINK can be improved, addressing the few parameters that could benefit from a calibration/validation campaign (with proper instruments), once it will become possible.*

To clarify, we'll modify the sentences in the revised manuscript at lines 58-64 as follows: "... CML attenuation data, using a well-established, freely-available algorithm (i.e. RAINLINK, Overeem et al. (2016a)), over two areas of interest in the Po Valley (provinces of Bologna and Parma), where CML data have been obtained from Vodafone (direct purchase). Both areas contain river basins of considerable local interest, which will be addressed specifically. The further aim of the validation study is to set the background for possible inclusion of CML data in the operational routine procedures for precipitation monitoring in the Meteorological Service of the Regional Agency for Environmental Protection and Energy (Arpae-SIMC), showing baseline potential of the methodology and indicating a direction toward which to direct the implementation and tuning effort."

General comments:

1. The results show systematic underestimation of QPE derived from CMLs. RAINLINK package contains several strong assumptions (constant WAA of 2.3 dB, constant k-R parameters etc.) which can influence the results significantly. Recent knowledge shows that WAA is complex process with many unknowns (e.g. Leth et al., 2018). The dataset probably contains a certain portion of sensors with low sensitivity (this is reviewer assumption since the CML statistic is not provided) to rainfall where WAA can play dominant role in resulting rainfall retrieval. I would recommend to make at least sensitivity analysis of the results to most significant parameters.

It is well known (van Leth et al., 2018 among many others) that antenna wetting is one of the main problems in microwave estimation of precipitation, and for this reason we

think we cannot address this issue with our operationally oriented verification system. We remark that to address this issue properly, van Leth et al. (2018) deployed a unique experimental setting, with extremely controlled antenna conditions (time-lapse camera pointing the antennas) and accurate reference measurements (five disdrometers along link path). Even with this unprecedented experimental setting, neither van Leth et al. (2018) could definitively address this issue in a general way.

To give some more hints to the reader interested in the use of RAINLINK, we'll add some trials we made, changing the fixed WAA threshold, and discuss the results.

2. Spatial interpolation is based on assumption the path-integrated rainfall is represented as a point measurement. This assumption can be used for rough grid 5x5 km and shorter CMLs. However, it is weak for single link comparison (section 4.1) including single event comparison. Here, spatial-temporal structure of rain together with the layout of given RG and CMLs can play significant role. Then it is impossible to compare single point measurements and CMLs observations.

We thank the reviewer for pointing out this issue and agree that the comparison between single link and single rain gauge is affected by many uncertainties. However, similar shortcomings should also apply when comparisons with other instruments are considered. As an example, radar data, which could be in principle preferred because of its spatially integrated nature, suffer by many other uncertainties that make the precise comparison with line integrated CML estimate questionable. The only way to proceed properly seems to be to follow the van Leth et al. (2020) approach or similar. Anyway, we believe that our analysis, could still give the reader some valuable hints to understand the behaviour of interpolated RAINLINK products used in the following sections of the paper. In the discussion, we'll consider the possible shortcoming of our analysis. We'll also add some statistics regarding CML-gauge distances which prove that the averaging of the rainrate along the path and the comparison with a nearby raingauge are assumptions of the same order of magnitude for what concerns the scale of *the variance of the precipitation field.*

3. Since rainfall maps are the key product of the presented study, I would expect to show visually CML rainfall maps – event-based or cumulative rainfall compared to reference.

According to also the other reviewer, we'll show 2 case studies in the revised manuscript, with maps and skill indicators, and the cumulated map for the whole period.

4. I am missing relevant discussion section in the paper

We would prefer not to change the structure of the paper, but we will evaluate whether to deeper discuss the issues suggested by the reviewer point by point in the Results section or to add a separate Discussion section

5. I am not satisfied with the conclusions which do not provide novel information beyond the state of the art in the field of CML rainfall retrieval.

We'll better illustrate the results of our work, keeping in mind that we want to be at the application side of the problem.

Specific comments:

L. 33-45. I don0t agree with this paragraph since the first sentence refer to CMLs. The provide references are partly based on experimental microwave link setup, not CMLs. I wonder we know accurate algorithms for DSD, water content etc. based on CML observation.

The reviewer is right: the sentence was badly structured. We will rewrite as: "Accurate experiments and numerical simulation were used to assess the capability of microwave links to measure average rainfall rates (Rahimi et al., 2003), drop size distribution (Rincon and Lang, 2002; van Leth et al., 2020) and water content (Jameson, 1993). On the same token, the possibility to have a spatially continuous rainfall pattern depends on the density and distribution of the links, making this approach of particular interest

for urban areas. . . "

L. 70. observation period – since later in the manuscript some analysis are event based I would add into the Supplementary material information and data about precipitation events during observation period. For selected rainfalls and locations used later in section 4.1 some detailed rainfall metrics would be welcome.

We'll add to the Supplementary material the PDFs of rainrates to characterize precipitation during the observation period.

