Impact of Scattering Model on Disdrometer Derived Attenuation Scaling

Ka 13: Propagation I

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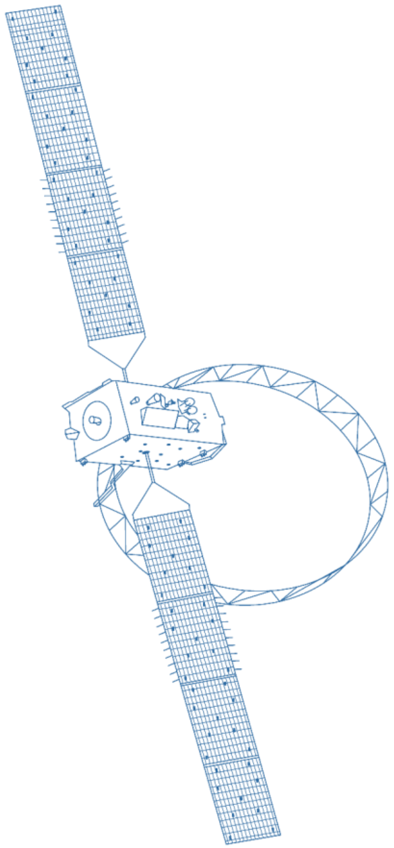
Presentation Overview

Alphasat in Ariane 5 fairing.
(Photo: ESA)



Alphasat wireframe model (deployed).
(Photo: ESA)

Motivation & Goals

Launch of Alphasat on an Ariane 5, July 2013.
(Photo: ESA / CNES / ARIANESPACE)

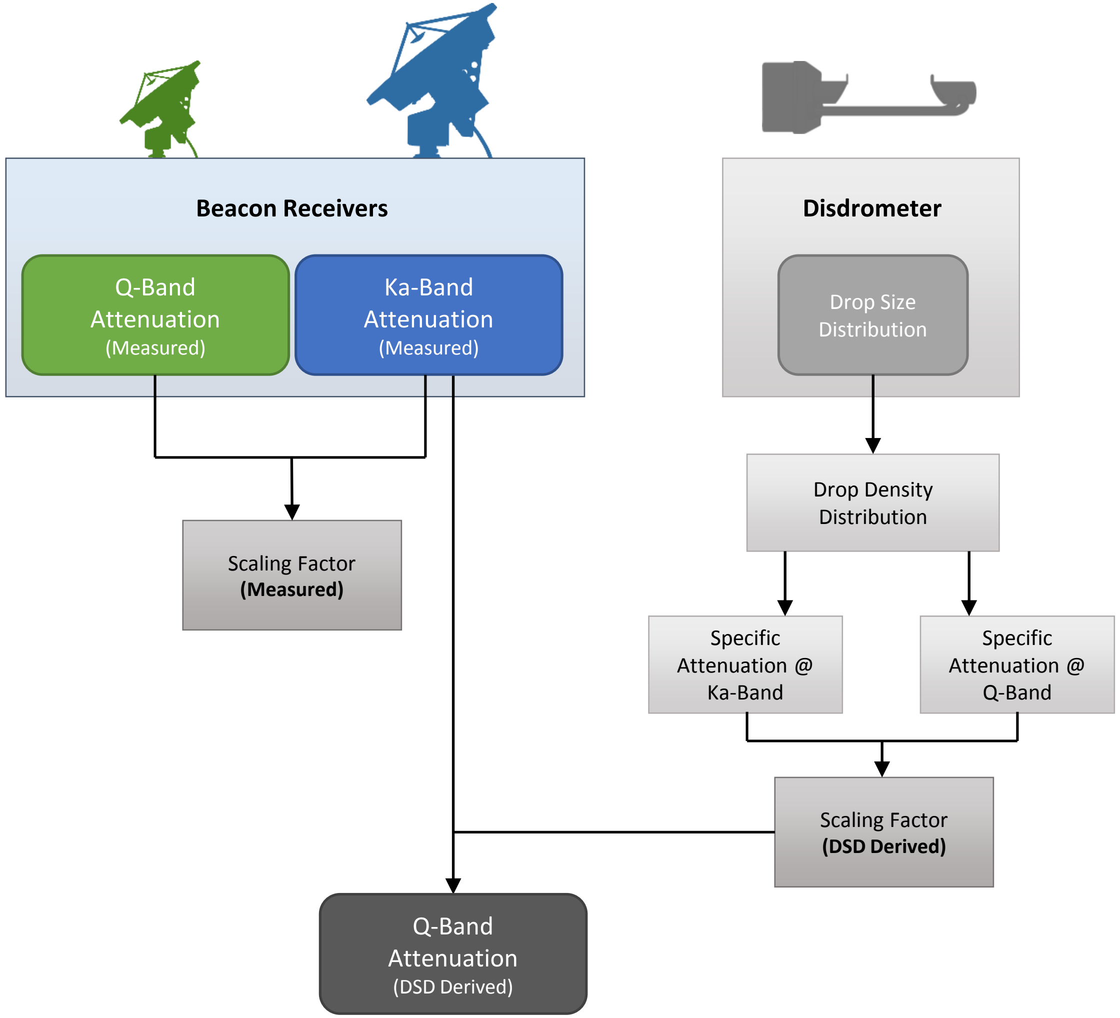
Experiment Goals

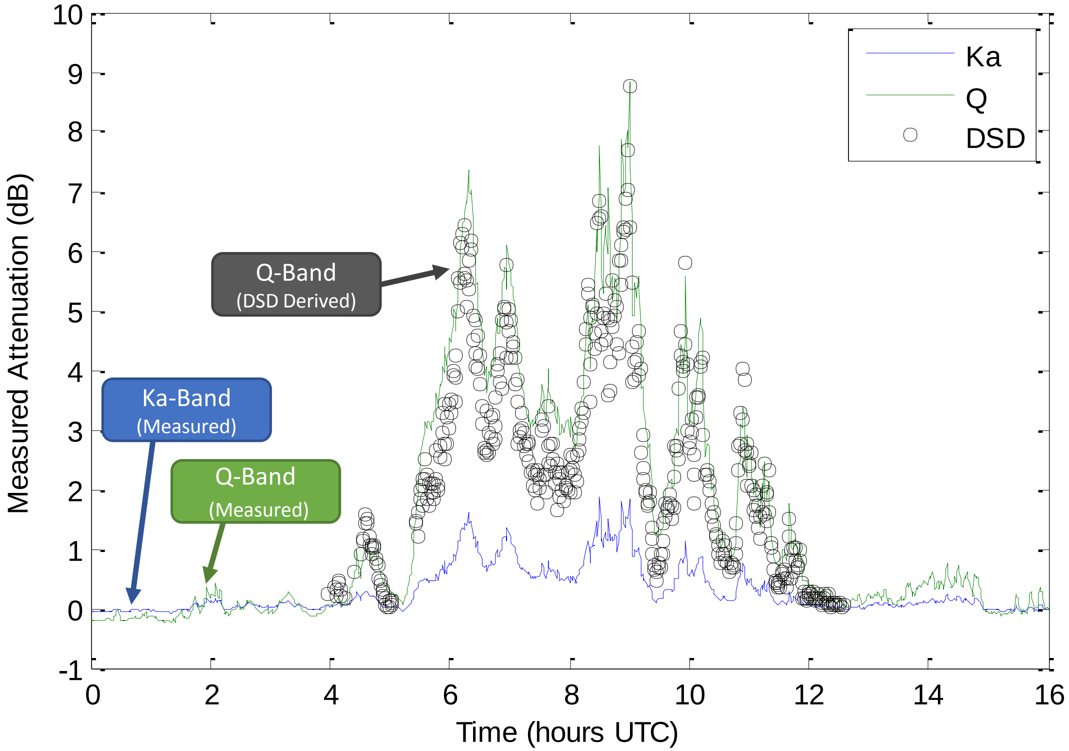
- To **assess the impact** of rain attenuation and scintillation effects on links operating in the Q-band
- To **develop a physical model** to improve predictions of atmospheric attenuation within the desired spectrum
- To conduct long term **site diversity** experiments at Q-band in coordination with Spino d'Adda site (20km)

NASA Motivation

- NASA's allocation of 4 GHz of contiguous bandwidth in the Q-band provides an opportunity to meet next generation bandwidth requirements
- Preliminary architecture studies of the next generation TDRS system will require higher downlink bandwidths than available in the current Ku-band allocation

Motivation & Goals

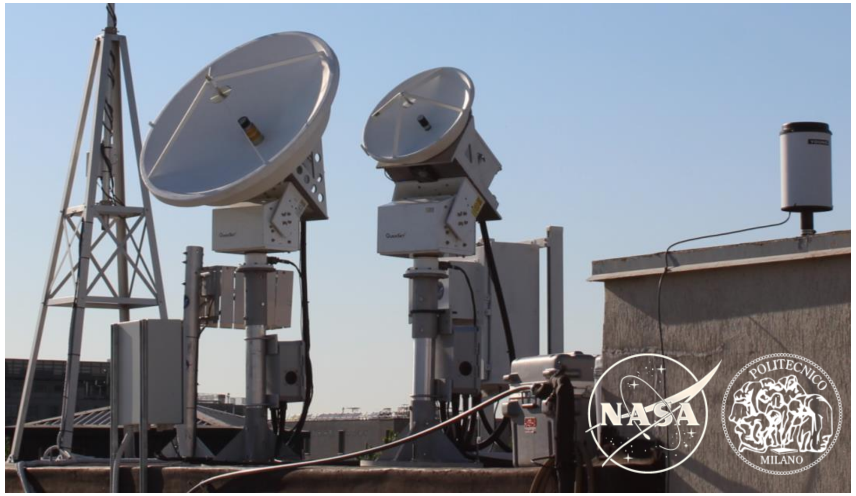


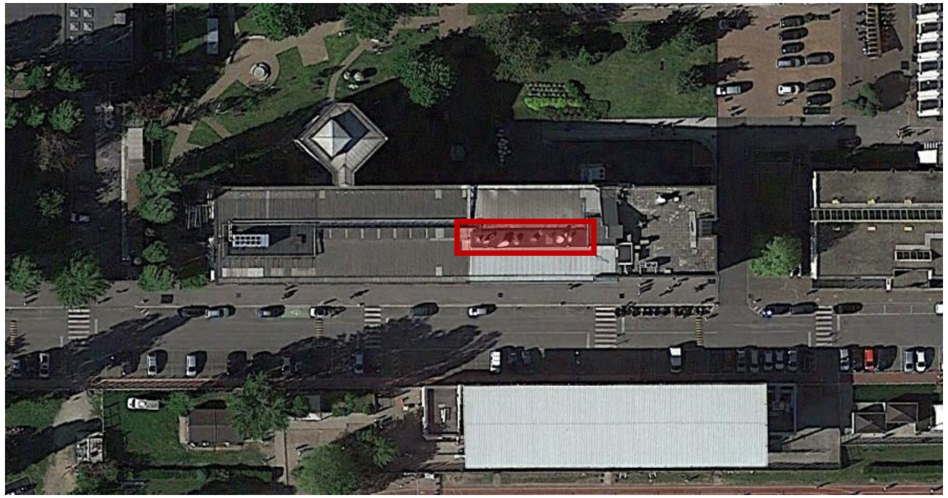


Drop Size Distribution (DSD) data from a disdrometer can be used to derive a scaling factor to scale measured attenuation data to other frequencies.

