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On the concurrent use of radar, microwave links and raingauges: results from the Mantissa experiment

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Abstract. An innovative method of estimating rainfall via the attenuation it causes to a ground-based microwave link is presented. This provides measurements of path averaged rainfall, and it can provide also data on a much finer time scale (virtually continuous) than will either a radar or a raingauge. Two case studies are presented and discussed.

1 Introduction

All hydrological models need information about the spatial distribution of the rainfall, the exact amount and distribution of which are not known and can only be estimated from measurements on the ground (e.g. raingauges) or in the air (e.g. radars). Extrapolation from raingauge data into spatial distributions has long been understood to be as highly speculative. Radar data give the spatial distribution and provide a good basis for short term forecasts necessary for any kind of control and warning, but have their deficiencies in terms of quantitative reliability.

An innovative method of estimating rainfall is via the attenuation it causes to a ground-based microwave link. This provides measurements of path averaged rainfall. It can provide also data on a much finer time scale (virtually continuous) than will either a radar or a raingauge. To investigate the potential of this new technique the European Commission funded the MANTISSA (Microwave Attenuation as a New Tool for Improving Stormwater Supervision Administration) project in Framework V.

In this contribution we present some results from the experimental campaigns carried out in Italy in the framework of the MANTISSA project; in particular, we report on the results obtained with the concurrent use of radar (C-band, dual polarisation), raingauges and a dual-frequency microwave link in the Rio Centonara basin, in the Apennines near Bologna. Two case studies will be presented and discussed; it will be shown how, if ground clutter is properly removed from radar data, there is an encouraging agreement among the three instruments.

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2 Microwave links as electromagnetic raingauges

It is well known in the propagation community that electromagnetic waves at frequencies above 10 GHz suffer from attenuation when propagating through precipitation. In particular, specific attenuation γ (dB/km) can be related to point rain rate R (mm/h) through the power-law relation:

$$\gamma(R) = kR^{\alpha} \quad (1)$$

where k and α depend on frequency, drops shape, drop size distribution DSD and temperature. The average specific attenuation $\bar{\gamma}$ experienced by the radio link can be calculated from the total measured attenuation A_{tot} (that is the integral of (1) along the radio path), dividing it by the link length L:

$$\bar{\gamma} = \frac{1}{L}\int_0^L \gamma(R(r))dr = \frac{1}{L}A_{tot} \quad (2)$$

The unknown average rain rate $\hat{R}$ is calculated from $\bar{\gamma}$ by inverting the exponential relation (1), i.e. $\hat{R} = c\bar{\gamma}^d$. The set of coefficients used in our analysis can be found in Table 1. Since actual drops shape, DSD and temperature are not known, this inversion is subject to errors. A theoretical analysis has shown that the biggest source of error is variability in the DSD.

On this respect, a recent study on propagation data from the Olympus Satellite (Hardaker, 1997) has shown that the sensitivity to DSD variation is strongly reduced if a dual-frequency link is used, and $\hat{R}$ is evaluated from the differential attenuation $\Delta\bar{\gamma} = \bar{\gamma}_1 - \bar{\gamma}_2$, where $\bar{\gamma}_1$ is the specific attenuation measured at the higher frequency. In this case, an almost linear dependence between attenuation and rain rate is found; for our set of frequencies (see further on) it is $\hat{R} = 10.2\ \Delta\bar{\gamma}$.

Since our estimation procedure derives rain rate from microwave attenuation, it is essential that attenuation data are cleared from contributions due to multi-path and gases present in the atmosphere (especially water vapour); these contributions, whose effects on measured attenuation are not constant in time and vary with each event, can be summarized in the so-called "baseline" attenuation level. Once the