L. 90-94 The usage of CMLs with low operating frequencies 6 – 15 GHz is questionable for QPE because of low sensitivity of those devices to rainfall even with longer path lengths. It would be useful to provide statistic evidence of different frequency bands in the data set including calculated theoretical sensitivity to rainfall. Then the effect of constant WAA to the results would be much clearer.

We thank the reviewer for having pointed this topic out. The sensitivity characteristics of the CML network will be reported in the Supplementary material, and briefly summarized and discussed in the revised text. Low sensitivity links will be removed from the data set before updating the results, which are yet expected to remain almost unchanged.

L. 104 Spatial distribution of LC – could you explain why the LC is lower in the main regional cities (Parma and Bologna) than in countryside – Figure 1?

In Italy and generally in the world, most of the CMLs in urban areas are being substituted by underground optical fibre cables. We'll add a comment on this.

Section 2.1.2 Transmitting power levels I found this paragraph a little bit confusing. I would ask to rephrase it to provide clear information about ATCP processing.

We'll rephrase the paragraph, improving clarity and describing the manual correction of the ATPC in detail.

L. 193 Interpolation – please explain how path-averaged rainfall depth from each CML is implemented into spatial interpolation. This not very clear from provided description Section 4.1 Single link verification – see my general comment about point and pathaveraged rainfall estimates. This is difficult to understand especially when we don't see detailed information about precipitation metrics during observation period. The data also does not correspond with previous statement in Section 2, that in higher altitudes are higher amount of rains.

Interpolation of the point path-averaged rainfall estimates (placed in the middle of the links' paths) is performed through ordinary kriging with range, sill and nugget derived from seasonal spatial correlation analyses of two years of gauge data of our region. More details on the precipitation characteristics involved in the analyses of Section 4.1 will be added in the revised manuscript.

The sentence in Section 2 was related to the rainfall climatology of the region. The case study likely represents an exception to the climatology.

L. 228 I suggest this statement as weak and confusing "They have been chosen in areas with different terrain and network density and far from the cities, as CMLs in urban areas are already well studied and also the most eligible to be replaced by optic fibres." I don0t see why CMLs in cities should work in different way than in country side. Is there evidence that CML in cities are already well studied and in the countryside not? Network development is not relevant for this paper and this sentence is speculation.

CML network characteristics are different going from cities to the countryside. Specifically, in the cities there are fewer CMLs since most of them have been already replaced with optical fibre (see also the answer to the comment on L104 and the recent The Netherlands' situation reported for example in Overeem et al. (2016), Introduction section, 4th paragraph). We provide many references for metropolitan CML studies with short links. Moreover, implications of network's developments on operational retrieval

capabilities are among the most relevant topics in the CML field.

Sections 4.1.1.-4.1.2. - Best and Worst Case Example – I do not understand why there is no text information and results interpretation with respect to rainfall intensity and rainfall characteristics. 4.1.2 represents light rain when the sensitivity to rainfall of CMLs is low. WAA is significant here anyway. Also, data provided from NMS system in form Pmin Pmax are limiting factor. This shows clear limits of CML for light rainfalls and Pmin Pmax approach.

We thank the reviewer for this comment: we'll include a more detailed discussion on these results, addressing especially the type of precipitation and the Pmax-Pmin approach, and also considering previous reviewer's comments.

Section 4.1.3 – I do not think that this melting layer story fits to this story. First, the data set is presented as spring – summer period. The article is focused on liquid precipitation, this is another story.

The melting layer episode does not belong to the 2-month dataset used for the main study, but it was a standalone dataset obtained from Vodafone for preliminary checking. This event occurred in February when freezing level could reach the ground, especially on the hills. Since liquid precipitation at midlatitude originates from frozen hydrometeors, the bright band is a rather common feature in our regions and introduces errors in the radar estimates often difficult to correct. Anyway, we understand that this issue is a bit far from the mainline of the work, so, we decided to remove this subsection.

L. 320-330 I do not fully agree with those statements about LC. Different LC often means different frequency bands distribution. In the region with high LC one can expect higher frequency bands with higher rainfall sensitivity.

We did not find any correlation between frequency and LC to date, but we thank the reviewer for the hint. As anticipated, we will carry out a deeper analysis of the links' sensitivity and we will discuss it in the revised manuscript, also deepening the under-

standing of LC contribution to our sensing performances.

Figures general – I found inconsistency when using brackets for units – none, () or [] in different figures

Thank you for noticing this, we will fix this inconsistency.

Figure 7. I do not understand the "bad“ results of adjusted radar in comparison to the reference which was used for radar adjustment. The results are comparable to unadjusted radar data. Could you explain that?

The adjustment is performed with gauges and not with the interpolated reference, as specified in Section 2.2.3. The procedure matches the rainrates estimated over the gauge locations but does not ensure the consistency of the whole radar field with the gauge interpolated one, mostly because of the high spatial variance of the radar field (as already discussed in Section 4.2.2, L356). Therefore discrepancies in the areal averages are not only to be tolerated but also expected. Moreover, the spatial autocorrelation of the G/R adjustment factor is even lower during convective events, leading to a less effective correction. We'll mention this in the revised manuscript and we will add some documentation regarding the radar adjustment statistics and performances in the Supplementary Material.

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