Statistical Analysis of Instantaneous Frequency Scaling Factor as Derived from Optical Disdrometer Measurements at V/W Bands

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Abstract

Since October 2015, NASA Glenn Research Center (GRC) and the Air Force Research Laboratory (AFRL) have collaboratively operated an RF terrestrial link in Albuquerque, New Mexico to characterize atmospheric propagation phenomena at 72 and 84 GHz. The W/V-band Terrestrial Link Experiment (WTLE) consists of coherent transmitters at each frequency on Sandia Crest and a corresponding pair of receivers in south Albuquerque. The beacon receivers provide a direct measurement of the link attenuation, while concurrent weather instrumentation provides a measurement of the atmospheric conditions. Among these instruments is an optical disdrometer which can be used to derive an instantaneous scaling factor (ISF) by which the measured data at one frequency can be scaled to another. Given the availability of both the disdrometer prediction and the directly observed 84 GHz attenuation, WTLE is uniquely able to assess the derived ISF [1-3], particularly for terrestrial links at the V/W-bands where the ISF is low and where the link is sensitive to atmospheric effects.

Experiment Design

The W/V-Band Terrestrial Link Experiment (WTLE) comprises a transmitter on Sandia Crest and twin receivers on the roof of a University of New Mexico research center (COSMIAC) in south Albuquerque. The slant path spans approximately 24 km with a look angle of 3.9°. The transmitter system consists of two coherent continuous wave (CW) beacons at 72 and 84 GHz with an EIRP of 40 dBm using two lens antennas with a 3° beam-width and 35 dBi directivity. Polarization is LHCP.

Fig. 1. The location of the V/W-band beacon receivers at the COSMIAC facility (left) and the location of the transmitter atop Sandia Crest (right) in Albuquerque, NM.

The receiver system consists of two 0.5m V and W-band Cassegrain reflectors which observe both the co- and cross-polarization components of each channel and downconvert the signals to 7 MHz at the feed before digitization. After digitization, the signals are processed using an algorithm developed in previous NASA propagation terminals [5, 6] which uses a frequency estimation technique to coherently track and measure the amplitude of the beacon signals [7]. An overall measurement rate of 10 Hz is implemented in order to characterize scintillation effects. Ultimately, the receivers achieve a dynamic range of approximately 75 dB [8].

Fig. 2. The twin V/W-band beacon receivers (left) and the Thies Clima optical disdrometer (right).

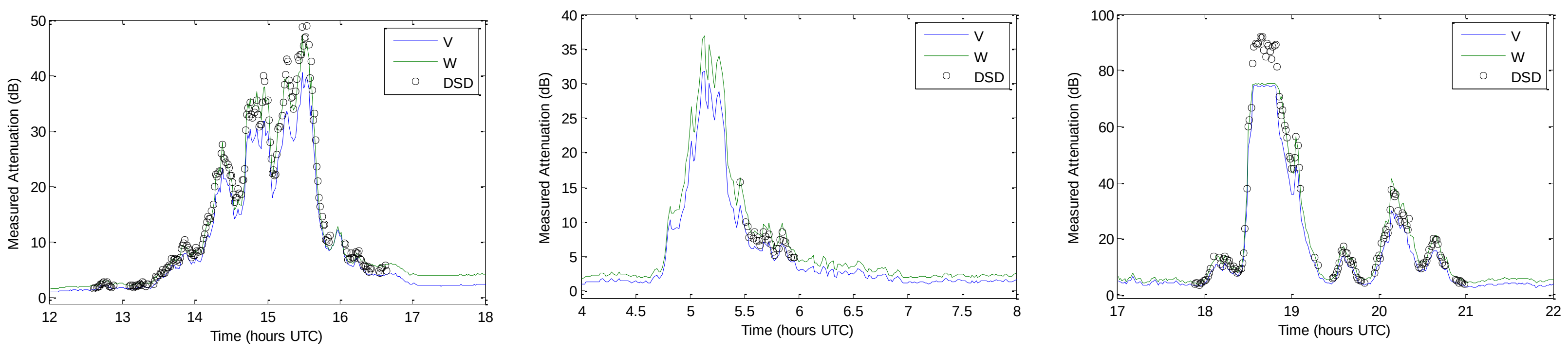

Fig. 3. Examples of a light rain event (left), a light rain event occurring primarily on the path and not over the disdrometer (center) and a heavy rain event exceeding the receiver dynamic range (right).