The NASA-POLIMI Alphasat terminal in Milan has the capability to directly measure 20 GHz and 40 GHz attenuation as well as concurrent DSD data, and thus is uniquely situated to assess and characterize these techniques.

Site of Study





Politecnico di Milano, DEIB Building
(Photo: Google Earth)

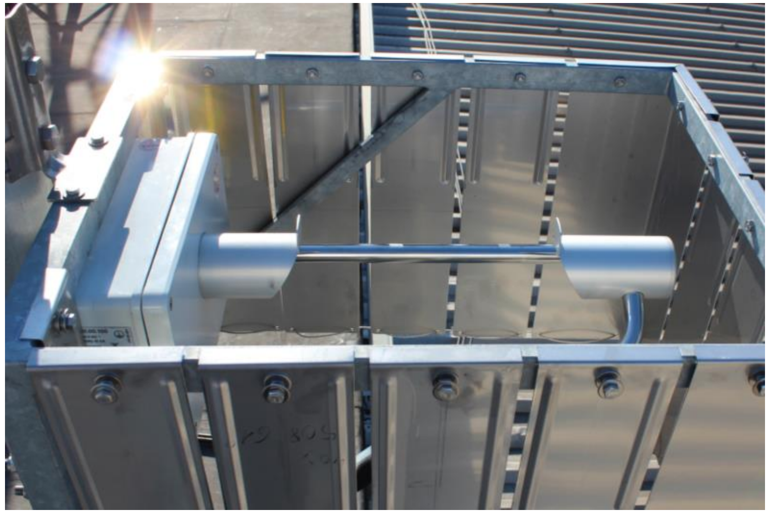
		Milan, Italy
Ground Station	Installation Date	April 2014
	Latitude	45.4787° N
	Longitude	9.2327° E
	Altitude	138 m
Satellite	Name	Alphasat
	Nom. Elevation	35°
	Nom. Azimuth	158°
	Beacon Freqs.	19.701 GHz 39.402 GHz

Instrumentation

Beacon Receivers

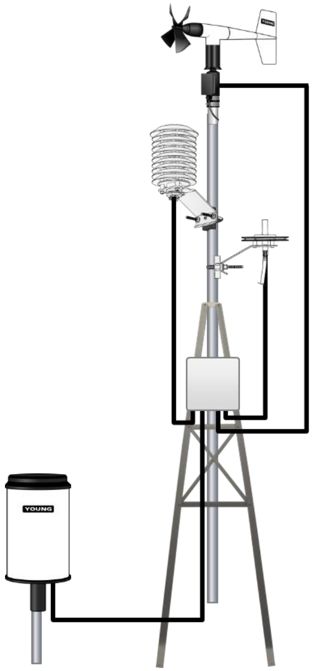
Antenna Gain	45.6 dBi (Ka / Q-band)
Sampling Period	0.125 sec (8 Hz)
Antenna Tracking Period	60 sec
Antenna Tracking Resolution	0.01°

Optical Disdrometer



Model	Thies Clima 5.4110
Sampling Period	60 sec
Measurement Area	4650 mm^2

Weather Instrumentation



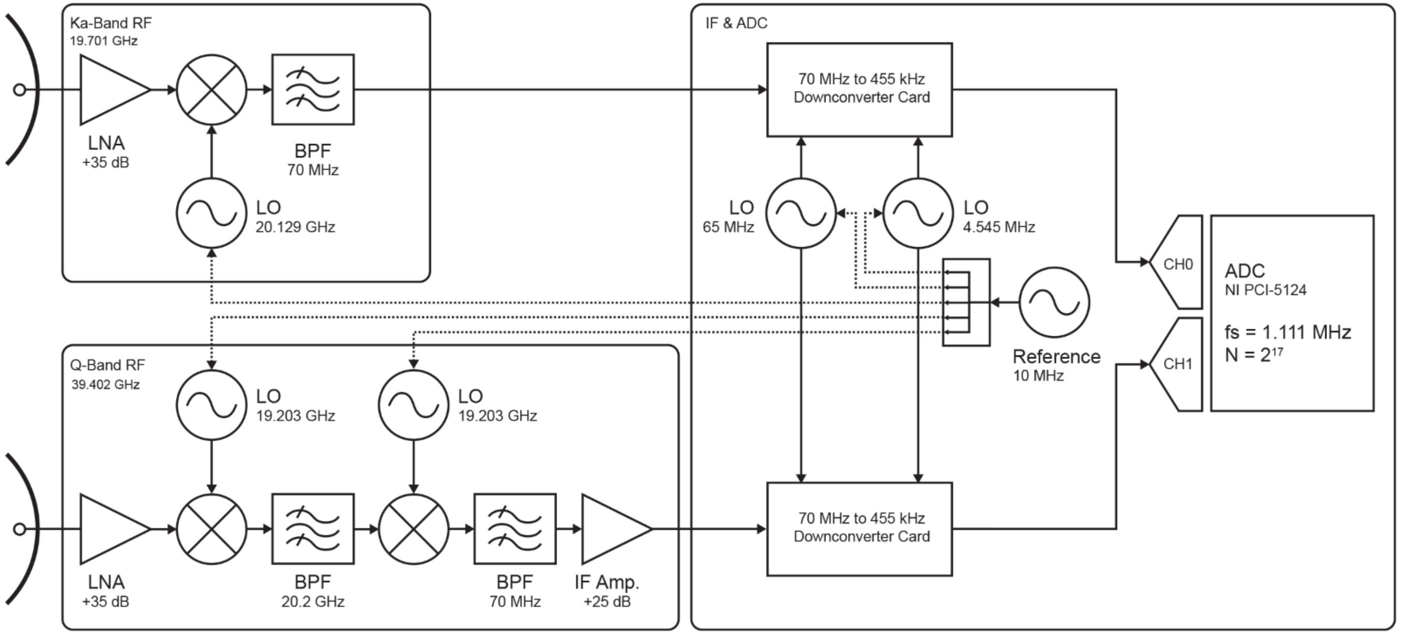
Anemometer:
Young 05178A

Temperature/Humidity Sensor:
Young 41382VC

Pressure Sensor:
Young BPV3000

Tipping Bucket:
Young 52203

Beacon Receiver Design



Beacon Receiver Specifications	
Downconversion (Ka)	3-step down to 455 kHz
Downconversion (Q)	4-step down to 455 kHz
System Noise Temperature	504 K (Ka-band) 720 K (Q-band)
Dynamic Range	38 dB (Ka-band) 40 dB (Q-band)
ADC Sampling Rate	1.111 MHz
ADC # of Samples	2^{17}
Time Series Output Rate	8 Hz / 1 Hz (averaged)

- Common ultra-stable 10 MHz ref. oscillator
- T_{LNA} temperature controlled within ±0.1°C
- $T_{RFplate}$ temperature controlled within ±0.01°C
- T_{IF} temperature controlled within ±0.25°C

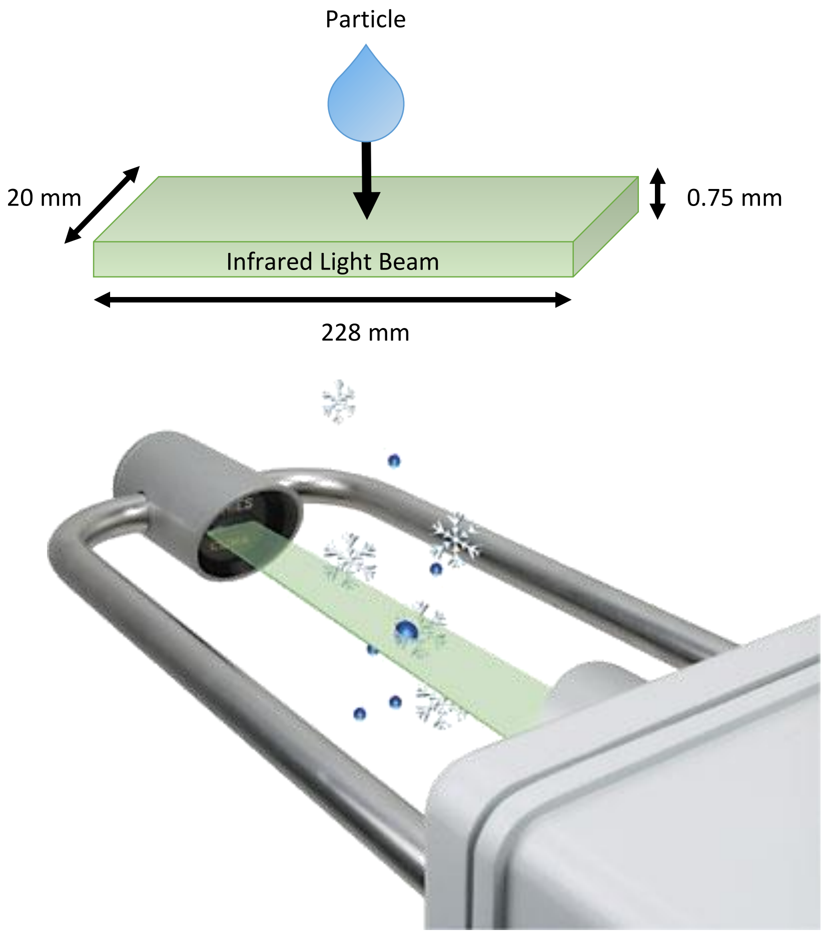
Disdrometer Specifications

- The disdrometer utilizes an infrared laser diode to generate a **785 nm** parallel light beam covering a **4560 mm^2** area swath.

