How Well Can ARM Measure Liquid Water Path During Precipitation?

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MULTI-WAVELENGTH RADAR OBSERVATIONS

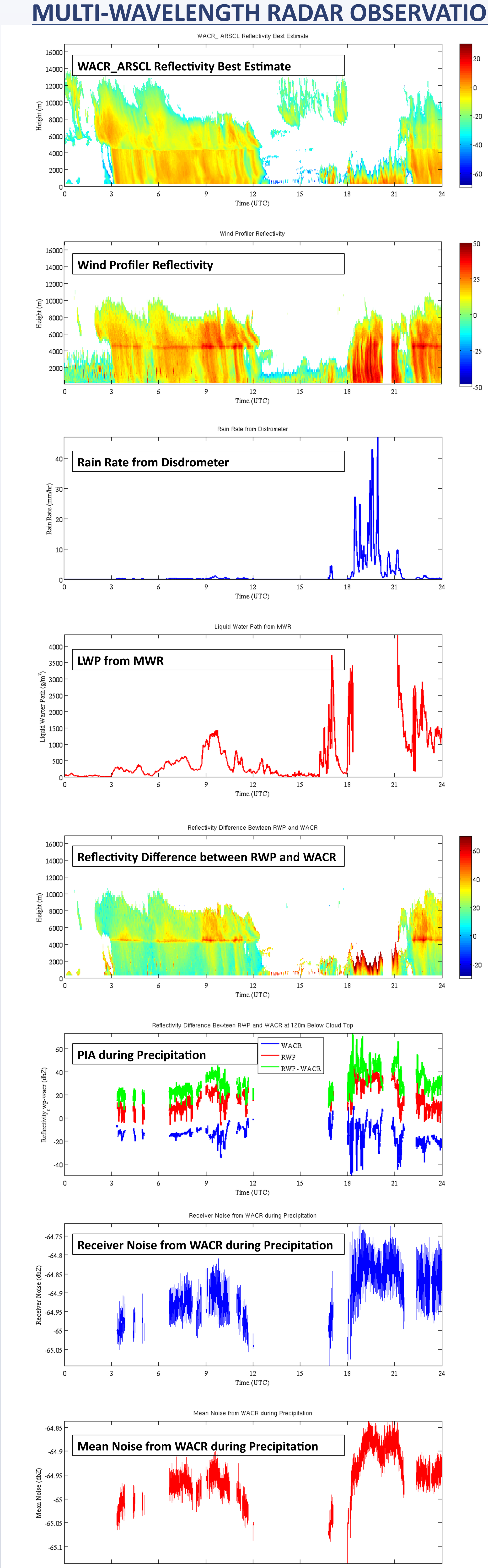

Figure 1: Time series comparison of multi-wavelength radar and PIA at MAO, Brazil, 20150222, during GOAMAZON Campaign.

ABSTRACT

Column integrated liquid water path (LWP) measurements are a critical parameter for cloud and precipitation studies. However, our ability to measure the LWP when a measurable amount of precipitation reaches the ground is limited. Here, first, we investigate at what point, the MWR LWP measurements become unreliable. Second, we investigate the potential of radar-based techniques to provide an estimate of the LWP using Path Integrated Attenuation (PIA) techniques based on multi-wavelength radar observations that account for the wet radar radome effects. Furthermore, a preliminary analysis is presented of the feasibility of using the calibrated sky brightness noise observed at every time profile by the W-band ARM Zenith-pointing Radar (WACR) to estimate LWP during precipitation.

MOTIVATION

LWP, defined as the integral of liquid water content, is an important quantity in understanding radiative transfer in the atmosphere. On one end of the spectrum (thin clouds), accurate measurements of low LWP values are needed to accurately assess the radiative effect of clouds and parameterize their propensity to precipitate (e.g., autoconversion schemes). A number of retrieval techniques that combine active (e.g., dual-wavelength radar) and passive (infrared and microwave) techniques have been developed to improve our ability to measure low values of LWP. On the other end of the spectrum (deep precipitating clouds with high liquid water amount), the ARM program upgraded its radar facilities with the intent to measure precipitation. A number of radar-based techniques that can provide estimates of the rain water path and in-situ ground-based sensors that measure rain rate and raindrop size distributions at the surface are available. However, our ability to measure the LWP when a measurable amount of precipitation reaches the ground is limited. During precipitation, microwave radiometer (MWR) measurements become unreliable due to wetting of the sensor. In addition, non-Rayleigh effects can introduce biases to the measurements. The lack of LWP measurements will hinder our ability to conduct closure studies and investigate precipitation efficiency at the ARM sites.