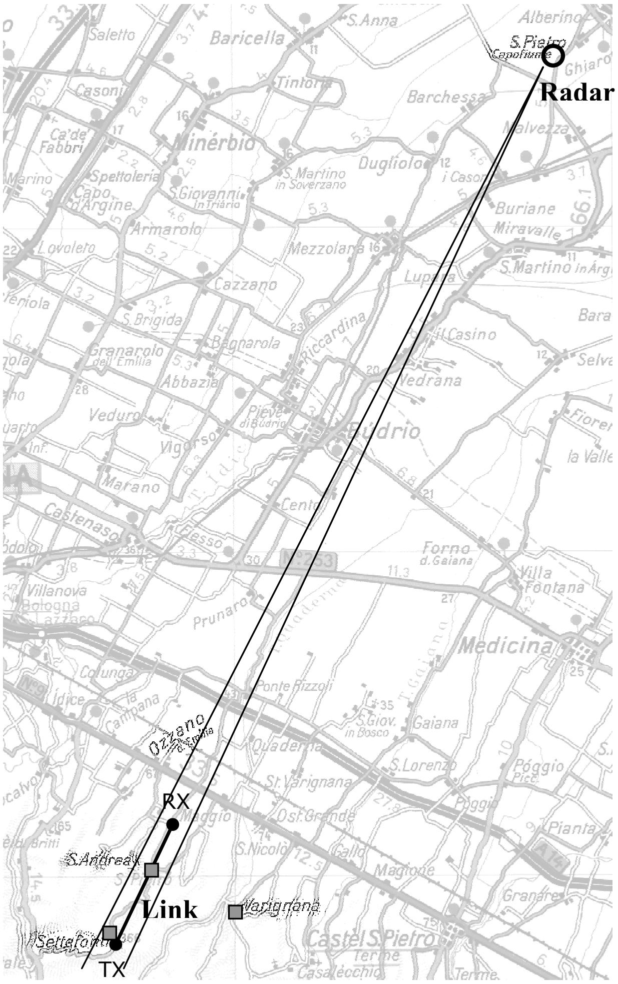

Fig. 1. Geographical location of experimental site. Gauges are indicated by squares.

baseline level is estimated, attenuation due to rain is obtained by subtraction.

The algorithm that we have developed for the automatic baseline evaluation will be now described.

As a first step, an approximate baseline level is estimated as the mean attenuation value in supposedly dry intervals. This first guess is needed for the correct identification of "wet" and "dry" periods: recorded data are subdivided in 15 minutes interval; one interval can be flagged as being "wet" (meaning that some rain occurred) or "dry" (no rain occurrence). It is essential that those intervals identified as dry are indeed dry. A wrong classification of a wet period marked as dry would lead to great inaccuracies in rain rate estimation, since it would result in a overestimated baseline attenuation level, thus leading to an underestimation of the rain rate. On the contrary, if a dry period is wrongly identified as wet, the resulting error in rain rate estimate would be less critical, for the estimated amount of rain in that period would be small anyway (being the attenuation and the attenuation difference small for that time interval). Therefore, one "guard region" is left before and after each sequence of one or more wet intervals; those regions span over a whole 15 min interval, and are defined as "buffer" intervals. These intervals may contain some minutes of rain, and are therefore discarded when the baseline attenuation level is calculated.

Table 1. Coefficients of the $\hat{R} - \bar{\gamma}$ relation.

	c	d
f=13.5 GHz	21.63	0.847
f=24.1 GHz	7.63	0.927

To identify wet and dry periods we have developed a procedure that makes use of three variables derived from link data: two are specific attenuation $\hat{\gamma}_1$ and $\hat{\gamma}_2$ (obtained subtracting the approximate baseline from the measured attenuation), averaged over one minute; the third variable is the standard deviation σ of the frequency scaling f_{sc}, defined as $f_{sc} = \hat{\gamma}_1/\hat{\gamma}_2$. We must stress here the importance of "cleaning" the times series of attenuation from spikes and artefacts that can be generated by devices malfunction, noise, propagation effects (scintillation), etc.; this is of fundamental importance since the standard deviation of frequency scaling is extremely sensitive to these anomalies.

In detail, our procedure states that a 15 minute interval can be classified as wet if both of the two following conditions hold: first, for each frequency, specific attenuation is greater than the value expected for a rain rate of 1.2 mm/h at least for one of the 15 values in the whole interval (there is no need that attenuation thresholds are exceeded in the same minute of the interval at both frequencies); second, the standard deviation σ is less than 1.2. To compute critical limits for the specific attenuations we used (1) assuming a gamma DSD with μ=0, raindrops of Oguchi spheroidal shape and a water temperature of 10°C.