- A photodiode on the receive end monitors the reduction in signal strength as precipitating particles cross the beam. From this measurement, details on the particle size and fall velocity can be derived from the magnitude and duration of the signal attenuation, respectively.

- On-board DSP classifies the type, intensity, quantity, and particle spectrum of precipitation over 1 minute intervals, as well as estimating rain rate from the DSD.

- Spectrum is classified into 22 diameter bins from 0.125 mm to 8 mm and 20 velocity bins from 0 to 10 m/s with non-uniform bin widths.



Depiction of disdrometer particle detection.
(Photo: Thies Clima)

Specific Attenuation from DSD Data

Specific attenuation is a function of the wavelength, forward scattering coefficient, and drop density distribution [5].

The **forward scattering coefficient** is dependent on frequency, radius of the rain drop, and temperature, and is calculated utilizing the **Mie scattering model** [6].

Drop density distribution is calculated from the binned DSD data using the relation shown [7].

All of these parameters are directly available from the recorded DSD data and the specifications of the disdrometer hardware, except for the **terminal velocity**, which is modelled using the analytical fit of measured data by Gunn and Kinzer [8-10].

Specific Attenuation

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

γ	*Specific attenuation*
λ	*Wavelength*
Re{S(0)}	*Forward Scattering Coefficient*
N(D)	*Drop Density Distribution*
ΔD	*Drop Size Interval*

Drop Density Distribution

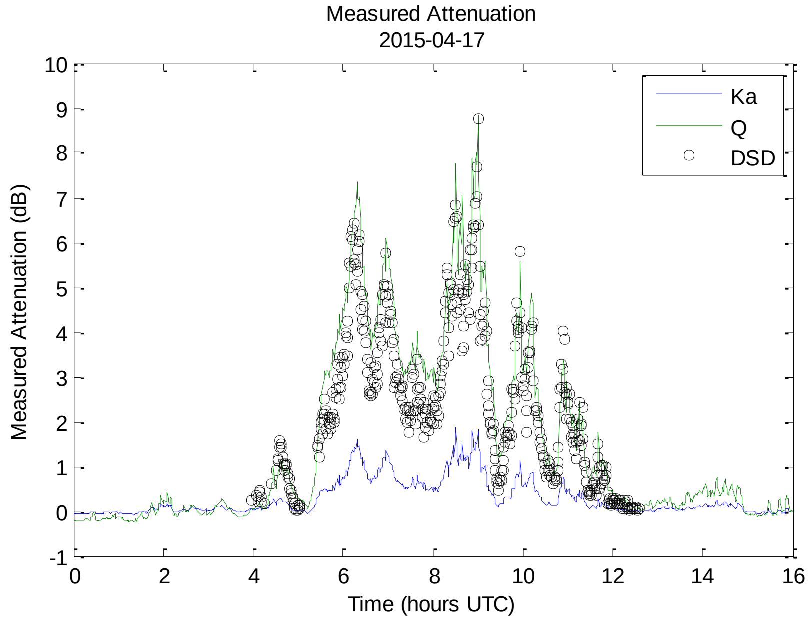
$$N(D_i) = \frac{n_i(D_i) \times 10^6}{v(D_i) \times S \times T \times \Delta D_i}$$

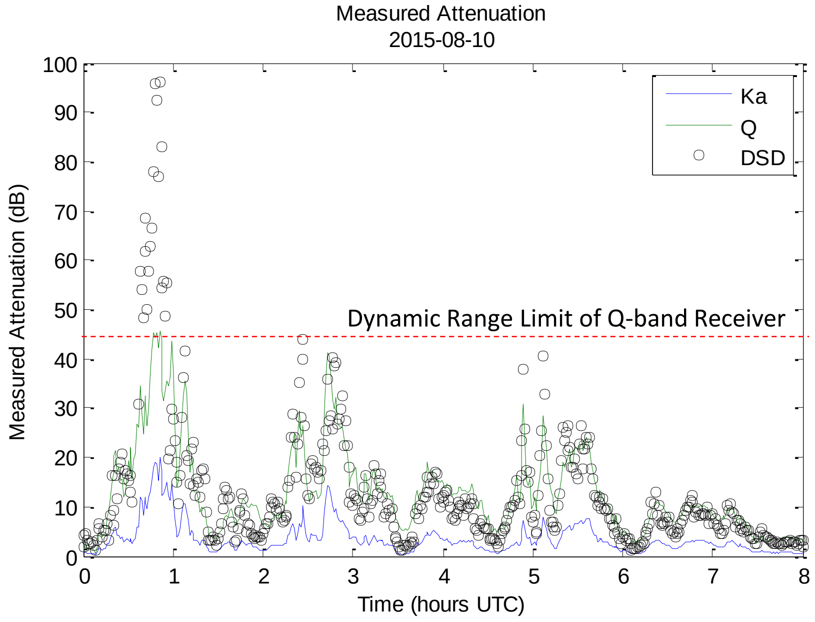
i	*ith bin*
$n_i(D_i)$	*Number of Drops with Mean Diameter* D_i
$v(D_i)$	*Terminal Velocity in Still Air*
S	*Disdrometer Sample Area (4560 mm²)*
T	*Integration Time (60 sec)*
ΔD_i	*Bin Width of Drop Size Class*

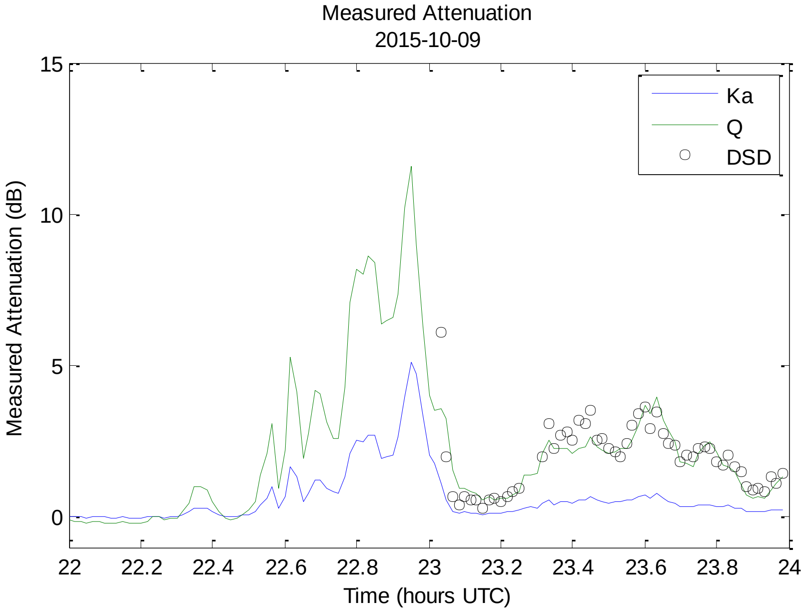
Terminal Velocity

$$v(D_i) = 9.65 - 10.3e^{-0.6D_i}$$

Instantaneous Frequency Scaling







Light Rain Event *(<10 mm/hr)*

The prediction tracks well throughout the event.

Heavy Rain Event *(<40 mm/hr)*

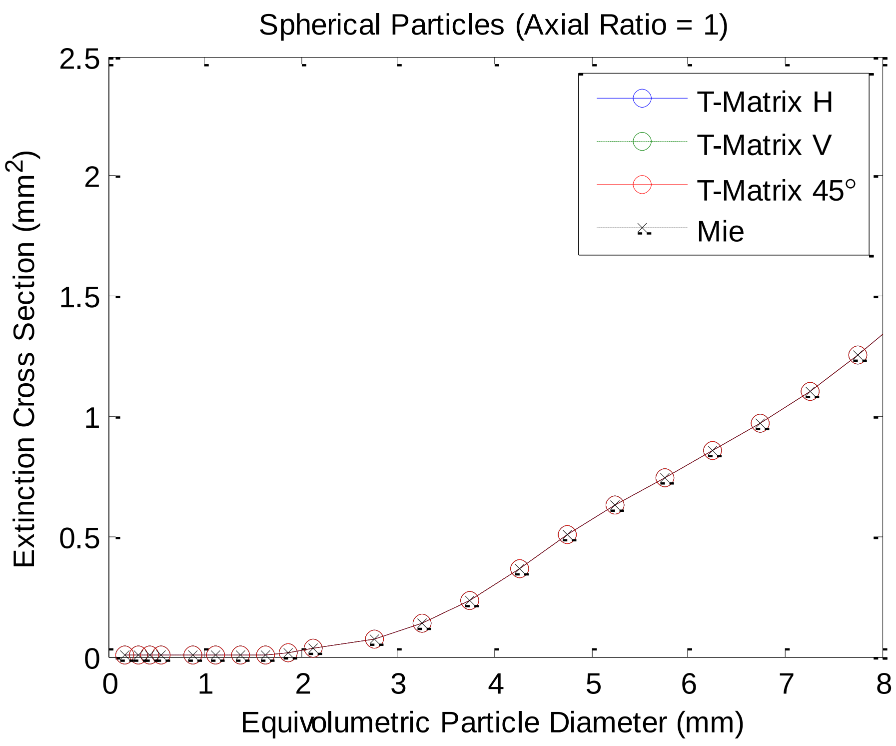
Attenuation exceeds the Q-band system dynamic range (40 dB) from approximately 00:45 – 01:00 UTC, while the DSD predicts attenuation up to 96 dB during this period.