Analysis & Results

The instantaneous frequency scaling factor can be derived by using the drop size distribution (DSD) to calculate the specific attenuation (γ) at the frequencies of interest. The ratio, $\gamma_{84} / \gamma_{72}$, is then used to scale the measured 72 GHz data to 84 GHz and compare with the measured data taken at 84 GHz. The calculation of specific attenuation is given as in [10]:

$$\gamma = 4.343 \times 10^3 \frac{\lambda^2}{\pi} \sum Re\{S(0)\} N(D) \Delta D$$

For this analysis, the forward scattering coefficient is calculated using the Mie scattering model [11], which assumes a spherical droplet shape. The data used in this analysis spans from October 1, 2015 through June 30, 2016 and was first calibrated for system gain variation using the gain calibration tone of the receiver. After calibration, applicable rain events were isolated through a combination of automated and manual processing. Events were removed from the analysis if the disdrometer was not operational, if the receivers were not operational, or if rain was not measured by the disdrometer (i.e. occurring solely along the path). For each rain event, the attenuation level before and after the event was averaged and subtracted from the measured rain attenuation to isolate the excess attenuation due to rain.

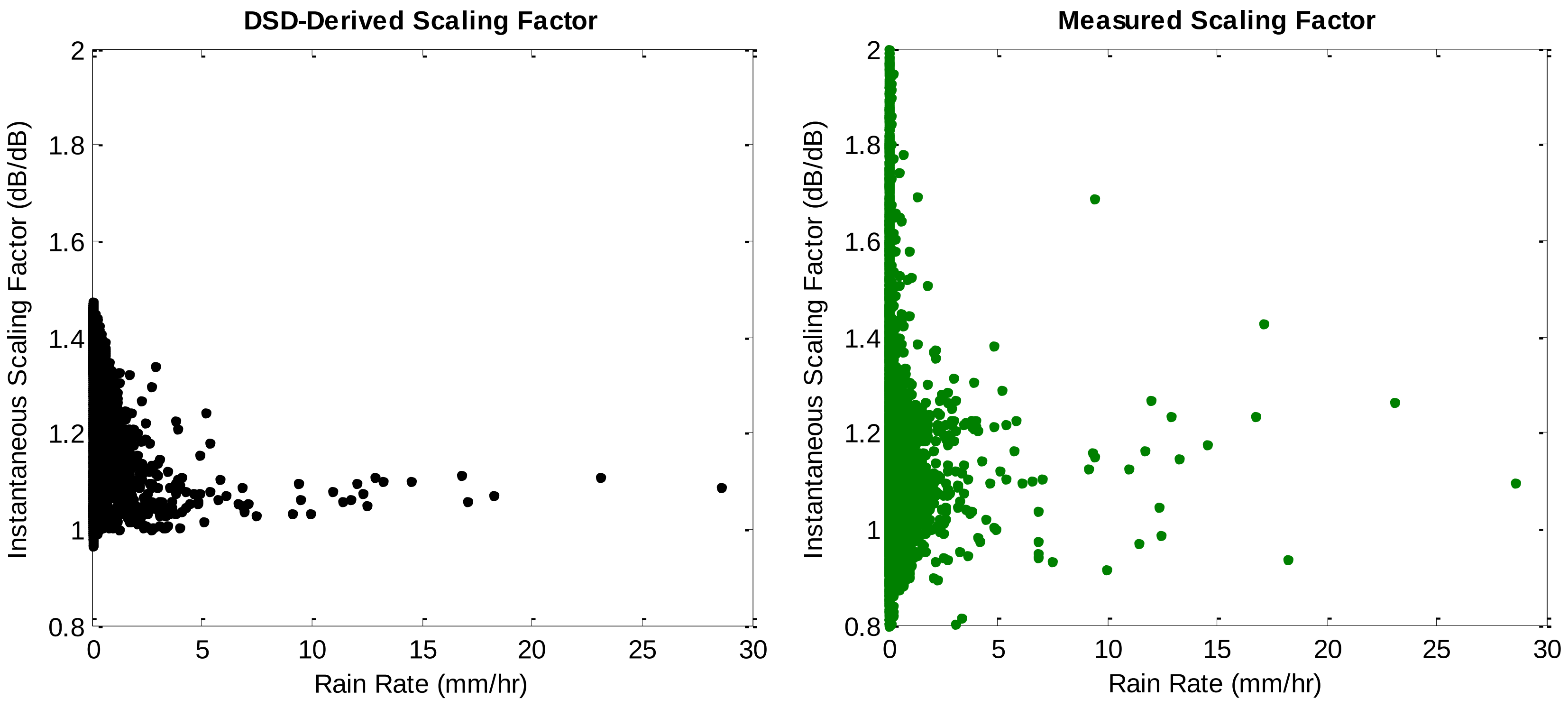

Fig. 4. The average instantaneous scaling factor for a given rain rate, as derived from the DSD (left) and as measured by the receivers (right). As shown, the ISF is averaged across rain rate bins of 0.05 mm/hr.

