Sources of uncertainty in rainfall maps from cellular communication networks

by M. F. Rios Gaona, A. Overeem, H. Leijnse and R. Uijlenhoet

Reviewer's comments

Summary

The authors present a method for quantifying the two major sources of uncertainty (i.e., measurement and mapping) associated with rainfall estimation from microwave link networks. They apply their method to operational link data collected in the Netherlands and evaluate their results using independent radar rainfall estimates. The main conclusion is that, in relatively dense networks, the measurement part accounts for most of the errors/uncertainty.

Recommendation

The paper is well written and the methodology is described in great detail. The idea of quantifying the relative errors associated with microwave link measurements/mapping is compelling. I could find no major flaw in the paper. There are, however, some aspects that could be investigated in more detail. Specifically, I think that both the mapping part and the issue of the network topology could be studied in more detail. My main criticism is that all the conclusions are drawn from a single case study and interpolation method (i.e., ordinary kriging). Additional results based on different interpolation methods, network topologies (e.g., only high- or low-frequency links) or stochastic simulations would give more weight to the authors' conclusions and recommendations. The topic is definitively of interest but more in-depth analyses would help to increase the reader's confidence in the results.

My recommendation: **Major review**

Major comments

1. The presentation of the results and the discussion that follows are rather superficial and could be substantially improved. Let's be honest! Given the large number of links, it should come as no surprise that the measurement and representativity errors constitute the major source of uncertainty. The idea of assessing the relative error associated with mapping is new but the methodology used to tackle this issue could be further improved. For example, other interpolation methods (e.g., universal kriging and splines) and network topologies (e.g., various subsets of the considered network) should be considered before drawing any hasty conclusions.

2. The title of the paper is somewhat misleading: it gives the false impression that this is a general and exhaustive analysis of the different error sources involved in microwave link rainfall estimation. In reality, however, the authors provide a case study for the Netherlands and only consider two main sources of errors (i.e., measurement and mapping). A better phrasing that is more aligned with the content of the paper would help.

3. There is a general confusion between "measurement" errors and "link-radar representativity" errors in the paper. Often, the term "measurement error" is used to denote both types of errors (e.g., p.3301, ll.6-7 and p.3302, ll.1-2). At other instances (e.g., p.3305, ll.3-6), the "link-radar representativity" is grouped with the mapping errors. This absolutely needs to be clarified to avoid any confusion.

4. Some additional details about the variogram used to krige the rainfall fields (LINK, partSIM and fullSIM) are required. Please specify if you used a single variogram for all three cases and all time steps or if some kind of estimation/adjustment was performed. If the kriging of the link data was performed using a climatological variogram, please mention it. Also, it might be worth mentioning what happens to the interpolation in case the variogram has to be estimated from the link data.

5. What about a simulation approach? If you know the variogram, you can generate artificial rainfall fields with similar spatial structures. This could be used to study the importance of the interpolation method and of the network topology.

6. What about intermittency? Is intermittency the reason why on p.3300 ll.5-6 you restrict the comparison to points with at least 0.1 mm accumulation? Please specify the underlying assumptions and comment on the effects they might have on the results (i.e., bias, CV and non-stationarity).

7. p.3301, ll.15-17, *We see that the biases are hardly reduced and therefore conclude that the underestimation noted earlier must be almost entirely due to errors introduced by the incomplete spatial sampling.*
I would be more careful with this statement. The observed differences can also be the result of a sub-optimal interpolation method. In this case, the major issue is not the fact that you have incomplete sampling but the stationarity assumption behind ordinary kriging (i.e., constant mean and variance). In other words, the fact that partSIM has only a slightly lower bias than LINK may also be because ordinary kriging is not the best interpolation method in this case. The point I try to make here is that the choice of the interpolation method and the assumptions behind it matter, especially in networks with highly variable densities. Maybe if you had used another interpolation method, the differences in bias between partSIM and fullSIM would not have been that large...