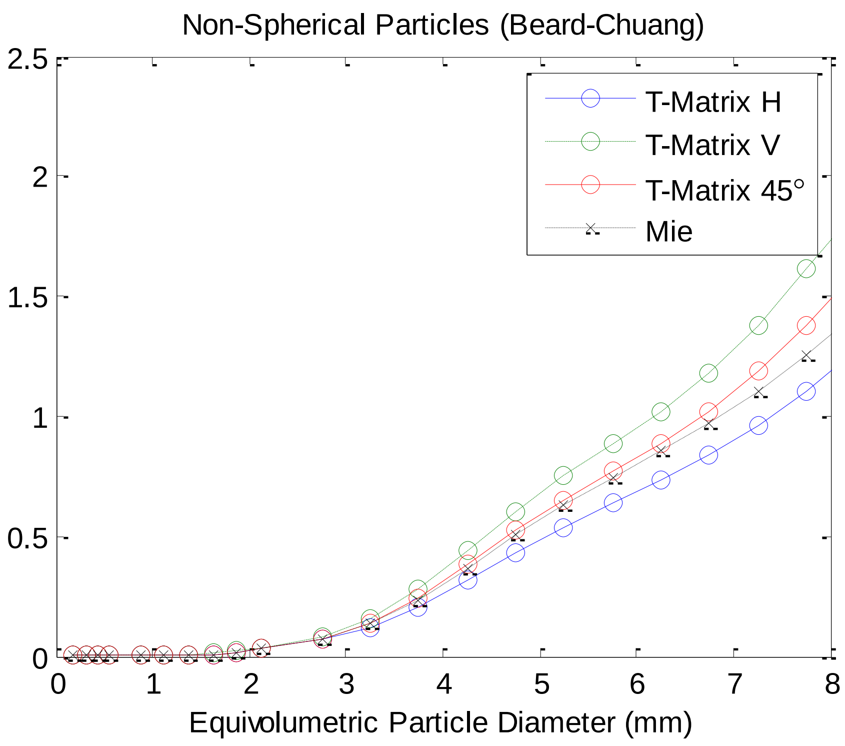
Rain Event along Path *(<10 mm/hr)*

Attenuation up to 11.6 dB is measured during the first half of the event, but no rain is measured at the site, indicating that the rain is along the path. By the end of the event, the rain cell appears to have moved overhead the receiver, and the DSD prediction tracks the measurement.

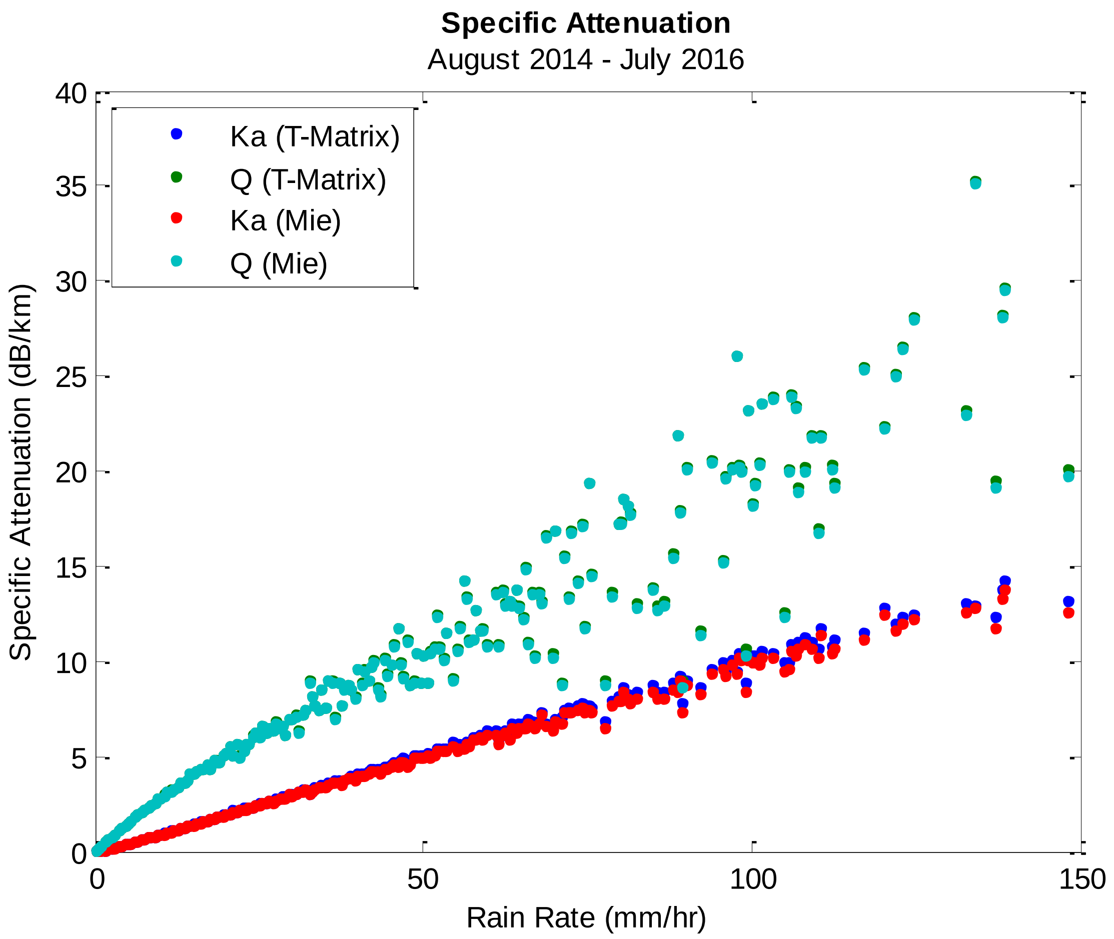
The figures above plot examples comparing the measured Ka- and Q-band attenuation to the DSD-derived Q-band attenuation calculated by applying the instantaneous scaling factor to the Ka-band measurement.