When wet and dry periods are identified, baseline level is computed through a linear interpolation of the attenuation values measured immediately before and after the event itself, i.e. in correspondence of the two dry periods that delimit the "wet" period.

3 The experimental campaign

To test the effectiveness of the new method, two dual-frequency links were installed in December 2002 in Northern Italy; both of them use the frequency pair 13.5 and 24.1 GHz, horizontal polarization. One link is located in the "Mallero river" basin, near Sondrio (Alps); the total length of the radio path is 7.5 km; three raingauges are also installed, one at the transmitter site (Primolo, 1240 m a.s.l.), one at the receiver site (Valdone, 650 m a.s.l.) and one in the mid point (Torre, 720 m a.s.l.). A second link is located in the "Rio Centonara" basin, near Bologna (Apennines); the total length of the radio path is 3.6 km; two raingauges are available, one at the transmitter site (Settefonti, 280 m a.s.l.) while the other one is about half-away along the link path (Ossani). Since

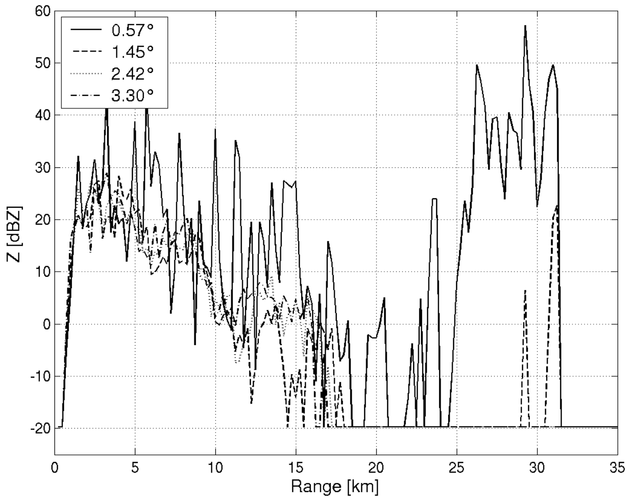

Fig. 2. Radar reflectivity versus range at different elevations. Data collected during a dry day. The first elevation (0.57°) shows clear signs of ground clutter contamination.

data from those raingauges were not always available (due to technical problems), we exploited also a nearby device belonging to the agricultural department of Bologna University (Varignana, 350 m a.s.l.). Moreover the Regional Meteorological Service ARPA/SMR also provides radar data, that have been used in this work. The radar is located near Bologna, in San Pietro Capofiume, at about 27.5 km from the experimental site; the radio link is parallel to the radar beam; please refer to Fig. 1 for a map of the experimental site. The radar sensor operates at C band, and it has Doppler and dual-polarization capabilities; the resolution is 250 m in the radial direction, and 1 deg in the transverse directions (beamwidth); this means that there are 14 cells over the radio link.

The first elevation (0.57 deg.) shows clear signs of ground clutter contamination; this can be deduced from Fig. 2, that shows radar reflectivity versus range for different elevations, gathered during a dry day.

For this work we have used the 1.45 deg. elevation, that showed to be a good compromise between freedom from clutter echoes and minimization of the probability of intercepting the bright band. To clarify this point, Fig. 3 shows radar reflectivity versus range for different elevations, gathered during the event of December 31 (that will be presented later) at 07:48; there is a clear bright band present, that "appears" over the link if the 3.30 deg. elevation is used.

4 Two case Studies

In this section the results related to two events of persistent rain will be shown. A preliminary analysis has been carried out on radar data, to assess the absence of significant attenuation along the path towards and from the cells located above the link. C-band radars can – in fact – experience significant propagation effects during heavy rain events, that usually translate into a significant underestimation of rain rate.