WHEN DOES THE MWR STOP WORKING?

LWP measurement from the MWR becomes ambiguous when precipitation presents. Moreover, the LWP value does not represent a valid measurement during heavy precipitation because of sensor saturation (reaching its max value) or water on the sensor window. Figure 1 (c),(d) and Figure 2 present LWP measurement from MWR aligned with rain rate from disdrometer, in 3 precipitation during GOAMAZON Campaign, at Manaus, Brazil (3 6' 47" S, 60 1' 31" W).

Figure 3 illustrates when the MWR stops reporting LWP during precipitation by introducing probability of detection $PoD = \frac{\# MWR_{work}}{\# TOTAL\ EVENTS}$. Assuming POD>=0.66 is acceptable, which corresponds to a rain rate of 0.25 mm/hr, the MWR LWP has more than a 34% failure rates. During the 3-day case study, a majority of surface rainfall (70%) fell into that category.

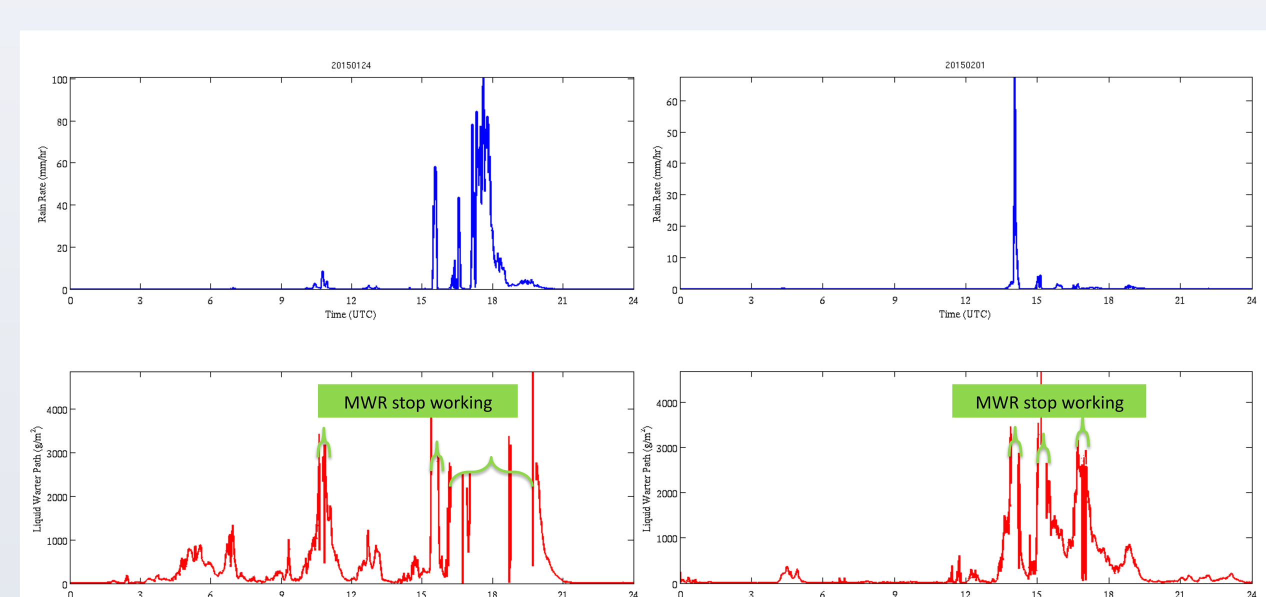

Figure 2: LWP measurement from MWR aligned with rain rate from disdrometer, showing gaps in LWP data during heavy precipitation.