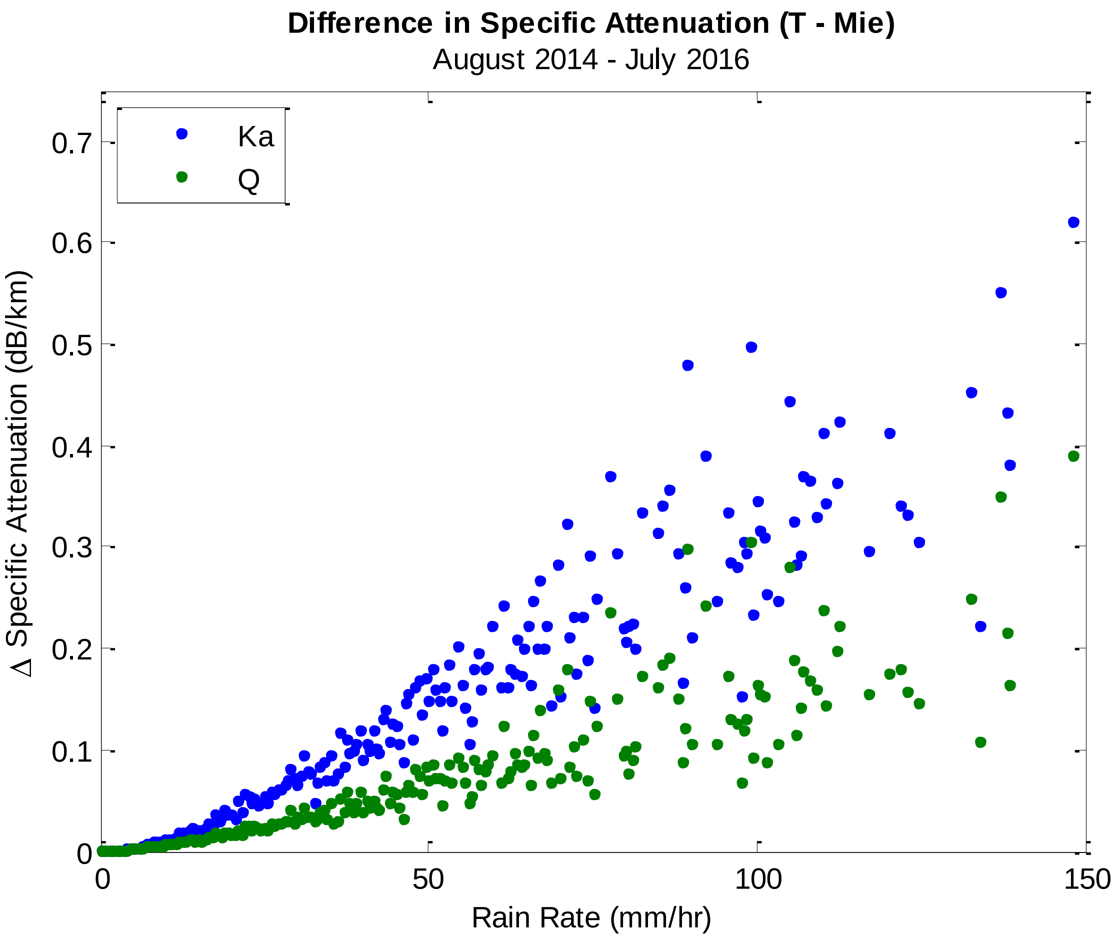
Mie vs. T-Matrix



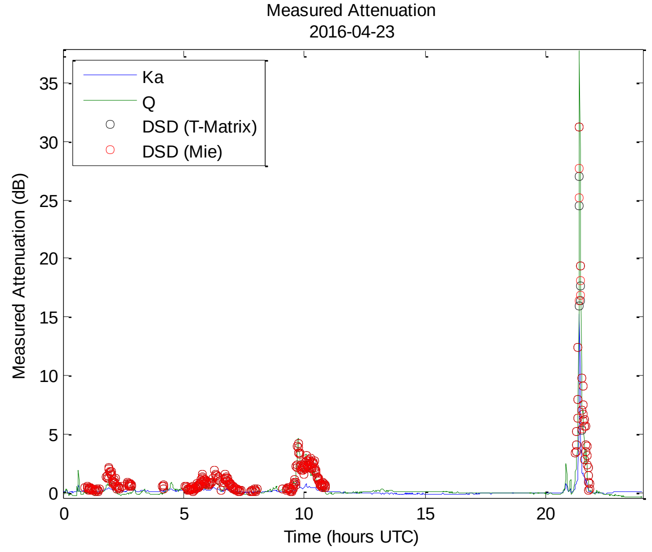


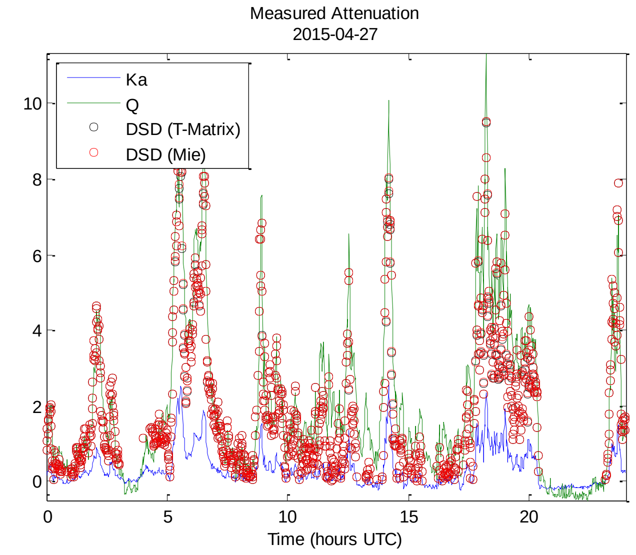
Change in Specific Attenuation

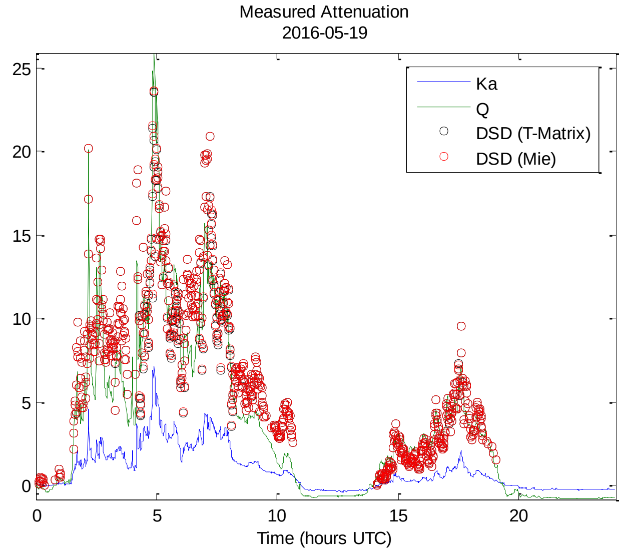


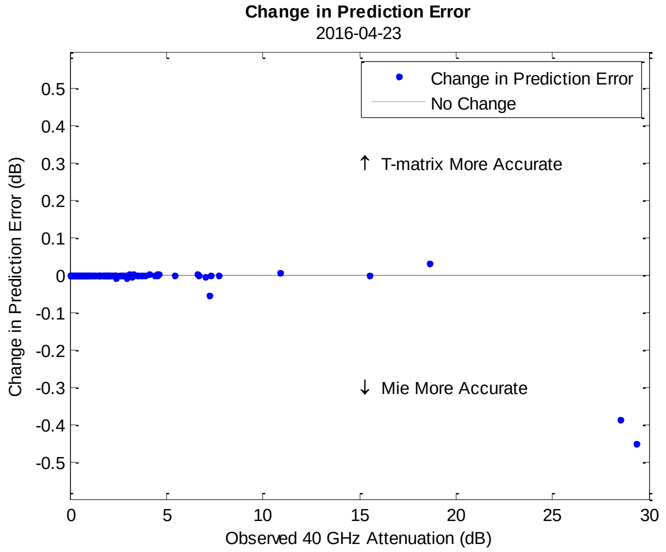


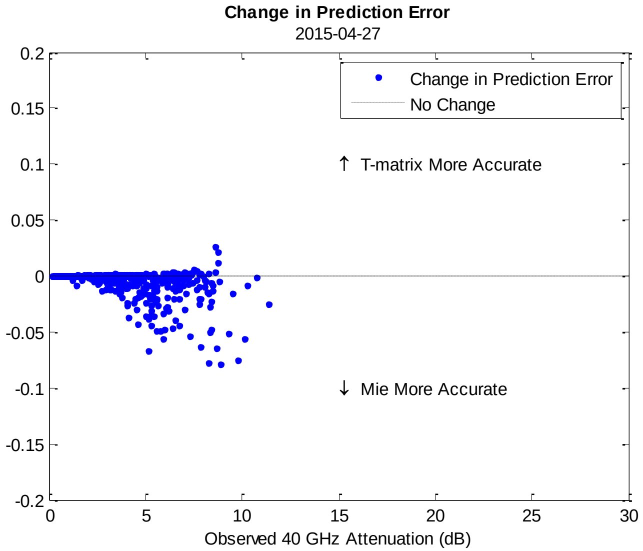
Scattering Model Accuracy

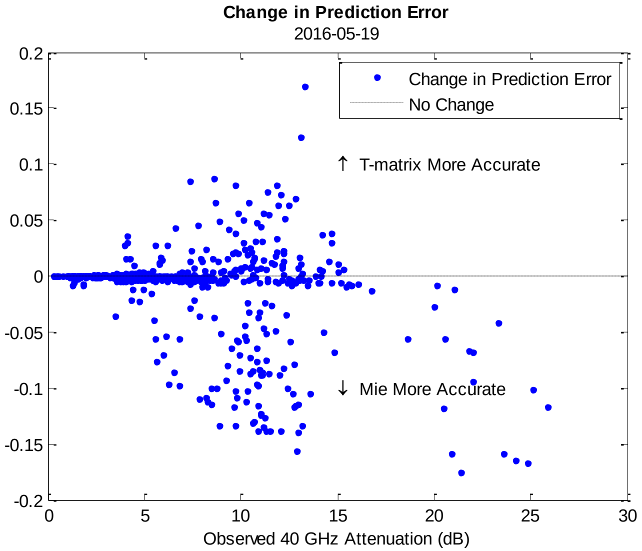




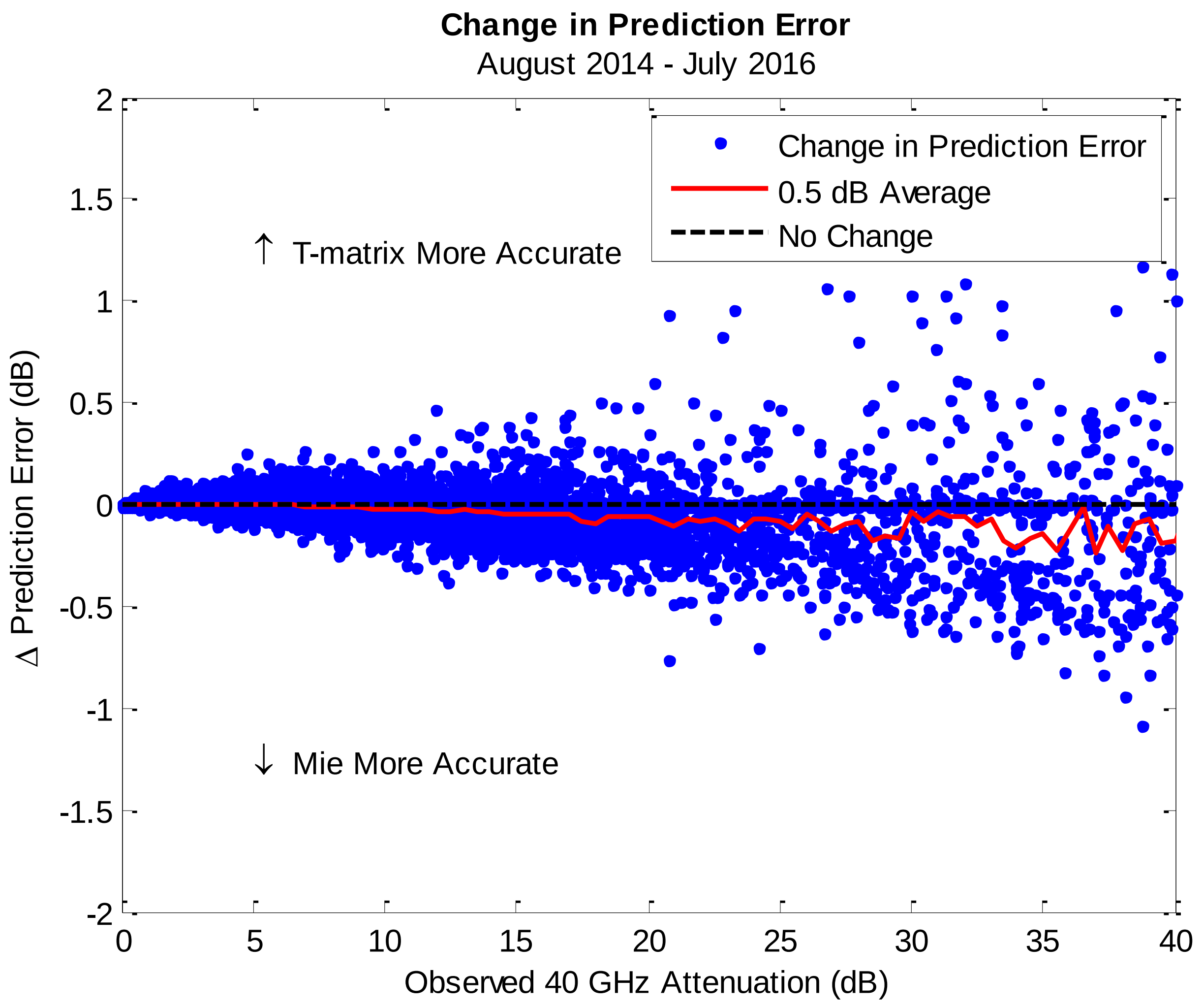




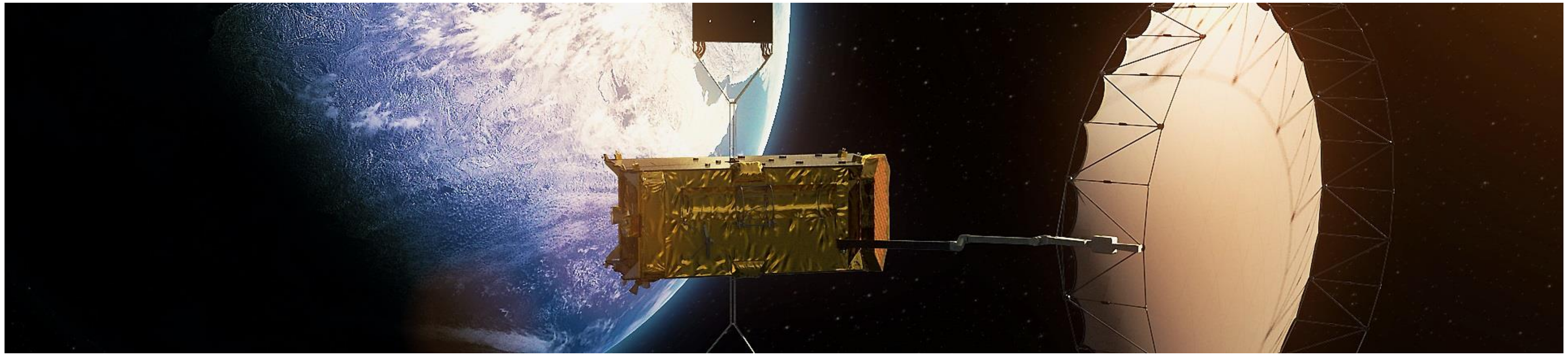




Change in Prediction Error



Concluding Remarks



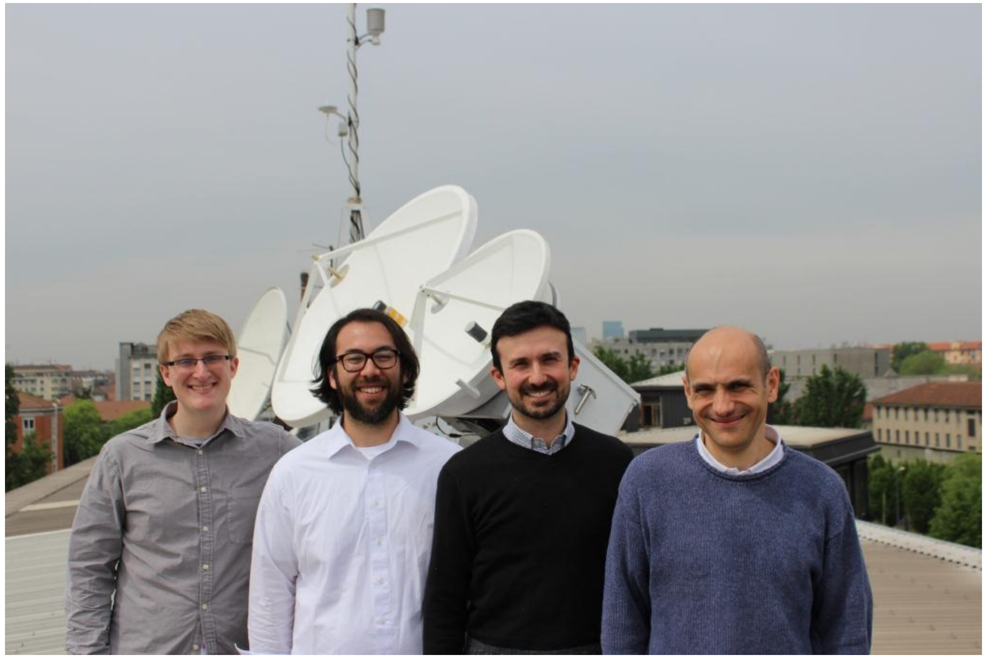
Conclusions:

- Prediction of expected attenuation is necessary and may be derived from scaling of existing data at lower frequencies. Use of a disdrometer at the ground station site could reduce uncertainties in these predictions of rain attenuation.

- The Mie and T-Matrix models do not significantly diverge until a droplet diameter of at least 3 mm -- and in the 45° polarization case, not until approximately 6 mm or greater, which is rarely observed.

- In many cases, particularly for low rain-rate events, there was found to be little difference between the two models (Fig. 4d), with **97.2%** of observations showing **less than 0.1 dB change** between the errors of the two predictions, and the change never exceeding **1.8 dB**.

- At higher rain rates, one model does tend to be preferable but only on a specific case-by-case basis, with a bias toward the **Mie** model being the preferred model more frequently. This may be due to the fact that the disdrometer DSD becomes less representative of conditions along the path for larger diameter DSDs, due to its small measurement area.



Thank you!

Appendix Charts

Contact Information

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Data Processing Procedure