8. p.3303, ll.25-26, *We found that link rainfall retrieval errors themselves are the source of error that contributes most to the overall uncertainty in rainfall maps from commercial microwave link networks.*
It's more correct to say that the major error is due to the retrieval and/or the representativity error between link and radar, with no way of knowing which contributes most. Also, you forget to say that this result is based on the assumption that the variogram of the rainfall field is known a priori. If you had no radar nor gauge data, the variogram would have to be estimated directly from the (incomplete) link data, which adds another dimension to the problem.

9. More generally, it would be interesting to see how the relative contributions of measurement errors and mapping errors change as a function of the number of links, their density or any other characteristic related to the network's topology. Intuitively, the mapping error is going to increase with decreasing link density. I understand that this is a difficult question to answer. But at least, the authors could discuss it a little bit more.

10. Is a relative bias of 15%, a CV of 121% and a coefficient of determination of 0.37 at 15 min acceptable for practical applications in hydrology or not? If not, what could and should be done to overcome these issues and improve the overall accuracy of rainfall maps derived from microwave links?

Minor comments

11. Section 3 (Results) is very short. It could easily be merged with Section 4 (Discussion).

12. It would be nice to mention the main result in the abstract as well, and not just in the conclusion.

13. p.3292, l.19 ... *that is, the physics involved in the measurements such as wet antenna attenuation, sampling interval of measurements, wet/dry period classification, drop size distribution (DSD), and multi-path propagation.*
    The sampling interval and the wet/dry classification are not exactly related to the physics of the problem. It's more a sampling and signal processing issue. Please reformulate. In addition, you could include the dry weather baseline attenuation in the list of uncertainties.

14. p.3296, ll.8-10. *Simulated rainfall depths are based on radar data; hence, they largely reduce the sampling differences between radar and microwave links measurements.*
    This sentence is confusing. Are you referring to the weighted averaging of the radar data with respect to the link path? Or am I missing a crucial point here? Please clarify.

15. p.3296, ll.25-26, *Kriging is ideally suited for interpolation of highly irregular-spaced data points.* This statement needs to be nuanced a little bit. Kriging is a good (linear) interpolation method that takes into account the spatial structure of the data but also comes with its own limitations. In particular, ordinary kriging assumes second-order stationarity of the process. Thus the mean and variance of the process are assumed to be constant. In reality, however, rainfall often turns out to be spatially heterogeneous and non-stationary. Typically, the stochastic relation linking the rainfall at two separate sites depends not only on the relative distance separating the two sites but also on surrounding topographic features and their location with respect to the flow of weather. By applying ordinary kriging, you assume that there are no trends and heterogeneities in the field. This should be clearly mentioned in the text as it is a strong hypothesis.

16. Please reconsider the color scales in Fig 6 and Fig 7. Red is perceived as a bright color and should therefore be associated with large values (and vice-versa for green). Also, a significant fraction of the population has problems differentiating between red and green tones. Blue-red, green-purple or shades of gray are common alternatives.

17. In general, it would be nice to have a more consistent use of color scales throughout the paper.

Typos and Editing

18. p.3290, l.25 *These rainfall maps were compared against ...*
    Not sure which rainfall maps you are referring to. The 3500 ones mentioned on l.23 or the simulated ones from l.24? Please clarify.

19. p.3292, l.2 the reference to Messer et al., 2012 should be put into parentheses.

20. p.3292, l.25 I'm not sure if the term *physical errors* is appropriate here. Maybe "measurement" or "sampling" would be more appropriate.

21. p.3293, l.10, The parentheses in (2011) are not really necessary.

22. p.3294, l.17 *(2) there are gaps in the network, without link data at all ...*

23. p.3295, l.10 ... *the performance of the link network assuming that all links provide perfect measurements ...*

24. p.3300, l.21, *Figure 4a, d and g show the relation between the actual link...*

25. p.3303, ll.1-2 *In other areas, the nugget of the employed variogram has a similar effect of reduction on large errors.*
    This sentence is not clear. Please reformulate.