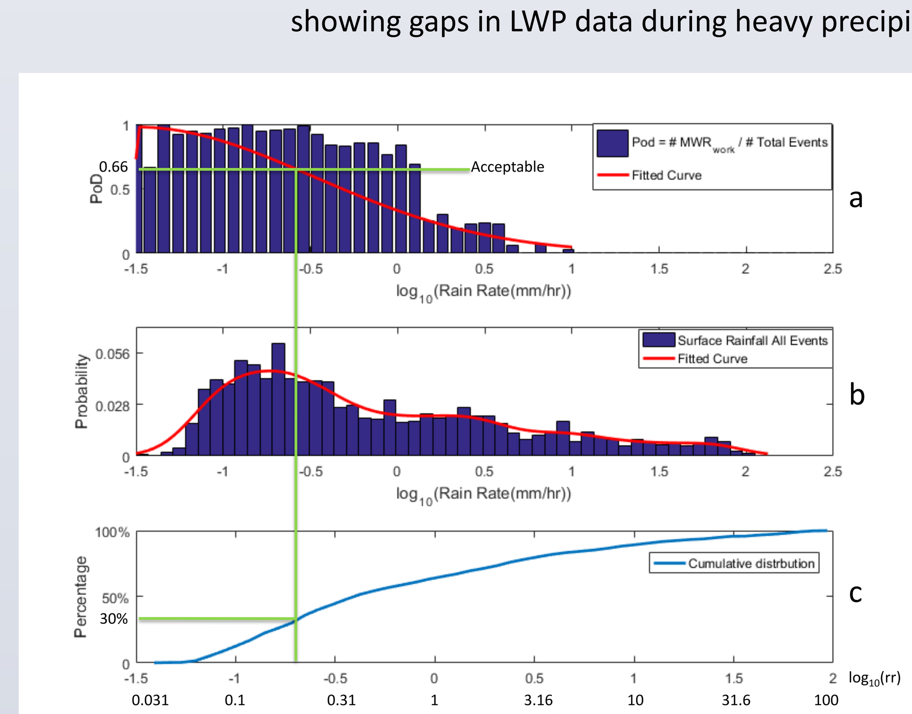

Figure 3: 3-day (20150124, 20150201, 20150222) case study at MAO site.

(a) Histogram of MWR probability of detection during precipitation.

(b) All surface rainfall distribution in log scale.

(c) Cumulative distribution function of rain rate

INTEGRATED ATTENUATION (PIA) TECHNIQUES

Attenuation accrues when a radar beam moves downstream, passing through hydrometeors, due to absorption. The beams of shorter wavelength radars, such as the WACR, attenuate more rapidly than those of long wavelength radars such as the RWP. Integrated Attenuation (PIA) thus is directly proportional to the total liquid water content in a column, which is LWP.

$$PIA = Reflectivity_{RWP} - Reflectivity_{WACR}\ |_{120m\ below\ common\ cloud\ mask\ top\ when\ rain\ rate > 0}$$

The green line in Figure 1(f) is the time series PIA for the events studied on 20150222.

At the same time, the radar also receives energy from backscatter. Backscatter cross section ($log(\sigma_b(mm^2))$) is typically orders of magnitude smaller than the actual particle physical cross section. The emission of radiation from backscatters provides the mean noise power received by radar.

$$mean\ noise\ power = mean(total\ signal\ power\ outside\ of\ cloud)|_{when\ rain\ rate > 0}$$

Receiver noise is the total sky noise power received prior to spectrum computation. Figure 1(g),(h) shows receiver noise and mean noise over the same time scale in dBZ.

CALIBRATED SKY BRIGHTNESS NOISE VS. LWP

Figure 4 illustrates a preliminary analysis of the feasibility of using the calibrated sky brightness noise from the zenith-pointing W-band ARM Radar (WACR) to estimate LWP during precipitation. An power fitted curve presents the following relationship:

$WACR_{noise} \propto a \cdot X^b$ X stands for LWP or rain rate

$PIA \propto a \cdot X^b$

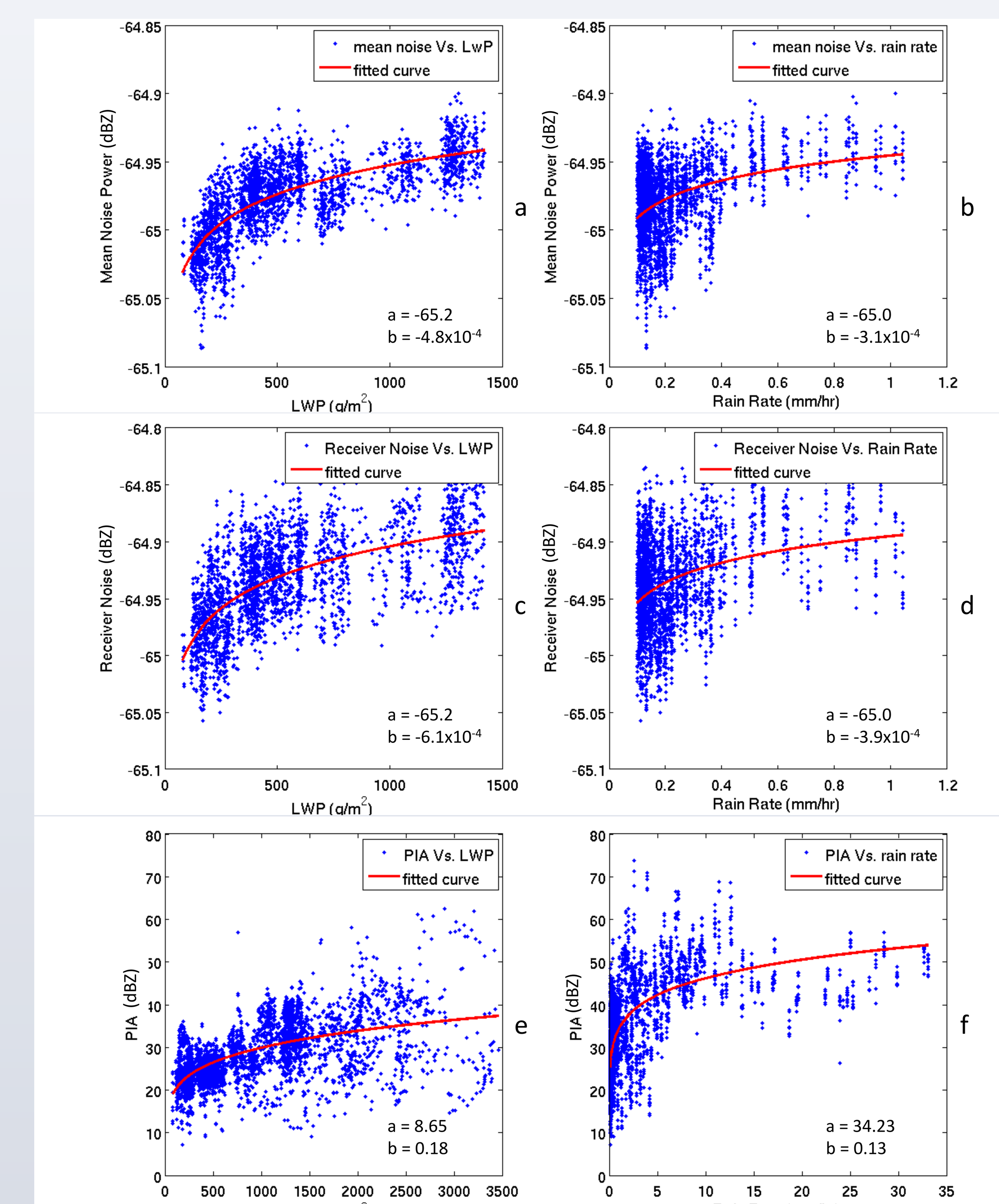

Figure 4: PIA, receiver noise and mean noise power VS. LWP and Rain Rate at MAO site, 20150222

CONCLUSIONS

- Statistical analysis reveals that MWR LWP measurements are not available during the majority of surface rainfall events. This result motivated the search for an alternative method to estimate LWP when MWR fails.
- The PIA technique is applied successfully to estimate radar attenuation. PIA show reasonable agreement with LWP, however additional filtering of the data is needed to reduce the scatter. One drawback of the PIA technique is that requires that the WACR or KAZR to penetrate the liquid layer of the precipitation.
- WACR sky brightness noise as well as mean noise show reasonable relationship to LWP. Both noise vs. LWP relationships show promise in estimating LWP when traditional MWR data is not available, however there is considerable scatter.