Observation Period - Data used in this analysis spans from **August 2014 through December 2015** (17 months) and was processed to isolate applicable rain events. Altogether, 867 hours of rain events were isolated across 187 days containing rain.

Spurious Events - Events were removed from the analysis if the disdrometer was not operational, if the receivers were not operational, or if rain occurred along the path but was not measured over the site by the disdrometer.

Attenuation Calibration - For each rain event, the attenuation level before and after the event was averaged and subtracted from the measured rain attenuation in an effort to isolate the excess attenuation due to rain, though this method is not perfect and other sources of attenuation (e.g. clouds) may still bias the result. Instances where this was apparent were removed by inspection (e.g. slow-varying, high attenuation consistent with snow or water on the feed/reflector).

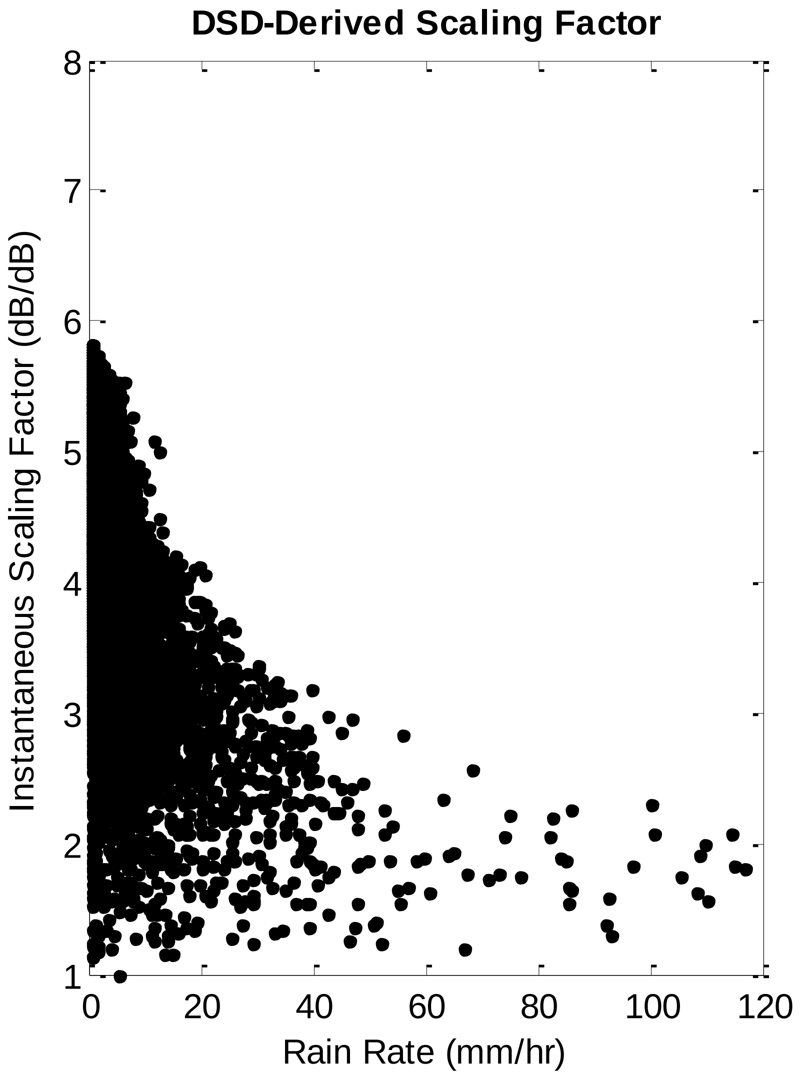
Isolation of Rain Events - Rainy periods were defined as any 1 minute period where the disdrometer observed more than 5 precipitating particles (roughly 0.03 mm/hr depending on particle class), and days were included in the analysis if they included at least 10 minutes exceeding this level of activity.

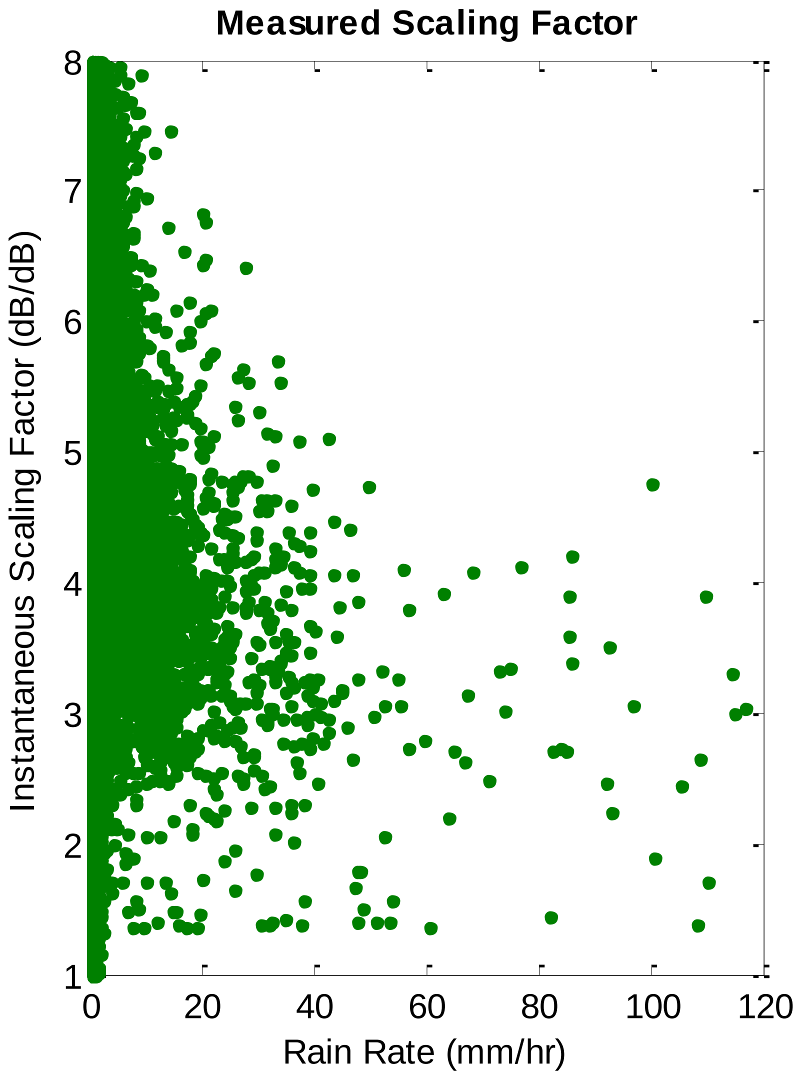
Diameter and Speed Classes

Class	Diameter (mm)	Class Width (mm)
1	≥ 0.125	0.125
2	≥ 0.250	0.125
3	≥ 0.375	0.125
4	≥ 0.500	0.250
5	≥ 0.750	0.250
6	≥ 1.000	0.250
7	≥ 1.250	0.250
8	≥ 1.500	0.250
9	≥ 1.750	0.250
10	≥ 2.000	0.500
11	≥ 2.500	0.500
12	≥ 3.000	0.500
13	≥ 3.500	0.500
14	≥ 4.000	0.500
15	≥ 4.500	0.500
16	≥ 5.000	0.500
17	≥ 5.500	0.500
18	≥ 6.000	0.500
19	≥ 6.500	0.500
20	≥ 7.000	0.500
21	≥ 7.500	0.500
22	≥ 8.000	∞