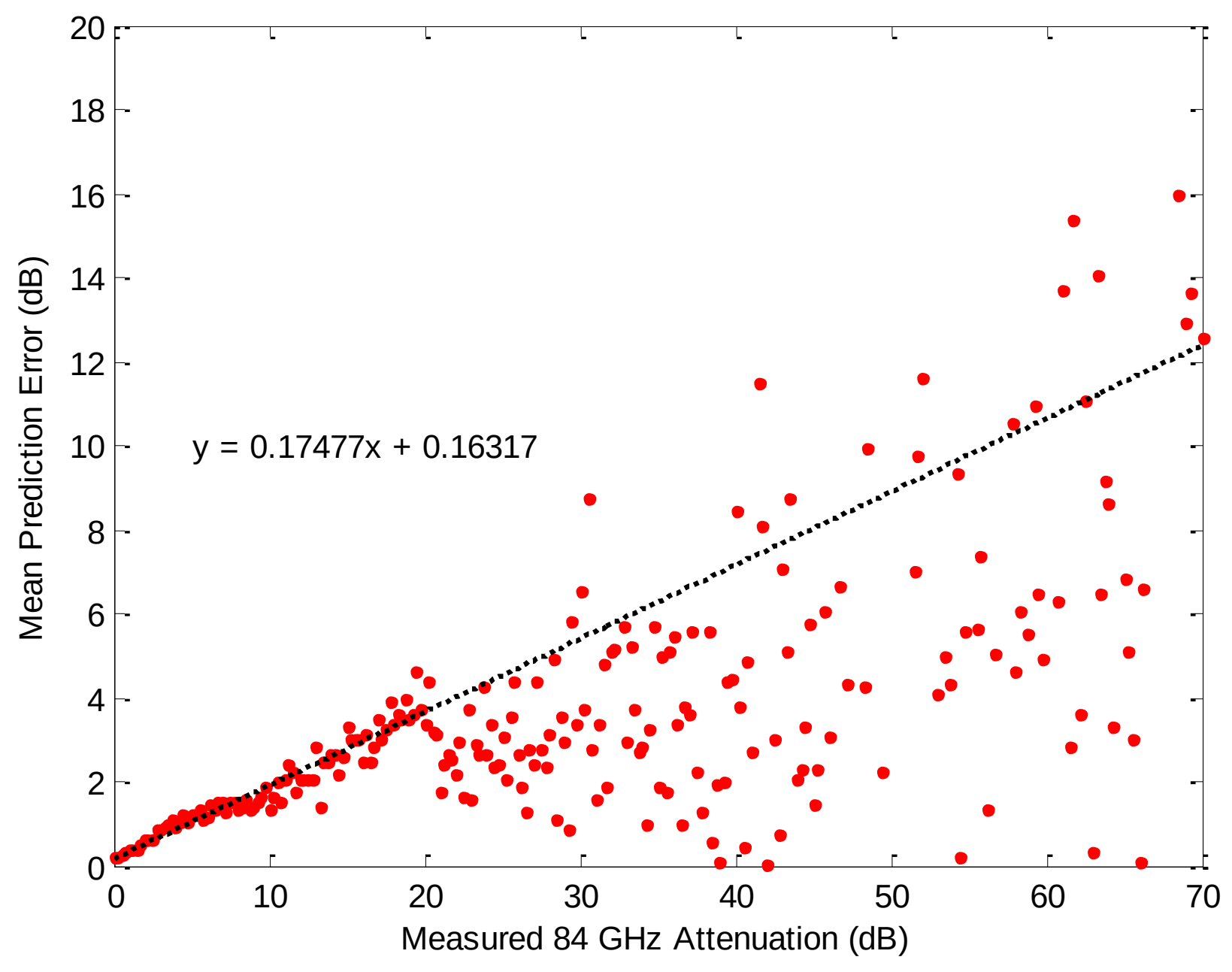

Fig. 5. The error in the DSD-predicted attenuation as a function of attenuation.