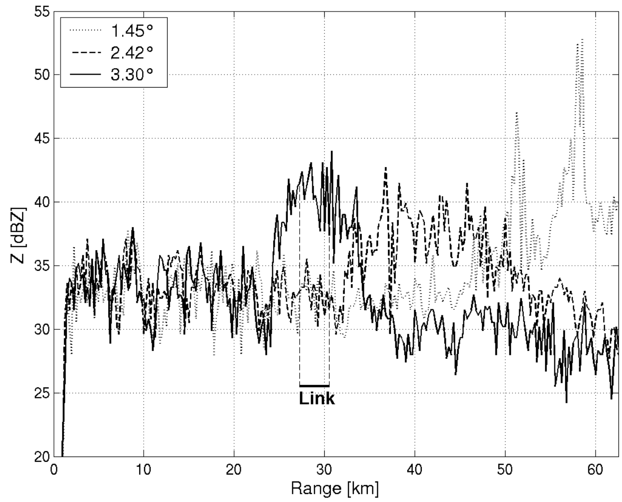

Fig. 3. Radar reflectivity versus time at different elevations. Data collected on December 31, 2002, at 07:48.

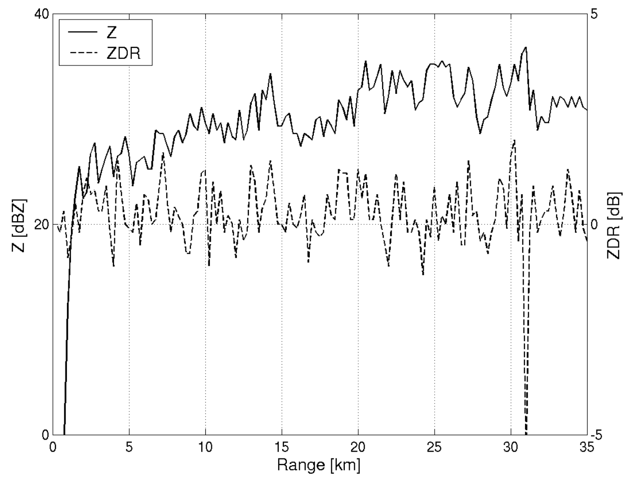

Fig. 4. Differential radar reflectivity and horizontal radar reflectivity. Data collected on December 31, 2002, at 15:48.

To this purpose, differential reflectivity values have been investigated at the time of maximum detected rainfall, for each event; one example of this is shown in Fig. 4, that refers to the event of December 31 (that will be presented later) at 15:48. It can be easily verified that the average value of Z_{DR} is almost constant with distance, thus revealing the absence of significant levels of differential attenuation (and hence of attenuation).

For each event, we first tried to compare the time series of R relative to raingauges detection, microwave links and radar estimates. We found out that the substantial differences in time resolution among these instruments do not allow for a meaningful comparison. In particular, radar and raingauges are not always able to detect peaks of precipitation that last for a few minutes only; these peaks are usually detected by the microwave link. A more reliable (i.e. stable) measurable is the cumulated rainfall, and we used that to compare the different instruments.

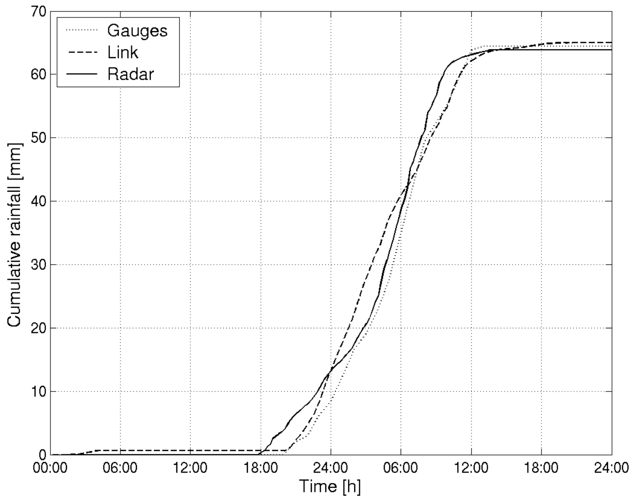

Fig. 5. Time series of cumulative rainfall obtained from link measurements, rain-gauges and radar data; data collected on December 17–18, 2002 in Bologna (elevation 1.45°).