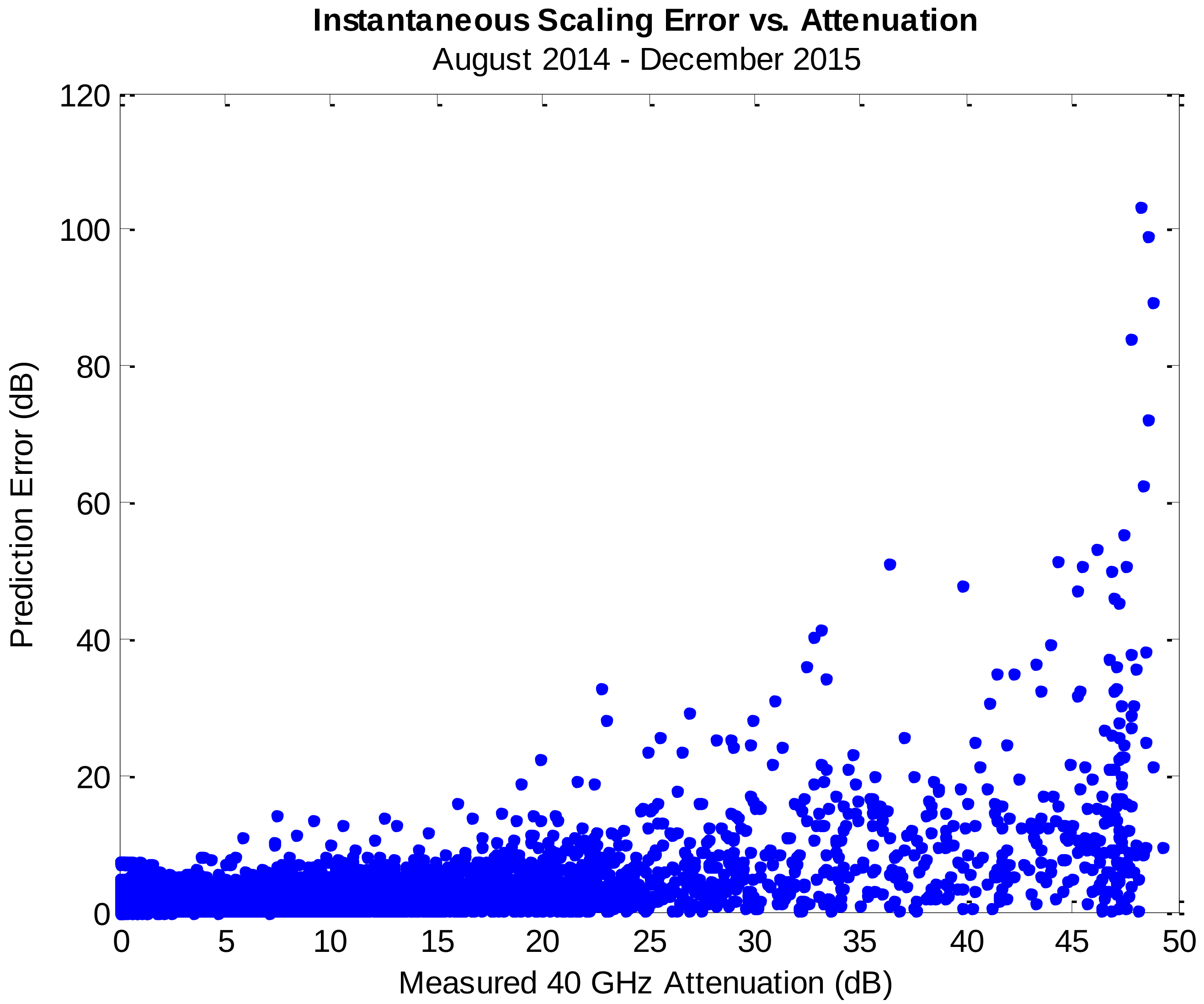
Class	Speed (m/s)	Class Width (m/s)
1	≥ 0.000	0.200
2	≥ 0.200	0.200
3	≥ 0.400	0.200
4	≥ 0.600	0.200
5	≥ 0.800	0.200
6	≥ 1.000	0.400
7	≥ 1.400	0.400
8	≥ 1.800	0.400
9	≥ 2.200	0.400
10	≥ 2.600	0.400
11	≥ 3.000	0.400
12	≥ 3.400	0.800
13	≥ 4.200	0.800
14	≥ 5.000	0.800
15	≥ 5.800	0.800
16	≥ 6.600	0.800
17	≥ 7.400	0.800
18	≥ 8.200	0.800
19	≥ 9.000	1.000
20	≥ 10.000	10.000
-	-	-
-	-	-

Pre-Averaged Scaling Factor vs. Rain Rate





Pre-Averaged Error vs. Attenuation



Link Budgets

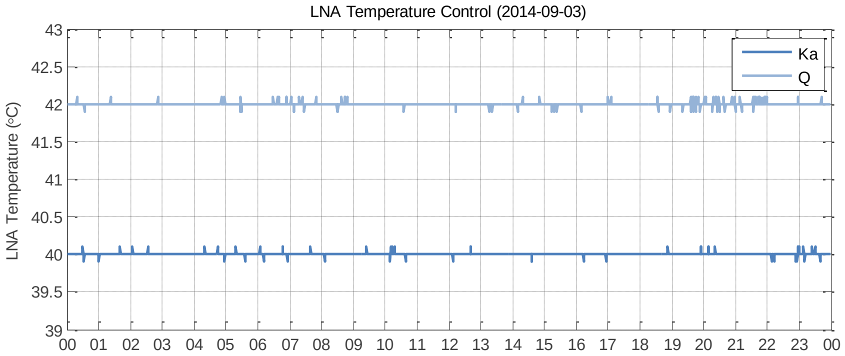
19.701 GHz Beacon

Parameter	User Inputs		Calculated	
Frequency of Operation	19.701	GHz		
Wavelength			0.015	m
Effective Isotropic Radiated Power (EIRP)			**19.50**	**dBW**
Propagation Channel Parameters				
Transmitter → Receiver Range	38600	km		
Gaseous Absorption Loss	0.5	dB		
Rain Attenuation	0.0	dB		
Pointing Loss	0.0	dB		
Polarization Loss	0.0	dB		
Free Space Loss			210.06	dB
Receive Antenna Parameters				
Antenna Diameter	1.2	m		
Illumination Taper Factor	70	deg		
Half Power Beamwidth			0.888	deg
Antenna Efficiency	60	%		
Antenna Gain			45.66	dB
Noise Temperature Contributions:				
Cosmic Background Noise Temperature	2.8	K		
Atmosphere Physical Temperature	290	K		
Antenna Noise Temperature (Clear Sky)			34.03	K
Antenna Noise Temperature (Rain)			34.03	K
Receiver Noise Temperature	600	K		
System Temperature			634.03	K
			28.02	dBK
Boltzmann's Constant			-228.60	dBW/K·Hz
Noise Spectral Density			-200.58	dB
Gain over Noise Temperature Ratio (G/T)			**17.63**	**dB/K**
Received Carrier Power (C)			**-145.41**	**dBW**
Carrier to Noise Density (C/N0)			**55.17**	**dBHz**

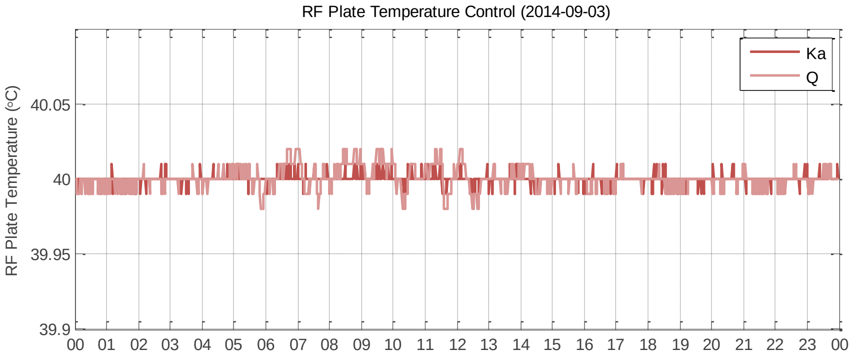
39.402 GHz Beacon

Parameter	User Inputs		Calculated	
Frequency of Operation	39.402	GHz		
Wavelength			0.008	m
Effective Isotropic Radiated Power (EIRP)			**26.50**	**dBW**
Propagation Channel Parameters				
Transmitter → Receiver Range	38600	km		
Gaseous Absorption Loss	0.5	dB		
Rain Attenuation	0.0	dB		
Pointing Loss	0.0	dB		
Polarization Loss	0.0	dB		
Free Space Loss			216.08	dB
Receive Antenna Parameters				
Antenna Diameter	0.6	m		
Illumination Taper Factor	70	deg		
Half Power Beamwidth			0.888	deg
Antenna Efficiency	60	%		
Antenna Gain			45.66	dB
Noise Temperature Contributions:				
Cosmic Background Noise Temperature	2.8	K		
Atmosphere Physical Temperature	290	K		
Antenna Noise Temperature (Clear Sky)			34.03	K
Antenna Noise Temperature (Rain)			34.03	K
Receiver Noise Temperature	800	K		
System Temperature			834.03	K
			29.21	dBK
Boltzmann's Constant			-228.60	dBW/K·Hz
Noise Spectral Density			-199.39	dB
Gain over Noise Temperature Ratio (G/T)			**16.44**	**dB/K**
Received Carrier Power (C)			**-144.43**	**dBW**
Carrier to Noise Density (C/N0)			**54.96**	**dBHz**