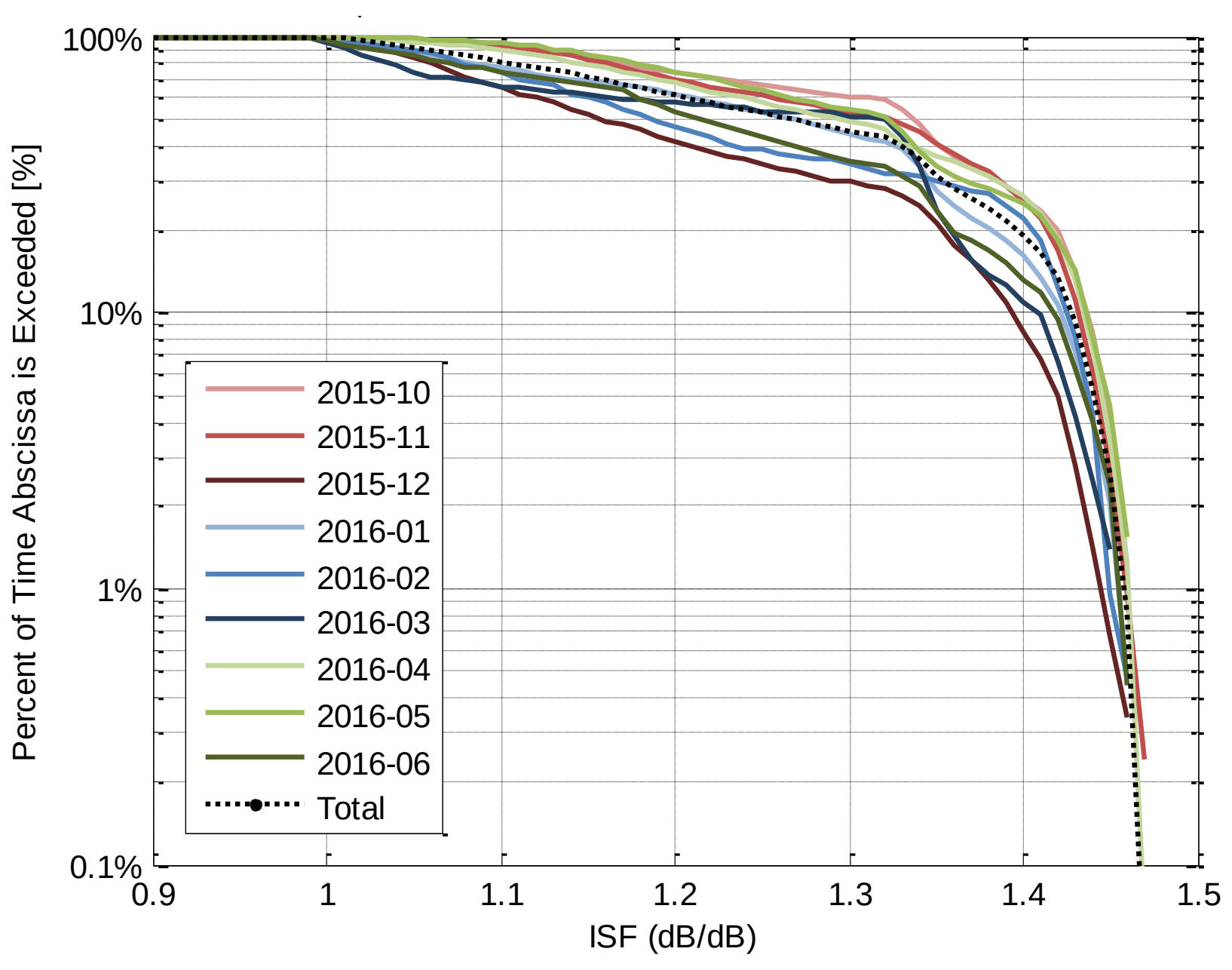

Fig. 6. The monthly and total CDFs of the DSD-derived scaling factor over 9 months.

Conclusions

In this work, we investigated the use of the optical disdrometer measurements to derive an instantaneous scaling factor for use in predicting rain attenuation at 84 GHz by the scaling of measured attenuation at 72 GHz. This analysis indicates that the instantaneous scaling factor decreases as a function of rain rate, but not to the extent demonstrated in previous work at lower frequencies when scaling over a larger range (20 GHz to 40 GHz) [1]. Also, the error of the scaled predicted attenuation was observed to increase linearly as a function of attenuation level -- a linear trend of 0.17 dB error per dB attenuation. Statistically, the ISF was observed to vary only slightly from month to month over the 9 month measurement & test period.

References are available in the full paper through the conference proceedings and/or IEEE Xplore.

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