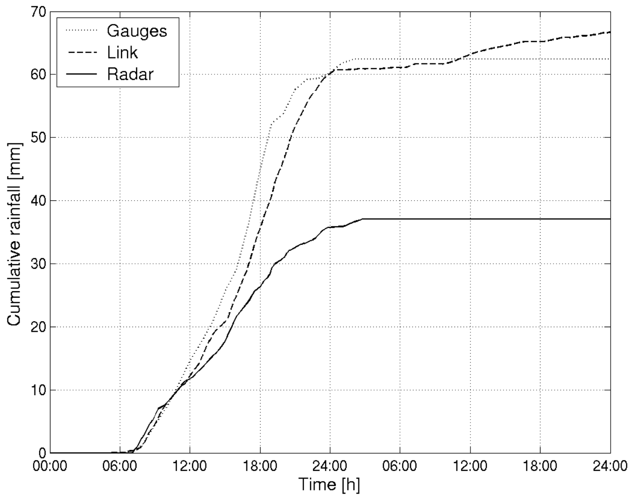

Fig. 6. Time series of cumulative rainfall obtained from link measurements, rain-gauges and radar data; data collected on December 31, 2002–January 1 ,2003, in Bologna (elevation 1.45°).

The first event occurred on December, 17–18 2002. For this event, raingauges records rain between 20:00 pm, December 17, and 13:00, December 18, as shown in Fig. 5; radar detects precipitation two hours earlier, while the end of the event is detected at the same time as rain gauges. The link detects the beginning of the event coherently with raingauges observations (apart from a negligible detection at 04:00, December 17), while the end of the event is observed 5 h later than the other detection devices. All the instruments agree very well on the cumulative amount of rainfall.

For the second event raingauges, radar and link detect the beginning of the event at about 07:00, December 31. The end of the event is at about 02:00, January 1, for the gauges whilst the radar observed the end 1 hour later, as shown in Fig. 6; the link detects “rain” until 12:00, January 1. For this event, the radar ends up detecting a smaller cumulative rainfall amount than the other instruments; this is intriguing,

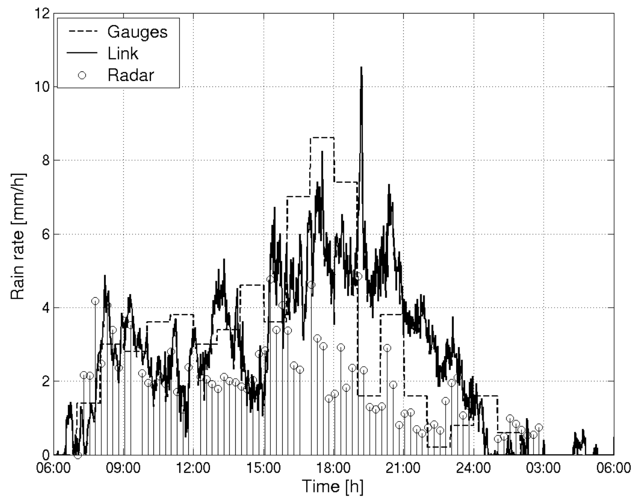

Fig. 7. Time series of path-averaged rain rates obtained from rain-gauges, from link measurements and from radar; data collected on December 31, 2002–January 1, 2003 in Bologna.

since we have evidence that no significant attenuation was experienced at C band, and that hydrometeors were actually raindrops (temperature was well above 0°C); moreover, using the contiguous radar beams (both in azimuth and elevation) we get substantially the same results. So we have no explanation for this behaviour, other than hypothesizing an effect of the drop size distribution.

To get the complete picture, in Fig. 7 we plot the time series of the rain rate, as estimated by the three instruments. It can be seen that they agree reasonably well up to 13:00, December 31; afterwards the radar systematically underestimates the precipitation.

5 Conclusions

An innovative method of estimating rainfall via the attenuation it causes to a ground-based microwave link has been described. Few results obtained with the concurrent use of radar (C-band, dual polarisation), raingauges and a dual-frequency microwave link have been presented. It has been shown that there is an encouraging agreement between the results obtained by the three instruments. As a consequence we can conclude that the microwave link is eligible as a reasonable complementary way to detect rain rate together with the other discussed devices.

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