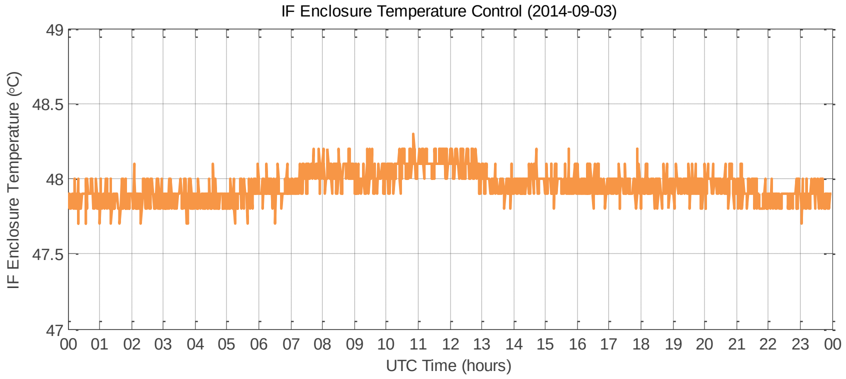
Hardware Temperature Stability



T_{LNA} ±0.1°C

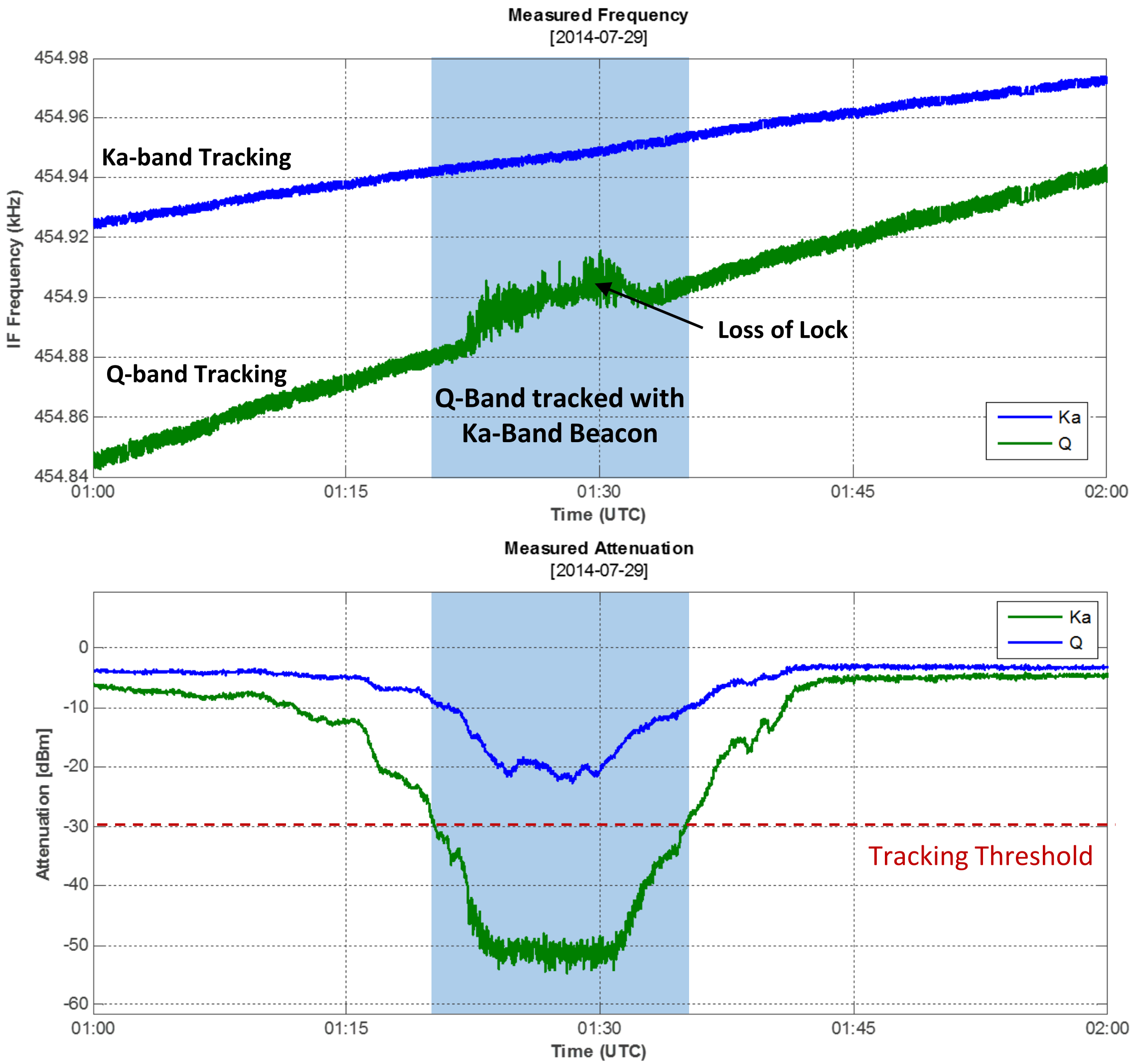


$T_{RFplate}$ ±0.01°C



T_{IF} ±0.25°C

System Performance



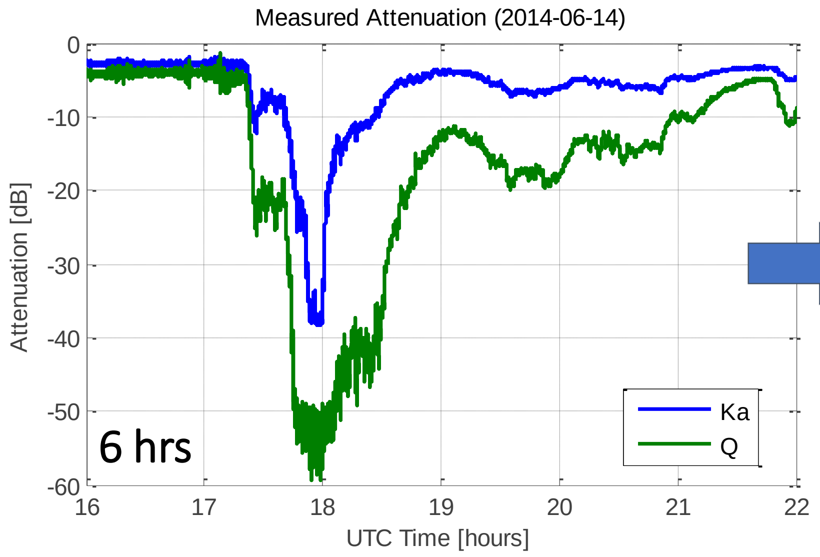
Under normal operating conditions, the K-band and Q-band receivers track their respective beacon signals independently.

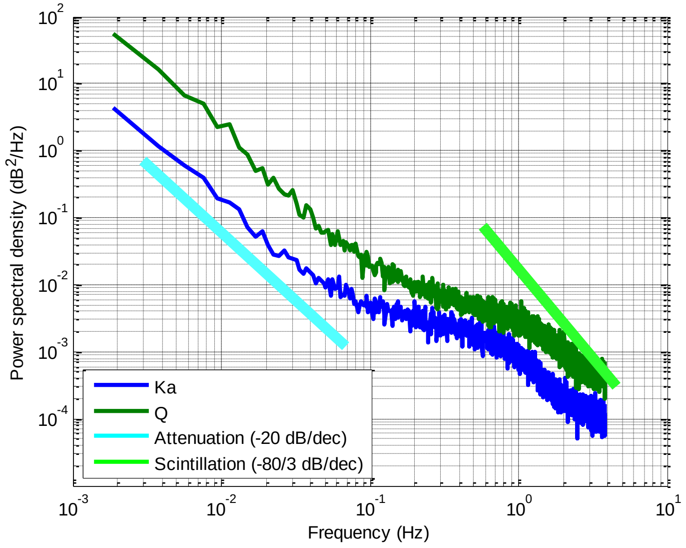
When attenuation exceeds 30 dB on the Q-band channel, the receiver utilizes the coherent K-band channel to maintain lock on the Q-band (region shown in blue).

Eventually, for deep rain fades, lock can no longer be maintained and the noise floor of the Q-band receiver is reached.

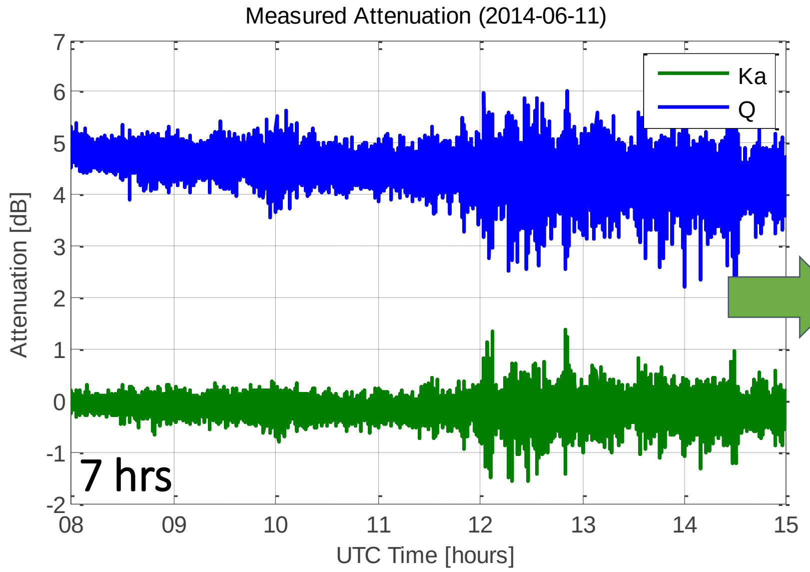
Signal lock is immediately regained when the signal reappears above the noise floor.

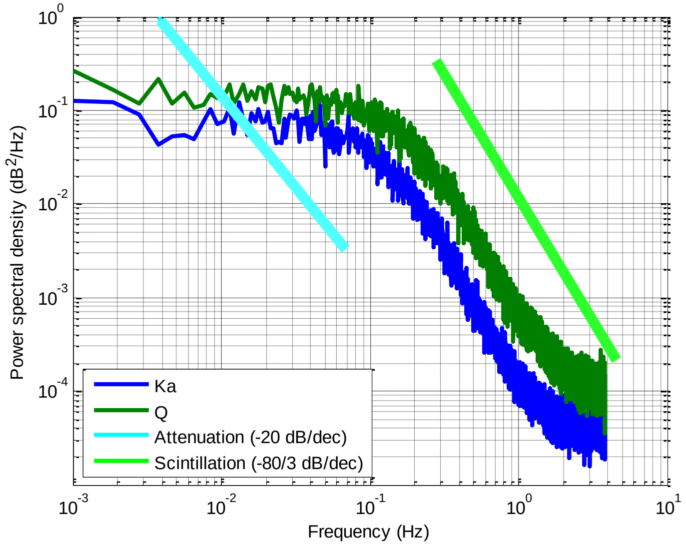
Measurement Spectral Density





Attenuation





Scintillation